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DMICS
Disaster Management, Initiatives and Convergence Society
Envisioning a Disaster Resilient Future

World Congress on Disaster Management

Fourth World Congress on Disaster Management

Volume III

Mumbai | India


Edited by
Dr S. Ananda Babu
President and Convener
DMICS-WCDM

This is the third in the series of three-volume compendium of 48 papers, presented at the Fourth World Congress on Disaster Management held in Mumbai in 2019. Authored by researchers, policy makers and practitioners, the papers cover a wide range of themes arranged around technology, infrastructure and resilience of urban systems.

Dr S. Ananda Babu is a PhD from Osmania University (OU), India. He is a societal awareness specialist and scholar, an author and editor of numerous books including *Disaster Risk Reduction, Community Resilience and Responses*. In addition, Dr S. Ananda Babu is the Founder President of the Disaster Management, Initiatives and Convergence Society (DMICS) and the Convener of the World Congress on Disaster Management (WCDM) established in 2005. In the aftermath of the Indian Ocean Tsunami, to enhance understanding and awareness among people about the risk of various types, dimensions of disasters and the measures to be taken for reducing the risks, for better preparedness, response and recovery, the DMICS and the WCDM takes on the task of creating awareness through multi-disciplinary research, publications and multi-stake holder's consultations.

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Technology, Infrastructure and Resilience of Urban Systems

WORLD CONGRESS ON DISASTER MANAGEMENT

Technology, Infrastructure and Resilience of Urban Systems

Papers Presented at the Fourth World Congress on Disaster Management, Mumbai, January 29–February 1, 2019

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Preface

The Fourth World Congress on Disaster Management (WCDM) was organised in Mumbai from January 29 to February 1, 2019, jointly by the Government of Maharashtra, the Indian Institute of Technology Bombay, the Tata Institute of Social Sciences Mumbai and the Disaster Management Initiative and Convergence Society Hyderabad which created the platform of WCDM. Over the years, WCDM has emerged as the largest biennial conference on Disaster Management in the developing world.

The theme of the fourth WCDM was *The Future We Want: Bridging Gaps between Promises and Action.* Nine Plenary Sessions, 62 Thematic Sessions, five Special Thematic Sessions and five Special Feature Events were organised around this overarching theme. More than 2000 participants from 68 countries attended these sessions.

While the Plenary Sessions were addressed by eminent speakers, the Special Thematic Sessions and the Special Feature Events were organised by the knowledge partners on different themes. It is the Thematic Sessions that received longest traction as Call for Papers was issued for these sessions months in advance and more than 600 researchers, practitioners and policy makers responded with abstracts of their ideas. These were reviewed by experts and 525 abstracts were selected for presentation in the 62 Thematic Sessions of the WCDM. Subsequently, 165 of these abstracts were developed as full papers. This is the third of three-volume series of compendium of these papers.

The papers have been published in the same form these were received without any peer review to provide a flavour of the raw ideas that emerged from the Thematic Sessions of the conference. Some of these papers presented by the young researchers and practitioners may not have the rigours of academic disciplines, but these do reflect the cross current of thoughts that went around in these sessions of the Conference. These provide new ideas and insights that provide value to the current discourses on the subject.

These papers have been arranged under three broad themes – first: hazard, vulnerability and risks of disasters, second: disaster impacts and risk governance and third: technology, infrastructure and resilience of urban systems.

The present volume is a compilation of 48 papers on the theme of technology, infrastructure and resilience of urban systems. The papers on technology have been arranged in three broad themes of remote sensing and GIS; drones and UAVs; and artificial intelligence, cloud and networking. The papers on infrastructure are classified under buildings, power, dams and other infrastructure. The papers on resilient urban systems are grouped on cities and mega cities. Understandably the papers do not cover every aspect of the themes; these discuss only those aspects that the authors have chosen to highlight.

The Conference secretariat has brought the papers together, but the credit lies solely and exclusively with the authors.

Dr S. Anandababu
Convener
Fourth World Conference on Disaster Management

Acknowledgements

The DMICS team and WCDM organising committee would like to convey utmost thanks to the Government of Maharashtra, IIT Bombay and Tata Institute of Social Sciences for the outstanding collaboration and support to the Fourth World Congress on Disaster Management.

We would also like to thank the co-partners: NDMA, NIDM & NDRF – Ministry of Home Affairs, Government of India, JNU-SCDR, UNICEF, Tata Trust, UNDP, HPCL, BPCL, IOCL, ACT, JSW, ADPC, Save the Children, KE and FICCI for their great support and contributions.

We sincerely thank all the speakers, presenters and delegates for their dedication and active participation in the conference activities.

Our special thanks to Dr P. G. Dhar Chakrabarti, Dr Muzaffar Ahmad, Prof. Ravi Sinha, Prof. Janki Andharia, Maj. Gen. Dr Naresh Chander Badhani, Mr Ray Kancherla, Dr A Kishan, Prof. (Dr) Namrata Agrawal, Prof. B. Gopal Rao, Dr Ram Bhavani, Mr Mohan Kasthala, Prof. V. Prakasam, Mr Pavan Parlapalli, Mr Y. Satyanarayana, Mr D. Sridhar, Dr A. Gayatri Devi, Ms Suparna Dutta and Mr Mahesh for their constant support and remarkable contribution in making the event a huge success.

The support of Macmillan Publishers India Private Limited in publishing the Fourth WCDM proceedings is also appreciable.

PART I TECHNOLOGY FOR DISASTER MANAGEMENT

I Remote Sensing and GIS

Identification of Groundwater Potential Zones Using GIS – Drought Mitigation Measure: The Case Study of Mettur, Salem District

C. Prakasam[a] and Saravanan R.[a]

ABSTRACT: Salem region is one of the drought inclined areas of Tamil Nadu. Being a rural zone, the area is finding a mitigation measure to keep the agri-business running. As a mitigation measure mapping the potential groundwater zones in the examination area will be a great alternate wellspring of water for rural purposes. The target of the study area is to delineate the groundwater potential zones using GIS software. Mettur is a panchayat town in Salem area inclined to dry spells. Sugarcane, paddy, turmeric, maize and cotton are main yields cultivated here. It is additionally renowned for custard (cassava roots). The different parameters that control the groundwater fluctuations, for example, geomorphology, contour, topography, land use/land cover (LULC), soil and rainfall, are broken down together as thematic maps. The slope map will be set up from DEM. These maps have been overlaid using the gauged overlay method using the Spatial Analysis tool in GIS. During the analysis, the ranking were given for every distinct bound of each thematic map and weights were relegated according to their influence for soil, land use/land cover, the density of drainage, rainfall, and slope. The resulting maps display the groundwater potential zones regarding Very Poor zones. The outcome which will portray the groundwater potential zones in the examination area will be useful in better planning and management of groundwater resources.

KEYWORDS: GIS, Salem, groundwater potential zones, remote sensing

Introduction

The Salem locale of Tamil Nadu is an agro-economic area and is deemed as a dry spell inclined zone among 20 other regions in Tamil Nadu. Despite what might be expected these locales additionally have seemingly contradictory weather conditions: Tamil Nadu and Karnataka got ordinary rainfall, about 46 per cent, recorded insufficient rainfall. Each of the three states additionally experienced far-reaching surges in August 2018 six locales in Tamil Nadu (Source: Indian Meteorological Department). Other than having wellsprings of water, the locale is inclined to dry season, and henceforth the mitigation measure ought to be designed in a way that utilises this wellspring of water in the examination area. On that note finding the zones where there is a potential wellspring of groundwater will be an imperative mitigation measure for dry spell zone or to a greater degree an adaptive strategy.

Finding the groundwater zones in the field will be a challenging process, but GIS applications make it simple to delineate the zones remotely and additionally give spatial and transient information about the groundwater zones in the locale. Magesh, N. S. Chandrasekar, N., and Soundranayagam, J. P. (2012) utilised the GIS strategies to delineate the groundwater potential zones in Theni

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area, Tamil Nadu, and MIF procedures. Waikar, M. L. and Nilawar, A. P. (2014) stated that the application of GIS and Remote Sensing (RS) can be considered for multi-criteria analysis in resource evaluation and hydrogeomorphological mapping for water resource management. The utilisation of remote sensing and GIS tools to separate nitty gritty drainage, incline and geomorphic features in parts of Parbhani District recommends appropriate methods for groundwater potential zone thinks about. Mwega, W. B., Mati, B. M., Mulwa, J. K. and Kituu, G. M. (2013) stated groundwater is a natural resource of the earth that sustains and supports the household, farming and industrial exercises. The generated groundwater potential zone delineates four groundwater potential zones, specifically, very high, high, moderate and low (Ramu, M. B. and Vinay, M. 2014). The parameters that are utilised for controlling groundwater zones are soil, drainage thickness, land use\ land cover, topography, geomorphology, rainfall, incline and contour (Rajendran, S. 2014). Dry spell mitigation measures ought to be utilised on a war footing and in a sustainable way. Groundwater recharging ought to be a top priority and any dry season mitigation plans should incorporate this key aspect.

Study Area

The investigation area in and around Mettur lies between the coordinates of latitude 110 45' to 11° 50' north and longitude 77°46' to 77°50' east. The total analysis area is around 68 sq. km. The real slope present in the investigation area is Palamalai (700 Mts.) and is located in the western corner of the investigation area and another slope, Seetharrulal (266), is located in the northeastern corner of 1hu investigation area Mettur town, on the north-eastern corner of Salem locale. In Mettur, a dam running to 1.5 km. in length is one of the best-developed masonry dams of South India.

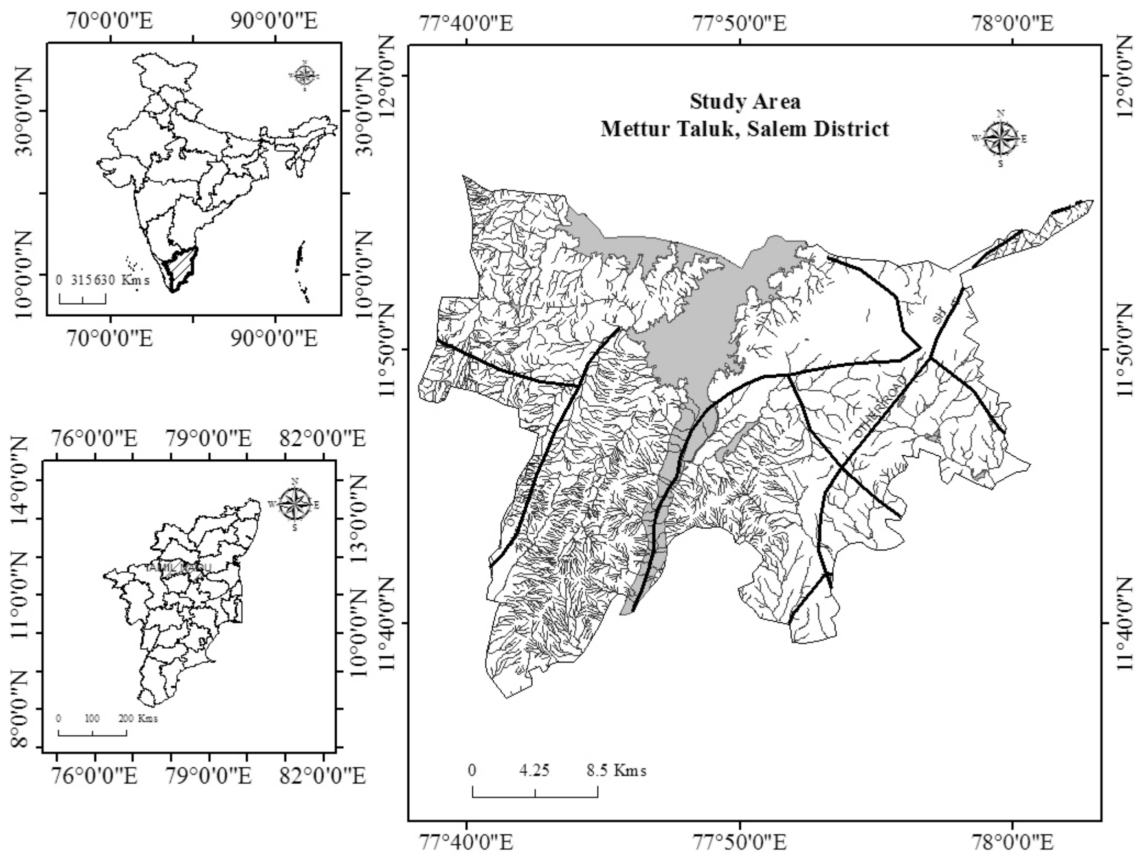

Figure 1: Study area map

The river Cauvery flows through Mettur and the Mettur reservoir can hold 95,660 million cubic feet water to the greatest dimension of 120 feet. The whole area in and around Mettur includes exceptionally transformed rocks. Mettur has a mean annual rainfall of 888.90 mm. Basic patterns in the high review terrain of Tamil Nadu have been worked out by numerous geologists and recently the definite land mapping has brought out huge areas occupied by very distorted charnockites and high review gneisses. In such areas, charnockite is intensively co-collapsed with a supracrustal group of rocks consisting of khondalite, quartz magnetite shake, pyroxene granulites and layered ultramafics. Further, these areas have experienced five periods of deformation, five generations of essential dyke exercises, four stages or migmatisation and two stages of metallogeny. Sugarcane, paddy, turmeric, maize and cotton are the main crops cultivated here. It is additionally popular for custard (cassava roots), and there are a few custard-based industries close to Attur today which fabricate items like "javvarisi" (sago) for business sectors all over India.

Methods and Materials

There are six imperative indicators: (i) geology, (ii) slope, (iii) geomorphology, (iv) land use/cover, (v) drainage and (vi) lineament for groundwater prospects. Preparation of maps for these themes (with the exception of slope) in view of picture attributes, for example, tone, surface, shape, shading and association, is standardised. The slope is obtained from ASTER DEM 30m resolution. Thematic maps of the examination area were prepared. To get the wholistic perspective of the previously mentioned indicators, overlay analysis is required. The task of rank to an individual class depended on the influence of these themes as mentioned in the literature. Rank- and weight-based thematic layers were integrated through GIS to find out the resultant groundwater potential zones. Overlay analysis was done from the determined multi-thematic layers in a GIS domain.

Slope

The slope is a vital factor for the identification of groundwater potential zones. A higher level of slope results in fast runoff and increased disintegration rate with weak energise potential. The slope map was developed from the ASTER DEM and classified into five categories. Slope values ranged from 0 to 90 degrees, as the study area contained hilly terrain. Gentle slopes (0 to 18) were spread over the area in a maximum range. Slopes greater than 54.1 degrees to 90 degrees represent the hilly slope in the region. The weight was determined from 1 to 5 based on the degree of slope in the region.

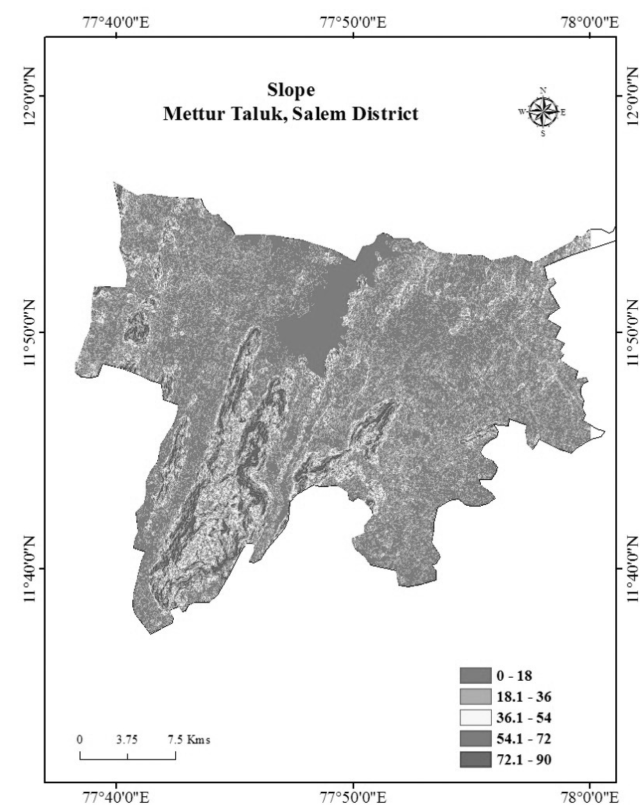

Figure 2: Slope map

Drainage

Drainage thickness is defined as the closeness of spacing of stream channels. It is a proportion of the total length of the stream section of all requests per unit area. The drainage thickness is an inverse capacity of porousness. The less porous stone is, the lower the infiltration of rainfall, which on the other hand will, in general, be concentrated in surface runoff. The weight was decided accordingly with respect to the density/ sq. km ranging from 1 to 5.

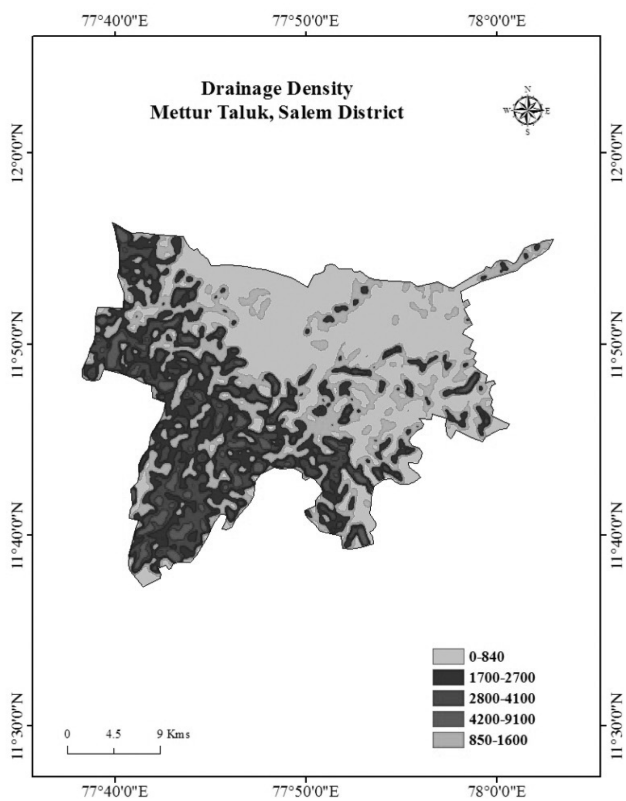

Figure 3: Drainage density map

Soil

Soil is an important factor for delineating the groundwater potential zones. The type of soil in the region reveals the groundwater recharge potential in the zone based on the soil properties such as permeability, conductivity, etc. Based on these the weight for the soil was given for sandy clay loam and loamy sand as 4, rock land as 1, sandy clay as 3 and clay loam as 2.

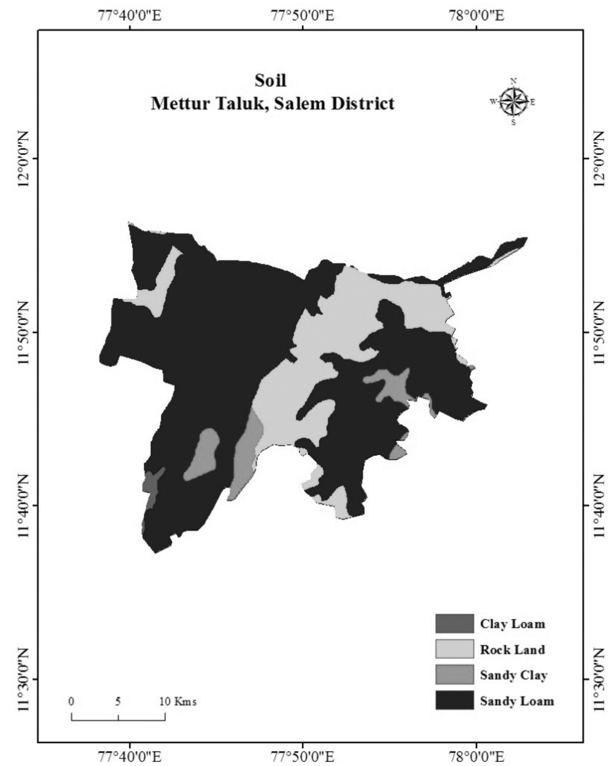

Figure 4: Soil map

Lineament

Lineaments are the surface manifestation of subsurface shortcomings or auxiliary relocation and deformations. It consists of profound seated blames, breaks and joints sets, drainage lines and distinctive litho-contacts. It is a linear and curvilinear feature that is noteworthy for groundwater, mineral and metal explorations and exploitations. Lineaments were digitised after calculating the hill shade slope in the ASTER DEM data. Similar to drainage density, lineament density's weight was given based on the densities.

Geology

The study area has a spread of crystalline rocks whose weight was given as 1 based on its properties in conducting the groundwater recharge, followed by intrusive rocks having the same weight as previously. The semiconsolidated sediments were given weight as 3 as they have moderate groundwater conducting properties.

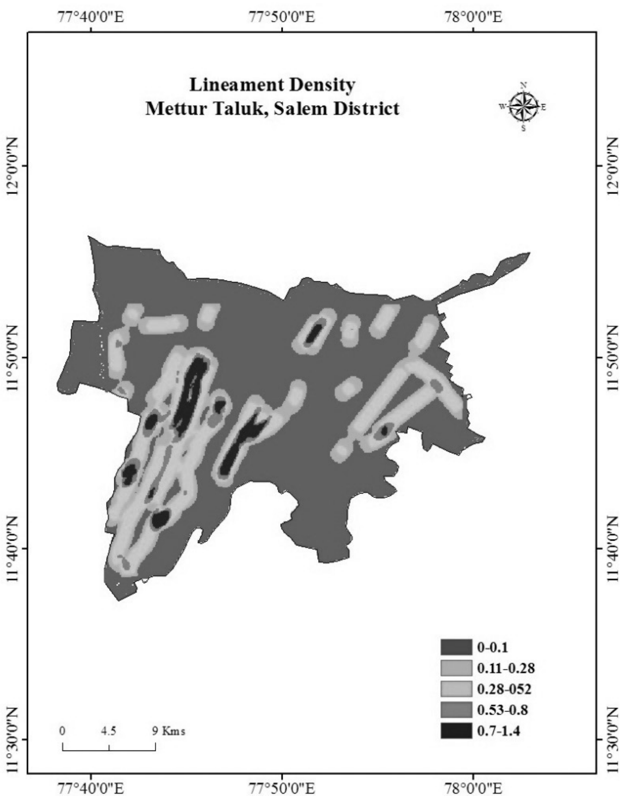

Figure 5: Lineament map

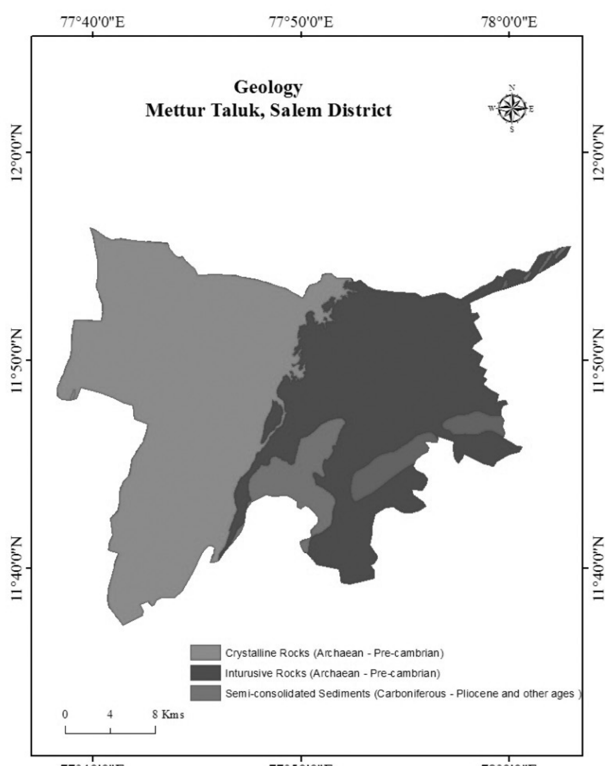

Figure 6: Geology map

Geomorphology

Geomorphological units are very important for the identification and characterisation of various landforms and structural features in the study area for groundwater development and management activities. Geomorphologic units are delineated based on image characteristics such as tone, texture, shape, colour, and association of features. Structural hills are observed in the study area, which mostly act as runoff zones due to their sloping topography. The pediplain was given the weight of 3 followed by Structured hills (2), Denudational hills (2), Flood plain (2) and Waterbody mask (5).

Land Use Land Cover

Baseline information about occurrences of surface and groundwater can be directly or indirectly obtained using land use/land cover information of that particular area. The effect of land use/land cover is manifested either by reducing runoff and facilitating or by trapping water on their leaf. The study area is categorised into six land use patterns: Water bodies (5), Dense forest (3), Degraded forest (3), Barren land (2), Fallow land (4), Agricultural land (4) from the Landsat 8 data and corresponding weights were given during the analysis.

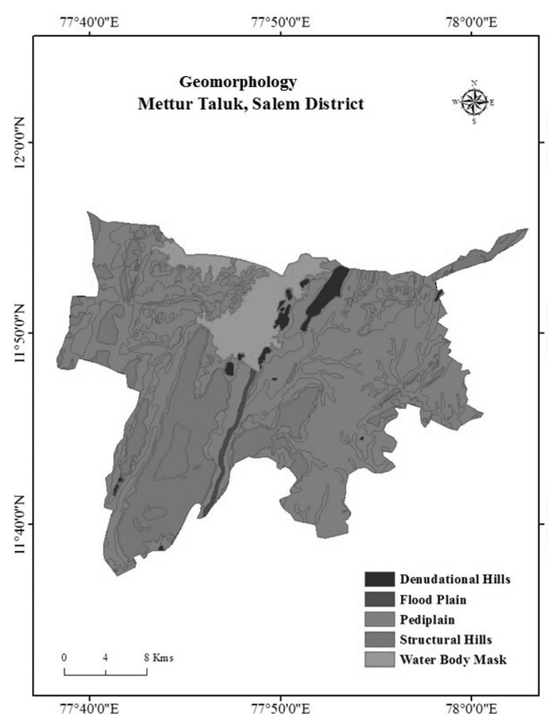

Figure 7: Geomorphology map

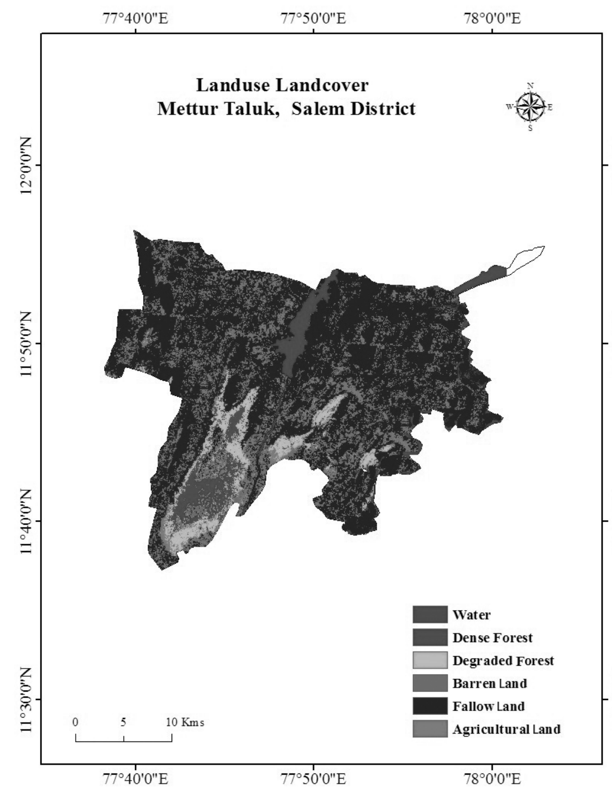

Figure 8: Land use/land cover map

Delineating the Groundwater Potential Zone

The groundwater potential zones for the study area were generated through the integration of various thematic maps, viz., drainage, slope, lithology, soil, lineament, rainfall, and land-use using remote sensing and GIS techniques. The demarcation of groundwater potential zones for the study area was made by a grouping of the interpreted layers through weighted multi-influencing factors and finally assigned different potential zones.

Conclusion

The groundwater potential zone of this study area can be divided into four grades, namely very good, good, moderate and poor. The groundwater potential map demonstrates that the moderate level of potential zones is present in the study area due to various factors involved. About 74.6 per cent of the total area falls under the 'moderate' zone, 12.3 per cent falls under the 'good' zone, 9.78 per cent falls under the 'poor' zone and 3.4 per cent of the study area falls under the 'very good' zone. The results predict that if the groundwater potential zones were utilised properly for exploring the water resources, drought could be managed with potential agricultural practices.

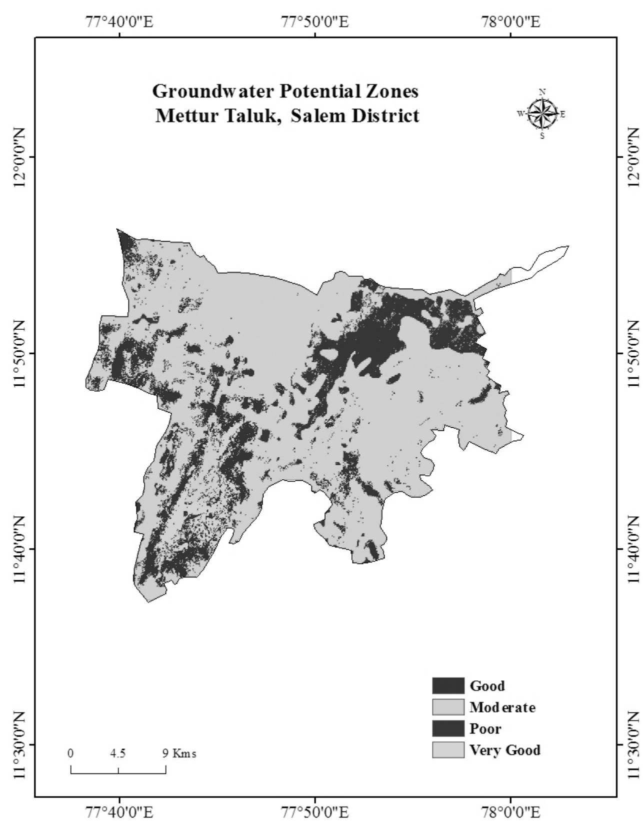

Figure 9: Groundwater potential zone map

Reference

Magesh, N. S., Chandrasekar, N., & Soundranayagam, J. P. (2012). Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. *Geoscience Frontiers*, *3*(2), 189–196.

Mwega, W. B., Mati, B. M., Mulwa, J. K., & Kituu, G. M. (2013, May). Identification of groundwater potential zones using remote sensing and GIS in Lake Chala watershed, Kenya. In *Proceedings of Sustainable Research and Innovation Conference* (pp. 42–46).

Rajendran, S. (2014). Drought Mitigation in Tamil Nadu. *Economic and Political Weekly*.

Ramu, M. B., & Vinay, M. (2014). Identification of groundwater potential zones using GIS and remote sensing techniques: A case study of Mysore Taluk, Karnataka. *Int. J. Geomat. Geosci*, *5*(3), 393–403.

Subburaj, A., Kumar, E. S., Suresh, S., Elanchelian, V., & Rajarajan, K. (2018). Impact Assessment of Demonstrative Project on Artificial Recharge to Groundwater in Gangavalli Block, Salem District, Tamil Nadu. In *Clean and Sustainable Groundwater in India* (pp. 191–202). Springer, Singapore.

Waikar, M. L., & Nilawar, A. P. (2014). Identification of groundwater potential zone using remote sensing and GIS technique. *Int J Innov Res Sci Eng Technol*, *3*(5), 12163–12174.

Earthquake Displacement Mapping Using Interferometric Synthetic Aperture Radar Data

Divya Sekhar Vaka[a] and Y. S. Rao[a]

ABSTRACT: Mapping the deformation extent due to an earthquake is very important for damage assessment. Interferometric Synthetic Aperture Radar is a space-borne remote sensing technique widely used for rapid mapping of a disaster with unprecedented accuracy and scale. The processing and analysis of the radar images from the Sentinel-1 microwave remote sensing satellite provide useful insights into the damage assessment and fault mechanism of an earthquake. In this study, we present the application of the Differential Interferometric Synthetic Aperture Radar technique to map the coseismic surface displacements of the 2017 M_w 7.3 Iran–Iraq earthquake. The earthquake has deformed an area of 40 sq. km. on the southwestern side and 15 sq.km. on the northeastern side of the epicentral area. The results indicate a minor strike-slip component and reverse faulting as the cause of the earthquake.

KEYWORDS: InSAR, disaster mapping, rapid processing, Sentinel-1, Iran–Iraq earthquake

Introduction

Earthquakes cause destruction and loss of human life. Mapping the extent of the surface displacements due to an earthquake is crucial for damage assessment. Over the last two decades, Synthetic Aperture Radar Interferometry (InSAR) has proved to be a prominent tool in precise mapping and measuring of ground displacements with millimetre-level accuracy. Differential SAR Interferometry (DInSAR) is widely used to monitor land subsidence, seismic deformations, volcanic eruptions, landslides and glacier movements (Massonnet and Feigl, 1998). Here, we present a primary example of InSAR for a geological application that demonstrates deformation mapping of an earthquake.

The latest microwave remote sensing satellite Sentinel-1 launched by the European Space Agency acquires Synthetic Aperture Radar (SAR) data all over the globe. The Sentinel-1 system is a constellation of two satellites (Sentinel-1A and 1B) operating in C-band. The constellation reduces the repeat frequency of the satellites to six days, improving coherence between two acquisitions. The Interferometric Wide Swath mode of the Sentinel-1 satellites covers approximately 250 x 150 km on the ground. The high revisit frequency and the broad coverage of these satellites lead to accurate and quick mapping of coseismic displacements.

Also, the ascending and descending data of the SAR satellites can be combined to derive three-dimensional components (East-West, North-South and up-down) of the observed displacement. The interferograms and line-of-sight (LOS) displacement maps generated from these vast amounts of SAR data are crucial for damage assessment, understanding fault mechanism and improving the fault model.

In this study, we present the displacement maps of the 12 November 2017 M_w 7.3 earthquake that occurred at the Iran–Iraq border. Sentinel-1 SAR data are used to map the surface displacements of the earthquake.

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Materials and Methodology

The epicentre (34.90°N, 45.95°E) of the 12 November 2017 Mw 7.3 Iran–Iraq earthquake is located 30 km from Halabjah city in Iraq and 51 km north of Sarpol Zahab city in Iran. The focal solutions suggested that reverse faulting was the primary cause of the earthquake because the Arabian plate is moving northwards at a rate of 25 mm $year^{-1}$ with respect to the Eurasian plate. The earthquake occurred in the high seismic Zagros Thrust and Fold Belt (ZFTB), which extends from western Iran to northeastern Iraq. The event happened in a less seismically active zone, which provides a unique opportunity to study the seismic activity in the northern part of the Zagros mountain range.

Two ascending pass and two descending pass images of the European Space Agency's C-band Sentinel-1 acquired over the study area are used to derive surface displacements due to the earthquake. The Sentinel-1 data used in this study are acquired in Interferometric Wide Swath (IW) mode with a spatial resolution of 5 x 20 m. Table 1 summarises the details of the SAR data used in this study.

The DInSAR methodology to map coseismic surface displacements of the 2017 M_w 7.3 Iran–Iraq earthquake is shown in Figure 1. A master and a slave image is coregistered with sub-pixel level accuracy to generate an interferogram. The topographic phase is removed by using a Shuttle Radar Topographic Mission (SRTM) 30 m Digital Elevation Model (DEM). Two differential interferograms (ascending and descending) corresponding to the coseismic cycle of the earthquake are formed after the topographic phase removal. The differential interferograms are then filtered, multi-looked and phase unwrapped. The phase unwrapping is performed using the SNAPHU algorithm (Chen and Zebker, 2001). The unwrapped values are converted into LOS measurements, and the displacement maps are geocoded to the WGS84 coordinate system.

Table 1: The Details of the Synthetic Aperture Radar (SAR) Data Used in the Study

Satellite	Pass	Master	Slave	Perpendicular Baseline (m)	Incidence Angle (degrees)
Sentinel -1A/1B	Ascending	11–11–2017	17–11–2017	62.2	43.9
Sentinel -1A/1B	Descending	12–11–2017	18–11–2017	53.4	34.0

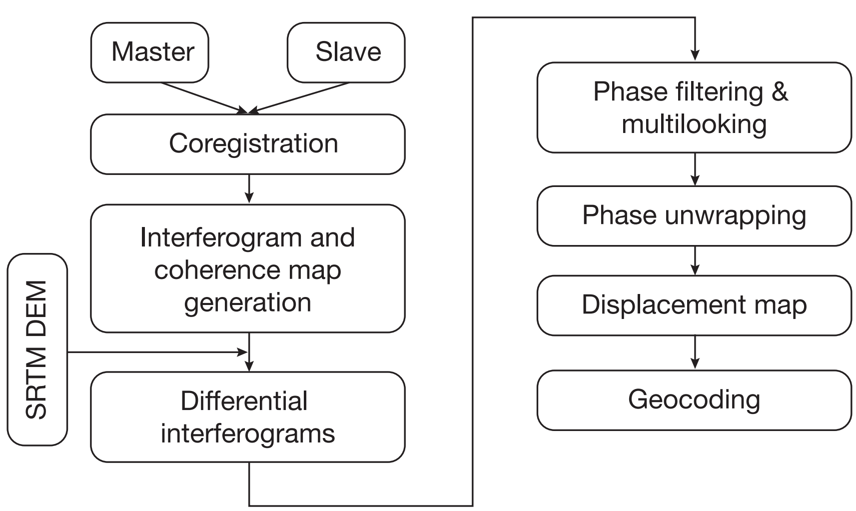

Figure 1: Methodology followed to map coseismic displacements of the Iran–Iraq earthquake

Results and Discussion

The coseismic interferograms and displacement maps of the earthquake are shown in Figure 2. Two differential interferograms (Figures 2a, 2b) and LOS displacement maps (Figures 2c, 2d) are generated after processing the Sentinel-1 ascending and descending pass images.

Each fringe in the differential interferograms corresponds to one full cycle of phase variation, which is equal to 2.8 cm of range change on the Earth's surface. Two clear lobes of deformation corresponding to uplift in the bottom part and subsidence in the upper part of the interferograms are observed. The variation in the size and extent of the lobes in ascending and descending pass interferograms corresponds to change in satellite pass and look direction. The variation also indicates some lateral movement in addition to the vertical deformation caused by a reverse faulting earthquake (Feng et al., 2018). No evidence of surface rupture is observed from the interferograms.

The white rectangles in Figure 2a indicate landslides triggered by the earthquake. These landslides occurred on the mountainous slopes, where the elevation varies from 800 to 1600 m.

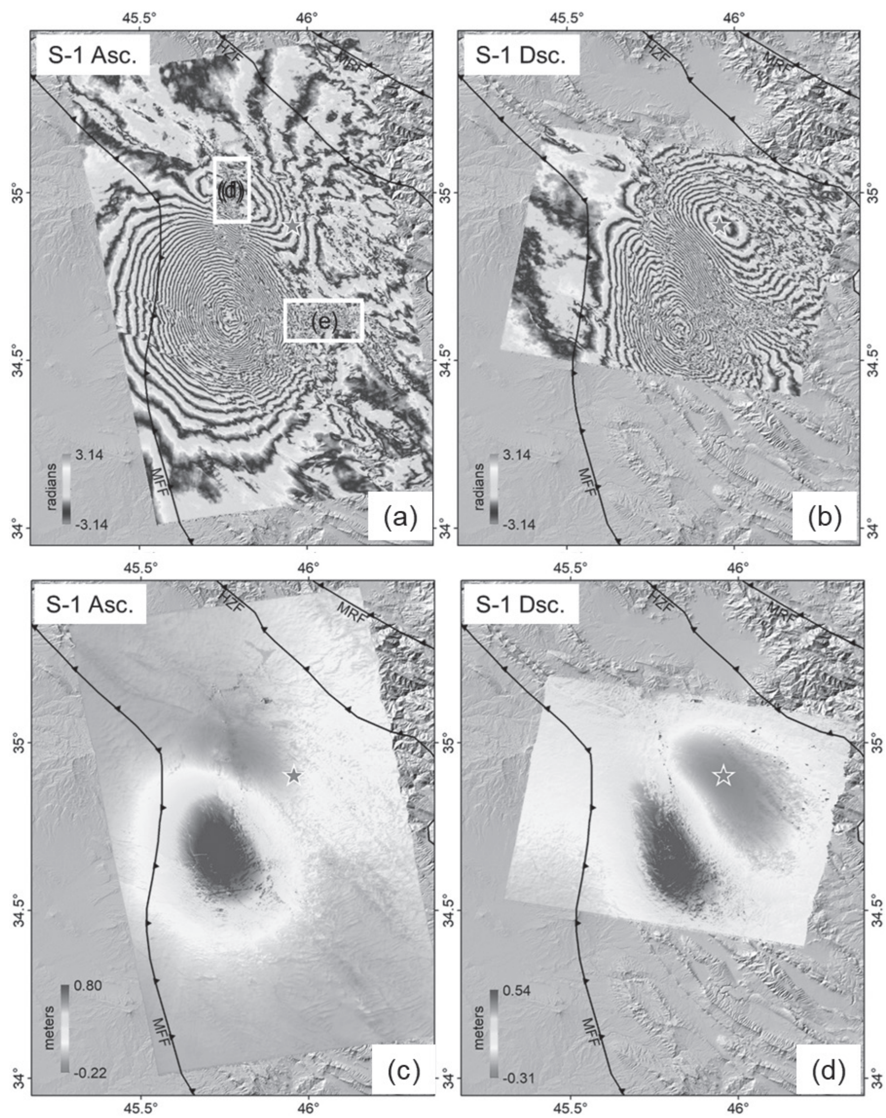

Figure 2: (a), (b) are the differential interferograms and (c), (d) represent the line-of-sight displacement maps generated from the Sentinel-1 ascending and descending pass images. Each fringe in the interferograms corresponds to 2.8 cm of range change. The white rectangles in (a) correspond to the landslide areas triggered by the earthquake. A red star represents the epicentre of the earthquake

The earthquake has uplifted an area of approximately 40 sq.km. on the south-western side and also resulted in 15 sq.km of subsidence on the northeastern side of the epicentral zone. The coseismic displacement maps shown in Figures 2c and 2d indicate two lobes of deformation corresponding to the movement towards (+, blue) and away (-, orange) from the radar respectively. The line-of-sight displacement maps indicate a maximum uplift of 80 cm and subsidence of 22 cm in the source region supporting a reverse faulting mechanism of the earthquake (Tavani et al., 2018; Yang et al., 2018).

Conclusion

The 2017 M_w 7.3 Iran–Iraq earthquake is mapped using the DInSAR technique. The C-band Sentinel-1 satellite data with six days temporal gap is used to map displacements due to the earthquake. The higher revisit time of the Sentinel-1 constellation helped in the rapid mapping of the disaster. The results indicate subsidence and uplift in the epicentral region. In general, the results provide comprehensive information about the Earth surface deformation in active seismic zones. These observations can be used in disaster preparedness and management. Nowadays, the free availability of SAR data and high-end computation facilitates rapid data processing and disaster mapping.

Acknowledgements

Sentinel-1 data were provided free of cost by the European Space Agency (ESA) through the Copernicus Open Access Hub.

References

Chen, C.W., Zebker, H.A., (2001) Two-dimensional phase unwrapping with use of statistical models for cost functions in nonlinear optimisation. Journal of the Optical Society of America A 18, 338–351. https://doi.org/10.1364/JOSAA.18.000338

Feng, W., Samsonov, S., Almeida, R., Yassaghi, A., Li, J., Qiu, Q., Li, P., Zheng, W., (2018) Geodetic constraints of the 2017 Mw7. 3 Sarpol Zahab, Iran earthquake and its implications on the structure and mechanics of the north-west Zagros thrust-fold belt. Geophysical Research Letters. https://doi.org/10.1029/2018GL078577

Massonnet, D., Feigl, K.L., (1998) Radar interferometry and its application to changes in the Earth's surface. Reviews of geophysics 36, 441–500. https://doi.org/10.1029/97RG03139

Tavani, S., Parente, M., Puzone, F., Corradetti, A., Gharabeigli, G., Valinejad, M., Morsalnejad, D., Mazzoli, S., (2018) The seismogenic fault system of the 2017 M_w 7.3 Iran-Iraq earthquake: constraints from surface and subsurface data, cross-section balancing and restoration. Solid Earth Discussions 2018, 1–30. https://doi.org/10.5194/se-2018–21

Yang, Y., Hu, J., Yassaghi, A., Tsai, M., Zare, M., Chen, Q., Wang, Z., Rajabi, A.M., Kamranzad, F., (2018) Midcrustal Thrusting and Vertical Deformation Partitioning Constraint by 2017 Mw 7.3 Sarpol Zahab Earthquake in Zagros Mountain Belt, Iran. Seismological Research Letters. https://doi.org/10.1785/0220180022

Soil Desertification Severity Modelling for Dharmapuri District of Tamil Nadu Using Microwave Remote Sensing Techniques

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ABSTRACT: Desertification is a prolonged stage of soil degradation which directly produces a significant impact on soil fertility, thereby reducing vegetation production, and it is mainly induced by three vital components, namely climate, anthropogenic activities and active geological elements in the semi-arid region. The present research was carried out in the Dharmapuri district of Tamil Nadu. The Optical Remote Sensing models have experienced difficulty in the estimation of soil salinity in the study region due to the extensive distribution of *Nerium oleander* plants and waterlogged conditions. The RISAT and Sentinel-1 of C-band (5.36 GHz) frequency of microwave data product were employed in the research. The influence of the vegetation (σ^o_{veg}) on the total backscattering coefficient (σ^o_{total}) has been significantly reduced from the SAR data to extract the backscattering coefficient of soil (σ^o_{soil}) by proposing a model 'Dual Polarisation SAR Vegetation Index (DPSVI)' and employing the Modified Water Cloud Model (MWCM). The resultant product of DPSVI has a good correlation with Actual Ground Biomass (AGB) (R^2 = 0.73). The real part of the dielectric constant (ε') of the soil has been measured from σ^o_{soil} by employing the Modified Dubois Model, which has shown adequate accuracy (R^2 = 0.77) with ground moisture measurements. Similarly, the imaginary part of the dielectric constant (ε'') derived from a simplified Hallikainen empirical model has a good correlation with ground Electrical Conductivity (EC)/Fluoride (F) measurements (R^2 = 0.73) irrespective of the presence of salt-tolerant vegetation. The distribution of high saline affected category was identified at about 101821 ha, which is 16 per cent higher than the area identified by multispectral models. Through the sequence of SAR modeling, the actual intensity of soil salinity has been effectively measured, through which the appropriate reclamation measures were suggested to farmers, and it has been proved that a considerable period of such practice has contributed to a stable vegetation productivity rate.

KEYWORDS: soil salinity, SAR vegetation model, soil backscattering, soil dielectric constant, soil reclamation measures

Introduction

Desertification is defined as 'Degradation of the soil, landscape, and bio-productive terrestrial system, in arid, semi-arid and sub-humid areas resulting from several factors including climate change and human activities' (UNCCD 1994). Climatic factors initially induce this phenomenon, becoming accelerated when combined with human actions (unsustainable agricultural practices) and the functions of active geological elements (Lin and Tang 2002) such as fluoride (F) and arsenic (As) in the groundwater, which causes an adverse effect on the soil, people and the ecological system. Natural enrichment and mobilisation of rocks and sediments elevate the concentration of fluoride (F) and arsenic (As) in the groundwater (Currell et al. 2011). The dominant soil taxa found with a high percentage of clay and loam has higher possibility to inherit the

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fluoride content naturally from the groundwater through capillary action. Upon reaching the soil, the fluoride (F) concentration adversely affects the soil ecology and microbial activity, and it is believed to be one of the significant causes of desertification in semi-arid regions of Tamil Nadu.

According to various research reports (Mohamed et al. 2011), the degradation of vegetation is a primary indicator of desertification. The vegetation indices from optical and hyperspectral remote sensing can provide a measure of terrestrial biomass that could describe the actual condition of the land susceptible to degradation and desertification (Shrestha et al. 2005; Veron and Paruelo 2010; Higginbottom and Symeonakis 2014). However, as far as soil is concerned, the surface level properties can be assessed effectively by optical and hyperspectral remote sensing only when the land is not covered with vegetation, and atmospheric disturbances like aerosol, cloud cover, rain, etc. are considerably lower during the period of assessment. Furthermore, the presence of salt-tolerant plants is consistently reported in the highly saline affected (Shoba and Ramakrishnan 2017) agricultural patches of semi-arid regions, which significantly reduces the accuracy level of the indices of optical and hyperspectral sensors like Normalised Differential Vegetation Index (NDVI). Hence, the necessity for the technology which could reach the soil surface after being penetrated with terrestrial vegetation to investigate the actual intensity of soil contamination and to recommend the appropriate control measures.

The 'Synthetic Aperture Radar (SAR)' of microwave remote sensing offers significant measurement capacity towards soil desertification due to its high penetration capability through the atmospheric interfering components and target features that have an advantage over optical and hyperspectral remote sensing. The backscattering coefficient is a function of the various system and target parameters (Ackermann 2015). Frequency, incidence angle and polarisation are the system parameters, and dielectric constant, temperature, orientation and surface roughness are the target parameters. Among various target parameters, dielectric constant has the higher potential to describe the intensity of soil desertification even under the influence of vegetation.

The semi-empirical Water Cloud Model (WCM) (Attema and Ulaby 1978) consists of the backscattering coefficient of vegetation and soil. The model has been employed in various studies to investigate the soil moisture variations based on different vegetation characteristics and has yielded satisfactory results (Kumar et al. 2014; Liu and Shi 2016). However, there is no such model reported so far to study the influence of the vegetation and extract the backscattering coefficient of the same from total backscattering coefficient. This process is essential to separate the vegetation influence from the total backscattering coefficient to study the physical and chemical properties (to some extent) of the soil when land degradation and desertification is the main concern. Hence, to meet the research gap, the model DPSVI (Dual Polarisation SAR Vegetation Index) (Shoba 2018) has been developed only from vertical dual polarisation datasets (σ^o_{vv} and σ^o_{vh}). In the present research, the DPSVI model has been employed in WCM as a vegetation parameter to assess and extract the influence of vegetation components from the total backscattering coefficient.

The complex dielectric constant is composed of two parts, namely the real part or permittivity and the imaginary part or loss factor. The real part (ε') of the complex dielectric constant governs the propagation velocity of the wave through the medium, called permittivity (Li et al. 2014), and usually varies depending on the presence of soil moisture content. According to Lasne et al. (2008), the imaginary part (ε'') represents the attenuation of radar signal due to the conductivity of the material/surface, and is hence termed loss factor. The imaginary part or the dielectric loss factor is susceptible to the soil salinity (Gong et al. 2013). The positive linear correlation of soil salinity with soil fluoride (F) concentration has been well established by various researchers (Adhikary et al. 2014), and hence, with this evidence, the ε'' of dielectric constant is also influenced by the presence of fluoride (F) in the soil. There are several models reported so far in estimating ε'' of dielectric constant (Dobson 1985; Hallikainen 1985; Dubois et al. 1995) by which the possibility of examining the intensity of soil salinity was demonstrated. However, these models had some practical limitations because of the complexity and the requirement of more field samples to execute the model. Quan et al. (2014) have modified the existing Hallikainen model in a more convenient form to estimate the soil salinity by simulating the parameters through the least squares regression model for obtaining the calibration coefficients for 5.3 and 6.9 GHz. In the present research, the modified Hallikainen model was further modified and employed for the backscattering coefficient of soil, which was estimated from the modified WCM to estimate the intensity and areal distribution of fluoride (F) concentration.

The research on assessing the soil fluoride contamination and subsequent agro-economical loss in the study region was already initiated in 2015 by modelling RISAT, a set of Indian Microwave mission data. According to the results determined on the intensity level, the recommendations for the appropriate land reclamation processes were given to inhabitants of the region in the same year. The level of contamination has been continuously monitored from both in-situ measurements and microwave remote sensing imagery (Sentinel-1) for the subsequent years (2016, 2017 and 2018). The promising results of reduced fluoride (F) level and increased productivity have been found even from the four cycles of practising appropriate land reclamation measures. The objectives of the present research work are to i) estimate the degree of fluoride (F) contamination in soil by analysing the imaginary part of dielectric constant from RISAT data product of C-band frequency (5.36 GHz), ii) recommend the suitable natural remedial measures to reduce the soil contamination, iii) investigate the level of soil contamination in the land patches where the sustainable land reclamation measures have been practised for the subsequent years (2016, 2017 and 2018) through microwave vegetation models and dielectric mixing models from Sentinel-1 data product of C-band frequency.

Study Area

The study was conducted in Dharmapuri district, one of the fluoride-rich districts of Tamil Nadu that geographically lies between 11°47′ and 12°33′ N and 77°28′ and 76°45′ E (Fig. 1). Since the region is located on the leeward side of the Western Ghats, it is continuously affected by erratic climatic events which are generally believed as a catalyst for desertification in this area. However, due to natural enrichment of rocks, the groundwater of the region is being contaminated with fluoride (F) content more than the permissible level (1.5 mg/L) as prescribed by the Central Ground Water Board (2009). The soil of this region is found to have a high percentage of loam and clay that can stimulate capillary action, resulting in inherited soil salinity from groundwater. In addition, the region is strongly associated with the cultivation of *Nerium oleander* plants with the assumption that the land could not support any other agro-economic plants. According to the report of the Central Ground Water Board, the groundwater in aquifers, in general, is alkaline in nature. The study is essential for this region as 70 per cent of the population depends on agricultural productivity.

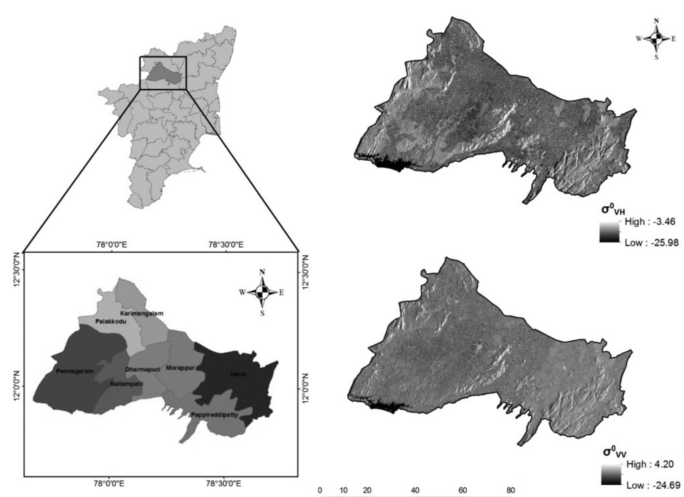


Figure 1: A map showing the extent of the study region along with the SAR imagery of VH and VV polarisation for the same

Materials and Methods

Datasets

Microwave Data Product – RISAT (HH and HV)

RISAT, an Indian microwave mission of C-band (5.36 GHz) frequency deployed in five different modes of operation and available to users in two different types of polarisation state, namely HH and HV, intends to support different land applications. The Moderate Resolution Scan SAR (MRS) mode of single and dual polarisation has azimuth and slant range resolution of 24 and 8m. The sensor has operated on the incident angle ranging from 20.5° to 49.7° and look angle ranging from 18.7° to 44.3°. The L2 (GRID) product was collected for the crop growing period for the year 2015, from the National Remote Sensing Centre (NRSC), India, and the images were processed to extract the backscattering values from the DN values.

Microwave Data Product – Sentinel-1 (VV and VH)

The Sentinel-1 is a microwave data product of the European Space Agency that operates in C-band (5.36 GHz) frequency. The product has four different modes of data acquisition, namely Stripmap (SM), Interferometric Wide swath (IW), Extra-Wide swath (EW) and Wave (WV) in which IW mode is meant for land application. The mission supports operation in a single (HH or VV) and dual polarisation (HH and HV or VV and VH). The azimuth and range resolution of the product is 5m and 20m respectively and the incidence angle varies from 29.1° to 46.0°. The Level-1 GRD (Grid) products were obtained for the crop growing period from the Sentinel scientific data Hub from 2016 to 2018.

Modelling Target Parameters

Estimating the Influence of Vegetation

The C-band frequency is suitable for the assessment of lower biomass due to the signal penetration through leaves and multiple scattering between branches (Ghasemi et al. 2011). The model Radar Vegetation Index (Kim and Van Zyl 2009) is an effective tool to estimate the terrestrial biomass only when the Quad pol (HH, HV or VH and VV) information is available. However, the necessity for the SAR vegetation model from dual polarisation products has attained significant attention in the recent era. Hence, the DPSVI model (Shoba 2018) was developed based on the scattering behaviour of various surface features in the two-dimensional scatterplot between the backscattering coefficient of VV (σ^o_{vv}) and (σ^o_{vh}) polarisation to address the research gap. The model has been further refined with the integration of *Inverse Dual Polarisation Diagonal Distance (IDPDD*) and *Vertical Dual De-polarisation Index (VDDPI).* The model has a higher potential and could act as an effective indicator of terrestrial biomass irrespective of crop season and weather.

Modified Water Cloud Model (WCM)

The Water Cloud Model (WCM) (Attema and Ulaby 1978) was developed with the hypothesis that the total backscattering coefficient is a function of soil and vegetation components. The potential of the model in the estimation of soil moisture has been demonstrated by various researchers (Capstick 1998; Dabrowska-Zielinska 2007). The model requires the Leaf Area Index (Leaf Area Index) and Plant Water Content (PWC) as vegetative descriptors to estimate the influence of vegetation in the backscattering coefficient. The complexity in the spatial deployment of the model has been resolved in the present research by employing the resultant product of the DPSVI as vegetation descriptors. The empirically adopted vegetation (A and B) and soil coefficients (C and D) were applied according to the findings of Bindlish and Barros (2000). by knowing the influence of vegetation and total backscattering coefficient, the base model (1) was inverted to extract the backscattering of soil (σ^0_{soil}) for the datasets of 2016, 2017 and 2018. For 2015, the model was applied for RISAT data for HH and HV polarisation with actual LAI and PWC as vegetation descriptors.

$$\sigma^0_{vv-total} = \sigma^0_{vv-veg} + L^2 * \sigma^0_{vv-soil} \qquad (1)$$

With $L^2 = exp^{(-2*DPSVI*B)/cos\theta_L}$

Where

$\sigma^0_{vv-total}$ is total backscattering coefficient of VV polarisation.

σ^0_{vv-veg} is total backscattering coefficient of the vegetation of VV polarisation.
$\sigma^0_{vv-soil}$ is total backscattering coefficient of the soil of VV polarisation.
θ_L is an incidence angle.

Imaginary Part of Dielectric Constant (ε'')

The real (ε') and imaginary parts (ε'') of the complex dielectric constant of the σ^0_{soil} are highly influenced by soil moisture and salinity. The real part of the dielectric constant (ε'_{soil}) has been estimated for $\sigma^0_{vv-soil}$ using the Dubois model (1995), and corresponding soil moisture (m_{v-soil}) has arrived from Topp's model (1980). Quan et al. (2014) have reduced the complexity of the basic Hallikainen model by modifying the parameters through a least squares regression model (2). The author also demonstrated the model accuracy with 1.4 GHz frequency when compared with the Dobson model but not for 5.36 GHz. In addition, there is no work reported on modifying the model for the investigation and estimation of soil fluoride concentration, which is also an influential factor where the imaginary part is concerned. In the present research, the model has been modified with the inclusion of ε'_{soil} to represent the relative percentage of clay (C), the resultant product of vertical cross-polarisation (h_{rms}) to represent sand (S) and m_{v-soil} to represent the moisture content for C-band frequency.

$$\varepsilon''_{soil} = a_0+a_1S+a_2C+b_0m_v+b_1Sm_v+b_2Cm_v+c_0m_v^2+c_1Sm_v^2+c_2Cm_v^2 \quad (2)$$

An imaginary part of the dielectric constant (ε''_{soil}) has been estimated from Equation (2). The model was performed for various soil categories such as calcareous clayey loam soils, calcareous clayey soils, calcareous gravelly clay soils, calcareous gravelly loam soils, calcareous loamy soils, clay loamy soils, clay soils, clay soils with rock outcrops, gravelly clay loamy soils, gravelly clay soils, gravelly loam clay soils, gravelly loam soil with rock lands, gravelly loam soils, laterite gravelly soil, loamy clay soils, loamy soils and loamy soils with rock outcrops to assess the rapidity of the process of fluoride through capillary action.

Results and Discussion

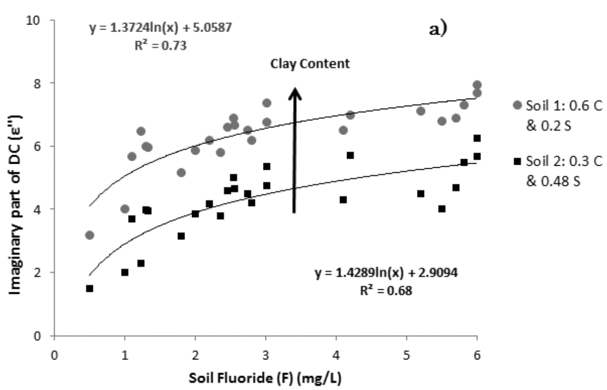
The accuracy of an optically derived soil salinity model, namely Diagonal Soil Salinity Index (DSSI) (Shoba and Ramakrishnan 2017), has been significantly diluted due to the high distribution of *Nerium oleander* plants on the fluoride (F) affected track. Since these plants have the potential to grow and survive even under extreme soil contamination, farmers have started planting such crops in extremely polluted tracks because their flowers have good market value (Fig. 2).

Figure 2: The agricultural patch with *Nerium oleander* plants

Hence, the effect of the distribution of *Nerium oleander* could not be eliminated as it affects not only the accuracy of the results on soil contamination but also the subsequent recommendation of remedial measures. The DSSI model yielded moderate accuracy (R^2 = 0.395) when the places of *Nerium* plants were included in the model validation. Furby et al. (1995) have reported that the multispectral reflectance is confusing in some areas that are non-saline and saline-affected.

The SAR-based models have estimated the level of electrical conductivity (EC)/fluoride (F) contamination with adequate accuracy level (R^2 = 0.73) (Shoba and Ramakrishnan 2017) irrespective of overlying vegetation from RISAT data. The distribution of the high fluoride (F) affected category in 2015 was identified at about 101821 ha, which is 16 per cent higher than the area identified by multispectral models. Hence, the actual level of fluoride (F) contamination has been identified from microwave models, and according to the intensity and upheaval rate of such pollution, we have recommended the process of soil leaching and refilling as a remedial measure before every sowing. Soil refilling is the process of filling the polluted land with fertile soil at a 1m depth just before the sowing period. The soil refilling process has been recommended for most of the agricultural patches of blocks, namely Nallampalli, Dharmapuri and Morappur, experiencing a high rate of soil fluoride (F) upheaval. However, the process is not necessary for soils with a lower degree of upheaval. Hence, we recommended a leaching process using gypsum for the land patches of Pennagaram, Palakodu, Karimangalam, Harur and Pappireddypatty.

The modified Hallikainen model has attained good accuracy in estimating the level of fluoride (F) concentration in the soil when the relative proportion of clay is high in the soil (R^2 = 0.73). The scenario demonstrates that the capillary action is significantly triggered in the clay soil and hence found with a high degree of fluoride (F) upheaval. The linear fitting model follows a logarithmic trend and gets saturated when the imaginary part of DC exceeds 8 and soil fluoride contamination exceeds 6 mg/L. Hence, the model is not applicable to demonstrate the level of soil fluoride contamination when the intensity rate exceeds 6 mg/L. The fluoride (F) level of such patches for the subsequent cycles of sowing and harvesting from 2016 to 2018 was monitored from Sentinel-1 data. The degree of upheaval of contamination through capillary action is being controlled to some extent by practising proper land reclamation, which was recommended according to the intensity of the pollution. The category of high fluoride (F) concentration (more than the permissible limit >1.5 mg/L) has been gradually reduced from 2015 to 2018 (Fig. 3b).



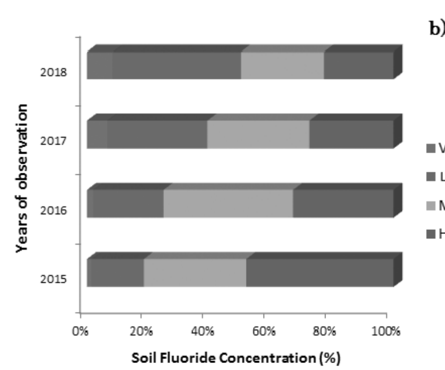


Figure 3: (a) The microwave model could yield adequate accuracy when the relative percentage of clay is significantly higher. (b) The areal distribution of different categories of fluoride contamination from 2015 to 2018. The moderate (1.5–3 mg/L) and high (3–6 mg/L) categories have continuously decreased from 2015 to 2018

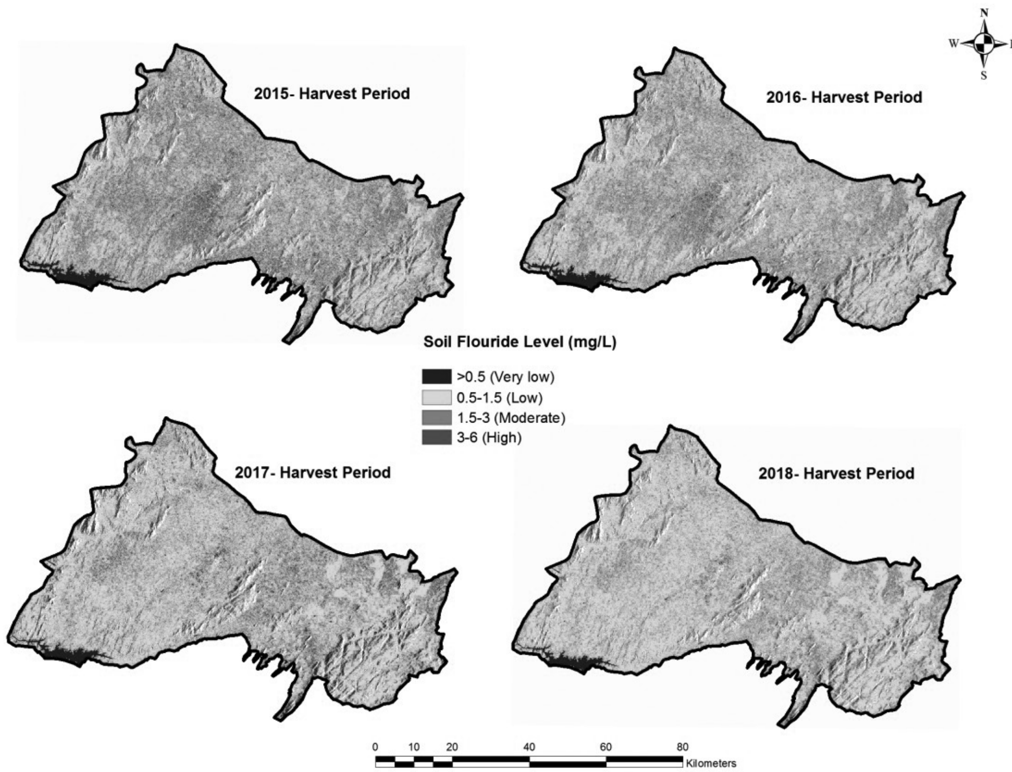


Figure 4: The map showing that fluoride (F) contamination is constantly decreasing from 2015 to 2018 due to the implementation of an appropriate remedial measure with respect to the intensity of the soil pollution

The areal distribution of the highly contaminated category has been significantly decreased by 20 per cent; the moderate category has decreased by 15 per cent. The very low and low categories of contamination have been gradually increased from 2015 to 2016, which indicates that the continuous sustainable land reclamation processes could control the contamination to an adequate extent. The rate of vegetation production by land patches was assessed in the harvest period to investigate the variation in the soil productivity. The increased rate of vegetation from 2016 to 2018 in those places is clear evidence for the reduced upheaval of fluoride (F) in the soil. Hence, the soil degradation due to an uncontrolled upheaval of fluoride (F) has been significantly prevented from desertification.

The DPSVI model could act as an effective model in representing terrestrial biomass irrespective of season and weather by maintaining good accuracy level with actual ground biomass (AGB) (R^2 = 0.73) and the Normalised Differential Vegetation Index (NDVI) (R^2 = 0.75). Hence, to investigate the condition of the vegetation in the agricultural patches for which the remedial measures have been carried out for the subsequent years (2016, 2017 and 2018), we employed the DPSVI model. The condition of the vegetation continually increased from 2015 to 2018 because of the controlled upheaval of fluoride (F) in the soil (Fig. 5). The controlled contamination resulting in the increased productivity of terrestrial biomass was noted in the blocks particularly where the land refilling process was recommended. Since the short-rooted plants were recommended in the areas where the soil refilling processes have been carried out, the percentage of fluoride (F) inheritance by the plants has also been significantly controlled.

During the questionnaire survey, after six cycles of sowing and harvesting, the farmers are reported with the satisfactory yield when compared to previous harvests and reduced impact level of such contamination in the soil and plants due to the practice of appropriate land refilling process according to the actual intensity of the prevailing contamination. Hence, the practice of employing such proper land regeneration measures over a prolonged period will certainly prevent the soil from being desertified.

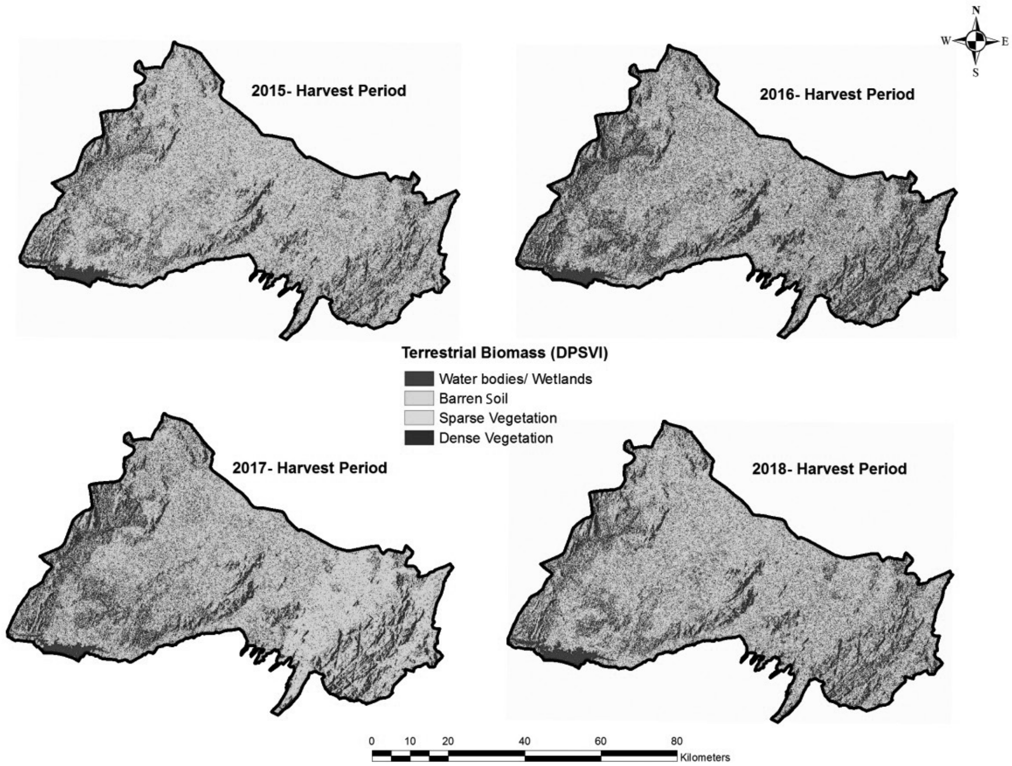


Figure 5: The map showing that the vegetal status has been consistently increased from 2015 to 2018 due to the practice of appropriate remedial measures employed according to the intensity of the pollution

Conclusion

The research has been carried out to estimate and investigate the degree to which fluoride (F) contaminates soil and its direct correlation with desertification. Since the region is highly distributed with salt-tolerant plants for most of the year, the assessment of vegetal degradation and soil desertification was not possible by optical and hyperspectral remote sensing models. The SAR technique of microwave remote sensing has been employed in the research due to its penetration capacity and sensitivity towards dielectric constant and roughness. According to the research findings, natural remedial measures were recommended based on the intensity of pollution. The condition of the soil and vegetation growth has shown significant improvement in six cycles of sowing and harvesting because of implementing the proper land reclamation process. Due to active geological elements in the region, the problem of soil contamination and subsequent desertification cannot be eradicated. However, the problem could be controlled to an adequate extent by adopting appropriate measures.

Acknowledgements

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References

Ackermann N (2015) Growing Stock Volume Estimation in Temperate Forested Areas Using a Fusion Approach with SAR Satellite Imagery, Springer, Switzerland. DOI 10.1007/978–3-319–13138–2.

Adhikary PP, Dash CJ, Sarangi A, Singh DK (2014) Hydrochemical characterization and spatial distribution of fluoride in groundwater of Delhi state, India. Indian J Soil Conserv 42: 170–173.

Attema EP, Ulaby FT (1978) Vegetation modelled as a water cloud. Radio Sci 13: 357–364.

Bindlish R, Barros AP (2000) Multifrequency soil moisture inversion from SAR measurements with the use of IEM. Remote Sensing of Environment 71: 67–88.

Capstick DR (1998) The application of ERS-2 SAR data in the prediction of sugar beet and potato crop yields. Thesis (MSc), Department of Geography, University College London.

Currell MJ, Han DM, Chen ZY, Cartwright I (2012) Sustainability of groundwater usage in northern China: dependence on palaeowaters and effects on water quality, quantity and ecosystem health. Hydrol Process 26: 4050–4066.

Dabrowska-Zielinska K (2007) Inferring the effect of plant and soil variables on C- and L-band SAR backscatter over agricultural fields, based on model analysis. Advances in Space Research 39: 139–148.

Dobson MC, Ulaby FT, Hallikainen MT, El-Rayes MA (1985) Microwave dielectric behaviour of wet soil—Part II: Dielectric mixing models. IEEE Trans Geosci Remote Sens 23: 35- 46.

Dubois PC, Van Zyl J, Engman T (1995) Measuring soil moisture with imaging radar. IEEE Transactions on Geoscience and Remote Sensing 33: 915–926.

Furby SL, Wallace JF, Caccetta P, Wheaton GA (1995) Detecting and monitoring salt-affected land, Report to LWRRDC project CDM1.

Ghasemi N, Sahebi MR, Mohammadzadeh A (2011) A review on biomass estimation methods using synthetic aperture radar data. Int J Geomat Geosci 1: 776–788.

Gong H, Shao Y, Brisco B, Hu Q, Tian W (2013) Modeling the dielectric behaviour of saline soil at microwave frequencies. Can J Remote Sensing 39(1): 1726.

Hallikainen MT, Ulaby FT, Dobson MC, El-Rayes, MA, Lin-Kun Wu (1985) Microwave Dielectric Behavior of Wet Soil-Part 1: Empirical Models and Experimental Observations. IEEE Transactions on Geoscience and Remote Sensing 23(1): 25–34.

Higginbottom TP, Symeonakis E (2014) Assessing Land Degradation and Desertification Using Vegetation Index Data: Current Frameworks and Future Directions. Remote Sens 6: 9552–9575. DOI 10.3390/rs6109552.

Kim Y, Van Zyl J (2009) A Time-Series Approach to Estimate Soil Moisture Using Polarimetric Radar Data. IEEE Transactions on Geoscience and Remote Sensing 47: 2519 – 2527. DOI 10.1109/TGRS.2009.2014944.

Kumar K, Hariprasad KS, Arora MK (2014) Study of water cloud model vegetation descriptors in estimating soil moisture in Solani catchment: Water Cloud Model Vegetation Descriptors. Hydrological Processes 29(9). DOI 10.1002/hyp.10344.

Lasne Y, Paillou P, Ruffie C, Serradilla F, Freeman A, Farr T, McDonald K, Chapman B, Malezieux JM (2008) Effect of salinity on the dielectric properties of geological materials: implication for soil moisture detection by means of radar Remote Sensing. *IEEE Transactions on Geoscience and Remote Sensing* 46(6): 1674–1688.

Lin NF, Tang J (2002) Geological environment and causes for desertification in arid-semi-arid regions in China. Environ Geol 41: 806–815.

Liu C, Shi J (2016) Estimation of Vegetation Parameters of Water Cloud Model for Global Soil Moisture Retrieval Using Time-Series L-Band Aquarius Observations. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 9(12): 5621 – 5633. DOI 10.1109/JSTARS.2016.2596541.

Li Y, Zhao K, Ren J, Ding Y, Wu L (2014) Analysis of the Dielectric Constant of Saline-Alkali Soils and the Effect on Radar Backscattering Coefficient: A Case Study of Soda Alkaline Saline Soils in Western Jilin Province Using RADARSAT-2 Data. Scientific World Journal 14.

Mohamed NAH, Salih EM, Abdu AS (2011) Monitoring Vegetation Degradation as indicator of Desertification in Sudan using NDVI data 1993 – 2003. Sudan J Des Res 3(1): 15–27.

Quan C, Jiuli L, Zhihua T, Jiangyuan Z, Yan L (2014) Study on the relationship between soil moisture and its dielectric constant obtained by space-borne microwave radiometers and scatterometers. Earth and Environmental Science 17: 1–6.

Shoba Periasamy (2018) Significance of dual polarimetric synthetic aperture radar in biomass retrieval: An attempt on Sentinel-1. Remote Sensing of Environment 217: 537–549. DOI 10.1016/j.rse.2018.09.003.

Shoba Periasamy, Ramakrishnan S Shanmugam (2017) Multispectral and Microwave Remote Sensing Models to Survey Soil Moisture and Salinity. Land Degradation & Development 28: 1412–1425. DOI 10.1002/ldr.2661.

Shrestha DP, Margate DE, Van Der Meer F, Anh HV (2005) Analysis and classification of hyperspectral data for mapping land degradation, An application in southern Spain. Int J Appl Earth Obs Geoinf 7: 85–96.

Topp GC, Davis JL, Annan AP (1980) Electromagnetic Determination of Soil Water Content: Measurement in Coaxial Transmission Lines. Water Resources Research 16: 574–581.

UNCCD 1994, United Nations Convention to Combat Desertification, Geneva, Switzerland, United Nations, Available from: https://www.kcl.ac.uk/projects/desertlinks/downloads/deliverables/Deliverable%201.2b_en.pdf, pp. 58.

Veron SR, Paruelo JM (2010) Desertification alters the response of vegetation to changes in precipitation. Journal of Applied Ecology 47: 1233–1241. DOI 10.1111/j.1365–2664.2010.01883.x.

LiDar-Based Land-Water Boundary Identification during Floods

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ABSTRACT: In recent years, the frequency and the intensity of floods is increasing, putting more life and property at risk. In order to plan and execute the rescue operations efficiently, it is important to know the rate at which the topography of the area is changing. This serves as the motivation for our work wherein we are trying to differentiate the inundated areas from the rest using LiDAR (Light Detection And Ranging) data which would be collected by a UAV (Unmanned Aerial Vehicle) flying over the area of interest with a light-weight LiDAR mounted on it. We hope to compute the rate at which the land and water boundary is advancing or receding with time by comparing the current topography with previous topography. The principle that is involved in this work is that different terrains have different reflection properties. The LiDAR returns two kinds of information, the intensity of the reflected beam and the range information or the distance of the reflected surface from the LiDAR. The intensity of the reflected beam depends on different properties of the surface. For the experiments, we have used Benewake TF02 LiDAR. The results obtained show that mean intensity value, percentage of miss points and amount of scatter are good enough to differentiate land from water.

KEYWORDS: LiDAR, photogrammetry, flood management, land-water boundary

Introduction

There has been considerable interest in the applications of Unmanned Aerial Vehicles (UAVs) over the past decade, and a number of methods that use UAVs, especially multi-rotors, for versatile applications to aid in flood management have been proposed. The advantages of UAVs are especially significant in disaster management, since they could greatly alleviate the dangers faced by human responders. Furthermore, since they are highly mobile, they could potentially cover much larger areas in shorter periods of time. In a flooding situation, it is often desirable to quickly determine if regions of land have become inundated by flood water. Traditionally, LiDARs have been extensively used in the creation of highly detailed topographic Digital Elevation Maps (DEMs), providing thousands of data points per scan, even when the ground is obscured by the forest canopy. Large regions can be registered within short time-frames and DEMs are interpolated from the individual 3D range-points. LiDARs have proved so advantageous with their high resolution and coverage that they have become one of the most widely used methods of generating DEMs.

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White paper	Up to 100 per cent
Snow	80–90 per cent
Beer foam	88 per cent
Deciduous trees	~60 per cent
Coniferous trees	~30 per cent
Dry sand	57 per cent
Wet sand	41 per cent
Asphalt with pebbles	17 per cent
Black neoprene	5 per cent
Clean water	<5 per cent

Figure 1: Spectral reflectance values of different materials

In order to create accurate DEMs, it is necessary to distinguish between land and water in the regions with water bodies, such as coastlines. Leckie et al. demonstrated that it is possible to distinguish between land and water given high-resolution multispectral imagery. The classification of water was especially accurate in their analysis. Mundt et al. demonstrated that the LiDAR data accompanied with multispectral imagery significantly increases the accuracy of classification. However, the addition of multispectral imagery in a UAV might be difficult due to the strict weight constraints. Brockmann et al. proposed an approach which uses the prior knowledge of the 2D position of the river, along with bathymetric measurements for the same. This is because accurate prior knowledge of water location is difficult to obtain in a flooding situation. Brzank et al. presented the use of the LiDAR intensity information for the classification. However, this method does not use the original LiDAR range information but rather the grid information, which is generated post flight using several LiDAR scan strips. Brzank et al., in another work, use a number of parameters and a fuzzy classification algorithm to distinguish between land and water. However, the topographic LiDARs used for these purposes tend to be heavy, typically in the range of hundreds of kilograms, and are often mounted on planes that are flown over the area of interest to be mapped. Therefore, a much smaller and lighter LiDAR is required if it is to be mounted onto a much smaller UAV. Such LiDARs, typically with a single return, often only provide one range measurement per scan. In this paper, we aim to show that a LiDAR can be used to obtain range information that could be used to determine the level of inundation and assist in the landing the UAV, and to quickly distinguish between land and water.

Methodology

A LiDAR measures the distance to a target by illuminating it with laser light, typically in the near-infrared region, and measuring the time taken for the reflected pulses to return. A large number of such measurements can be used to make a high-fidelity 3D-digital representation of the target. Associated with each range measurement is an intensity value which is essentially a measure of the strength of the signal that is returned. The intensity value is often represented as a scaled integer as the ratio of the power of the incoming pulse to that of the power of the outgoing pulse, as in the case of Benewake TF02 LiDAR, where it ranges from 0 to 2000.

The LiDAR intensity values play an important role in distinguishing between the land and the water points, since they provide information about the material of the surface the LiDAR beam reflects off of, because of the spectral reflectance of the surface. The spectral reflectance is defined as the fraction of electromagnetic power that is reflected from a surface. The greater the reflectance value of the material, the higher the incident energy that is reflected from the surface and the stronger the received intensity value signal of the LiDAR should be. Figure 1 presents the table which contains the values of the spectral reflectance of different materials.

From the table it can be seen that the magnitude of the intensity of a returned laser beam echo for an illuminated water area is lower than the intensity echo of an illuminated land area within the survey area. This is because a vast part of the emitted radiation energy is absorbed by the water and a very small portion of the energy is reflected back. We define 'missed points' as the occurrences where the LiDAR sends an outgoing pulse of energy but does not receive a signal back, or the return signal is so weak that the LiDAR does not recognise it. It is also important to note that as much of the emitted energy in the near-infrared region is absorbed by water, the LiDAR signal cannot penetrate into the water to obtain depth measurements. Thus, a LiDAR that operates in the near-infrared region can only return the distance between the surface of the water and itself. We identify three parameters that help us identify water in the recorded LiDAR data:

- The presence of scatter in the LiDAR intensity data, since the water surface usually has ripples
- The mean of the intensity data that is lower than that of land
- The presence of a greater number of missed points as the spectral reflectance of water is much lower than that of land, which greatly increases the odds of missed points

Figure 2: Benewake TF02 LiDAR

Experimental Results

A number of experiments were conducted in both indoor and outdoor environments to test the soundness of the methodology. The details of the experiments and the results obtained are summarised as follows.

Hardware

The Benewake TF02 LiDAR (see Fig. 2) was used to perform our experiments because of its low cost and weight. Some of its specifications are mentioned as follows:

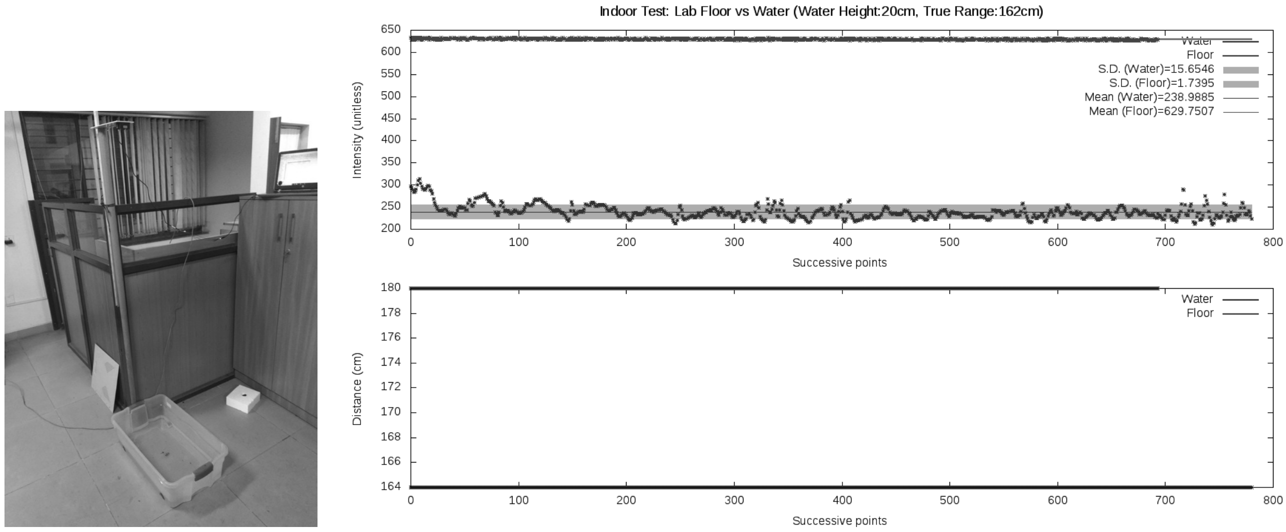
- Wavelength: 850nm
- Indoor Operating Range
  - Surface reflectivity 10 per cent: 0.4–10m
  - Surface reflectivity 90 per cent: 0.4–22m
- Outdoor Operating Range (100Klux)
  - Surface reflectivity 30 per cent: 0.4–10m
- Accuracy: ≤ 6cm
- Range resolution: 1cm
- Frequency: 100Hz
- Returns a value of 2200 if no return signal is received

Experiment I

In the first set of experiments, the LiDAR was mounted indoors in a laboratory setup at a height of 182 cm, facing downwards. Initially, the LiDAR was kept facing the floor and the range and intensity values were recorded. Then, this procedure was repeated for a container of water with depth 20 cm. An image of the experimental setup can be seen in Fig. 3. From the range plots, it can be seen that the LiDAR identifies the land to be at a distance of 180 cm and water surface to be at a distance of 164 cm, which is more or less correct since depth of water is 30 cm and the light is reflected off the surface of the water. At the same time, the intensity plots for land and water show that the mean of the intensity value for land is greater than that of water. The scattering of intensity values is also more for water than for land, which can be seen from the intensity standard deviation (SD). Thus, land and water can be successfully distinguished based on the described methodology.

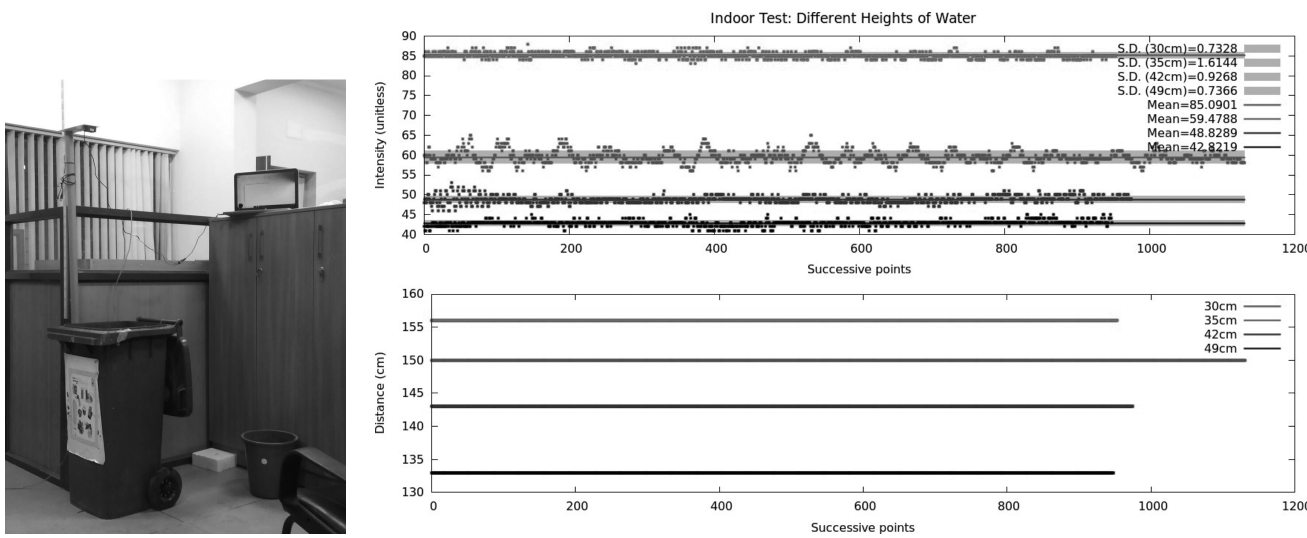
Experiment II

In the second set of experiments (see Fig. 4), the LiDAR was mounted indoors in a laboratory setup at a height of 182 cm from the ground, facing downwards. Containers of water with depths 30 cm, 35 cm, 42 cm and 49 cm were then kept below the LiDAR respectively and the range and intensity values were recorded for all four cases.



(a) (b)

Figure 3: Experiment I (a) experimental setup (b) results



(a) (b)

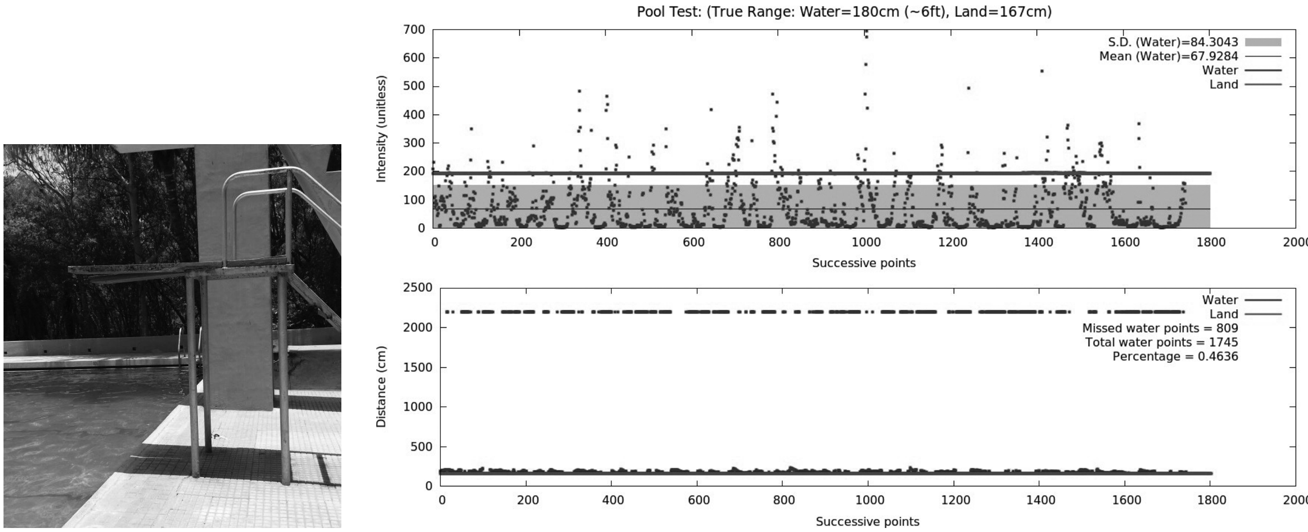
Figure 4: Experiment II (a) experimental setup (b) results

From the range plots, it can be seen that the LiDAR identifies the various water levels at depths of 26 cm, 32 cm, 39 cm and 48 cm respectively. Thus, there is a penetration of about 1 to 3 cm before light beam is reflected back. From the intensity plots one can see that as the depth of water increases, the mean of the intensity of the reflected beam decreases.

Experiment III

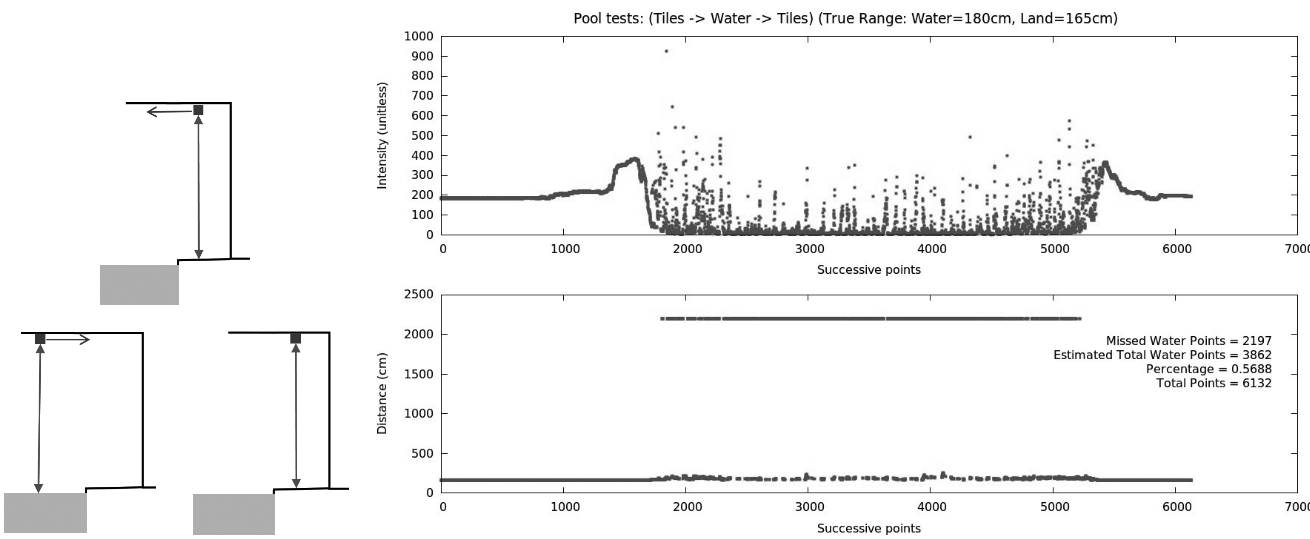
In the third set of experiments (see Fig. 5), the LiDAR setup was taken outside and was mounted such that it faced the land surface from a height of 165 cm and water from a height of 180 cm. The range and intensity values were subsequently recorded for both the cases.

For the Beneweke TF02 LiDAR, the missed points give an arbitrary reading of 2200 cm in the range readings. It can be clearly seen that in the case of water there are a lot of missed points. At the same time, the mean of the intensity values is less for water than for land and there is also much scattering in the values for water. Thus the above experiment shows the soundness of the methodology in the outdoor scenario.



(a) (b)

Figure 5: Experiment III (a) experimental setup (b) results



(a) (b)

Figure 6: Experiment IV (a) experimental setup (b) results

Table 1: Expeimental Results

Experiment	Intensity Mean		Intensity S.D.		Missed Points	
	Land	**Water**	**Land**	**Water**	**Land**	**Water**
Experiment I	629.7507	238.9885	1.7395	15.6546	0 per cent	0 per cent
Experiment III	189.5608	67.9284	0.0	84.3043	0 per cent	46.36 per cent
Experiment IV	204.108	59.5362	37.8203	100.5036	0 per cent	56.88 per cent

Experiment IV

In the fourth set of experiments (see Fig. 6), the LiDAR setup was mounted at a height of 165 cm from the ground outdoors for 15 seconds. It was then slowly moved at a near-constant velocity keeping its height level such that it faced the water surface at a distance of 180 cm. It was kept facing the water for 30 seconds and then it was again moved inland. The range and intensity values were recorded continuously throughout the experiment.

It can be clearly seen from the range plots that the number of missed points increases significantly when the LiDAR is kept over water. The range values for land are quite consistent. At the same time, the mean of the intensity values is less for water than for land and there is also much scattering in the values for water. Thus the LiDAR gives accurate results even when it is in motion. Table 1 gives a summary of the experimental results for distinguishing land and water.

Discussion

In the present state of this work, the primary experiments for distinguishing the water from the land and various other surfaces like concrete and vegetation have been carried out, with the LiDAR being slow moving or stationary. The results obtained from these experiments have been discussed above (see Section III). However, the expectation of the project is that the LiDAR should be mounted on the UAV which flies over the flooded area, to distinguish between the land and the inundated areas to detect the land-water boundary. Following this, the behaviour of the boundary is to be studied to extract and predict the relevant information for the aid of the first responders and the authorities in the flood scenario, to help them plan and manage the evacuation, rescue, resource distribution, routing and other critical operations. For this, we have planned our experiments using a Tarot IronMan 650 quadcopter with the Benewake TF02 LiDAR mounted on it using a gimbal. The gimbals are used to ensure that the LiDAR always points downward, which is the desired and the most efficient setup to get the highest quality data. The UAV flies over the desired area in a pre-specified path and the LiDAR continuously fires pulses and records returns all along, to be analysed at the base after the return of the UAV. This setup will be used to obtain pre-flood land-water status data of the flood prone area which will be used as reference for the comparison with the data obtained during the UAV flights during the flood. Another important aspect of the study is the performance of the LiDAR while the UAV is in flight, and how it behaves for different speeds of the UAV. The data obtained from multiple UAV runs is then to be used for prediction of future instants using state-of-the-art curve fitting methods.

Conclusion

In this paper, a method to use light-weight LiDARs mounted on a UAV to distinguish between land and water in a flooding scenario was presented. A LiDAR is used to fire pulses and record return signals, and the algorithm classifies the return surfaces based on the intensity of the return signal, number of missed points and extent of scattering of the pulse. The information obtained is used to mark the land-water boundary and study its behaviour over some time to predict the future information, to help the ground-based teams in the flooding scenario. The details of a simple methodology to achieve the mentioned objective were discussed along with experimental methods to validate the proposed method. The scope and extension of the proposed concept to be used on unmanned aerial systems to be deployed in a real flooding scenario were discussed, along with the associated issues and remedies.

Acknowledgements

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References

[Online]. Available: http://web.pdx.edu/jduh/courses/geog493f12/Week04.pdf

[Online]. Available: http://www.benewake.com/en/down.html

A. Brzank, J. Gopfert, and P. Lohmann, "Aspects of lidar processing in coastal areas," *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 36, no. Part 1, p. W3, 2005.

A. Brzank and C. Heipke, "Classification of lidar data into water and land points in coastal areas," in *Int. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 36. Citeseer, 2006, pp. 197–202.

D. G. Leckie, E. Cloney, C. Jay, and D. Paradine, "Automated mapping ofstream features with high-resolution multispectral imagery," *Photogram- metric Engineering and Remote Sensing*, vol. 71, no. 2, pp. 145–155, 2005.

H. Brockmann and G. Mandlburger, "Construction of a digital terrain model of the watercourse of the grenzoder," *Remote Sensing and Geoin- formation*, vol. 110, pp. 199–208, 2001.

J. T. Mundt, D. R. Streutker, and N. F. Glenn, "Mapping sagebrush distribution using fusion of hyperspectral and lidar classifications," *Photogrammetric Engineering and Remote Sensing*, vol. 72, no. 1, pp. 47–54, 2006.

Monitoring Terrestrial Resources Using Sentinel-2A Satellite Data for Natural Resource Management: A Case from Hiran Basin, Gujarat, India

Rahim Dobariya[a]

ABSTRACT: A simple yet successful case of vegetation and surface water bodies monitoring is presented with a case from Hiran basin in Gujarat, India. Watershed was delineated using the SRTM digital elevation model (DEM) and processed with the ArcHydro tool within the ArcGIS environment. Google Earth Engine cloud computing platform was used to analyse Sentinel-2A imagery. Out of 117 Sentinel-2A images spanning from 1 January 2016 to 31 December 2018, 69 images with cloud cover less than 10 per cent were used. A monthly composite was generated, further filtering the cloud pixels. The Normalised Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI) were created using the monthly composite image. The values of greater than 0.2 for NDVI and greater than 0 for NDWI were used as threshold values to classify vegetation and water body respectively.

The study showed that water bodies in the area shrink by 68 per cent during summer, resulting in decrease of vegetation cover by 70 per cent. Strong correlation between water bodies and vegetation covered area suggests the impact of surface water on vegetation cover. Based on the research findings, several interventions at village level are recommended.

KEYWORDS: Sentinel-2, NDVI, NDWI, mapping, remote sensing

Introduction

Over the past few decades, satellite remote sensing has been playing a crucial role in forest monitoring, disaster management, and water and agricultural applications. Various satellites possess different retrieval characteristics due to their customised sensors. Remote sensing images may be produced by optical sensors with a good number of spectral bands and require a tailored analysis depending on specific applications. So far, a common approach in satellite remote sensing is use of indices to facilitate the classification of diverse land covers or plant phenology. The most basic indices are the Normalised Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI). NDVI, proposed by Rouse et al. (1973), has the ability to classify land covers, as well as vegetation vitality. This index is defined by the reflectance of red and near-infrared (NIR) bands. Thus, this index can be applied to classify land covers. NDWI was proposed by McFeeters (1996) to assess water status by the combination of green and near-infrared (NIR) bands.

Surface water bodies are dynamic in nature, because they shrink or expand with time, owing to a number of natural and human-induced factors. Variations in water bodies have significant impacts on natural

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resources and human assets and further influence the environment (Karpatne et al., 2016). Also the water has direct correlation with vegetation cover. Spatiotemporal monitoring of water body dynamics is thus essential for understanding water availability and providing descriptive insights about the natural processes.

This study is therefore aimed to analyse and understand surface water and the seasonal vegetation pattern and its correlation using the latest tools and techniques. This is completely a desktop offsite study (with some field knowledge) based on freely available remote sensing data. The study demonstrates the potential of Sentinel-2A imagery and the Google Earth Engine (GEE) platform. User-friendly tools and procedures were developed which have the potential to replicate in other areas with little modification. The tools and procedures have potential to narrow down the field study area to identify a suitable location for building small dams and tree plantation with the ultimate aim of increasing water availability and vegetation coverage.

The Geographic Information System (GIS) and remote sensing (RS) technologies are mainly used and play a key role in the research. ArcGIS desktop 10.6 and the GEE platform were used to perform geospatial analysis and generate different outputs. The GEE cloud computing platform was used to analyse Sentinel-2A imagery. It is the most advanced cloud-based geospatial data processing platform, which provides a new way to acquire satellite imagery. The user-friendly front end provides a workbench environment to interact with data and algorithm development which enables the user to detect changes, analyse trends and quantify differences on the Earth's surface. It was successfully utilised for studying global forest loss and gain (Hansen et al., 2013; Kim et al., 2014).

Study Area

The study area is located about 400 kms south-west near to the Arabian Sea from Gandhinagar, the state capital of Gujarat, and Ahmedabad city. It is located at 70.5° longitude and 21.1° latitude, in the Hiran basin, the catchment in the Gir Somnath District (Figure 1), with an area of 500 km^2. The river originates in the Gir Forest, flows south-west and meets the Arabian Sea near Prabhas Patan.

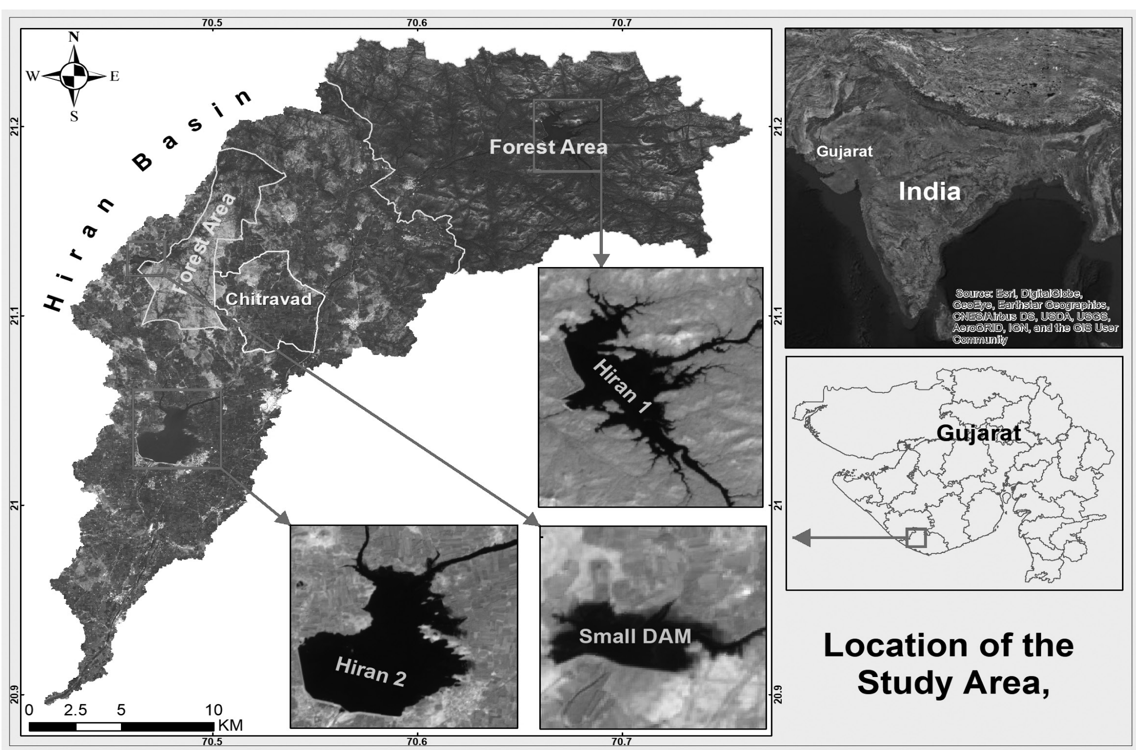


Figure 1: Extent of study area: Hiran basin, Gujarat, India

A total of 90.4 per cent of the river basin lies within the Talala subdistrict of Gir Somnath district and a small patch lies in Junagadh district and an other subdistrict of Gir Somnath. While the southern side of the basin is relatively flat, the northern part of the basin is hilly. Around 44 per cent of the basin is covered by forest. Chitravad village is spread over 4.4 per cent of the basin, the largest area compared to other villages in the basin.

Generally, the winter season in the area is mild, pleasant and dry. Average temperatures range between 29°C in the day and 12°C at night. In the monsoon, the temperatures remain around 35°C with high levels of humidity. Mostly rainfall occurs during the monsoon season, June to October. Rainfall data during the period 1988–2017 shows that Talala subdistrict receives an average of 1029 mm rainfall annually. It is the subdistrict with the second highest average rainfall after Visavadar subdistrict, in the Saurashtra region and 40 subdistricts of Gujarat state. Talala received 563 (55 per cent) mm of rainfall in 2015, 1116 (108 per cent) mm in 2016, 1101 (107 per cent) mm in 2017 and 1116 (108 per cent) mm in 2018 (GSDMA, n.d.). Usually the summers are considered as quite hot and dry with daytime temperatures up to 41°C and nighttime temperatures dropping to around 29°C.

The Hiran basin has two major man-made reservoirs (dam): Hiran-1 (elevation 192 m) upstream and Hiran-2 (elevation 63 m) located downstream. Hiran-I has 3.35 km^2 and Hiran-II has 8 km^2 at full reservoir level. Hiran-I and Hiran-II dams have 81 km^2 and 349 km^2 catchment areas respectively (Narmada, Water Resources, Water Supply and Kalpsar Department, n.d.). Hiran basin also has a small reservoir with 0.6 km^2, located on the mid-west side of the basin.

Materials and Methods

First, watershed characteristics were extracted using a 30 m resolution digital elevation model (DEM) of the Shuttle Radar Topography Mission (SRTM); changes in the vegetation and surface water were investigated over the time period (January 2016 to December 2018) using GEE. Using remotely sensed NDVI and NDWI values, different temporal patterns in coniferous and deciduous vegetation and surface water stands were identified. Monthly extent of vegetation and surface water area was extracted from 10 m Sentinel-2A imagery with the unsupervised classification method.

Watershed Delineation

Watershed was delineated using SRTM DEM V3 and processed with the ArcHydro tool within the ArcGIS environment. It is a 30 m resolution DEM freely available around the world (Farr et al., 2007). It is a popular source for hydrological modelling because of its simple data structure and widespread availability.

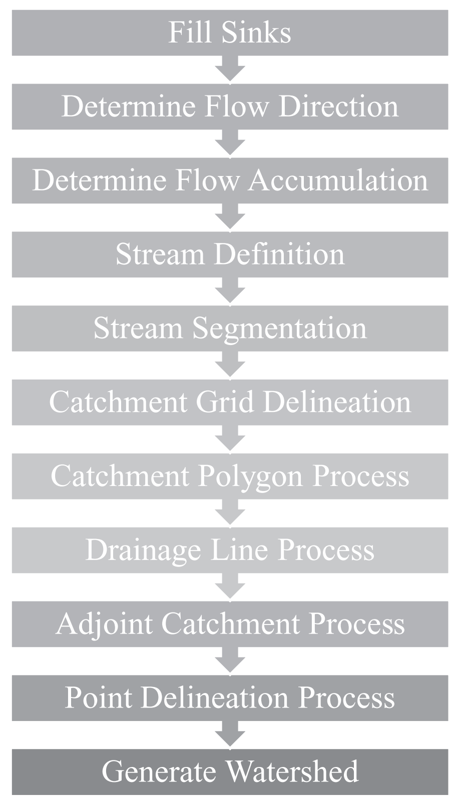


Figure 2: Steps of watershed boundary delineation

DEM data of Hiran basin area was processed using a set of tools of ArcHydro (ESRI, 2011) as summarised in Figure 2. The process began with filling of artificial depressions in the DEMs using the “Fill Sink” tool, and later the flow direction map was created using the “Flow Direction” tool. Each cell in the flow direction map contains eight possible direction values: 1, 2, 4, 8, 16, 32, 64 and 128. Subsequently, other tools were used to generate flow accumulation, stream definition, stream segment, etc. In the "Stream Definition" tool, a threshold value of "1" was assigned. Stream networks were created using the "Drainage Line Processing" tool, and catchments were created using the "Catchment Grid Delineation" and "Catchment Polygon Processing" tools. Finally, a catchment polygon and drainage network were generated.

The waterbody was digitised manually using Google Earth and OpenStreetMap. Forest area and the Chitravad village boundary were digitised using the maps of the Revenue Department, Government of Gujarat (Revenue Department, n.d.,), Google Earth and OpenStreetMap. The watershed boundary was imported in GEE to spatially filter sentinel-2A imagery.

Extraction Vegetation and Surface Water

Sentinel-2A satellite imagery was used to extract vegetation and surface water between January 2016 and December 2018. The Sentinel-2A optical sensor launched in 2015 as a part of the European Space Agency's (ESA) Copernicus Programme with improved radiometrics, increased number of bands, shorter revisit time, higher spatial resolution and free availability. The near-infrared band and short-wave infrared band provide more details that are helpful for water, agriculture, forest monitoring and natural disaster management applications.

Using GEE, parameters were extracted from sentinel-2A imagery such as NDVI and NDWI, followed by changes in detection in vegetation and surface water, over the study period. GEE code editor scripts were used to process satellite images. Custom script was developed referring to official Google resources (Google, 2019). The watershed boundary generated was imported to GEE, which was then used to spatially filter and clip imagery to an area of interest. The developed tool using script consists of six main steps to derive the desired results as summarised in Figure 3. The tool is accessible from the GEE platform (https://rahimweb.users.earthengine.app/view/ndi).

The sensor was filtered by Sentinel-2A and image collections were temporally filtered from 1 January 2016 to 31 December 2018. Further, image quality was filtered with less than 10 per cent cloudy pixel. Figure 4 illustrates that during July and August satellite images are not available with less than 10 per cent cloudy pixel, which limits the extraction of vegetation and water surface area during these months. A total of 117 images were found in catalog. Images with more than 10 per cent cloud were excluded, further filtering the cloud pixels. As a result, 69 images were found and considered for further analysis.

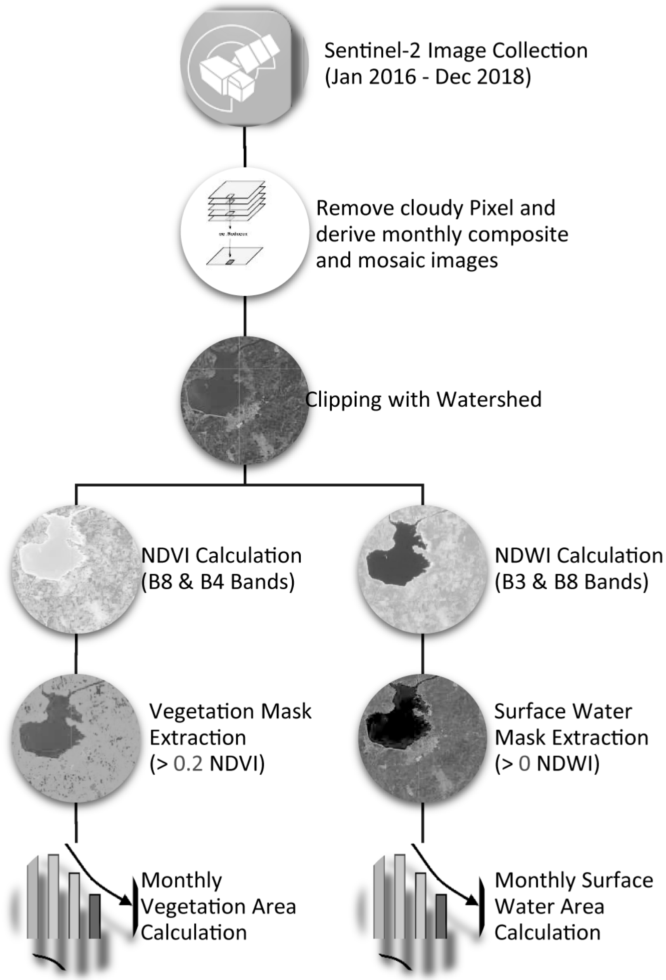


Figure 3: Process of vegetation and surface water extraction

Monthly composite images were derived combining spatially overlapping images into a single image based on median aggregation function in GEE. Later, using the mosaicking function the images were stitched to produce a spatially continuous image. As a result, image collection contains one image per month from January to December except for July and August.

The bands B02 (Blue), B03 (Green), B04 (Red) and B08 (NIR) were clipped with watershed polygon of Hiran basin and true colour composite monthly images as presented in Figure 5 were prepared.

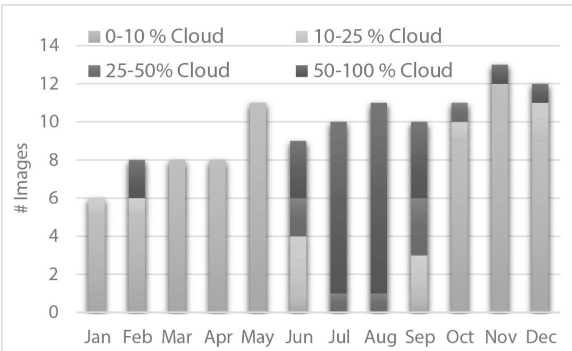


Figure 4: Monthly Sentinel-2A imagery collection from 2016 to 2018

NDVI was used to calculate the biomass vegetation quantity based on red band and near-infrared band (NIR). It is a simple but effective index used to calculate green vegetation. It normalises green leaf scattering in the NIR wavelength and chlorophyll absorption in the red wavelength. The value of NDVI ranges between -1 and 1. Negative values of NDVI (values approaching -1) correspond to water. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock/stone, sand or snow. Low positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values approaching 1 indicate temperate and tropical rainforests (Sentinel Hub, n.d.). Pixel value less than 0.2 was excluded and masked with NoData. Pixel value 0.2 and above was assigned with value 1 representing vegetation.

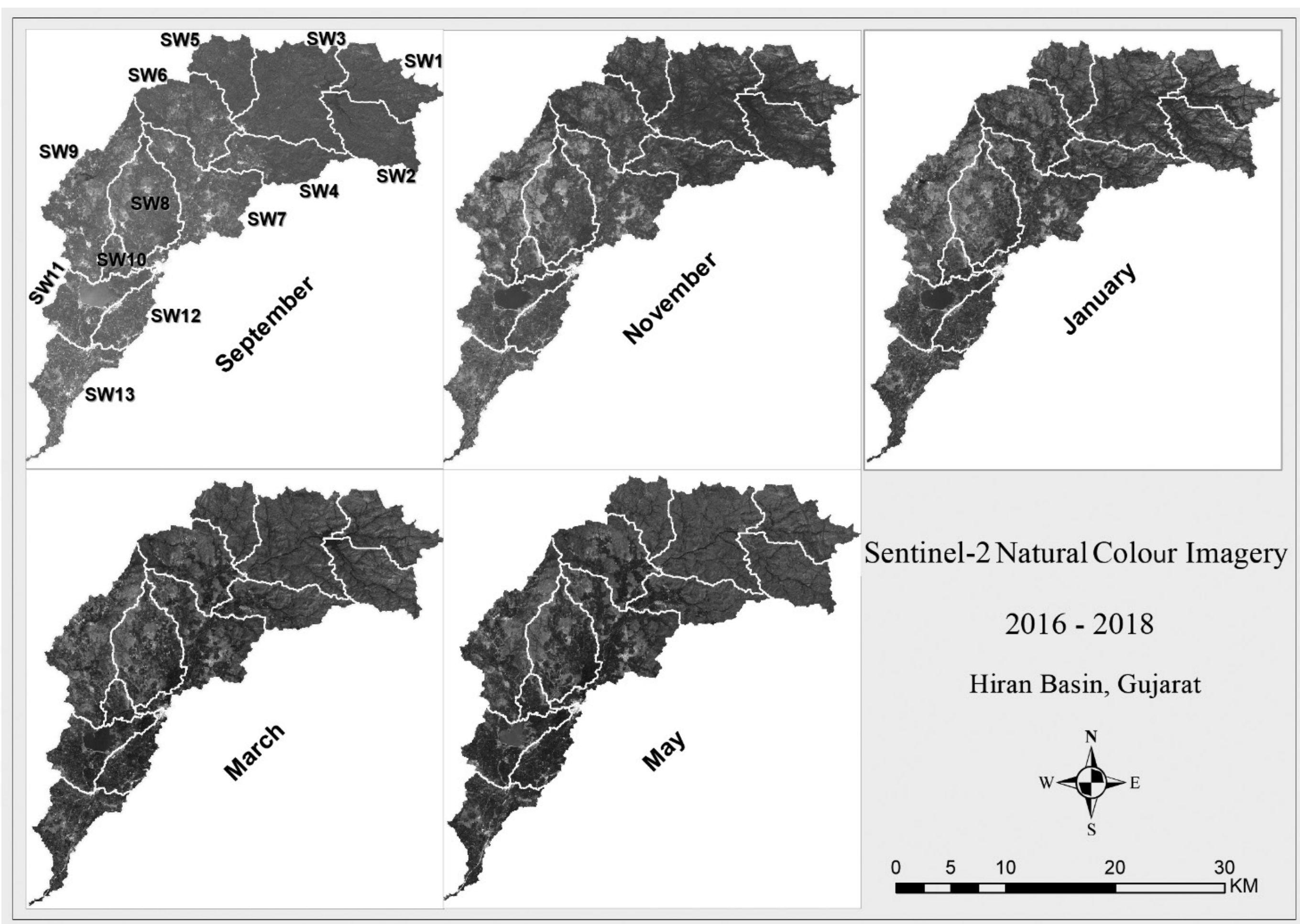


Figure 5: Natural (true) colour imagery (bands red/green/blue)

NDWI values which range between -1 and 1 were used to identify water bodies. NDWI enhances detection of water bodies using green and NIR bands. The NDWI index is most commonly used to identify surface water. Water features have positive values, whereas soil and terrestrial vegetation features have zero or negative values (McFeeters, 1996). Moreover, the NDWI is built to avoid water content in leaves of vegetation and floating leaved vegetation and only extract pure standing water (Karsli et al., 2011). Based on the reflectance characteristics of water, NDWI values for water are usually greater than 0. Therefore, a threshold of 0 is often applied to extract water from index images (Xu, 2006). However, it has been suggested that adjustment of the threshold value could usually achieve better extraction results (Ji et al., 2019). In this case, 0 threshold value was applied. Pixel value less than 0 was excluded and masked with NoData while pixel value above 0 was assigned 1 representing waterbody.

In this final step, the area covered by vegetation and surface water was calculated for each month. The time series graphs were generated from the image collections. Necessary raw and processed images and generated graphs and statistics were exported to the local computer to prepare better maps and graphs using ArcMap and statistical software.

Results

Figures 6 and 7 show DEM (left) used as a base input and delineated watershed (right) including digitised waterbody, forest area and Chitravad village boundary. The average and maximum elevation of the basin are 154m and 423m, respectively. The lowest elevation in the DEM is 0m at downstream. The watershed is a dendritic type with 13 sub-watersheds which are named SW1 to SW13 for identification purposes and generate different analysis.

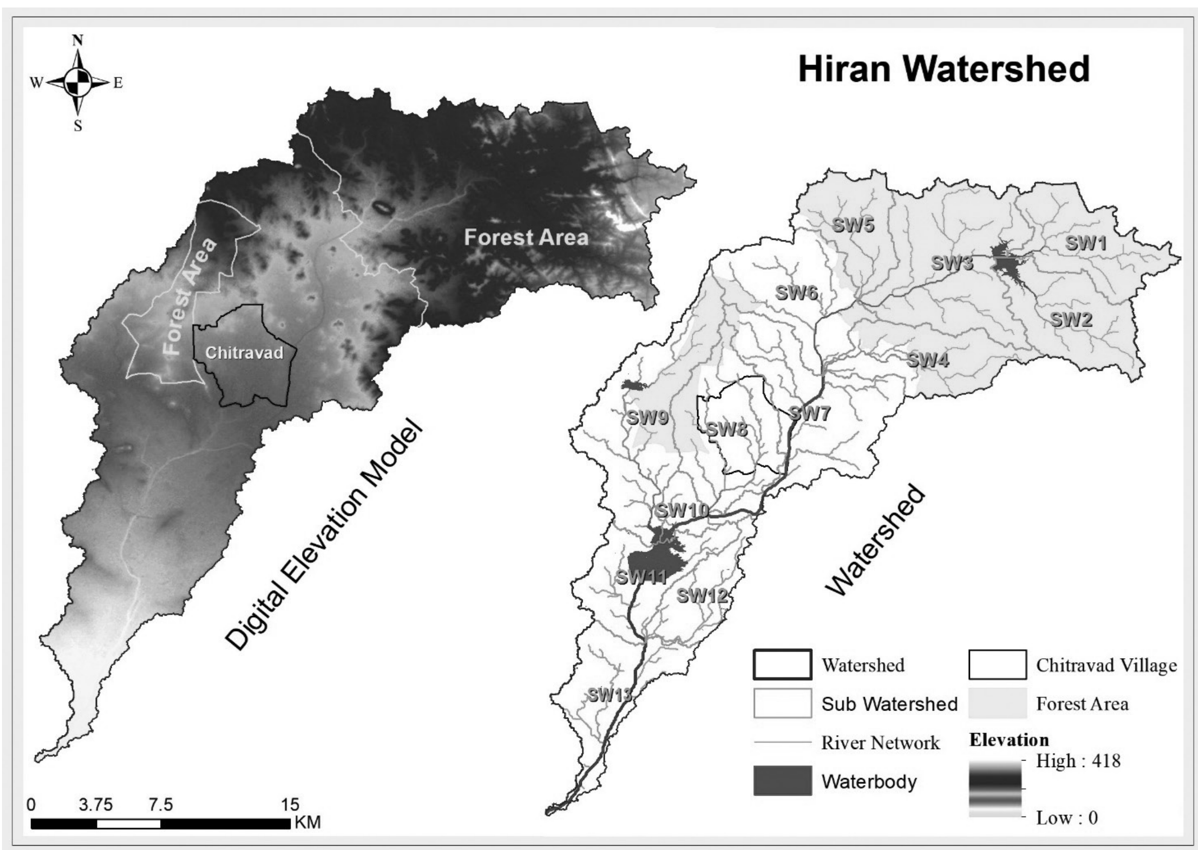


Figure 6: The delineated watershed including sub-watershed boundary

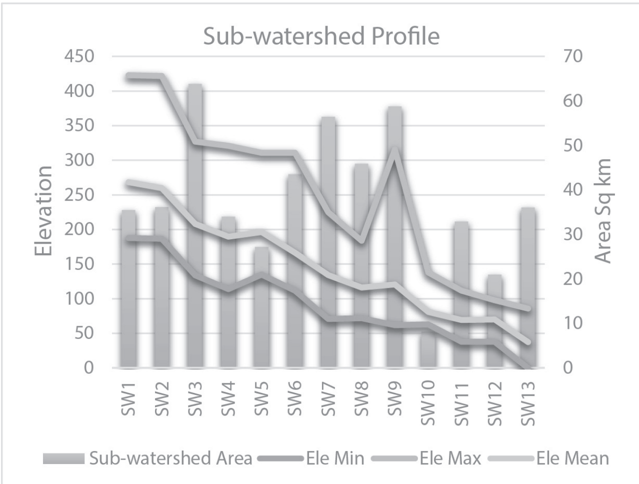


Figure 7: Sub-watershed elevation and area profile

SW3 is the largest sub-watershed while SW10 is the smallest sub-watershed. SW1 and SW2 are situated in a high elevation area. SW12 and SW13 are situated in a low elevation area. SW1 to SW7 and SW9 are hilly while other sub-watersheds are relatively flat. The watershed has three man-made reservoirs. The watershed polygon was used to extract vegetation and surface water area over the period of time in GEE.

Satellite data for three years was acquired and monthly NDVI and NDWI composite were calculated for the study area. Monthly vegetation and surface water patterns were derived after processing 69 satellite images as presented in Figures 8, 9 and 10.

The Hiran basin is extensively covered by vegetation and surface water during the monsoon, with more than 95 per cent and 2.1 per cent monthly average, respectively. Surface water is detected mainly in three man-made reservoirs, Hiran-1, Hiran-2 and Small DAM (Figure 1), which account for more than 90 per cent of the surface water of the entire basin. The vegetation and water body coverage decreases during November and December to 91 per cent and 2 per cent, respectively. The summer season records the lowest monthly average, especially during the months of May and June when the average decreases to 30 per cent and 0.7 per cent. By the end of the summer, Hiran-1 shrinks by 67 per cent, Hiran-2 shrinks by 71 per cent and Small DAM (located in SW9) is dry by March.

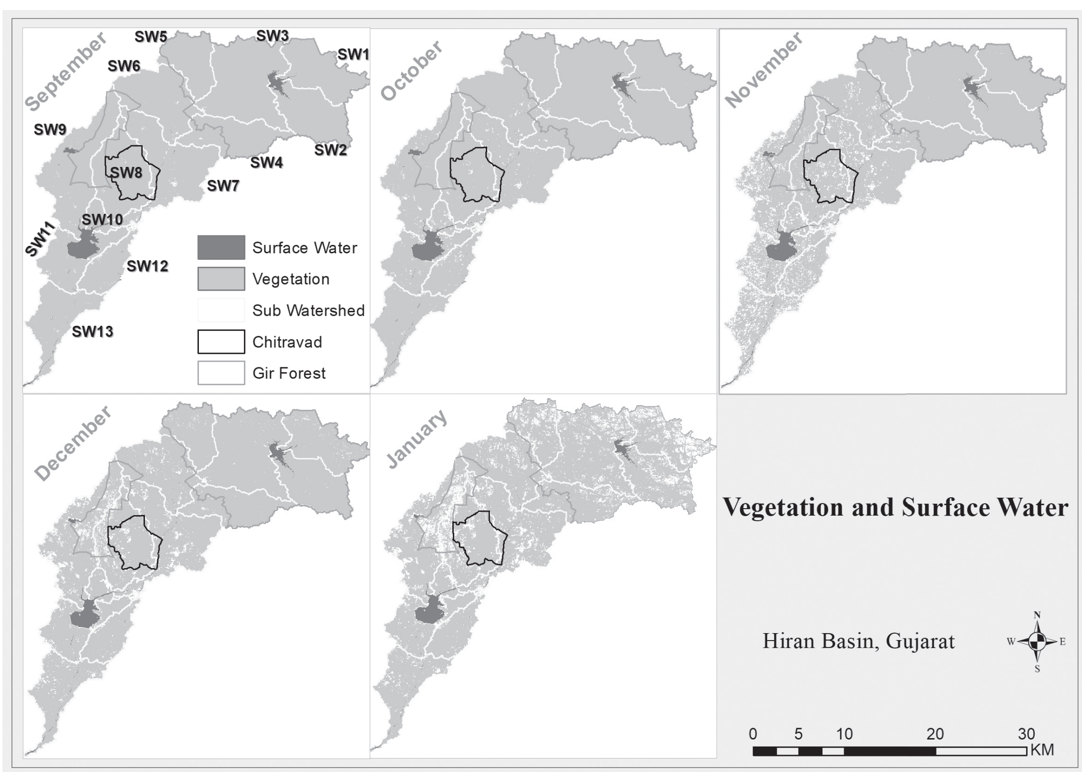


Figure 8: September to January vegetation and surface water coverage

During the monsoon, rainfall is sufficient for producing crops and agriculture is less dependent on ground or surface water. Hence, surface water and vegetation are well maintained during the monsoon (July to October). Vegetation coverage decreases slightly in the month of November and increases again in the month of December. This can be attributed to the changing cropping patterns in the area. Farmers usually harvest monsoon crops in October or November and then begin working on winter crops. The new crop is usually visible only after 20–30 days. Hence, this up-down can be seen in the month of November. The same pattern can be observed during February-March due to changing crops from winter to summer. Winter and summer crops are fully dependent on ground and surface water, which results in decreasing surface water. In addition to this, people also use water for various domestic purposes, creating an adverse impact on vegetation coverage during winter and summer. This shows a strong correlation between water and vegetation coverage.

The area located downstream near to the main river and reservoir is usually covered by vegetation throughout the year. Water is regularly released in adequate quantities from Hiran-I and Hiran-II reservoirs in order to keep water flowing in the main river till end point of the basin. As a result, a majority of the area of the sub-watershed (SW4, SW6, SW7, SW10, SW11, SW12 and SW13) near the main river gets water regularly and hence it is usually covered by vegetation.

The area (SW1, SW2, SW3, SW5, SW8 and SW9) situated far from the main river and reservoir starts facing water scarcity mainly after December. The impact in SW8 and SW9 is mainly due to the main river being far away and the small reservoir located in this area (SW9) getting dry by March. As a result, vegetation coverage decreases in the small forest area (located on west side of Chitravad village) from the month of February, which indicates low density of trees. Forest area is usually fully covered by vegetation during the monsoon and half of the winter season, which indicates presence of grassland and dependency of trees on rain. As a result, grassland and trees are becoming bare from the month of February.

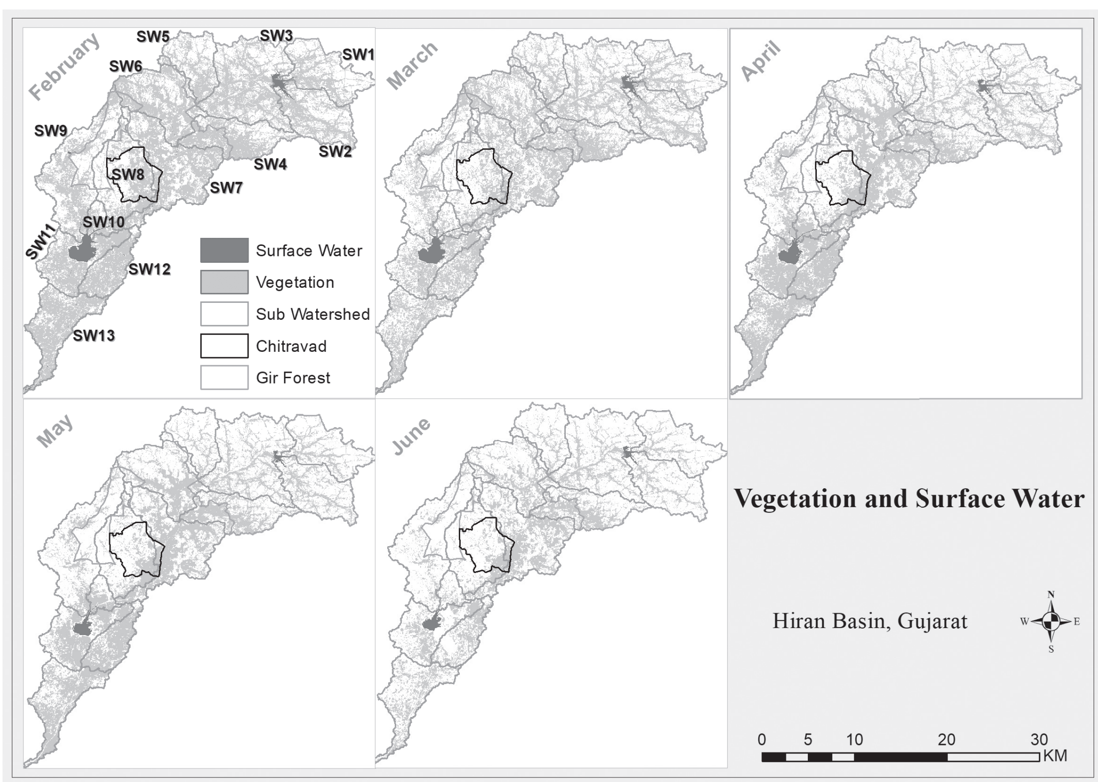
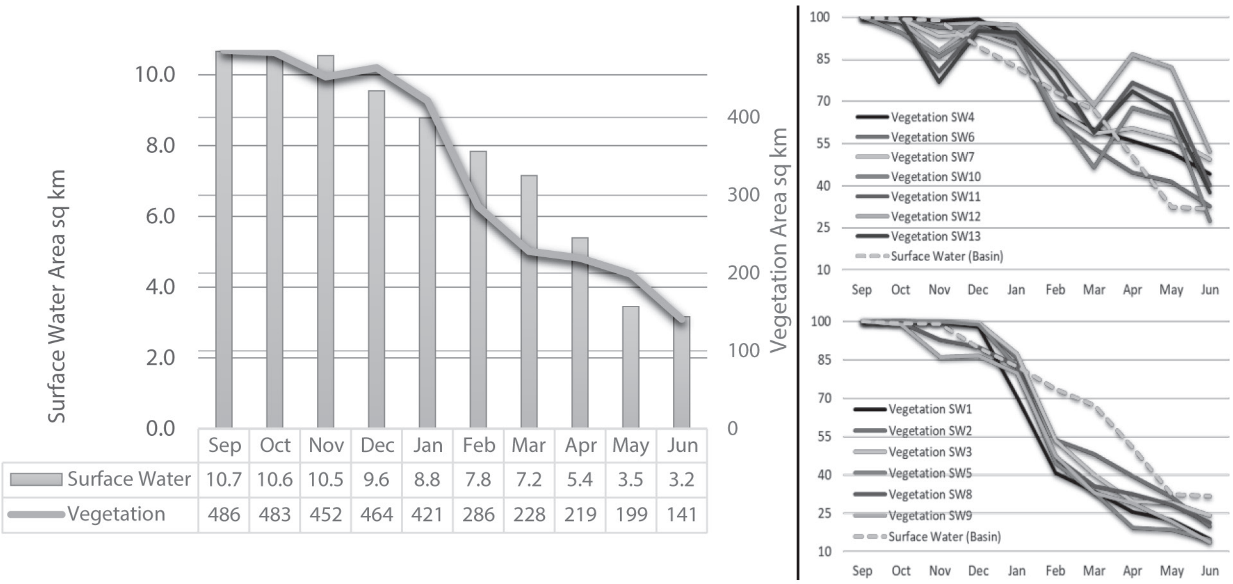


Figure 9: February to June vegetation and surface water coverage



	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Surface Water	10.7	10.6	10.5	9.6	8.8	7.8	7.2	5.4	3.5	3.2
Vegetation	486	483	452	464	421	286	228	219	199	141

Figure 10: Correlation between surface water and vegetation

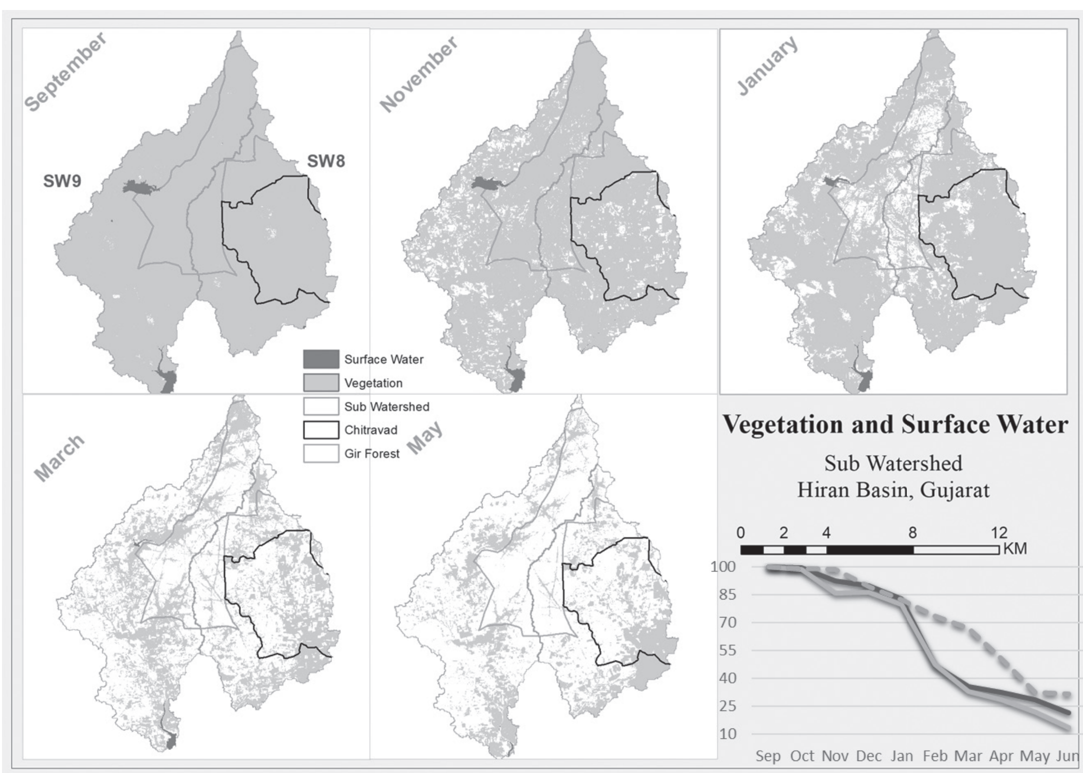


Figure 11: Impact in sub-watersheds 8 and 9 due to decreasing surface water

Figure 11 shows that the presence of vegetation during September indicates that most of Chitravad village is being utilised for agricultural purpose. The higher elevated area starts facing water scarcity from the month of January while the lower elevated area (eastern-southern part) receives water through the ground fed by the river. The presence of vegetation in the agriculture area indicates that it receives groundwater throughout the year since it is situated near to the main river (Figure 6).

Proposed Interventions

Two locations are identified (Figure 12) to address the water scarcity issue in the area of Chitravad village. One location (A) is situated on the north side of the village having around 1.1 km^2 unused land (135 m elevation). The second location (B) is situated on the west side having around 1.7 km^2 unused land mainly in the forest area (123 m elevation). Identified locations are larger than the small dam located in WS9 (C). The majority of the area downstream of or nearby the small dam (C) is usually covered by vegetation until the month of March. Considering the similarity between the small dam and the identified locations, it indicates that identified locations could potentially increase water availability in Chitravad.

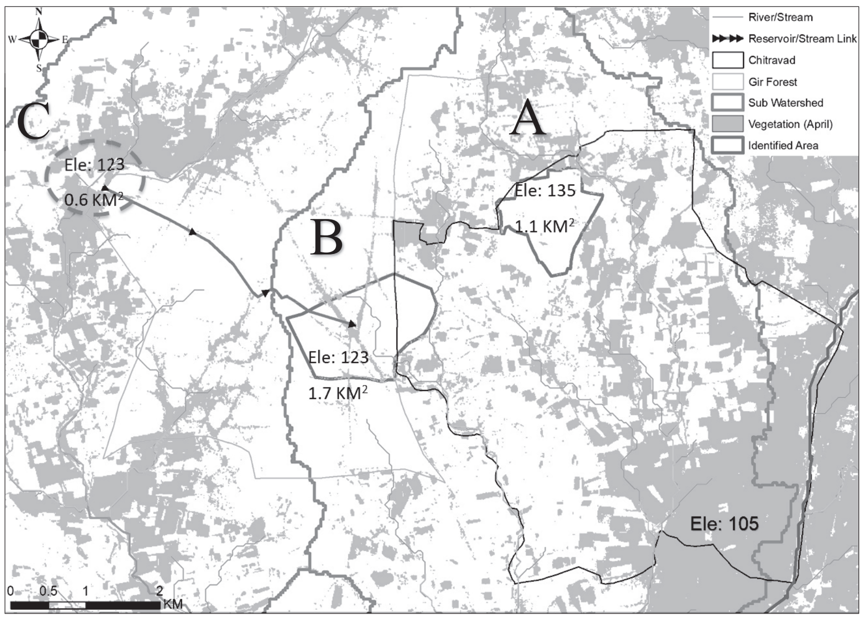


Figure 12: Identified suitable location to build small dam and tree plantation at village level

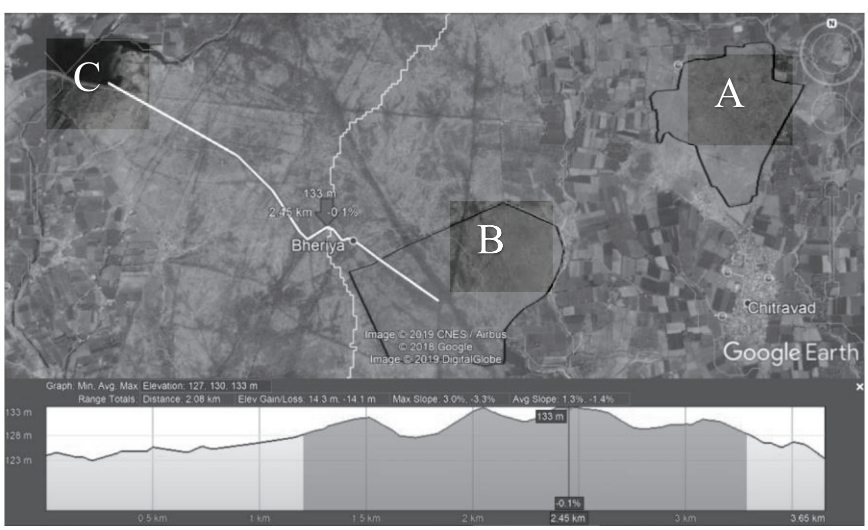


Figure 13: Elevation profile to link two rivers/streams

The elevation profile given in Figure 13 indicates the possibility to link two streams using a siphon technique to maintain water in the existing and new suggested dam and deal with adverse impacts like floods.

Since the study is based on remotely sensed data, it is essential to verify ground practicality. Hence, it is necessary to conduct field studies and make other sets of interventions to address the identified issue. Identified locations are open and unused land, which increase the possibilities of its use for water storage by constructing a small dam. A field study could include land ownership, government permissions, interest of local communities, interest of forest department and an assessment of potential adverse impacts such as flooding. The field study will give more practical direction and help to take a decision based on cost benefit analysis.

Groundwater mapping and identification of water recharge location: It is suggested to map groundwater level using existing wells and borewells with the help of local farmers. This will give accurate an correlation between vegetation and groundwater instead of surface water. The derived results will help identify water recharge locations. However, identified locations (in Figure 12) have the potential to use groundwater recharge to create a new borewell and later use that water for domestic purposes during the summer.

Tree plantation: Since both the identified locations are unused land to be considered for tree plantation, tree plantation drives can be conducted involving the Department of Forestry and the local community. The area near (south-east) to the main river is another preferred area to be considered since availability of groundwater is higher throughout the year, which increases the survival rate. As observed, less density of trees and presence of grassland in small forest areas, there is possibility to plants more trees. It is proposed to identify and plant trees which can survive with less water.

Near-real-time groundwater mapping: Develop a user-friendly MobileApp to collect water level data. MobileApp must allow collection and analysis of data related depths to well water level, rainfall amounts and check dam water levels. It should engage farmers, schools and local communities in groundwater monitoring, which shall help in easy collection and availability of groundwater and other related data. This will also help to visualise groundwater data and empower farmers to self-manage groundwater sustainably at the village and Gram Panchayat levels. The MobileApp must forecast groundwater level correlating rainfall data, current water level upstream and historical data. It should guide farmers to select appropriate crops when there is less rainfall.

Rainfall monitoring: Since the rainfall sensor is located far from Chitravad village, it may not be appropriate for Chitravad village. It is suggested to provide necessary techniques, tools and training to the local community, which will enable them to measure the amount of rainfall within Chitravad village. This will help farmers to decide appropriate crops for the winter and summer seasons and also sensitise them optimum use of water while there is less rainfall.

Crop study: It is suggested to conduct a study aiming at identification of suitable crops for Chitravad land which may use less water. Such crops will benefit farmers when there is less rainfall.

Empowering the local communities is a key parameter for the success of the project. It is suggested to share all the results with the community as generated through remote sensing data and the proposed interventions and study. Wherever applicable, the community members should be trained to ensure the sustainability of the project.

Discussion and Conclusion

Accurate mapping of surface water and vegetation is an essential part of environmental monitoring that is often carried out using measurements from multiple sources. RS is a cost-saving and quick alternative for that but is often challenged due to sensor limitations, complex land cover, topography and atmospheric conditions. The latest tools and techniques like GEE enable quick and continuous monitoring of natural resources and allow appropriate actions to be taken on the basis of evidence. A simple yet successful method in mapping vegetation cover and water bodies was useful to understand the situation. This is very important for us to identify and execute appropriate interventions to address area-specific issues. The tools developed through this research is accessible from the GEE platform. The tool and procedures have the potential to replicate in other basins. Hence, interested users can use the one developed online and others can use the desktop tools to conduct similar research.

It is evident from the study that vegetation and agricultural production during non-monsoon months are dependent on water from reservoirs. This highlights the need to invest in activities that ensure water recharge in the area. The plantation of trees in the recharge area is considered a natural way of handling the situation. This, however, will entail field investigation to first identify the recharge areas. It is felt that without involvement of communities protecting forests is challenging. Thus educating communities on the benefits of afforestation and their involvement in the effort is felt to be crucial.

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References

ESRI, 2011, Arc Hydro Tools – Tutorial, Version 2.0 – October 2011. [Online] Available at: http://downloads.esri.com/archydro/archydro/tutorial/doc/[Accessed: 01/01/2019].

Farr, T.G., Rosen, P.A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Oskin, M., Burbank, D., and Alsdorf, D.E., 2007, The shuttle radar topography mission: Reviews of Geophysics, v. 45, no. 2, RG2004, at https://doi.org/10.1029/2005RG000183.

Google, 2019: Documentation. < https://developers.google.com/earth-engine/> Online: 01.01.2019

GSDMA, n.d., Rainfall Report, [Data] Retrieved 31st October, 2018, from http://gsdma.org/rainfalldata-2?Type = 2

Hansen M.C., Potapov P.V., Moore R., Hancher M., Turubanova S.A., Tyukavina A., Thau D., Stehman S.V., Goetz S.J., Loveland T.R., Kommareddy A., Egorov A., Chini L., Justice C.O., Townshend J.R.G. (2013): High-Resolution Global Maps of 21st-Century Forest Cover Change. Science. Vol 342 (6160), pp. 850–853

Ji, L., Zhang, L., & Wylie, B. (2009). Analysis of dynamic thresholds for the normalised difference water index. Photogrammetric Engineering and Remote Sensing, 75(11), 1307–1317.

Karpatne, A., Khandelwal, A., Chen, X., Mithal, V., Faghmous, J., & Kumar, V. (2016). Global monitoring of inland water dynamics: State-of-theart, challenges, and opportunities. In J. Lässig, K. Kersting, & K. Morik (Eds.), Computational Sustainability (pp. 121–147). Cham: Springer International Publishing.

Karsli, F.; Guneroglu, A., and Dihkan, M., 2011. Spatio-temporalshoreline changes along the southern Black Sea coastal zone.Journal of Applied Remote Sensing, 5(1), 053545

Kim D.-H., Sexton J.O., Noojipady P., Huang C., Anand A., Channan S., Feng M., Townshend J.R. (2014): Global, Landsat-based forest-cover change from 1990 to 2000. Remote Sesnsing of Environment. Vol 155, pp. 178–193

McFeeters, S.K. (1996): The use of normalised difference water index (NDWI) in the delineation of open water features. International Journal of Remote Sensing. 17:1425–1432.

Narmada, Water Resources, Water Supply and Kalpsar Department, n.d., Hiran River, Retrieved January 01, 2019, from https://guj-nwrws.gujarat.gov.in/showpage.aspx?contentid = 1625&lang = english

Revenue Department, n.d., Government of Gujarat, Village Maps, [Online] Available at: https://revenuedepartment.gujarat.gov.in/village-map [Accessed: 01/01/2019]

Rouse, J.W. – Haas, R.H. – Schell, J.A. – Deering, D.W. (1973): Monitoring vegetation systems in the great plains with ERTS. Third 80 ERTS Symposium, NASA SP-351, pp. 309–317. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19740022614.pdf

Sentinel Hub, n.d., NDVI Documentation <https://www.sentinel-hub.com/eoproducts/ndvi-normalised-difference-vegetation-index> Online: 01.01.2019

Xu, H. Q. (2006). Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. International Journal of Remote Sensing, 27(14), 3025–3033.

GIS-Based Relational Weather Forecasting System (RWFS) at Taluka Level

Nongmaithem Bragy Singh[a], Hari Krishna Dv[a], Abhishek Banerjee[a] and Rajnish Ranjan[b]

ABSTRACT: The earliest fielded automated systems, the Automated Meteorological Observing System (AMOS) and the Remote Automated Meteorological Observing System (RAMOS), were deployed in the 1960s and 1970s. These systems reported only the objective elements of ambient and dew point temperature, wind (speed and direction) and pressure. With the complex in spatially observed elements of sky condition and visibility had to await advances in sensor technology and improvements in computer processing. More information was gathered in the atmosphere, and higher frequency and more locations were determined to be the key elements to improving forecasts and warnings. Thus, Automatic Weather Observing Systems (AWOS) were developed.

This study aimed at establishing a network of Automatic Weather Stations (AWS), at a rate of one AWS in every revenue circle, which will measure wind direction, wind speed, air temperature, relative humidity and rainfall. This information, as of now, is proving to be helpful for farmers who can then manage sowing in a much better and planned way, as per the weather conditions. A dedicated portal has been developed for data management and distribution so that there is easy data access and visualisation of the data of any station. The portal aims at being simple and user friendly in its design, providing data in just one click, as well as user-defined data downloading options, daily average, maximum, daily minimum value of the desired parameter, and easy tracking of the nature or trend of the desired parameter for any individual day.

Thus, the study aimed at bringing better and more localised weather forecasting compared to the government portals for four zones and providing forecasts up to the taluka level.

KEYWORDS: GIS, agriculture, weather forecast, automatic weather station

Introduction

The Upanishadas and other philosophical writings of the 3000 B.C. era talk about the formation of clouds, rain, seasons and the movement of Earth. *Brihat-Samhita*, the classical work of Varahamihira, provides evidence that knowledge of atmospheric processes existed. Kautilya's renowned *Arthashastra* has records of scientific measurements of rainfall and its application to the country's revenue.

The invention of instruments like the thermometer and barometer in the 17th century provided the scientific basis for present-day meteorology. For studying the weather and climate the British East India Company established some of the oldest meteorological observations in the world, for example those in Calcutta and Madras.

The India Meteorological Department was established in 1875, after a disastrous cyclone hit Calcutta in 1864, and the following monsoons in 1866 and 1871 failed. This aimed to bring all the meteorological work in the country under a central authority.

Agrometeorology is an interdisciplinary holistic science forming a real bridge between physical and

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biological sciences and beyond. It deals with a complex system involving soil, plants, atmosphere, agricultural management options and others, which are interacting dynamically on various spatial and temporal scales.[1]

Automatic Weather Systems (AWS)

Background

The earliest fielded automated systems, the Automated Meteorological Observing System (AMOS) and the Remote Automated Meteorological Observing System (RAMOS), were deployed in the 1960s and 1970s. They were first developed by the US National Weather Service in 1969.[2] These systems reported only the objective elements of ambient and dew point temperature, wind (speed and direction) and pressure. More information was gathered in the atmosphere, and more frequently and more locations were determined to be the key elements of improving forecasts and warnings. Thus, Automatic Weather Observing Systems (AWOS) came into existence.

AWOS can detect significant changes in the weather by disseminating hourly and specific observation through their distribution networks as dictated by end user requirements. AWOS operate non-stop, 24 hours a day, annually. The constant stream of AWOS data has been proved beneficial to the forecast and research communities in the promotion of more accurate forecasts of all kinds. AWOS sensors also perform well at night, which is challenging for human observers in making accurate observations.

History of AWS in India

After the launch of the INSAT-1B satellite by the Indian Space Research Organisation, the India Meteorological Department installed 100 Automatic Weather Stations (AWS) during 1984–85. The operational status at that time was more than above 60 per cent. After 10 years, India completed its 15 state-of-the-art AWS, procured and installed during 1996–1997. The operational status of AWS in India after 7 years of operation is above 90 per cent.

IMD has been operating a network of 100 AWS in India since 1984. The technology had become obsolete and after 10 years of operation the old Data Collection Platforms (DCPs) now renamed as AWS were replaced with state-of-the-art AWS systems during 1997–98. The AWS data was compared with surface observatory data, standard deviation, scattered diagrams and correlation coefficients for a few stations and this was plotted and data quality was found within WMO accuracy limits.

Automatic weather stations are used for increasing the number and reliability of surface observations. They do this by:

- Increasing the density of an existing network by providing data from new sites and from sites which are difficult to access and are inhospitable
- Supplying, for manned stations, data outside the normal working hours
- Increasing the reliability of the measurements by using sophisticated technology and modern digital measurement techniques
- Ensuring homogeneity of networks by standardising the measurement techniques
- Satisfying new observational needs and requirements
- Reducing human errors
- Lowering operational costs by reducing the number of observers
- Measuring and reporting with high frequency or continuously

An AWS network is capable of

- Collecting, processing and displaying meteorological data
- Performing automated generation and transmission of meteorological reports
- Being configured to support a wide range of sensor configurations
- Supporting a number of data communication options
- Managing all communication protocols for the various sensors and other associated data communication equipment
- Storing all relevant data for immediate or future retrieval as required
- Allowing manual input of additional information that cannot be automatically measured

- Providing the first level of quality control on both data measurement and message generation
- Allowing authorised users to access data remotely

Types of AWS Networks

AWS networks generally fall into three categories:

- Real-time data or event-recording networks
- Climatic data networks
- Agricultural (near-real-time data) networks

Real-Time Data or Event-Recording Networks

This is one of the most common types of AWS network. These networks are developed to provide warnings for the effects of severe weather conditions such as

- Maximum, minimum and average temperatures
- Wind direction and wind speed
- Precipitation
- Relative humidity

Real-time networks typically recover information through satellite data transfer or GSM/GPRS.

Climatic Data Networks

In climatic data networks, real-time or near-real-time data recovery is unnecessary and data recovery by cassette tape or solid-state memory is often sufficient. The purpose of a climatic data network is to gather the data needed to characterise a climatic region. Therefore, weather stations are designed to gather a standard set of data from sites that are typical of the climate being assessed.

Agricultural Networks

Agricultural networks require dissemination of data the day after recovery. Data is collected typically by telephone modem, radio telemetry, infrared telemetry or satellite transfer. Using AWS networks facilitates data recovery and dissemination to users. Agricultural data is most often used for evapotranspiration estimation and pest management, so locating stations in areas representative of agriculture is an important concern.

The type of network to be established depends on the purpose for which data is acquired.[3]

Advantages and Limitations

Advantages

Automated Weather Stations have many advantages over manual systems. These advantages are summarised as follows:

- Standardisation of network observations, both in time and quality
- Real-time continuous measuring of parameters on a 24/7 basis
- High accuracy
- More reliable
- Conduct automatic data archiving
- Provide higher data resolution
- Collection of data in a greater volume
- Adjustable sampling interval for different parameters
- Generally free of reading errors
- Generally free from subjectivity
- Automatic Quality Check applied during collection and reporting stages
- Automatic message generation and transmission
- Monitoring of meteorological data
- Access to archived data locally or remotely
- Data collection in harsh climates

Limitations

The following are some of the limitations of Automatic Weather Stations:

- Limited area representation, which may cover a diameter of about 10 kms around the sensor site (AWS).
- It is not possible to observe all parameters automatically as done through a manual approach towards taking an observation or an approach whereby the automatic observation is augmented by a human observer, for example cloud coverage and cloud types.
- Requires periodic routine maintenance.
- Periodic testing and calibration.

- Intervention of well-trained technicians and specialists required for maintenance.
- Requires higher cost of instrumentation and operation. However, the greater efficiency gained through higher levels of automation may result in some cost benefits.

Components of AWS

- Sensors
- Data logger
- Enclosures
- Communication device
- Power supply
- Mast

A **sensor** is a device which detects or measures a physical quantity. Sensors are usually placed to measure temperature (thermometer), rainfall (rain gauge), wind speed (anemometer), wind direction (wind vane) and relative humidity (hygrometer).

The **data logger** is the device that collects information from every sensor and stores the data in a memory device like an SD card; the data logger at times is used to process the data too.

Figure 1: AWS showing different components, Narayangoan, Pune

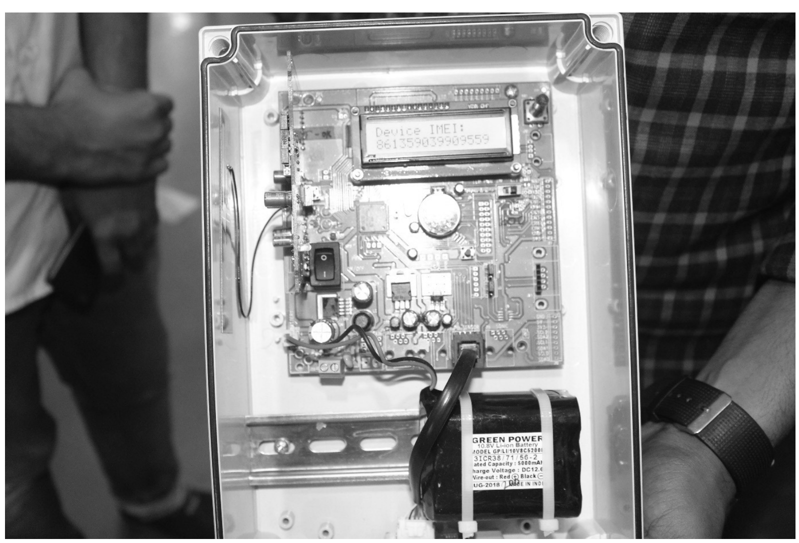


Figure 2: Data logger with enclosures

The **enclosure** is normally a weatherproof box which contains communication devices and the data logger.

The **communication device** manages the communication protocols to the remote server. Many of the times either GSM or GPRS are used. Also, an option of manual access to data is possible, if the communication fails, the data can be retrieved by a person manually.

Power Supply of AWS is usually managed by solar cells; sometimes wind turbines are also used, most of the time off the electrical grid.

Mast is the pole on which all the devices and sensors are mounted.

Parameters of Weather Station

Temperature: A temperature is an objective comparative measure of hot and cold. Temperature is usually measured by a thermometer. Several scales and units are available for measuring the temperature: most common unit is Celsius (°C, formally known as centigrade), but it is also measured in Fahrenheit (°F) and Kelvin (K).

Humidity: The amount of water vapour present in the air is known as humidity. Water vapour is the gaseous state of water and is invisible. Relative humidity is measured in per cent.

Rainfall: Rainfall is liquid water in the form of droplets that have condensed from atmospheric water vapour and become heavy enough to fall under gravity. Raindrops have sizes of 0.1 to 9 mm in diameter above which they tend to break up. Rainfall is measured in millimetres.

Wind: Wind is a flow of gases on a large scale on the surface of the Earth. Wind consists of bulk movements of the air. Wind speed is usually calculated in metres/ second or kilometres/hour.

Applications of AWS

Importance of Weather Data in Agriculture

Weather plays a very important role in agricultural production. It has a significant influence on the growth, development and yields of a crop, incidence of pests and diseases, water needs and fertiliser.

Table 1: Example of Weather Requirements for Rice Farming Operation in the Humid Tropics[4]

Farming Operation	Air Temperature (°C)	Wind Speed(kmph) Farming Operations	Soil (Moisture) Condition	Sky Condition
Land Preparation (ploughing/harrowing)	< = 40 and > = 15	< = 50 for comfort of workers	Moist or wet	Clear or cloudy
Seeding in seedbed or field, AI. dry seeds, A2. pre-germinated	<33 and > = 15	<20 desired to minimise evaporation	Moist or wet	Clear or cloudy
Transplanting seedlings	< = 40 and > = 15	0–30 for comfort of workers	Wet	Clear or cloudy
Hand weeding/cultivating	< = 40 and > = 15	< = 50 during operation	Moist or dry	Clear or partly cloudy
Irrigation	> = 15	Not Critical	Moist or dry	Clear or cloudy
Spraying pesticide	<33 and > = 15	0–18	Moist or dry	Clear or cloudy
Threshing/sun drying	> = 15	< = 25 During grain cleaning operation	Not applicable	Clear or partly cloudy for threshing and clear for sun drying

Occurrences of erratic weather situations are beyond human control. But it is possible to adapt to or mitigate the effects of adverse weather if the advance information about the inclement weather or other uncomfortable weather conditions is available.

The AWS networks help in providing the real-time weather data. Sensors in AWS generate data and send it periodically to a server where it gets processed. This information can be interpreted to generate probable weather forecasting and weather monitoring information.

Forecasts and Alerts

With real-time data in hand and automated data analysis systems, when current data is superimposed on the historically available data patterns, alerts can be issued automatically.

Crop Insurance

Most Indian farmers are small and marginal, and if their crop gets damaged because of a meteorological reason, their income for the year is at risk; this might even push them into debt trap conditions. Insurance is a tool to protect anyone against a small probability of large unexpected loss. It is a technique of providing people a means to transfer and share risk where losses suffered by few are met from the funds accumulated through small contributions made by many who are exposed to similar risks. Insurance is not a tool to make money but a tool to help compensate an individual or business for unexpected losses that might otherwise cause a financial disaster (Department of Agriculture, Co-operation and Farmers' Welfare n.d.).

Crop insurance is a means of protecting the agriculturists against financial losses due to uncertainties that may arise from crop failures/losses arising from named or all unforeseen perils beyond their control (Department of Agriculture, Co-operation and Farmers' Welfare n.d.).

Two types of crop insurance in India:

- Yield-based crop insurance
- Weather-based crop insurance

Pradhan Mantri Fasal Bima Yojana (PMFBY) aims at supporting sustainable production in the agriculture sector by way of:

- Providing financial support to farmers suffering crop loss/damage arising from unforeseen events
- Stabilising the income of farmers to ensure their continuance in farming
- Encouraging farmers to adopt innovative and modern agricultural practices
- Ensuring flow of credit to the agriculture sector, which will contribute to food security, crop diversification and enhancing growth and competitiveness of agriculture sector besides protecting farmers from production risks

The following are stages of crop and risks leading to crop loss are covered under this scheme.

- **Prevented Sowing/Planting Risk:** Insured area is prevented from sowing/planting due to deficit in rainfall or adverse seasonal conditions
- **Standing Crop** (Sowing to Harvesting): Comprehensive risk insurance is provided to cover yield losses due to non-preventable risks, viz. drought, dry spells, flood, inundation, pests and diseases, landslides, natural fire and lightening, storm, hailstorm, cyclone, typhoon, tempest, hurricane and tornado.
- **Post-Harvest Losses:** Coverage is available only up to a maximum period of two weeks from harvesting for those crops which are allowed to dry in cut and spread condition in the field after harvesting against specific perils of cyclone and cyclonic rains and unseasonal rains.
- **Localised Calamities:** Loss/damage resulting from occurrence of identified localised risks of hailstorm, landslide and Inundation affecting isolated farms in the notified area.

One of the preconditions for implementation of the scheme is that the State/Union Territory should be willing to facilitate strengthening of the weather station network.

When a claim is made the insurance provider notifies the concerned weather data provider whose report will be used in assessing the extent of losses and computation of payment.

For many crop risks which lead to crop loss, rainfall data, other weather data, satellite imagery and crop condition reports by district-level state government officials, supported by media reports, are used as indicators/proxy-indicators.

Even in the loss assessment procedure the in-charge committee shall decide the eligibility for on-account payment based on the weather data (available AWS notified by the Government)/long term average rainfall data/satellite imagery supported by estimated yield losses at notified insurance unit level.

Mahavedh Project

Mahavedh is a Public Private Partnership (PPP) project on a build-own-operate (BOO) basis. Through this project, the Government of Maharashtra (GoM) has established a network of Automatic Weather Stations (AWS), with a frequency of one AWS in every revenue circle. The AWS network will comprise an area of 12 square km in flatland topography, whereas they are established in 5 square km areas in the highland.

Dedicated Portal for Data Management and Distribution

Skymet has developed a dedicated portal for data management and distribution so that Government officials and end users can easily access to visualise the data of any station. Some of the unique features of this dedicated portal are as follows:

- Designed in a simple and user-friendly manner
- Data availability in just one click
- User-defined data downloading options - daily average, maximum, daily minimum value of the desired parameter
- Easy tracking of the nature or trend of the desired parameter for any individual day

The project was aimed at bringing better and more localised weather forecasting, as compared to other meteorological agencies. Mahavedh aims to provide forecast data up to the taluka level.

Salient Features of Mahavedh

- Mahavedh is one of the most unique projects in the country, which will measure wind direction, wind speed, air temperature, relative humidity and rainfall. This information is providing to be helpful for farmers who can then manage sowing in a much better and planned way, as per the weather conditions.
- The weather conditions for farmers in different regions will be available on the Mahavedh portal (Maharashtra agriculture weather information network) and the mobile application of Skymet.
- The IMD forecast is limited to four zones. However, this new system of AWS is providing forecasts up to taluka level. Each approximately 12×12 km area of the taluka will have one AWS.
- This project will is helpful for better crop management and damage prevention.
- The Skymet AWSs are providing real-time weather information every 10 mins, which is being collected at the College of Agriculture, Pune. The specific information is being taken out from this central data pool and forwarded to the area concerned.
- The idea was to create a decentralised system that would provide accurate weather-related information right up to the village level.

Figure 3: Mahavedh Skymet Data Centre, Department of Agricultural Metrology, College of Agriculture, Pune

How Mahavedh Aims at Helping Farmers

One of the most important events that comes in the claim settlement when the farmer has to receive assistance due to crop damage is the certificate from the recognised weather agency. This is a significant problem because not many have the data of each and every location. If the area where the crop loss happened is far from the weather station or if it is in a different geographical place, chances are high that the required data will not have been noted. As Mahavedh has an AWS in every revenue block or one for every 12 sq kms, this problem is solved.

There are many other uses of AWS in agricultural practice as they are highly dependent on weather. Weather data provides information to farmers as to when to plough, when to sow and when to harvest, as well as guiding them in crop selection and scheduling, when to spray the fertilisers, etc. So the forecasts from the network of AWS after several quality checks and rounds of analysis give a clear idea as to what is to be done and what should not to be done.

Mahavedh also acts as an Early Warning System for the many hydro-meteorological disasters: the data that is saved every day helps in predicting the coming drought or heavy rains. Thus vulnerability of different disasters can be minimised.

Figure 4: Automatic Weather Station (AWS) installed by Skymet under Mahavedh Project at Narayangoan, Pune

Effect on Agricultural Practices

Agricultural practices include activities like crop selection, tilling the ground and making the land ready for sowing, spraying fertilisers and pesticides, irrigation, harvesting, etc. Weather has a deep impact on almost all of the agricultural practices. Therefore, it is very important to keep weather conditions in mind before planning any such activities. Farmers actually spend time to know about the weather conditions on the day of performing the activity and this influences their decision as to whether to carry on or not. For example, in order to spray fertiliser, there shouldn't be a heavy rain in the forecast as most of the fertiliser washes away with rain, so farmers look up the weather report or use their traditional methods to predict it and then choose a day, making sure that it is not going to rain anytime soon. In some cases, the forecast report can alert farmers and enable them to take preventive measures. For example, if the crop is almost ready to be harvested and if there will be heavy to very heavy rains in the coming two days, instead of waiting for the crop to mature fully, the farmer can harvest the crop as soon as possible in order to avoid the loss if he had not taken any action. Also, if the crop is harvested and spread in the field for drying, then the forecast alert will tell the farmer to store the produce in a safer place, so that it won't get wet and rot. Skymet gives accurate data because of its presence in every block. There are Automatic Weather Stations in less than 12 km range, each collecting real-time data.

Prevention and Preparedness to Deal with Hydrometeorological Disasters

The network of the Automatic Weather Stations which is established as a part of Mahavedh Project by the Department of Agriculture, Government of Maharashtra, can also be used to effectively predict hydrometeorological disasters. The advantage of this network is the presence of Automatic Weather Stations in all the revenue blocks or tehsils in the state. This network has the capacity for not only predicting the hazards but also conveying the areas that might be affected in future. This also helps the authorities to identify places which are safe.

The four elements of Early Warning Systems are:

Risk Knowledge: People should have prior knowledge about the risks they might face and hazards that might come in that area

Warning Service: Sound scientific basis should be present in predicting the risks, so constant monitoring of precursors should exist to generate accurate warnings in a timely fashion.

Dissemination of understandable warnings: The warnings should definitely reach those at risk and these warnings should be understandable too and should contain useful information that enables proper responses.

Response Capability: It is important that communities understand their risks and know how to react.

The same four elements should be used here too. The repository of data from the weather stations can be used to predict the disasters if analysed properly. Based on the prediction, necessary arrangements can be made by the farmers individually.

Enhancement of Crop Selection Capability

Crop selection is the process of choosing which crop to cultivate. This depends on various factors as shown in Figure 5.

The Krishi Vigyan Kendras (KVK) give advisories to farmers before the commencement of the cropping season. In addition, have on-campus training sessions where farmers are invited to their campus and off-campus training sessions where the scientists go to the farmers and explain/demonstrate the best practices, share knowledge, etc. Apart from this, farmers also follow the agriculture media of various print and electronic outlets. There are dedicated television programmes and newspapers/magazines to give inputs to farmers; they also have content like success stories, best practices, new inventions, etc. These are the conventional methods and most of the farmers still follow these only.

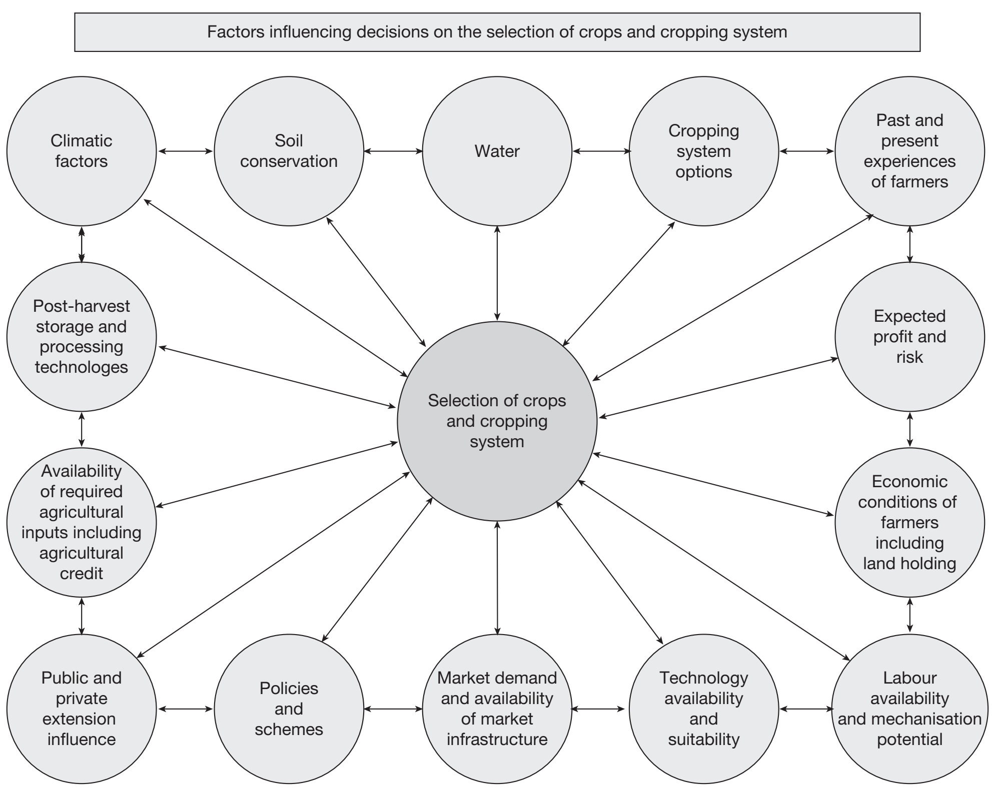


Figure 5

Analysis

The present study is based on the assessment of Mahavedh Project, which was signed between Government of Maharashtra and Skymet Weather Services Pvt. Ltd. to establish a network of Automatic Weather Stations primarily in the arrangement of one AWS in every revenue circle area. With the application of AWS data, weather parameters like rainfall, air, temperature, relative humidity, and wind speed and direction are recorded at specified intervals and with specified accuracy levels. The planning and implementing of Mahavedh Project is through a Public Private Partnership (PPP) on the basis of Build, Own and build-own-operate (BOO). The real-time weather data provided by Skymet are for a long-term basis and can be used for public purposes in implementation of schemes funded from public money. Skymet AWS network meets the standard and technical norms prescribed on the basis of the India Meteorological Department and works according to the guidelines issued by the Department of Agriculture Maharashtra, Ministry of Agriculture and Farmers Welfare, Government of India.

The AWS real-time weather data is useful for studying change in climatic conditions and other public good such as for implementation of welfare and development schemes, Research and Development in agrometeorology work, developing weather advisory/ agrometeorology advisory, disaster management, state agriculture universities, and to develop genetic crops through Indian Council of Agricultural Research (ICAR).

Still we need to work more on providing alert services in any form; sometimes it may be for a particular crop or sometimes a whole crop. At the same time we need to give our farmers handson training on how to check weather updates and how to use smartphones for smart and safe farming. At same time ICAR KVK should analyse these weather data and produce weather resistant crops which are part of genetically modified crops. As we face climate change, much research and development of crops is necessary at the same time.

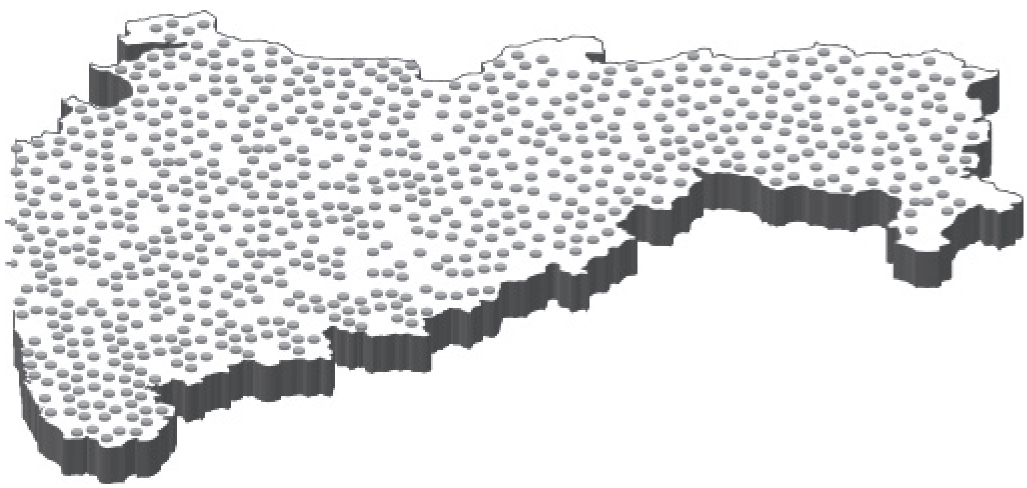
Lastly, cumulative approach will work in the long run. This will overcome the challenges which are faced by farmers such as smartphone issues, lack of network, handling issues, etc. With a cumulative approach, local smartphone manufacturers can distribute phones with basic Internet connectivity, on which the farmers can see the real-time weather forecast and at the same time the agriculture department can also upload the use of different machinery and crop yielding techniques videos so that farmers learn something new. Skymet should also link up with different government and non-government organisations for this cumulative approach.

Conclusion and Recommendations

Based on the above-mentioned study on the Mahavedh Project and its social impacts in rural areas of Maharastra, the following recommendations are suggested:

1. **Skymet should start giving training to the farmers on how to use the app service, in the form of hands on, a small video clip in the regional language or slides.**

   Although the app gives real-time accurate data, which has potential to guide the agricultural practices in the state, most of the farmers, are not aware about how to use the application. It is therefore recommended that the existing knowledge dissipation mechanism of Krishi Vignan Kendra be utilised by Skymet. The training sessions both on-campus and off-campus of KVK can also be utilised by Skymet for knowledge dissemination. KVK have full audiovisual setups on their premises, so if a short digital video is made in Marathi it can be shown to farmers at the end of the session. This video can be sent to schools and with the AV technology in the school the video can be shown to the farmers. In addition, awareness posters can be made, which are self-explanatory, and can be sent to every panchayat. The best outcome can be seen when the people get to know the full potential of their handheld device. People should know about the science and logic behind the concept. If people know that this benefits them, then comes the sense of belonging. This also brings down the theft of equipment from their sites.



2. **For Mahavedh Project, Skymet should also link up with m Kisan portal.**

mKisan SMS Portal for farmers enables all Central and State government organisations in agriculture and allied sectors to give information/services/advisories to farmers by SMS in their language and according to their preference of agricultural practices and location. These messages are specific to farmers' specific needs and relevance at a particular point of time and generate heavy inflow of calls in the Kisan Call Centres where people call up to get supplementary information. As per the proposal, Skymet's data is recognised as the official data. Instead of Government promoting one app and Skymet promoting another one, a single app should exist.

3. **More ways to disseminate information**

Currently, a lot of the weather data and forecasting is shared through apps and websites, but on the other hand the smartphone penetration in rural India is not very high, and there are villages where most of the people are illiterate. There are some villages where there is no mobile network too. So more ways of disseminating information should be explored, one such being sending emails to the panchayat office and the government officials, who can then print them out and stick them on walls in two or three places in the village, if not daily, once in a week. For example, one such forecast poster is put up at the milk collection centre and the people who go there take a look at it every morning and discuss among themselves and spread the information by word of mouth.

A school is also one such place where internet connectivity is expected, if the kids in the school come to know about the weather forecast and if they are taught the importance of this information, the kids can be given responsibility to convey the same to the elders back at home.

4. **Skymet should start giving advisories to the farmers.**

With many players in the market, while giving services to the farmer, these should be wholesome; farmers need advisories and if they are not getting them on the Skymet app, they look for other sources, and there are many available, examples being Krishi Vignan Kendras and extension activities of agriculture universities. With the help of agricultural experts, advisories also should be sent, and sophisticated machine learning programmes and Artificial Intelligence can be utilised for automation.

Notes

[1] Eitzinger, Josef, Prof, Branislaba Lalic, Dr, and Levent Saylan, Prof. "Agrometeorology: From Scientific Analysis to Operational Application." *Atmosphere*.

[2] Koul, Opender, Gerrit W. Cuperus, and Norman Elliott. *Areawide Pest Management Theory and Implementation*. Wallingford: CABI, 2008.

[3] Beerling, D. J., and G. Stanhill. *Advances in Bioclimatology, 4*. Berlin: Springer, 1996.

[4] Doblas-Reyes, F. J., Anice Garcia, James Hansen, Luigi Mariani, Ajit Nain, K. Ramesh, L. S. Rathore, and R. Venkataraman. "Weather and Climate Forecasts for Agriculture." *Guide to agricultural, meteorological practices*(2003): 57.

Bibliography

Beerling, D. J., and G. Stanhill. *Advances in Bioclimatology, 4*. Berlin: Springer, 1996.

Doblas-Reyes, F. J., Anice Garcia, James Hansen, Luigi Mariani, Ajit Nain, K. Ramesh, L. S. Rathore, and R. Venkataraman (2003). "Weather and Climate Forecasts for Agriculture." *Guide to agricultural, meteorological practices* 57.

Eitzinger, Josef, Prof, Branislaba Lalic, Dr, and Levent Saylan, Prof. "Agrometeorology: From Scientific Analysis to Operational Application." *Atmosphere*.

India. National Institute of Agricultural Extension Management. by P. Chandra Sekhara and Ajit Kumar. http://www.manage.gov.in/publications/farmerbook.pdf.

Koul, Opender, Gerrit W. Cuperus, and Norman Elliott, 2008. *Areawide Pest Management Theory and Implementation*. Wallingford: CABI.

Mr. Dipak V. Sose, Dr. Ajij D. Sayyad (June 2016), "Weather Monitoring Station: A Review"; International Journal of Engineering Research and Application, Vol. 6, (Part-1) pp. 55–60.

Proceedings of Early Warning Systems—Interdisciplinary Observations and Policies from a Local Government Perspective, Fairfax, Virginia.

R. D. Vashistha, B. Amudha & Rudra Pratap; "Present Status of Surface Meteorological Measurements in India", Instruments Division, India Meteorological Department, Pune-411005, India.

R. L. Snyder, P.W. Brown, K.G. Hubbard and S.J. Meyer, "A Guide to Automated Weather Station Networks in North America".

II Drones and UAVs

Detection and Tracking of Land-Water Boundary in Flooded Regions Using UAV-Based Images

Sachin Shriwastav[a] and Debasish Ghose[a]

ABSTRACT: Disaster management is a time-critical and extremely sensitive operation where any information of the affected area that aids the management process and personnel is a bonus. In flood relief operations, the information on current state of the waterfront and its possible future behaviour plays a significant role in planning evacuation, resource and personnel relocation, road traffic management and more. In this paper, we present an approach to detect land-water boundary using Unmanned Aerial Vehicle (UAV)-acquired images of the area and tracking it to predict the information of future instants, to support emergency flood planning and management operations. In this approach, one or more UAVs perform periodic coverage of the affected area through pre- specified paths to capture images, which are mosaicked to create a single image of the area. Image processing is then used to choose representative image features and their threshold values for classification, which are then used by the sliding box method to examine and classify each such box in the image. This is done to detect the underlying boundary frames and thus the land-water boundaries in the area image, to compute the percentage of inundated area and then use information of multiple such UAV runs to predict the land-water boundaries at future instants. The simulation results of an image of actual flooded area have been presented to prove the applicability and the efficacy of the proposed approach. Furthermore, the experimental arrangement to verify the overall working of the approach has been discussed.

KEYWORDS: disaster management, flood management, unmanned aerial vehicle, UAV-based imaging, image processing, computer vision, land-water classification

Introduction

Disaster management is a challenge on the global scale. Every year, many people lose their lives and heavy property damages are reportedly caused by various natural and human-induced disasters around the globe; flood being a frequently occurring disaster with severe impact. As disaster management is defined in general, the process can be divided into three stages, namely pre-, during and post-disaster stage, and each stage carries with it some critical issues to be addressed, with an intention to develop preparedness, minimise the loss of lives and property, and to scale down and stabilise the affected area in the aftermath of the disaster. In a flood-affected area, the major aspects of management are preparedness before flood, relocation to high ground and resource distribution for the victims during the flood and tracking the recurrence probability, prevention of diseases and chaos, and restoration of the societal amenities after the flood. The use of Unmanned Aerial Vehicles (UAVs) for disaster management is a fairly recent but important and effective trend as it is applicable in almost all the disasters for a range of applications

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like surveillance and information gathering, resource dispatch and distribution, fast and efficient area coverage and establishing communication or bridging communication gaps in the disaster-affected areas. UAVs can act as aerial support systems for ground-based teams, provide faster coverage of the area and, in many cases, access the areas which are either inaccessible or hazardous for humans. For large areas of interest and complicated missions, they can also be used as multi-UAV systems or networks in the disaster-affected areas, where each of the UAVs can be used to perform specific set of tasks to collectively achieve a bigger objective.

This paper combines various operations for the disaster management using UAVs, such as coverage and path planning, image acquisition, mosaicking of images, features-based image processing and more. Following are some of the works in the literature which have inspired the current work to some extent. Araujo et al. present an approach for multiple-UAV coverage of an area, by decomposing the area for the given number of UAVs and then finding the optimal paths for coverage, using various standard coverage algorithms. Goodrich et al. present a set of priority-based search coverage algorithms for minimum time path planning. The proposed algorithm computes and optimises the picture points, and sends a plan for the optimal route for the UAVs, considering equal workload. The UAVs then fly to those points and take pictures, pre-process and send to the ground station in real-time. Arthur et al. present an algorithm to create the orthophoto mosaic of the area using Scale-Invariant Feature Transform (SIFT) matching between the successive overlapping images. Similarly, the design of FAMUOS (Fully Autonomous Multi-UAV Operation System) is presented, in which the UAVs fly autonomously over a defined area and provide a high-resolution and up-to-date overview image, to be used to generate the final mosaic of the area. Jacobsen presents another set of mosaicking algorithms, including the Bundle Block Adjustment (BBA) algorithm, which uses the original image coordinates to give comparatively accurate results. This paper is closely related to Popescu et al., sharing the concepts of a set of representative image features to identify the water pixels in the area image. There is considerable amount of research work that addresses various problems related to flood-affected areas. Balasubramaniam et al. address the objective of land-water boundary identification based on information from LiDAR mounted on UAV, Kashyap et al. present an approach to reroute the resource traffic based on instantaneous inundation information, Ravichandran et al. present an approach for UAV-based detection and tracking of survivors in the flooded region, and Majumder et al. present a game theoretic model for need-based resource allocation in flooded areas.

In this paper, we present a method to detect and track land-water boundaries in a flooded region using UAV-based imaging. This helps in all three stages of the management of the flood scenario. Flood-prone areas can be surveyed during non-monsoon seasons to keep track of the boundaries, and accordingly prepare for possible flooding. During the flood, the land-water boundary needs to be tracked periodically to update the information on inundated parts of the area, usable road networks and safe zones to assist resource distribution and survivor relocation teams, and ground-based assistance teams. It can also be used to track and predict the spread or recession of flood water during and post- flood scenario. We opt for use of UAV for imaging as it can fly over the flooded area at desired altitudes in a specified path and at desired times, which is a clear advantage over satellite imagery during a cloud-covered situation like floods. UAVs are used as high-fidelity, intelligent and convenient agents in the sky, for image acquisition purposes. The ongoing project aims to develop robust UAVs which will be able to fly in adverse weather to serve the desired purpose, along with the task of developing other important modules required for emergency flood planning and management. The proposed approach can be divided into three phases. In the first phase, the UAV with a camera mounted on it flies over the desired area in a specified path. During its flight, it takes a series of images which are tagged in sequence of flight path and with their GPS locations. These images of sufficiently spaced time instants are merged together based on the image features and overlap in the second stage, to get the single image of the overall area of interest. In the next step, representative threshold features and values are decided upon by using sample training and test strips. These threshold values are then used by the sliding box method to classify each frame to search for the boundary frames in the area. In the last step, total inundation of the area is computed based on the classification information and information from different time instants is used to predict the spread of the flood in future.

The proposed approach intends to track the land-water boundary by classifying the underlying image frames into three categories, viz. water (W), land (L) and boundary (B). This is done by checking the sub-frames within the non-water frames, and if there is at least one water sub-frame, the frame is a boundary frame, else it is a land frame. The proposed approach also employs the concept of half-sliding box (see section on Sliding Box for the Land-Water Boundary Detection) to address the cases when the regular sliding boxes graze the boundary and cannot record them. The thresholds for classification of the frames and subframes are separately defined. The lawnmower sweep-through of the whole image can detect multiple such boundaries in the area and the percentage of inundated area can be calculated. The land-water boundary information from the images at different time instants can be combined with the Digital Elevation Map (DEM) information to predict the spread of the flood waters at future instants.

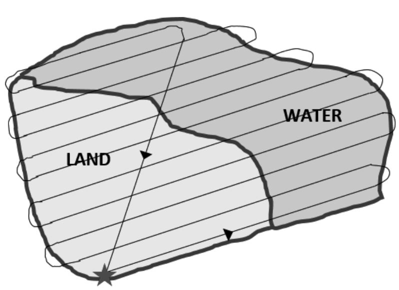


Figure 1: Lawnmower flight path for a UAV over an area

Proposed Approach

As discussed above, the proposed approach detects the land-water boundary in a flooded area using UAV-based images. The methodology followed in this paper is inspired from some standard methods in the literature, and provides the solution using one or more UAVs, based on the flooded area's size requirements. Below, we discuss the approach by breaking it down into the following five steps.

Acquisition of Images

The UAV with a downward-facing camera flies over the area in a predefined lawnmower pattern as shown in Fig. 1, taking off from and returning to the base marked by the star. It is to be noted that a fixed-wing UAV cannot take sharp rectangular turns as in a standard lawnmower pattern because of its mechanical and turn rate constraints. Thus, the UAV may have to fly a bit outside the desired area to address the constraints without missing any information in the area in approximately all the realistic scenarios, as shown in the figure. The gimbal compensates for the turn of the UAV to keep the camera facing downwards at all times. Another important consideration for path planning is that the flight direction of the straight line path of the lawnmower needs to be parallel to the longest edge (face) of the area to be covered, to minimise the number of turns. The UAV captures a series of images during its flight, which are tagged in a sequence in the flight direction of the UAV, along with their GPS location. As the UAV camera is mounted using a gimbal, it is always facing downward and the continuous recording by the camera allows the easy availability of sufficiently overlapping images (usually 80 per cent or more) to generate a near-accurate mosaic of the area.

For large areas, a single UAV will not be the best idea for time-critical missions because of the time taken and fuel constraints. This can be solved by using multiple UAVs, with the area to be covered divided among them. This area division and path planning for each UAV is pre-planned and a generic approach like Voronoi partition can be used to distribute the work load.

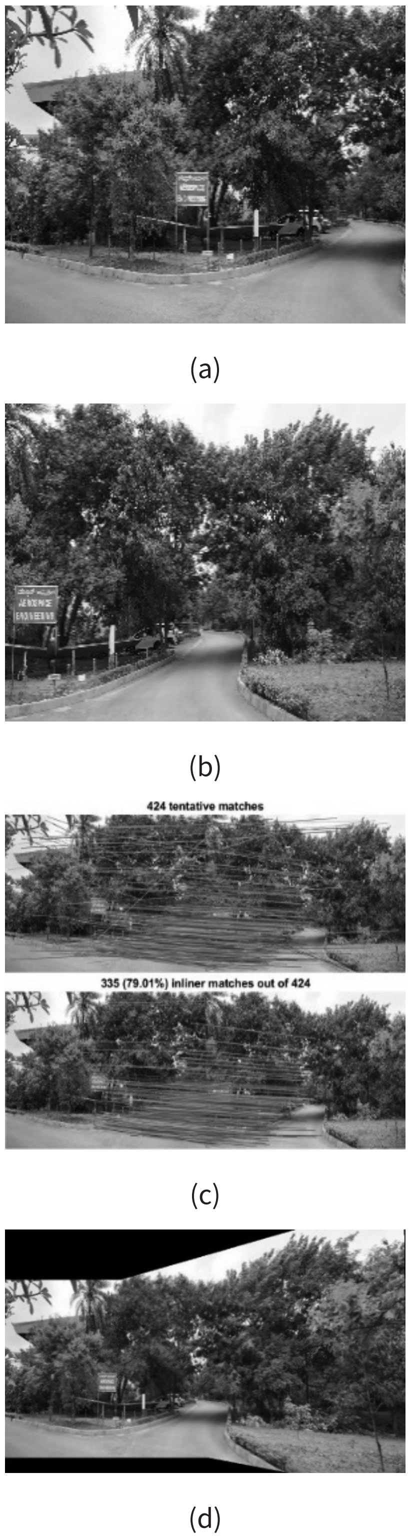


Figure 2: Mosaicking using SIFT: (a, b) image frames; (c) SIFT features and matching; (d) final mosaic image

Mosaicking

In this step, a single image of the whole area is created from the sequence of captured images. The proposed algorithm uses standard SIFT algorithm whose working can be divided into feature extraction, feature matching and an image pyramid approach to reduce computations. In these methods, the features in each image are extracted by using keypoints based on geometry, pattern, orientation, relation to surrounding and more. These keypoints are defined on local maxima or minima and are detected and localised in comparison with the surroundings. To receive rotation invariance, the orientation is maintained consistent. The keypoint count is then optimised by choosing more prominent features to reduce computations. Finally, the features in the sequential images are matched and overlapped, and the lay over results in the mosaic of the participating images. The higher the overlap between the images, the better (and accurate) the resultant mosaic is. A sample of mosaicking (overlap≈55 per cent) is shown in Fig. 2 for illustration, where two images are used to create a single image. The black portion in the final mosaic appears due to a significantly large disorientation of the camera and difference in focus and distance while capturing the images. The algorithm still works fairly well to generate the mosaic with all the image features intact. Also, these errors in capturing the images can be minimised to a great extent by a gimbaled downward-facing camera mounted on a UAV in a level flight.

Image Features and Threshold

To aid the sliding box approach, representative features are chosen for the image. The proposed method uses the six standard image features (RGBHSV: Red, Green, Blue, Hue, Saturation and Value) and seven components (Mean Intensity (Im), Contrast (Con), Energy (En), Entropy (Ent), Homogeneity (Hom), Correlation (Cor), Variance (Var)) for each feature, which combine to give 42 feature options for classification of the sliding boxes (e.g. ImR, ConG, EnB). To choose the four representative features out of these 42, separate arbitrary land and water samples are chosen from the image for threshold definition and testing. The sliding box algorithm is applied on the threshold definition samples and the land and water readings are separately recorded for each threshold option. For a distribution as shown in Fig. 3(a), the threshold value for the image feature is given by,

$$\text{Threshold} = \frac{(\mu_w - 3\sigma_w) - (\mu_l + 3\sigma_l)}{2} \quad (1)$$

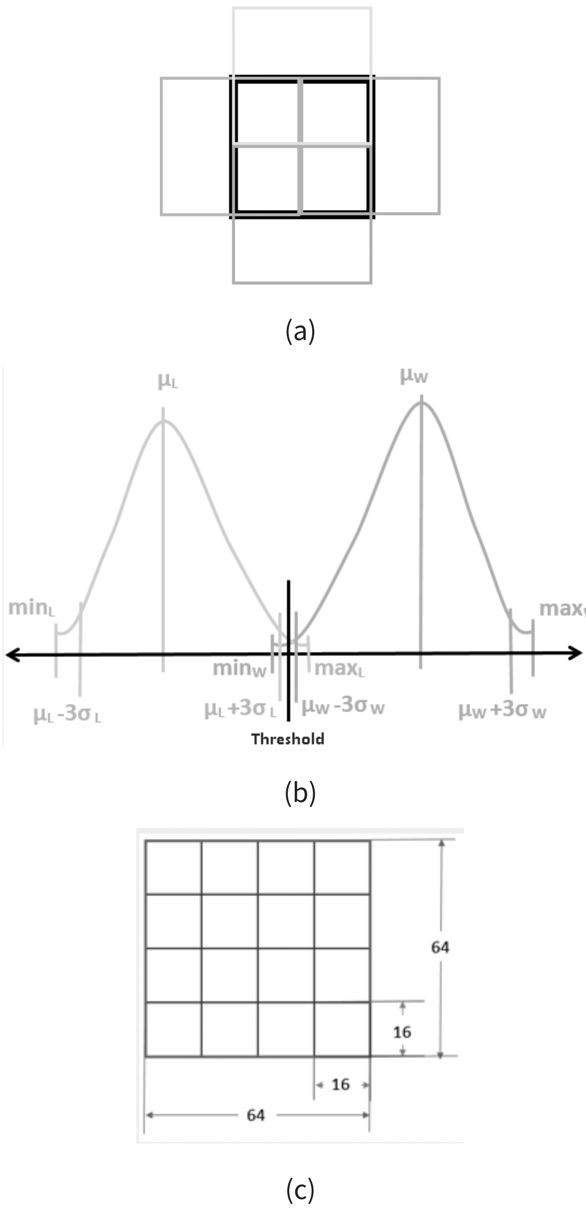


Figure 3: Calculating the threshold: (a) sample distribution of the water and land readings; (b) layout of the used frame and the subframes within; (c) half sliding frames to detect grazed boundary

where μ_l, μ_w are the mean values and σ_l, σ_w are the standard deviation values for the distribution of land and water readings, respectively. The sliding box algorithm is applied on the test samples and the threshold values are tested for obtaining standard performance parameters, which are given by,

$$Accuracy = \frac{TP + TN}{TP + FP + TN} \quad (2)$$

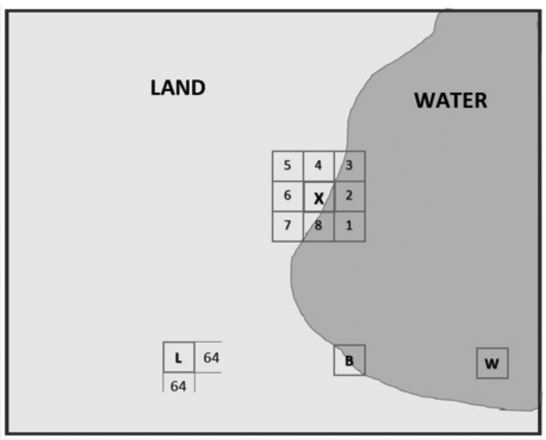
$$Specificity = \frac{TN}{FP + TN} \quad (3)$$

$$Sensitivity = \frac{TP}{TP + FN} \quad (4)$$

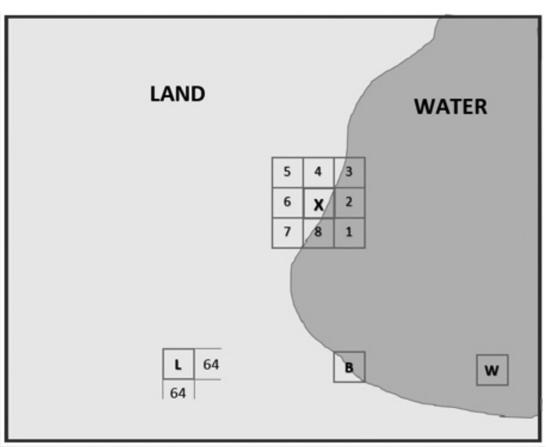
where *TP, TN, FP* and *FN* are the counts of the true positive, true negative, false positive and false negative readings, respectively. The top four performing features are selected as the representative features. This process is carried out separately for the frames and the subframes, to get their respective threshold features and values.

Sliding Box for the Land-Water Boundary Detection

Once the representative image features and their respective thresholds have been decided, the sliding box algorithm is implemented on the area image to detect the land-water boundaries. A frame (box) of resolution 64 × 64 pixels (arbitrarily chosen to be a square value) is slid across the image in the lawnmower pattern, and each one is tested for classification. Each frame has 16 underlying subframes of resolution 16x16 pixels in the layout as shown in Fig. 3(b). The surveillance area mostly remains same, so the area image is considered to be a grid with sliding frames, where each frame is tagged in the grid position (row and column) along with the GPS location (the centre of the frame). As the probability of the image resolution being an exact multiple of the frame resolution is very low, the image is mirrored by imposing standard mirror boundary conditions, in both lateral and vertical directions. This avoids the loss of data, as the sliding frames can now go up to one frame past the original image resolution. For special cases where the preceding frame is a boundary frame and the current frame is not, the algorithm accommodates a half-shift provision in which the frame is half-shifted in all the four directions to check if that can detect a boundary. This serves to detect the cases where the current frame may have grazed the boundary. For a frame with vertex extremes X, X + F, Y and Y + F, that is, with vertices (X, Y), (X +F, Y), (X +F, Y +F) and (X, Y +F), the four half-shifted frames will have the vertex extremes X +F/2, X -F/2, Y+F/2 and Y-F/2, where F is the frame size in pixels. The layout of the four half-shifted frames is shown in Fig. 3(c), where the black frame is the original frame and the coloured frames are the shifted frames. After checking the half-shifted frames for the necessary cases, the sliding box algorithm continues in the initial lawnmower pattern.



(a)



(b)

Figure 4: Proposed approach: (a) search of a new boundary in an area; (b) boundary search at some later instant

The proposed algorithm classifies the image frames into three categories, viz. water (W), land (L) and boundary (B). Each frame in the image is first checked if is a water frame, and if it is not, the subframes are checked for further classification into land and boundary. If at least one of the subframes is water, the corresponding frame is a boundary frame, else it is a land frame. The frame types with the resolution over a sample land-water boundary scenario are shown in Fig. 4(a). It can be seen from the figure that each frame in the grid has eight neighbouring frames and for every boundary frame, at least one of its neighbours is essentially a boundary frame. This has been summarised in Algorithm 1.

The lawnmower search hence marks all the boundary frames in the area image, and based on that and the pixel information related to the water frames, the percentage inundation can be computed. The centres of these boundary frames are joined to their closest neighbours to get the boundary line. In the image from next UAV run, the algorithm can start at a previously known boundary frame. If that frame is currently a water frame, it implies that the flood has spread, and if it is currently a land frame, flood has receded. Based on this, the frames in respective directions are checked till a new boundary frame is detected. The pattern then breaks off from there and the new boundaries can be tracked along the neighbouring boundary frames.

Prediction of Spread/Recession of the Flood

Algorithm 1 Sliding box method for classification of frames

```
//Get representative features and threshold set
(Rep_Th64
and Rep_Th16)
//Rep_Th64 = Frame values; Rep_Th16 = Subframe
for each frame do
    Calculate frame thresholds (Frame_Th64)
    if all Frame_Th64 satisfy Rep_Th64 then
        Frame is W
    else
```

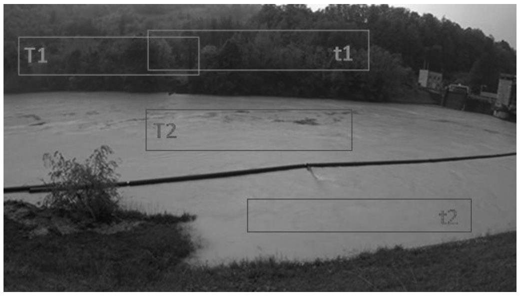
```
6:        Calculate subframe thresholds (Frame_Th16)
7:        for each subframe do
8:            if all Frame_Th16 satisfy Rep_Th16 then
9:                Frame is B
10:               Draw frame on the image
11:               break
12:           else
13:               Frame is L
14:           end if
15:       end for
16:     end if
17:     if Prev_Frame is B & Frame is L or W then
18:       Calculate four shifted frame coordinates
19:       for each shifted frame do
20:           Repeat steps 3 to 16
21:       end for
22:     end if
23:   end for
```

Flood-prone areas are usually surveyed in advance to get the Digital Elevation Map (DEM) information. The spatial gradient (Δx) and the height gradient (Δh) from the DEM can be combined with the information from the land-water boundaries of multiple time instants to fit a curve and predict the boundary at future instants. This information can be critical to ground-based rescue and relief teams, and for traffic and route management for evacuation and resource distribution vehicles as well as the civilians.

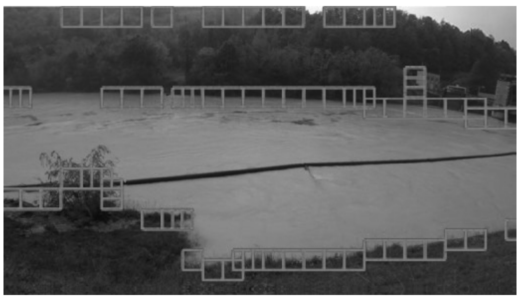
Simulation Results

The primary applicability of the proposed algorithm is successfully tested using a GoPro Hero 5-mounted UAV-acquired flood area images available on the Web. The simulations are performed in MATLAB v9 (R2015b), and the results for a sample image are presented in Figure 5. The original image with the training and test strips is shown in Fig. 5(a). The black line that runs across the water is some pipe-kind of structure which is of no importance or concern in the simulation, as if does not carry any information and did not affect the simulation in any undesired way. In the figure, T1 and T2 are the sample training strips for land and water, respectively. The sliding box algorithm was used on these strips to calculate the threshold values of all the competing features. After this, strips t1 and t2 were used as test strips to decide upon the representative features, which came to be: mean intensity of red (ImR), energy of green (EnG), entropy of red (EntR) and homogeneity of blue (HomB). After applying the proposed algorithm and classifying the frames on the image, the boundary frames are marked as shown in Fig. 5(b). It can be noted from the figure that there is a stretch of false positive frames on the top of the image. This is a result of the image feature thresholds similar to water for the hazy vegetation. The representative feature and the threshold definition part of the algorithm need to be further perfected to address this. However, as we intend to capture images with a downward-facing camera, such problems can be avoided in the final implementation of the algorithm. For the present simulation, these errors in false positive detection were removed by visual inspection to obtain the image in Fig. 5(c). This selection and rejection of error frames needs to be automated for the final algorithm.

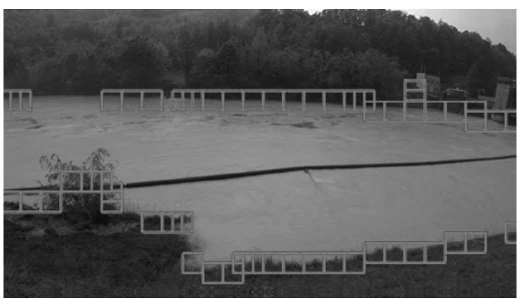
Furthermore, it can be noticed that there are a few false negative readings (the boundary frames not being detected) and a couple of false positive readings, which occur due to similar texture values of representative features for those frames. These can be further improved by modifying the part of algorithm to choose representative features. In the next step, the centres of the boundary frames are joined to obtain the boundary line (see Fig. 5(d)), as discussed in section on Sliding Box for the Land-Water Boundary Detection. It can be seen that the boundary line obtained by the proposed approach near-accurately draws the two land-water boundaries in the image, with slight errors as mentioned above. This proves the applicability of the proposed approach, and points to the directions that need further work.



(a)



(b)



(c)

(d)

Figure 5: Application on a flood area image: (a) original image (source: Google image search) with marked training and test strips; (b) boundary frames on the image; (c) image after removal of the error boundary frames; (d) boundary line drawn through the boundary frames

Discussion

Proposed Experimental Setup

This work is a part of an ongoing project which aims to develop an emergency flood planning and management system which intends to develop modules to detect and study flood situation, plan and assist resource allocation and traffic management, coverage of the area and a central decision system which manages the modules. The aforementioned objectives are to be achieved using unmanned aerial systems. For the proposed approach, an experiment has been set up to verify its applicability before it is used in the flood management system. For this, a Tarot IronMan 650 quadcopter will be used, with a GoPro Hero 5 digital camera mounted on it using Tarot TL3T05 gimbals. The quadcopter will be flown in areas with regular land-water boundaries (like lakes) and with moving waterfront, and the downward-facing camera will be used to capture images at multiple time instants to test the full implementation of the algorithm.

Future Work

The proposed algorithm needs some work to further improve the image processing requirements, which include the module to choose the representative feature and the computation of their values to minimise the false positive and false negative classifications. The boundary line drawing mechanism can be further improved to correctly compensate the shortcomings of the classification. Although the downward-facing camera will resolve it to some extent as the image will not contain the horizon and we can expect a top view of the area, further perfecting the algorithm will be a plus to make the algorithm more robust and efficient in all real-life flood scenarios. This will also serve the expectation from the proposed approach which is to be fully autonomous. After this, the objective will be to try and minimise the computations to be able to implement the algorithm online, to use the onboard computer of the quadcopter to track the boundary during the flight itself.

Conclusion

This paper presents an approach to detect and track the land-water boundary in a flooded area, to calculate the inundation and to predict the spread of the flood in future. This was achieved using basic concepts of image processing: image texture feature and threshold based classifications using the sliding box method. The objective serves as an aid to real-life flood planning and management modules where the updated and the predicted information could be of great help. The algorithm was successfully implemented in simulations and the results have been presented to prove its applicability to the planned experiments and thus real flood scenarios.

Acknowledgements

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References

Araujo J, Sujit PB, Sousa JB (2013) Multiple UAV area decomposition and coverage, in *Proceedings of 2013 IEEE Symposium on Computational Intelligence for Security and Defense Applications (CISDA),* pp. 30– 37, IEEE, Singapore.

Arthur M, Barbados M, Tahir A, Davis D (2012) Rapid processing of unmanned aerial vehicles imagery for disaster management," in *FIG Working Week*, pp. 6–10.

Balasubramaniam S, Kashyap A, Shriwastav S, Majumder R, Abhinay NS, Ghose D (2019) LiDAR based land-water boundary identification during floods, to appear in the *Proceedings of 4th World Congress on Disaster Management*, Mumbai, India.

Goodrich MA, Lin L (2009) UAV intelligent path planning for wilderness search and rescue, In *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 709–714, St. Louis, USA.

Jacobsen K: Block adjustment, [Online]. Available: https://www.ipi.unihannover.de/uploads/tx_tk_publikationen/blockadjustment.pdf

Kashyap A, Ghose D (2019) Planning of alternative street routes in urban areas during floods, to appear in the *Proceedings of 4th World Congress on Disaster Management*, Mumbai, India.

Majumder R, Warier RR, Ghose D (2019) Game theoretic model based resource allocation during floods, to appear in the *Proceedings of 4th World Congress on Disaster Management*, Mumbai, India.

Popescu D, Ichim L, Caramihale T (2015) Flood areas detection based on UAV surveillance system, in *Proceedings of 19th International Conference on System Theory, Control and Computing (ICSTCC),* pp. 753–758, IEEE, Cheile Gradestei, Romania.

Quaritsch M, Kruggl K, Wischounig-Strucl D, Bhattacharya S, Shah M, Rinner B (2010) Networked UAVs as aerial sensor network for disaster management applications, *E & I Elektrotechnik und Information-stechnik*, 127(3), pp. 56–63.

Quaritsch M, Kuschnig R, Hellwagner H, Rinner B, Adria A, Klagenfurt U (2011) Fast aerial image acquisition and mosaicking for emergency response operations by collaborative UAVs, in *Proceedings for the International ISCRAM Conference*, pp. 1–5, Lisbon, Portugal.

Ravichandran R, Abhinay NS, Ghose D, Das K (2019) Searching for survivors in a flood scenario using UAVs and ground based observers, to appear in the *Proceedings of 4th World Congress on Disaster Management*, Mumbai, India.

Drones: A Crucial Tool for Disaster Management

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ABSTRACT: Disasters wreak havoc on human life and property, testing the most fundamental instinct of human survival. In the event of a disaster, even with the tried and tested disaster management protocols, one thing that stands out is that it is a race against time. The first 72 hours of the disaster are the most crucial period in which Search and Rescue (SAR) operations have to be conducted quickly and efficiently enough to save lives, and the need for situational awareness during such period for driving SAR operations cannot be underestimated. Drones are the answer to this; it provides a bird's-eye view of the entire disaster-struck area to assess the disaster in a very short time.

The real-time transmitted videos from the drones provide the first responders with real-time knowledge of the situation to better understand about the extent of structural damages, the state of transportation infrastructure and stranded survivors. This helps them to plan and respond efficiently, sparing them the horror of confusion and chaos.

With drones, logistical planning becomes easy and taking decisions about resource allocation becomes easier. Drones can even help in directing stranded people to safe locations. Drones can also be used to set up a temporary ad hoc communication infrastructure in disaster-struck areas to connect mobile devices to the nearest network. Computer-vision-based approaches and sensory data analysis can further help in analysing damage in-depth with the aid of drone images for governmental reports and insurance-related field surveys. Drones can also be used for pre-disaster preparedness.

This paper explores more in detail the use of drones in the different stages of a disaster, viz. pre-disaster preparedness, disaster assessment and disaster response and recovery.

KEYWORDS: drones for disaster management, search and rescue, logistics, pre-disaster preparedness, disaster assessment, disaster response and recovery

Introduction

A disaster is a natural or man-made hazard which occurs in a relatively short time, resulting in significant damage and destruction involving human, material, economic or environmental losses and impacts. Disasters can stem from any event, including earthquakes, flash floods, tsunamis, hurricanes, chemical spills, nuclear blasts, explosions, etc. The extent of the disaster makes it very difficult for humans to cope with the situation with the available resources, as disasters to a great extent damage all kinds of infrastructures, including property and transportation structures. According to the data from the United Nations Office for Disaster Risk Reduction, the total economic and human impact due to global disasters from 2002 to 2012 is 1.2 million deaths, 2.9 billion affected people and $1.5 trillion in damages. It is estimated that climate change will only increase the frequency of disaster occurrences and these figures might probably increase further. Many significant research and development efforts are already being carried out in order to tackle these

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by predicting the possibility of disasters, and taking efficient measures to prevent, assess and fix damages to restore normalcy.

In the event of a disaster, the first 72 hours of the disaster are the most crucial period to save lives, and the key to this is the response time of the first responders. But major problems like lack of communication and situational awareness pressurises first responders to make unplanned decisions degrading the efficiency of the rescue mission. The need for fast and efficient situational awareness thus cannot be underestimated, and it can be achieved only through aerial assessment. Manned aerial assessments are very costly and also not feasible in such situations, and hence Unmanned Aerial Vehicles are the go-to choice with the advance in technology. In this paper, we not only outline the importance of UAVs as a complementary tool for rescue teams during disaster but also investigate their role and advantages in the different stages of disaster management.

UAVs in Disaster Management

Unmanned Aircraft Vehicles (UAVs), also known as Drones, Unmanned Aerial System (UAS) or Remotely Piloted Aircraft System (RPAS), are aircrafts which do not need a human pilot on-board and are controlled by 'pilots' from the ground with computers. UAVs were initially developed during World War I for military applications, but with their rapid awareness, they are changing human lives.

In general, disaster management protocol as proposed by the International Search and Rescue Advisory Group (INSARAG), the SAR mission, must be conducted by a team comprising a team leader, an incident commander and other team members. The SAR mission is usually conducted in four major steps, in which the commander first establishes a small search area so as to minimise communication problems among the rescuers, then a command post is set up in the search area; consequently the teams are divided into scouts and rescuers, in which the scout team scouts the search area and reports to the command post and the rescue team using the information from the command post sets out to rescue. When a UAV is brought into this SAR mission scenario, the unmanned aerial vehicle replaces the scout team, providing more in-depth information in a more efficient manner, and that too in a very short span of time.

Unmanned aerial vehicles in disaster management can provide a bird's-eye view of the disaster-affected area and in turn provide the first responders with a better understanding of the extent of damage inflicted by the disaster. The real-time transmitted images and videos from the UAVs can provide the first responders with first-hand knowledge of the structural damages, the state of transportation infrastructure and stranded survivors. This helps them to plan and respond efficiently with their limited available resources, sparing them the horror of confusion and chaos. Logistical planning becomes easy with UAVs and taking decisions becomes easier as the first responders are not forced into taking blind decisions.

UAV Integration in Disaster Management Phases

To effectively respond to disasters it is best to understand disasters and divide them into phases. The concept of disaster phases has been used since several decades to examine disaster and make emergency plans.

The disaster management process is divided into three phases, the phase in which countermeasures are planned before a disaster strikes, called the disaster preparedness phase; responding to the disaster as it strikes, called the disaster response phase; and the recovery phase, which relates to recovering after the disaster.

To integrate UAVs in these disaster management phases, the following operational lifecycle is mentioned:

- Disaster Preparedness – In this stage, the UAVs can be used as Early Warning Systems (EWS) to predict the possibility of disasters, so as to plan accordingly to respond to disasters.
- Disaster Assessment – During the disaster, the UAVs can provide real-time data to the first responders so as to provide situational awareness and better help in logistical planning.

- Disaster Response and Recovery – UAVs can help in SAR missions by scouting information and helping find stranded and lost people.

In each phase of the disaster management, the UAVs are required to do a set of tasks, each requiring different lengths of time and each varying in the priority level.

Disaster Preparedness

The disaster preparedness phase is usually not confined to a particular timeline; rather it can start several years before the anticipated disaster. UAVs can be used along with Wireless Sensor Networks (WSN) to collect information by leveraging their potential in structural and environmental monitoring, and then analysing the information for forecasting and early warning systems. In a general scenario, several wireless ground sensors can be deployed along water banks or mountains to collect physical information like water levels and mountain vibrations/displacement. The data from these wireless sensors and the data from the occasional drone surveillances can then be passed onto a centralised location for further analysis. But for resource-constrained sensors which are not within reach of cellular networks, UAVs can help as data mules to deliver the data from the sensors to the centralised locations, thus also avoiding the problems of routing and resource allocation problems of existing WSNs.

UAV fleets can also be used for obtaining data for prediction. Feng et al. propose a fleet of UAVs for flood monitoring by gathering data and using Random Forest Classifier algorithm for analysis and prediction, which achieves an accuracy rate of 87.3 per cent.

Disaster Assessment

When a disaster strikes, assessing the extent of damage is very important as disasters destroy human inhabitation, topographical regions and infrastructure. First-hand information during such period acts as a boon to the first responders to reach out to the people in need. Air assessment helps the first responders to streamline their response efficiently and also collect information from hard-to-reach areas for the recovery process.

Disaster assessment using UAVs during this phase helps in gathering information regarding broken-down power lines, unstable infrastructure and blocked roads, and relaying this data back to the control centre. This assists the first responders in planning out the quickest and safest routes for their team to navigate through and provide help.

The data from the UAVs can further be processed through computer-based software to create in-depth report on the health of infrastructure, number of damages identified and many more.

Disaster Response and Recovery (in Progress)

The images and video footage transmitted by UAVs in real-time provide the first responders with better situational awareness. They also help them in locating survivors, whether stranded or trapped, and can even help in delivering first-aid kits and equipment.

Search and Rescue Mission

Search and rescue missions with UAVs can immensely reduce the search time and also limit the potential risk to first responders, as rescue plans can be prepared by studying the situation in depth. Today, it is possible to stop humans with the help of thermal cameras fitted to UAVs, as thermal cameras pick out the body heat of humans. It is very easy to spot them amidst the rubble and vegetation. Since UAVs are equipped with GPS, the pilot can guide first responders to the exact location of the subjects.

Logistic Planning

The data from the UAVs can help first responders to choose the quickest and safest route to reach the stranded/trapped survivors.

Supply Drop

When people get stranded in disaster-struck areas due to damage in transport infrastructures, floods or due to water logging, UAVs can help by supplying emergency kits. Food packets, medicines, life jackets and even "rescue lines" can be dropped to the victims by the UAVs to help rescuers guide them to safety.

In Rwanda, a Silicon-valley based Zipline has been delivering blood to hospitals in need with UAVs, cutting delivery time from hours to minutes.

Standalone Communication

During disaster events, communication becomes difficult as communication infrastructure may get damaged, as evident from Hurricanes Irma and Maria, which struck Puerto Rico, leaving 90 per cent of cell sites damaged. This leaves the victims stranded in the area with no possibility to call for help. In such scenarios, UAVs can provide relief as a temporary fix for the communication problem. Existing nodes can be connected to form multi-hop networks using temporary UAVs for connectivity.

Recently, Verizon tested a 200-pound UAV carrying a "femtocell", or small flying cell site in New Jersey, which is designed to provide a 4G LTE signal throughout a one-mile range for areas that have lost coverage. The intent of the test is to supply a "cone of coverage" to first responders, who need communication to help in an event of disaster.

Madikeri Post-flood Disaster Management: A Case Study

In August 2018, heavy rains lashed in the Karnataka state in Southern India, leading to floods and major landslides. The worst-affected area was parts of Kodagu district, which is on the foothills of the Western Ghats. Several major highways were blocked because of landslides and had led to the stranding of scores of people in remote-areas awaiting rescue operations.

Ideaforge, in conjunction with the local government authorities, deployed a team of dedicated UAV pilots and their flagship professional UAV system Netra Pro & Netra Q2. Netra Pro, which has a flight time of 40 minutes, range of 4 km and altitude 400 m, was launched with a photogrammetric payload, while Netra Q2, having a flight time of 20 mins, range 2 km and altitude 400 m, was launched with an ordinary daylight payload.

Ideaforge UAVs mapped different locations under the Tribal Welfare Department of Madikeri, Coorg, Manglore at national highway 275 and some tribal areas in the southern Karnataka region bordering the state of Kerala, with seven flights over two days, and assessed the inflicted damage. The mapping was carried out at an average altitude of 100m due to intense fog cover and at a resolution range between <1cm and 2.7cm.

The post-disaster imagery was analysed with Agisoft photoscan software to provide an in-depth 3D surface model and orthomosaic map for determining the damage suffered due to floods and landslides. The complete analysis report was then submitted to the District Collector within a day.

The footage from the UAVs and the final analysed report assisted the Tribal Welfare Department in locating the primitive tribes of the region which were severely affected due to floods. It also helped the officials in assessing the damage in the inaccessible areas, determining the damage suffered by the tribal populace, checking for any stranded survivors and assessing governmental infrastructures like roads and tribal hamlets for damages from the flood and landslides.

The Karnataka State Police Department, Commissioner's Office, National Highway Authority of India and the local PWD also collectively used the images for rebuilding and rehabilitation operations.

Unmanned Power in Disasters Across the World

Hurricane Harvey–Houstan

In August 2017, Hurricane Harvey inflicted an estimated $120billion damage to Houston, flooding 30,000 houses and waterlogging millions of vehicles. In the heat of the most expensive natural disaster of the country, the Federal Aviation Administration issued atleast 43 separate authorisations for drones to help with the response and recovery efforts. The drones were used for inspecting a range of infrastructure, from roadways to railroad tracks, to assess their condition. Many oil and gas companies also used drones to inspect their facilities, oil refineries and power lines. Even insurance companies flew drones to tally up and verify damage claims.

Nepal Earthquake

In April 2015, an earthquake magnitude of 7.8 struck the Himalayan nation of Nepal, killing 10,000 people and leaving many homeless. Drones during the response and recovery efforts of this massive disaster offered the response teams with crisp and clear aerial images of the disaster-struck area. It helped in fast-tracking the recovery process by assisting in search and rescue operations, damage assessment of infrastructures, reconstruction and rehabilitation.

Hurricane Sandy – Haiti (2012)

During the disastrous event of Hurricane Harvey in Haiti 2012, UAVs provided aerial imagery of the damage caused by the hurricane. Along with the aerial images and the existing open-source imagery and census data, first responders were able to determine the exact place where assistance was needed. The images also helped them in locating standing water where mosquitoes and epidemics might spread. This helped them in better response and rebuilding of the society.

Applications of UAVs

UAVs have been used in many different disaster management applications, but mostly for the following:

- Monitoring, forecasting and early warnings – UAVs can be used as Early Warning Systems (EWS) by exploiting their potential to monitor and analyse infrastructures and the environment so as to forecast any disasters. UAVs can be further used with wireless ground sensors for better analysis.
- Situational awareness and logistics and evacuation support – UAVs can help in gathering real-time information in a disaster-struck area, especially regarding the state of transportation infrastructure, stranded people and deployed rescue teams.
- SAR missions – UAVs can help in search and rescue missions by locating lost, injured and trapped people.
- Standalone communication – UAVs can help establish a standalone communication network to replace the damaged or destroyed communication infrastructure during the disaster.
- Structural Integrity and Damage assessment – UAVs can help assess the damage to buildings and transportation infrastructure by structural health monitoring and UAV video inspection. This helps the first responders to plan SAR missions accordingly and take alternative routes if transportation infrastructures are damaged.
- Media coverage – UAVs can even be used for media coverage so as to deliver timely information to viewers for informational purposes.
- Infrastructure (re)construction – UAVs can help in mapping and inspection of the terrain and the damaged infrastructures. These can speed up the process of inspecting the area and provide improvements in the efficiency and precision of infrastructure reconstruction.
- Medical applications – specialised drones can deliver food and first-aid medical supplies in case of emergencies, especially when transport infrastructures are damages
- Disaster information fusion and sharing – UAVs can support other applications by combining different sources of available information to reach across different information technologies.

Challenges

Technology Maturity

Advanced research and technological integration are still under process, especially in the technical field of providing UAV-assisted communication during disasters. Since companies have only started testing them out, with some time, these will also become mature enough to be deployed confidently during disasters.

Psychological Barriers

People still have the notion that UAVs for disaster will just increase the complexity of the response and recovery efforts, but they have to overcome such psychological barriers. They have to look beyond their fear to fully understand the benefits of UAVs as a complementary tool for first responders.

UAVs as Complementary Tools Alone

People tend to forget that UAVs are only complementary tools that assist first responders to act better and the burden of responding actually lies with the people themselves.

Conclusion

Exploiting the potentials of UAVs and integrating them with the different disaster management phases is one of the quickest methods to respond efficiently during disaster. From disaster preparedness to disaster assessment and recovery, UAVs as complementary tools for first responders act as an eye in the sky, helping them in planning with better situational awareness.

References

https://www.hds.utc.fr/~enataliz/dokuwiki/lib/exe/fetch.php?id = en%3Apubli&cache = cache&media = en:cn2017.pdf

https://www.archives-ouvertes.fr/hal-01305371/document

https://bwn.ece.gatech.edu/papers/2017/uavs.pdf

https://www.wsj.com/articles/drones-play-increasing-role-in-harvey-disaster-recovery-efforts-1504474194

https://www.wired.com/story/houston-recovery-drones/

https://www.geospatialworld.net/article/mapping-nepal-drones-and-the-future-of-disaster-response/

https://www.washingtonpost.com/news/innovations/wp/2015/10/07/in-nepal-a-model-for-using-drones-for-humanitarianism-emerges/?utm_term = .934bcaeeede3

https://www.king5.com/article/news/local/disaster/after-disaster-could-drones-restore-cell-service/281–534197963

https://www.usatoday.com/story/tech/columnist/baig/2018/03/16/hurricane-wipes-out-cell-phone-service-here-comes-200-pound-drone/419614002/

Searching for Survivors in a Flood Scenario Using UAVs and Ground-Based Observers

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ABSTRACT: During floods, there are many survivors who are either stranded or are trying to reach dry areas in the flooded region. It is important to search for these survivors and help them to reach safe regions. During such times, the terrain is heavily damaged and this restricts the movement of land and water vehicles. Therefore, it is advantageous to execute the survivor search operation using aerial vehicles or Unmanned Aerial vehicles (UAVs). In this paper we propose two different UAV search patterns which increase the probability of finding survivors in flood-affected areas. When searching in a large area, it is nearly impossible to ascertain the location of the survivor without any initial input. Hence, we have considered stationary ground-based observers, placed at certain locations, which report the survivor's location and direction of motion to the UAV when a survivor comes within its field of view. In the first method, which is the Probability-Based Search (PS), the UAV creates a probability map of the possible places the survivors could be at after a certain time given their previous location and predicts the best possible location to search for based on probability; whereas in the second method, the Weight-Based Search (WS), the UAV creates a weightage matrix of the possible places where the survivor can be from the last known location of the survivor and predicts the best possible point based on size of the weightage cluster and nearness of the cluster. These two methods are simulated in the same environment and compared to a conventional method, where the UAV searches in an outward spiral, starting at the last known location of the survivor.

KEYWORDS: UAV search pattern, probability-based search, weightage-based search, ground-based observers, survivor search

Introduction

Floods are among the most common and destructive natural hazards which cause extensive damage to infrastructure and devastation to human settlements. Heavy floods wash away homes along with people residing in it and these people are stranded in unknown locations without proper food or water. Hence, in order to rescue the survivors, a search team is usually deployed. These search teams travel either by boat or by a land vehicle, and their movements are very restricted since most of the routes are damaged due to the flood. This makes the search process time-consuming and inefficient. This problem can be solved by having an aerial vehicle or an Unmanned Aerial Vehicle (UAV) search for survivors.

During the search for survivors, the UAV does not know the exact locations of the survivors and hence it has to search the entire area of the environment without any prior information. To reduce the total search time, it is assumed that there are ground-based observers placed at particular locations and they provide the survivor's location directly to the UAV when the moving survivor comes within the range of view of

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the observers. The UAV then plans its search to find and rescue the survivor. Here, the survivor is assumed to be constantly moving due to the flow of current or in search for a safe location. Hence, when the UAV reaches the last known location of the survivor, the survivor might have already moved to another location. At this point, the UAV has no other information regarding the survivor; hence, it has to either wait for the survivor to enter the range of view of another observer or do a spiral search around the last known location. From Fig.1 it can be observed that, if the UAV had gone to the last known location, it would have missed locating the survivor and it would have to decide which point to search next. But since it does not have any information, it cannot take any decisions and has to do an outward spiral search. These methods are time-consuming and the probability of finding the survivor is uncertain.

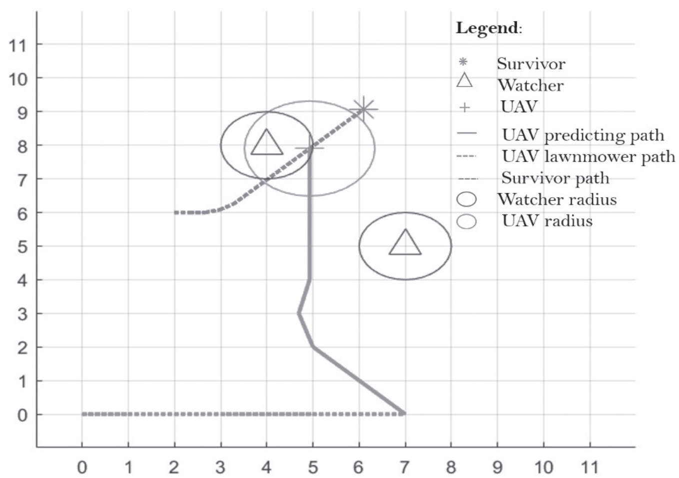

Figure 1: Conventional search

The problem of search and rescue during a crisis caused by either natural or man-made events is an important one and has been addressed by many researchers in the past. A cooperative path planning algorithm is proposed to track targets in an urban environment, in which the target motion is modelled as a second-order Markov model and is used to predict the future locations of the target. This work assumes that a digital elevation map is available initially and the environment is static, which is not true in the event of a flood. Also, in this work, an optimisation problem is solved in case of a single pursuer to choose the next location to be searched and a suboptimal auction-based scheme is employed to extend it to multiple pursuers. Similarly, it also addresses the same problem but in an indoor environment and uses A* algorithm for path planning. A heuristic-based surveillance algorithm is also proposed to increase the number of sightings of a target which is believed to be following a fixed path periodically. The problem of capturing a mobile target which is headed towards a known goal location is addressed using a UAV and ground-based observers, considering information delay between the observers and the pursuer, with an objective of capturing the target before reaching the goal. Another paper addresses the problem of mobile target tracking by a network of UAVs and requires terrain information of the area of operation. In this work only position information is used and the target motion is modelled as a diffusion process and a partial differential equation is developed which governs the evolution of probability distribution with time. This addresses the problem of search and tracking for lost targets using a recursive Bayesian technique. The kind of targets that are considered are people stranded in a sea or ocean due to a marine disaster and can only move at the will of the wind and current at their respective location. The problem of persistent sensing of a non-cooperative ground based target in an urban environment using a team of UAVs is addressed. In this work as well, a probabilistic approach was used with an aim to choose a location from which the availability of LOS is maximum. Here it is assumed that the target is primarily detected by some other means and it is not clear how the target's information is obtained. Moreover, it uses some behavioural characteristics of the target to find its intent so as to correct the probability distribution. The problem of following a target by UAVs is also addressed. This is an important problem because ground-based targets have relatively less speeds when compared to UAVs. A UAV implements a circular manoeuver, and until it is able to follow the target again, it keeps repeating the same trajectory. The search for lost targets is modelled as a planning problem instead of using a probabilistic approach of predicting the target's future locations. A predefined set of search patterns will be executed but the decision that has to be made here is the sequence in which they have to be executed and also the timing of each execution. A comparison study has been done on different strategies that could be used in search operations. This work compares deterministic and probabilistic methods and solves for an optimal path using dynamic programming to maximise the detection probability over a finite look-ahead window. The paper addresses the problem of searching from a game theoretic perspective and provides a survey of work done so far in search and pursuit evasion in mobile robotics. The problems encountered in flood-affected areas have been addressed by various other authors, such as addresses the research on land-water boundary identification using a LiDAR mounted on a UAV, addresses the research of identifying land-water boundaries from UAV-based imaging, presents an approach of re-routing vehicles in a flood affected area and presents a game-theory model for need-based resource allocation in flood affected areas.

In the proposed method, we present a search pattern which uses the last known location and the direction of heading of the survivor which is received from the observer to create a probability and a weightage matrix of the locations where the probability of finding the survivor will be high. This information can be used by the UAV to increase its chances of finding the survivor and hence making the entire process more efficient.

The objective of this method is to generate a map of probable survivor locations, so that the UAV searches the environment in a more efficient manner and has a better chance of finding survivors. To simulate the scenario, we have considered a discrete 2D model of the pursuer, observers and the survivor. The survivor is considered to be non-holonomic and moves continuously at a constant speed lower than that of the pursuer, which is also a non-holonomic vehicle with a constant search radius and can move at a maximum specified speed. The observers remain at a fixed position in the environment and have a constant field of view. The UAV initially performs a lawnmower search pattern in the environment until it receives information from an observer.

In the probability-based search, the probable locations of finding the survivor at a certain point of time are determined over a finite look-ahead horizon and the probabilities are computed based on the previously available information and are corrected when there is new information available.

In the weight-based method the pursuer computes a weightage matrix of the probable locations of the survivor and updates at every step. The generation and updation of the weightage matrix depends on the information received from the observers, that is, the last spotted location and the direction of heading of the survivor. This information is used to create a weightage matrix which expands outwards from the last known survivor location point at a rate that is the same as the speed at which is the survivor is moving. As the UAV moves towards the most probable location, it searches for survivors on its path. On its path, it updates the matrix at every instant, computes the next probable location using the updated matrix and proceeds to search that location.

Methodology

UAV Model

The UAV dynamics are given as follows:

$$\dot{x}_{uav} = v_{uav} cos\varnothing_{uav} \tag{1}$$

$$\dot{y}_{uav} = v_{uav} sin\varnothing_{uav} \tag{2}$$

$$\dot{\varnothing}_{uav} = \omega_{uav} \tag{3}$$

Since the simulations are in 2D, we have considered the UAV dynamics equivalent to a unicycle model.

Survivor Model

Similarly, the dynamic equations used for the survivor are also considered to be of a unicycle model. The survivor dynamics are given below:-

$$\dot{x}_{sur} = v_{sur} cos\varnothing_{sur} \tag{4}$$

$$\dot{y}_{sur} = v_{sur} sin\varnothing_{sur} \tag{5}$$

$$\dot{\varnothing}_{sur} = \omega_{sur} \tag{6}$$

Assumptions

Below are a few assumptions considered in order to simulate the search algorithms. The assumptions mentioned as (PS) are for the Probability-Based Search and (WS) are for the Weight-Based Search:

- Speed of the target is known to the pursuer without any ambiguity. (PS, WS)
- The maximum speed of the pursuer can at most be thrice that of the target. (PS, WS)
- The path between any two points in the grid must go through the intermediate grid points; that is, a single straight line paths joining the two points is not a valid path. (PS)
- The ground stations have full observation of the target when under their respective field of view. (PS, WS)
- It is assumed that the vehicles speed on the straight edges would be 1 unit and on diagonal edges would be $\sqrt{2}$ units. This helps in formulating the problem in a rectangular grid. (PS)
- It is assumed that all the observers are always within the communication range of the UAV and the delay in communication is neglected. (PS,WS)

Probability-Based Search (PS)

In this method, the probable locations where the survivor could be found in future time instances are determined based on the speed of the survivor and the probabilities are assigned to them accordingly. The points in the last known direction of travel of the survivor are assigned more probability value when compared to the other points, and the points in the opposite direction are assigned the least probability value.

We start by assigning probabilities to the eight neighbouring points of the last known location first and then repeat this process for the child nodes of each of those neighbouring points for a fixed time interval in the future. So, at time t = 1, we have eight possible locations where the survivor could be, and likewise at time t = 2 we would have 17 probable locations.

Now in order to choose the next point to be searched by the UAV, we calculate the time difference between the survivor and the UAV. The next probable location corresponding to a particular time is chosen such that the time difference is non-negative, since, in case of points with negative time difference, the survivor would have already passed through that point by the time the UAV reaches there. It is also possible that there are multiple points with non-negative time difference and hence we choose the correct point based on high probability and less time difference. If we choose a point with a high time difference, it would turn out to be a bad strategy if the UAV was unable to find the survivor at that point, since the UAV has lost more time in waiting. Now, if there are no points with non-negative time difference corresponding to a particular time instance, then we look for probable locations in the next time instance and continue looking until we find a suitable point to visit. The pursuer generally has a field of view whose radius is greater than zero, making it possible to consider the probable locations even with a small negative time difference. The magnitude of negative time difference that can be considered depends on the field of view of the UAV.

In case the heading information of the survivor is not available, then we assign equal probabilities to the immediate neighbours around the last known location. From the next time instance the probabilities are assigned based on the heading difference between the child node and the parent node.

The search will be terminated when the survivor comes into the field of view of the pursuer.

Probability-Based Search Algorithm

Data: UAV speed = 1, survivorspeed = 1/3, survivor's latest position and heading
Result: Next destination position for the UAV
start;
flag←0
while *survivor is not found by the UAV* **do**
  if *new information is available* **then**
    Identify the probable locations over a finite look ahead window
    Calculate the probability distribution
    k←1
  else

k←previous time instance in which the target was searched for
end
while *flag* **do**
for *i = k to length of the look ahead window* **do**
$time_{diff}$ ← time taken by the intruder - time taken by pursuer to reach the points of the *ith instance*
if *any of the points have a positive time difference* **then**
flag←1
break
else if *i > length of the look ahead window* **then**
k←length of look ahead window +1
Increase length of the finite look ahead window
Calculate the probability distribution
end
end
end
if *there are more than one point with positive time difference* **then**
destination ← point with maximum probability
return x,y co-ordinates of the destination point.
end

Weight-Based Search (WS)

In this method the UAV initially performs a lawnmower search pattern in the environment until it receives an information from an observer. It then creates a weightage matrix of the probable locations of the survivor and updates at every step. This is done so because the survivor is constantly in motion and by time the UAV reaches the last spotted survivor location, the survivor might have already moved to a different location. Hence, it is necessary to create a map of probable locations of the survivor and choose an optimum one. The generation and updation of the weightage matrix depends on the information received from the observers, that is, the last spotted location and the direction of heading of the survivor. This information is used to create a weightage matrix which expands outwards from the last known survivor location point at a rate that is the same as the speed at which is the survivor is moving. This matrix is then split into four quadrants at the last known location of the survivor. The weightages of the matrix are then assigned in such a way that a higher weight is assigned to the quadrant where the angle of heading lies (say, 1^{st} quadrant), the two adjacent quadrants (say, 2^{nd} and 4^{th}) are assigned a lower weightage with respect to the heading quadrant (say, 1^{st} quadrant) and the quadrant opposite to the heading quadrant is given the lowest weightage (say, 4^{th} quadrant).

Weight-Based Search Algorithm

Data: timetaken = -1/3, UAVspeed = 1, survivorspeed = 1/3
Result: Next position of the UAV
start;
while *survivor is not found by the UAV* **do**
watcher → last known survivor location(sxknown, syknown)
if *survivor is within the range of UAV* **then**
survivor found
if *not detected by watchers* **then**
UAV(x[k+1],y[k+1]) → lawn mower pattern;
else
timetaken + = survivorspeed;
for *i → sxknown + timetaken : 1 : sxknown - timetaken* **do**
for *j → syknown + timetaken : 1 : syknown - timetaken* **do**
if *(i,j) → within search radius of UAV* **then**
Weightage(i,j) = 0
end
if *(i,j) → quadrant with same direction of heading as of the survivor* **then**
Weightage(i,j) + = 10
else if *(i,j) → is in the adjacent quadrant* **then**
Weightage(i,j) + = 5
else
Weightage(i,j) + = 1
end
if *UAV(x[k],y[k]) = = predicted survivor location* **then**
(sxknown,syknown) = (x,y) of max(Weightage)

```
            if number of max(Weightage) locations > 1
            then
                (sxknown,syknown) = largest
                cluster(max(Weightage))
            end
            if multiple large weightage clusters then
                (sxknown,syknown) = closest
                largest cluster(max(Weightage))
                UAV(x[k+1],y[k+1] →
                (sxknown,syknown)
            end
        else
            UAV(x[k+1],y[k+1] → (sxknown,syknown)
        end
      end
    end
  end
end
```

When creating this matrix, the weightage matrix generates multiple equally high probable locations. Hence, to select the optimum one to go to, a series of conditions are imposed. The neighbours of these high probable points are checked to find the weightage density around that location. The higher the weightage of the neighbours surrounding the high probable locations, the higher would be its weightage density. Another parameter to determine the optimum search location is the distance between these locations and the UAV. The shorter the distance from the UAV to the location, the lower would be the total time taken to cover all these locations. The UAV then selects the location which is closer and with a high weightage density as the optimum location to search for survivors.

When the survivor comes within the range of view of another observer, the entire weightage matrix is reset and another matrix is created with a different last known location and the entire search process is repeated.

Simulation Results

To simulate the scenario in the weightage approach, we have considered a discrete 2D model of the UAV, observers and the survivor. The survivor is considered to be non-holonomic and moves continuously at a constant speed lower than the UAV; UAV is also non-holonomic with a constant search radius and can move at a maximum specified speed. The observers remain at a fixed position in the environment and have a constant search radius. The survivor's path is made to loop around the environment so that the UAV can continue its search until it finds the survivor. The parameters that are considered for the simulation are given in Table 1.

Table 1: Parameters Used in the Simulation of Search Algorithms

Parameter Name	Dimensions
Environment size	10×10m
Survivor's speed (v_{sur})	0.3 m/s
UAV's max speed	1 m/s
UAV search radius	1.44 m (WS), 1.1 m (PS)
Watcher's search radius	1 m
Watcher's positions	(4, 8); (7, 5)

The above-mentioned setup has been simulated in MATLAB using i5 intel processor, 8GB RAM PC. The setup was simulated for probability-based methods and weight-based methods. These results were compared with the conventional outward spiral search pattern on the basis of the total iterations taken to find the survivor and the average computation time taken to make a decision.

Conventional Search

This is one where the UAV initially performs a lawnmower search pattern until it receives information from the observers and then moves to the last known survivor's location. But since it only takes the survivor's last known position information from the watchers, the UAV starts searching in an outward spiral pattern and hopes to find the survivor at some instance. This method is inefficient and the chances of finding the survivors decrease as the radius of the spiral pattern increases. This is due to the fact that the survivor is constantly moving and the UAV does not revisit the previously searched places and keeps expanding its area of search while giving equal probability to every place in the environment.

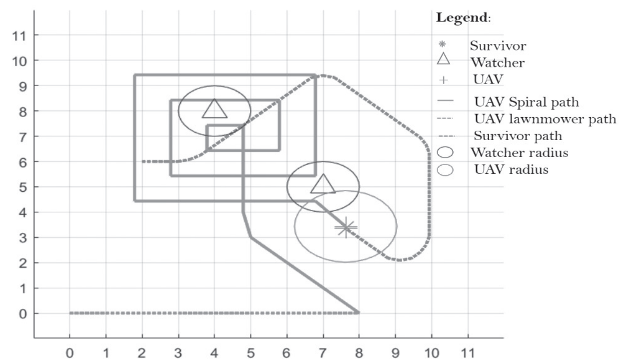

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Figure 2: Conventional search method

Probability-Based Search

This is one where the UAV initially performs a lawnmower search pattern until it receives information from the observers. The UAV takes additional information from the watchers and creates a map of probable points to predict the future position of the survivor. It then moves towards the most probable locations generated by the probability matrix.

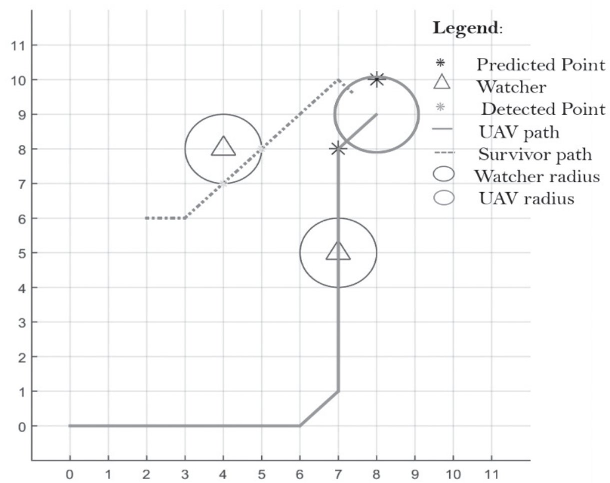

Figure 3: Probability-based search

Weight-Based Search

This is one where the UAV initially performs a lawnmower search pattern until it receives information from the observers. The UAV takes additional information from the watchers and creates a map of probable points to predict the future position of the survivor. It then moves towards the most probable locations generated by the weightage matrix.

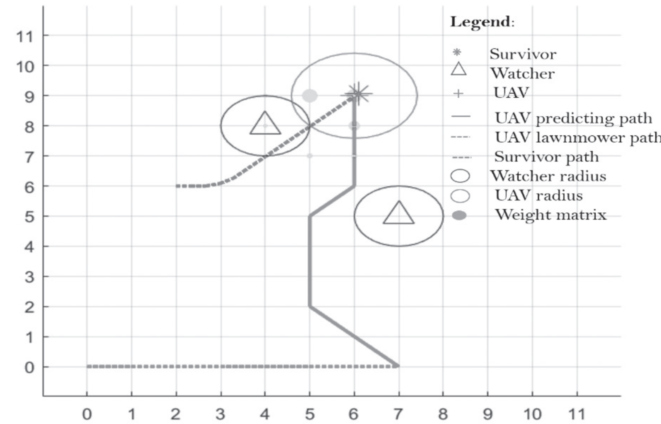

Figure 4: Weight-based search

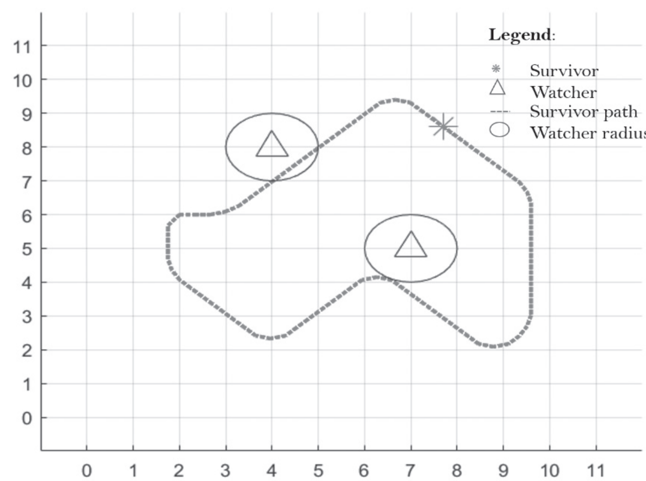

Figure 5: Survivor path

The simulation was tested on multiple survivor paths and some of the results are tabulated in Table 2. Survivor path 1 is displayed in Fig. 5 and the search algorithms by conventional, probability-based and weight-based methods are displayed in Figs. 2, 3, 4 respectively.

Table 2: Comparison between Different Types of Survivor Search Methods

Path Number	Probability Method		Weightage Method		Conventional Method	
	Average Decision Making Time	Number of Iteration to Find the Survivor	Average Decision Making Time	Number of Iteration to Find the Survivor	Average Decision Making Time	Number of Iteration to Find the Survivor
1	0.244	15	0.0152	18	0.0074	54
2	0.1509	17	0.0796	42	0.0074	46
3	0.1369	18	0.1197	71	0.0072	86
4	0.061	51	0.032	28	0.086	17
5	0.076	30	0.0165	16	0.0086	15

In the table, the average number of iterations taken for the UAV to find the survivor and the decision-making time are calculated for each of the methods.

Conclusion

From the above results, it can be concluded that on the basis of the number of iterations taken for the UAV to find the survivor, the probability and the weightage methods in most cases are much faster than the conventional method (as shown for paths 1, 2 and 3). Although the decision-making times of the two proposed methods are higher than that of the conventional method, the time taken is still in measures of milli-seconds. Hence overall, these algorithms are much more efficient when compared to the conventional algorithm and are also computationally less intensive. For paths 4 and 5, it can be observed that the conventional pattern locates the survivor faster than the proposed methods. This is true only for these specific survivor paths, but for the majority of cases, we expect the proposed methods yield much better results. This can be established by carrying out more extensive Monte Carlo simulations. This is the future direction of work we intend to pursue in order to evaluate the different methods.

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Bibliography

Balasubramaniam S, Kashyap A, Shriwastav S, Majumder R, Abhinay NS, Ghose D (2019) LiDAR based land-water boundary identification during floods, to appear in the Proceedings of 4th World Congress on Disaster Management, Mumbai, India.

Bernardini S, Fox M, Long D, and Bookless J, (2013), Autonomous search and tracking via temporal planning, in *ICAPS* 2013.

Bernardini S, Fox M, Long D, and Piacentini C, (2017), Deterministic versus probabilistic methods for searching for an evasive target, *AAAI* 2017, pp. 3709–3715.

Chung T H, Hollinger G A, and Isler V, (2011), Search and pursuit-evasion in mobile robotics, *Autonomous robots*, vol. 31, no. 4, p. 299.

Eagle J N, (1984), The optimal search for a moving target when the search path is constrained, *Operations research*, vol. 32, no. 5, pp. 1107–1115.

Fahd Rafi K S M S, Saad Khan, (2006), Autonomous target following by unmanned aerial vehicles, pp. 6230–8.

Furukawa T, Bourgault F, Lavis B, and Durrant-Whyte H F, (2006), Recursive bayesian search-and-tracking using coordinated uavs for lost targets, *Proceedings 2006 IEEE International Conference on Robotics and Automation., ICRA 2006.*, pp. 2521–2526.

Grundel D A, (2005), Searching for a moving target: optimal path planning, *Proceedings 2005 IEEE Networking, Sensing and Control*, pp. 867–872.

Kanchanavally S, Ordonez R, and Layne J, (2004), Mobile target tracking by networked uninhabited autonomous vehicles via hospitability maps, *Proceedings of the 2004 American Control Conference*, vol. 6, pp. 5570–5575.

Kashyap A, Ghose D (2019) Planning of alternative street routes in urban areas during floods, to appear in the Proceedings of 4th World Congress on Disaster Management, Mumbai, India.

Krishnamoorthy K, Casbeer D, Chandler P, Pachter M, and Darbha S, (2012), Uav search & capture of a moving ground target under delayed information, *IEEE 51st IEEE Conference on Decision and Control (CDC)*, pp. 3092–3097.

Majumder R, Warier RR, Ghose D (2019) Game theoretic model based resource allocation during floods, to appear in the Proceedings of 4th World Congress on Disaster Management, Mumbai, India.

Moors M, Rohling T, and Schulz D, (2005), A probabilistic approach to coordinated multi-robot indoor surveillance, *IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 3447–3452.

Ramasamy M and Ghose D, (2017), A heuristic learning algorithm for preferential area surveillance by unmanned aerial vehicles, *Journal of Intelligent & Robotic Systems*, vol. 88, no. 2, pp. 655–681.

Shin H S, Garcia A J, and Alvarez S, (2018), Information-driven persistent sensing of a non-cooperative mobile target using uavs, *Journal of Intelligent & Robotic Systems*, vol. 92, no. 3, pp. 629–643.

Shriwastav S, Ghose D (2019) Detection and tracking of land-water boundary in flooded region using UAV based images, to appear in the Proceedings of 4th World Congress on Disaster Management, Mumbai, India.

Vidal R, Shakernia O, Kim H J, Shim D H, and Sastry S, (2002), Probabilistic pursuit-evasion games: theory, implementation, and ex- perimental evaluation, *IEEE transactions on robotics and automation*, vol. 18, no. 5, pp. 662–669.

Yu H, Meier K, Argyle M, and Beard R W, (2015), Cooperative path planning for target tracking in urban environments using unmanned air and ground vehicles, *IEEE/ASME Transactions on Mechatronics*, vol. 20, no. 2, pp. 541–552.

Zhang M and Liu H, (2011), Persistent tracking using unmanned aerial vehicle: A game theory method, *AIAA Guidance, Navigation, and Control Conference* 2011, p. 6295.

III AI, Cloud and Networks

Artificial-Intelligence-Based Disaster Response Systems

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ABSTRACT: Social media has become an ever-active source of information, especially during times of disasters. People share their experiences and are keen to know about the safety of their near ones. Twitter, a microblogging platform, receives real-time information via informal conversations and has, accordingly, become the main source of data for research studies based on emergency situational awareness. In this paper, the techniques that an emergency-related Twitter feed monitoring system uses for collecting, processing and classifying the incoming tweets to extract valuable situational information out of them are briefly discussed. Thereafter, systems that reflect the state-of-art of drawing out actionable information using the tweets, which were tweeted relating to a specific disastrous event, are reviewed. Lastly, research challenges associated with the design and development of such disaster response systems are discussed.

KEYWORDS: disaster response, social media, situational awareness

Introduction

An emergency event can either occur naturally or because of human error. Natural disasters include destructive events such as floods, landslides, earthquakes etc., whereas man-made disasters include stampedes, terrorist attacks, wars, power outages, biological threats, nuclear accidents etc. During the occurrence of such events, social media acts as an active source of information (Imran et al., 2015) and as a result, first responders, decision makers and the public get continuous insights of the incident as it unfolds. Social media enables people to share information and interact with each other, especially during emergencies, when people tend to use social media more actively. It provides an easy and immediate access to information and, with the rise of social platforms like Facebook and Twitter, a tremendous amount of socially generated data becomes available that can be processed for extracting useful information to enhance and address the emergent situation.

Whenever a disaster occurs, people share their experiences, and/or usually query about their near ones' safety. Posting the details of a disaster event and inquiring about the safety of others usually happens in real-time. So, with millions of active users, platforms like Facebook and Twitter are more likely to receive tremendous bursts (Yin, et al., 2012) in the number of posts during such events. These publicly shared communications comprise up-to-date and actionable information, which could prove beneficial to first responders and decision makers.

Studies have shown that messages posted on various social media platforms, especially Twitter, (Abel, et al., 2012; Ashktorab, et al., 2014; Caragea, et al., 2011; Imran, et al., 2014; MacEachren, et al., 2011; Purohit & Sheth, 2013; Sheth, et al., 2011; Vieweg, et al., 2010; Yin, et al., 2012) genuinely contribute during emergency situations. Twitter (Kwak, et al., 2010) obtains real-time and highly informal communications because of its character limitations on each post (tweet). People often tweet what they're doing and

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whatever is on their mind, and they frequently come back to see updates about or posted by others as well. Hence, because of its real-time characteristic, Twitter has become the main source of data for research studies regarding emergency situational awareness (Priem & Costello, 2011; Rowlands, et al., 2011). Useful information about various disastrous events can be easily extracted from this platform using available *APIs* (Application Programming Interface). Millions of tweets are posted on Twitter every day (Twitter, 2019a). Whenever a disastrous event occurs, the frequency of tweets pertaining to the particular event is liable to rise beyond normal. Hence for a human, it is practically not possible to monitor each and every tweet, verify their authenticity and take actions accordingly, all in real-time. To address this, artificial intelligence (*AI*) techniques need to be devised in order to reduce the amount of information to be examined by a human.

This paper does a review of such existing emergency-related social media monitoring systems, whose primary focus is to extract emergency-related tweets from Twitter and infer essential knowledge out of the processed tweets in order to formulate a robust disaster response.

Twitter Data Extraction

All the systems discussed in literature use Twitter as the source of data for analysis of situational information during emergency events. Tweets related to disaster need to be extracted from the Twitter data for analysis. Data acquisition and geotagging, which can be used to extract such tweets, are discussed in the following subsections.

Data Acquisition

Twitter provides access to the tweets posted on its platform through two *API* types (Makice, 2009): *Search API* for extracting tweets, which have been tweeted in the past; and *Streaming API*, which allows the acquisition of tweets from the feed in near real-time.

Twitter Search *API* (Twitter, 2019d) enables the collection of at most seven-day-old tweets which successfully match a query. The query can be made based on various filters like location, time, language etc. Search *API* is not really effective for event detection and analysis that require real-time data. However, the *API* might come in handy while training the classifier by feeding the past seven-day-old tweets, which are relevant to an event.

Twitter Streaming *API* (Twitter, 2019b) allows near real-time access to the Twitter stream, allowing various filters to be used. However, this *API* has a limited approach to collecting tweets. It provides quite basic filtering attributes, like search by user ID, keywords, geographic location etc. These emergency-related Twitter stream monitoring systems make use of Streaming *API* to look for the occurrence of events (event detection) and topic discovery by being based on the near real-time incoming tweets.

Geotagging

Geotagging (Ghahremanlou, et al., 2015; Hong, et al., 2012; Compton, et al., 2014) refers to the extraction of tweets that have been tweeted from a specific geographical region. This is achieved by applying a filter around the geographic tag before sending the *API* request to Twitter servers. Geotagging facilitates an emergency-related social media monitoring system to visualise the analytic or descriptive information processed out of the tweets. But the complexity arises during the processing of tweets when the analysis involves geolocation. The main reason behind the complexity is the fact that only a small percentage of people provide reliable Global Positioning System (*GPS*) location in their tweets. The presence of geographic location in tweets is of utmost importance for the systems that make use of Twitter data for generating situational awareness information.

A study (Bennett, et al., 2018) using local data and spatial data was conducted between 2016 and 2017 in Southampton city with a geographic radius of 26 miles. Out of 5 million collected tweets, only 36,000 tweets were found out to have hardcoded coordinates; that is, 0.73 per cent of the 5 million tweets had a machine-readable geographic location in them. Similarly, in another study (Burton, et al., 2012) relating to the monitoring of online health information, it was found that around 2.02 per cent of tweets contained geographic information.

Various natural language processing approaches and machine learning techniques are applied to extract situational awareness information from the relevant Twitter data. The next section discusses further about processing of such extracted tweets.

Twitter Data Processing Using *AI*

Twitter is all about informal communications and, therefore, it thus becomes necessary to process the tweets to understand the informal sentences in order to extract meaningful and valuable information from them. Natural language processing and machine learning techniques can be used for processing Twitter data. These are briefly discussed below.

Natural Language Processing

Natural language processing (*NLP*) is a branch of *AI* that enables computers to read, decipher, comprehend, process and analyse human languages with the aim of facilitating interaction between computers and humans (Russel & Norvig, 2015). Various *NLP* toolkits like Natural Language Toolkit (Loper & Bird, 2002), Stanford *NLP* (Manning, et al., 2014) and Tweet *NLP ARK* (Bhatia, et al., 2019) essentially help in performing all sort of *NLP* operations like tokenisation, lemmatisation, stemming, parsing, part-of-speech tagging, word clustering etc. Tweet *NLP ARK* is much recommended if the task is to monitor and analyse Twitter feeds because this toolkit is itself trained on the Twitter data and is capable of relating informal words to their real form. For example, it can help in relating *ikr,* as I know right, *fb*, as Facebook, yo, as your, and *fir*, as a misspelt variant of *for*.

Machine Learning Techniques

Machine learning is a branch of *AI* that enables systems to automatically learn on their own from data in order to infer patterns that can aid in future decision-making (Russel & Norvig, 2015). Two types of machine learning approaches, that is, classification and clustering, are used by emergency-related monitoring systems for either classifying incoming tweets into various categories (damage, casualties) or from groups of event-specific tweets (Nepal earthquake, Kerala flood). Classification is a supervised machine learning approach which requires labelled data during training, while clustering is an unsupervised approach and does not necessarily need labelled data for training purposes.

The commonly used supervised machine learning algorithms, which classify short texts (Ashktorab, et al., 2014; Chan, et al., 2015; Cormack, et al., 2007; Hidalgo, et al., 2006; Healy, et al., 2004), include Naive Bayes, Logistic Regression, *K*-Nearest Neighbour, Support Vector Machines and Random Forests. Algorithms like *K*-means, mean-shift and agglomerative hierarchical clustering approaches are available which are capable of grouping tweets based on their thematic dimension. But some of these algorithms require an initial declaration of a number of clusters and some rely on a fully specified similarity matrix (Yin, et al., 2012). Hence, these algorithms are not suitable for clustering of tweets in real-time. For clustering purposes, Tweedr (Ashktorab, et al., 2014) uses two approaches for string matching, viz. Bloom filters and SimHash (Bloom, 1970; Charikar, 2002), and ESA uses a modified version of the single-pass algorithm (Yang, et al., 1998), considering cosine and Jaccard similarity as the similarity measures.

Such data processing techniques have facilitated researchers in the design and development of effective and efficient disaster response systems. Several artificial-intelligence-based response systems exist, of which some are briefly discussed in the next section.

AI-Based Disaster Response Systems

Several AI-based disaster response systems exist whose primary focus is to extract disaster-related tweets from Twitter and process them to infer valuable knowledge, so as to formulate effective and efficient disaster response. Some of these systems are running in a deployed state, while others are still under development. Table 1 lists a few of these, which are briefly discussed in the following subsections.

Table 1: *AI*-Based Disaster Response Systems

System	Features	URL
Twitris	Sentiment analysis, classification, geotagging	twitris.knoesis.org
SensePlace2	Geo-visual analytics, heatmaps, geotagging	geovista.psu.edu/SensePlace2
EMERSE	Mobile application, classification, translation, geotagging	emerse.ist.psu.edu
ESA	Detect burst, event detection, classification, clustering, geotagging	esa.csiro.au/aus/index.html
Twitcident	Semantic enrichment, event detection, classification	wis.ewi.tudelft.nl/twitcident
Tweedr	Classification, clustering, token extraction	github.com/dssg/tweedr
AIDR	Classification, manual labelling	aidr.qcri.org

Twitris

Twitris V3 (Purohit & Sheth, 2013), a successor of Twitris+ (Sheth, et al., 2011), provides an in-depth analysis of an event based on spatial (location of observation), temporal (time of observation), thematic (the theme of observations) and sentimental (opinion of people) dimensions.

The system is capable of monitoring the Twitter feed of an event at two levels, viz. micro level (looks at the keywords) and macro level (looks out for sentiment and evolution of community). Twitris+ can also classify tweets into categories (shelter, medical) and further express the actionable information on a map. Initially, the system needs a set of seed keywords that describe an event. These keywords are later replaced by the more influential set of n-grams that better describe the particular event. Twitris provides a graphical dashboard, which lists the trending topics, and the real-time stream of the tweets of the event that is being monitored. Besides, the system is also capable of performing sentiment analysis based on data related to an event.

Senseplace2

SensePlace2 (MacEachren, et al., 2011) is a web-based system which centres more on geo-visual analytics for situational awareness during emergency events using the data coming out of Twitter. Unlike other systems, which are surveyed, this system exclusively focuses on processing a large volume of tweets and visualises heat maps based on the geotagging concept for rendering the spatial, temporal and thematic components of the event being observed. SensePlace2 provides an interactive interface with five main components, viz. query panel for specifying search terms, timeline display/control for temporal filtering, tweet list for listing 500 top relevant query results, tweet map to facilitate selection of places and heat map for rendering an overview of the tweets.

Enhanced Messaging for the Emergency Response Sector

Enhanced Messaging for the Emergency Response Sector (*EMERSE*) (Caragea, et al., 2011) is basically an automated system which comprises four other components, viz. a mobile application, crawler, classifier and translator. The mobile application is used for capturing a photo, designating the geolocation and sending the captured photo to a server. A user should be registered to send any information to the server regarding casualties, aid requirements or the present scenario. The Twitter crawler pulls tweets using the Twitter *API*. The machine translation component translates the tweets that are in different languages to a common one, and the classifier classifies the tweets to be submitted to different departments based on their thematic information.

Emergency Situational Awareness

Emergency Situational Awareness (*ESA*) (Yin, et al., 2012) makes use of data mining and natural language processing techniques to extract situational awareness information during the occurrence of disaster events. The system uses both the Search and Streaming APIs to pull tweets pertaining to specific areas. Unlike other systems, *ESA* is capable of detecting bursty words from the tweet stream, which is helpful for identifying unexpected events, that is, event detection. Further, the system can classify the tweets that mention something about the infrastructure (road, bridge, buildings, etc.), which helps in understanding the magnitude of an event and the responders can act accordingly. Besides, the system is also capable of grouping similar tweets into clusters, where each cluster relates to a specific event. To improve the spatial rendering of situational information, *ESA* displays the tweets on a map based on the geolocation of the tweet, if it is available, else the location from the user's profile is used.

Twitcident

Twitcident (Abel, et al., 2012) is a framework that helps in the extraction of information about events from the stream of tweets having automated functionalities, including aggregation, filtering and semantic enrichment. Like *ESA*, Twitcident also has an event detection model built inside it. Tweets are automatically collected, filtered and also classified into various categories like casualties, risks and damages. Further, it provides an advanced search and detailed analytical options for extracting relevant situational information. The system makes use of semantic enrichment (Abel, et al., 2011) as the foundation for its semantic-faceted search. The experimental results in Abel et al. (2012) show that faceted search makes it easy to filter the tweets with greater specificity, and hence semantic enrichment appears to give better search performance than commonly used keyword-based strategies.

Tweedr

Tweedr (Ashktorab, et al., 2014) mines Twitter data for extracting situational awareness as well as actionable information during disaster events. It makes use of Gnip (social media API aggregation service) to search and collect data from Twitter based on keywords and geographical queries. The system in general is divided into three components, viz. classification, clustering and extraction. The classification part performs a binary classification, for example, like whether a tweet is about infrastructure damage or about human casualty. Those tweets which do not fall under infrastructure damage/human casualty are marked as negative examples. Only the positive examples are taken into consideration for classification. In the clustering phase, the related tweets are grouped, whereas in the extraction phase, tokens corresponding to the particular type of damage or number of injuries are identified from each positive example.

Artificial Intelligence for Disaster Response

Artificial Intelligence for Disaster Response (*AIDR*) (Imran, et al., 2014) also concentrates on extracting actionable and valuable insights out of the stream of tweets. The system utilises an active learning classifier, which classifies tweets into a predefined set of situation-specific categories, like needs and damage in real-time. *AIDR* filters the Twitter stream, based on a set of keywords and/or a geographical territory. Its dashboard provides information, including the number of tweets collected, the last processed tweet and the total time elapsed. After the collection of tweets, a sample of such tweets is taken out by the system and manually labelled by a human. Finally, these labelled tweets are used to train the classifier, whose task is to classify incoming tweets into various categories. Based on these categories, first responders and decision makers get proper hints about a situation as it unfolds, based on the tweets tweeted by people who have seen, felt or heard about a particular incident.

The phases of design, development and implementation of disaster response systems continually come face to face against numerous research challenges. The major challenges researchers face during the development of such systems are discussed in the next section.

Research Challenges

Although a lot of systems are being designed and deployed in the real world for extraction of situational awareness information from Twitter feeds, researchers are continuously facing a plethora of challenges. The challenges may be anything, including limitations in the extraction of Twitter data, geography-related hurdles (geotagging and geocoding), etc. Some such identified challenges are briefly outlined below.

Coverage

Social media platforms like Twitter help in reaching the public only in the developed geographical regions. Systems that are built by considering only Twitter data may not beneficial at those disaster locations where there is no access to the internet or where Twitter is rarely used for communication. Such systems might even fail to perform in developed areas, where internet services are not reliable. Therefore, emergency-related monitoring systems should consider other data sources along with or in addition to social media.

API Limitations

The limitations associated with Twitter Standard Search and Streaming *API* are another difficulty that researchers encounter during the data collection phase. In order to prevent the platform from abuse, Twitter has put limit constraints on *GET* and *POST* requests and resource per window (Twitter, 2019c). Besides, not all relevant tweets that match a query are made available through the Search *API*. Also, the Streaming *API* has the biggest limitation that the collected tweets are just a 1 per cent sample of the population. For an event detection system, missing a single tweet might also be critical.

Geographical Information

Only a small percentage of people make their exact location available while posting tweets. This is a serious limitation for researchers if an emergency-related monitoring system is designed to gather situational awareness information that utilises the geotagging concept. If *GPS* location is not hard-coded in the tweet, geocoding the address from a user profile to get the tentative location of the user raises questions about the authenticity of the obtained geolocation.

Heterogeneous Data Sources

A study (Sloan, et al., 2015) has shown that 67.5 per cent of total Twitter users fall in the age group of 16–22, and only 5 per cent of the total users belong in the age group of 40 or above. Keeping in view the preferences of the younger generation to use the platform for informal conversation, Twitter is relatively a better source for situational awareness information. But, emergency-related monitoring systems should not solely rely on a single source of data. With the limitations inherent in the extraction of tweets, and considering the fact that Twitter provides tweets from a sample of its population, it is necessary to factor in for the likelihood of the presence of biases in the collected tweets. So, such systems should use other sources for data, viz. *SMS*, News stream, *RSS*, blogs, tagged images and videos, as well for the overall extraction of situational information.

Tagging of Tweets

Almost all systems in the literature revolve around the concept of classification of tweets to various categories like needs, casualties, infrastructure damage, etc. Dealing with incorrectly classified texts and multi-class texts is a major classifier-related challenge that researchers need to overcome. The classifier learns from human-annotated examples. Hence, there should be minimum errors during the crowdsourcing of manual tagging classes for example tweets.

Conclusion

Social media has become the foremost active source of information for first responders (Police, Rescue team) and decision makers (governmental and non-governmental agencies) mainly during the occurrence of disasters. During disasters, social platforms, especially Twitter, receive a tremendous amount of socially generated posts, conversations and messages. These have been observed to contain a lot of actionable information, including real-time feeds about the on-ground situation, which can be used to extract situational awareness information. This paper discussed briefly about several emergency-related Twitter feed monitoring systems and the science that goes into the design and development of such systems. One common feature about all these systems is classification; that is, almost every system has a module that classifies incoming tweets into various categories like needs, casualties, infrastructure damage etc. Thus, classified tweets contribute a lot during disaster response. Tweets falling in a particular category can be sent to the department responsible for taking appropriate actions accordingly. The use of geotagging and geocoding also facilitates in identifying a tentative affected region. This provides first responders with an idea about the areas where life-saving strategies have a high probability of being successful. Further, the accuracy of learning classifiers can be improved by overcoming the inherent complexities associated with informal texts and multi-class texts.

References

Abel, F., Gao, Q., Houben, G.-J., & Tao, K. (2011). Semantic Enrichment of Twitter Posts for User Profile Construction on the Social Web. *In: Antoniou G. et al. (eds) The Semanic Web: Research and Applications. ESWC 2011. Lecture Notes in Computer Science. 6644*, pp. 375–389. Springer.

Abel, F., Hauff, C., Houben, G.-J., Stronkman, R., & Tao, K. (2012). Semantics + filtering + search = twitcident. exploring information in social web streams. *Proceedings of the 23rd ACM conference on Hypertext and social media* (pp. 285–294). ACM.

Ashktorab, Z., Brown, C., Nandi, M., & Culotta, A. (2014). Tweedr: Mining Twitter to inform disaster response. *Proceedings of the 11th International ISCRAM Conference.* University Park, Pennsylvania.

Bennett, N. C., Millard, D. E., & Martin, D. (2018). Assessing Twitter Geocoding Resolution. *Proceedings of the 10th ACM Conference on Web Science* (pp. 239–243). Amsterdam: ACM.

Bhatia, A., Das, D., Dyer, C., Eisenstein, J., Flanigan, J., Gimpel, K., Heilman, M., Kong, L., Mills, D., O'Connor, B., Owoputi, O., Schneider, N., Smith, N., Swayamdipta, S., Yogatama., D. (2019). *Tweet NLP*. Retrieved from http://www.ark.cs.cmu.edu/TweetNLP

Bloom, B. H. (1970). Space/time trade-offs in hash coding with allowable errors. *Communications of the ACM, 13*(7), 422–426.

Burton, S. H., Tanner, K. W., Giraud-Carrier, C., West, J. H., & Barnes, M. D. (2012). "Right time, right place" health communication on Twitter: value and accuracy of location information. *Journal of Medical Internet Research, 14*(6).

Caragea, C., McNeese, N.J., Jaiswal, A., Traylor, G.H., Kim, H., Mitra, P., Wu, D., Tapia, A.H., Giles, L.M, Jansen, B.J., Yen, J. (2011). Classifying text messages for the haiti earthquake. *In Proceedings of the 8th international conference on information systems for crisis response and management.*

Chan, P. P., Yang, C., Yeung, D. S., & Ng, W. W. (2015). Spam filtering for short messages in adversarial environment. *Neurocomputing, 155*, 167–176.

Charikar, M. (2002). Similarity estimation techniques from rounding algorithms. *Proceedings of the thiry-fourth annual ACM symposium on Theory of computing* (pp. 380–388). ACM.

Compton, R., Jurgen, D., & D. A. (2014). Geotagging One Hundred Million Twitter Accounts with Total Variation Minimization. *2014 IEEE international conference on big data* (pp. 393–401). IEEE.

Cormack, G. V., Hidalgo, J. M., & Sánz, E. P. (2007). Spam Filtering for Short Messages. *Proceedings of the sixteenth ACM conference on Conference on information and knowledge management* (pp. 313–320). ACM.

Ghahremanlou, L., Sherchan, W., & Thom, J. A. (2015). Geotagging Twitter Messages in Crisis Management. *The Computer Journal, 58*(9), 1937–1954.

Healy, M., Delany, S. J., & Zamolotskikh, A. (2004). An assessment of case base reasoning for short text message classification. *Proceedings of 15th Irish Conference on Artificial Intelligence and Cognitive Science.* Castlebar.

Hidalgo, J. M., Bringas, G. C., & Sánz, E. P. (2006). Content Based SMS Spam Filtering. *Proceedings of the 2006 ACM symposium on Document engineering* (pp. 107–114). ACM.

Hong, L., Ahmed, A., Gurumurthy, S., Smola, A., & Tsioutsiouliklis, K. (2012). Discovering Geographical Topics In The Twitter Stream. *Proceedings of the 21st international conference on World Wide Web* (pp. 769–778). ACM.

Imran, M., Castillo, C., Diaz, F., & Vieweg, S. (2015). Processing Social Media Messages in Mass Emergency: A Survey. *ACM Computing Surveys (CSUR), 47*(4), 67:1–67:38.

Imran, M., Castillo, C., Lucas, J., Meier, P., & Vieweg, S. (2014). AIDR: Artificial intelligence for disaster response. *Proceedings of the 23rd International Conference on World Wide Web*, (pp. 159–162).

Kwak, H., Lee, C., Park, H., & Moon, S. (2010). What is Twitter, a social network or a news media? *Proceedings of the 19th international conference on World wide web* (pp. 591–600). ACM.

Loper, E., & Bird, S. (2002). NLTK: The Natural Language Toolkit. *arXiv preprint cs/0205028*.

MacEachren, A.M., Jaiswal, A., Robinson, A.C., Pezanowski, S., Savelyev, A., Mitra, P., Zhang, X., Blanford, J. (2011). SensePlace2: GeoTwitter analytics support for situational awareness. *2011 IEEE Conference on Visual Analytics Science and Technology.* Providence, Rhode Island.

Makice, K. (2009). *Twitter API: Up and running: Learn how to build applications with the Twitter API.* O'Reilly Media, Inc.

Manning, C. D., Surdeanu, M., Bauer, J., Finkel, J., Bethard, S. J., & McClosky, D. (2014). The Stanford CoreNLP Natural Language Processing Toolkit. *Proceedings of 52nd annual meeting of the association for computational linguistics: system demonstrations*, (pp. 55–60).

Priem, J., & Costello, K. L. (2011). How and why scholars cite on Twitter. *Proceedings of the American Society for Information Science and Technology banner. 47*, pp. 1–4. Wiley.

Purohit, H., & Sheth, A. P. (2013). Twitris v3: From Citizen Sensing to Analysis, Coordination and Action. *Proceedings of the Seventh International AAAI Conference on Weblogs and Social Media.*

Rowlands, I., Nicholas, D., Russell, B., Canty, N., & Watkinson, A. (2011). Social media use in the research workflow. *Learned Publishing, 24*(3), 183–195.

Russell, S.J., & Norvig, P. (2015). Artificial Intelligence; A Modern Approach, Third Edition, Pearson Education India

Sheth, A., Purohit, H., Jadhav, A., Kapanipathi, P., & Chen, L. (2011). Understanding events through analysis of social media. *Proceedings of WWW'11.* Hyderabad.

Sloan, L., Morgan, J., Burnap, P., & Williams, M. (2015). Who Tweets? Deriving the Demographic Characteristics of Age, Occupation and Social Class from Twitter User Meta-Data. *PloS one, 10*(3), e0115545.

Twitter. (2019a). *Company*. Retrieved from https://about.Twitter.com/en_us/company.html

Twitter. (2019b). *Filter realtime Tweets*. Retrieved from https://developer.Twitter.com/en/docs/tweets/filter-realtime/overview.html

Twitter. (2019c). *Rate limits*. Retrieved from https://developer.Twitter.com/en/docs/basics/rate-limits.html

Twitter. (2019d). *Standard search API*. Retrieved from https://developer.Twitter.com/en/docs/tweets/search/api-reference/get-search-tweets.html

Vieweg, S., Hughes, A. L., Starbird, K., & Palen, L. (2010). Microblogging during two natural hazards events: what Twitter may contribute to situational awareness. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1079–1088). Atlanta: ACM.

Yang, Y., Pierce, T., & Carbonell, J. (1998). A study of retrospective and on-line event detection. *Proceedings of the 21st annual international ACM SIGIR conference on Research and development in information retrieval* (pp. 28–36). New York: ACM.

Yin, J., Lampert, A., Cameron, M., Robinson, B., & Power, R. (2012). Using social media to enhance emergency situation awareness. *IEEE Intelligent Systems, 27*(6), 52–59.

Location of Most Vulnerable Houses to Cyclone in Coastal India through Cloud Computing Technology

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ABSTRACT: This applied research paper proposes a framework model in which the ways to locate the most vulnerable houses to cyclones in the Indian coastal region through 'cloud computing' and 'data mining' technology have been discussed and also been tested, with the existing sample survey data of the Indian coastal village housing parameters. This research shows that the web service model of cloud computing technology can be used for the survey of houses in coastal India, for details of the housing location like the state/district/village/panchayat the house belongs to and housing construction parameters like the materials used/construction practices adopted/structure and design of village houses. This huge 'survey database', of 'any size' can be used 'anywhere' and 'any time' for the further process of 'calculation of cyclone damage index for Indian states' and for the location of the most vulnerable houses to cyclone in coastal India village houses. This paper is part of a PhD thesis work.

KEYWORDS: cyclone, vulneribility, cloud computing technology, cyclone disaster mitigation

Introduction

The coastal zone of India plays an important role for its economically through coastal tourism, coastal fisheries and most importantly 'human settlement'. Human settlements are more concentrated in the coastal zone than elsewhere. About 40 per cent of the world's population lives within 100 km of the coast and 10 per cent of the world's population resides in low-elevation coastal zones, thus making their lives highly vulnerable to coastal disasters. In total, 35 per cent Indians live within 100 km of the country's coast line measuring 7517 km. It is necessary to have a regular monitoring and suitable management plan to take decisions at the time of a disaster and save the people who are residing in the coastal region. To save time, money and manpower with regard to management plans and decision support systems, the adoption of the latest technology towards the frameworks and then to applications are necessary. One of the main agendas in 'WCDM 2019' is about the 'frameworks towards direct applications', to solve the problems of 'disaster management and mitigation', with relevant solutions.

The coastal villages of India are frequently battered by cyclones. One of the most common damages caused by cyclones are rural housing damages, which ends up in the loss of human life. To achieve sustainable rural development with socio-economic impact in such vulnerable regions, cost-effective retrofit measures of rural housing using local materials/construction practices are required for mitigating damage to housing due to cyclones. In this regard, cyclone vulnerability assessment of rural housing needs to be carried out, by using efficient Decision Support Systems for cyclone-resistant design of housing/retrofit measures. Such decision support systems need relevant domain

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information, which is extracted by organising and processing the collected/available raw data. Hence, collection/processing of data becomes a primary component of a decision support system.

Materials and Methods

This applied research analyses the ways to locate the most vulnerable houses to cyclones in coastal India, through two models.

(1) 'Web service model' for the survey of houses in coastal India, for the details of the housing location like the state/district/village/panchayat the house belongs to and construction parameters like the materials used/construction practices adopted/structure and design of village houses. Whatever be the kind of survey, the questionnaire plays an important role, which is proportional to the goal of the survey as well to the end results. The questionnaire used and will be used for the survey of Indian coastal village housing for construction/civil engineering/structural engineering details itself having a huge existing research background.

Since this applied research has been carried out under the R&D project of 'CYCLONE DISASTER MITIGATION' in the Wind Engineering Lab of CSIR-Structural Engineering Research Centre (SERC) Chennai, the existing standard survey consists of four types of questionnaire/proforma: (IS: 15499 (2004) - Proforma I, Proforma IIA, Proforma IIB, Proforma IIC, which is framed by CSIR-SERC under the the aid of a UNDP project and has been used as a sample questionnaire, for the proposed web-service-based survey model.

In the present research, a sample portion of all the four questionnaire/proformae has been considered for developing a cloud-based web service model to aggregate the survey data to be collected from various villages, which are located along the coastal regions of India. Since 'cloud computing' is a group of services which is available anywhere, anytime with any amount of data, this concept has been taken for this present research to develop a 'basic web service model', for the survey purpose, at present as a 'framework' and in future, for the full-scale hybrid cloud model to conduct the survey by using all the four proformae questionnaire, for the Indian coastal village housing for all the coastal districts of India.

For the present research, the model is developed, deployed and tested in the 'local host:8080' as a framework by using a sample question (Fig. 1), and the output data, along with the question and response, has been stored in a 'Java database'. With the full-scale survey implementation in future, the huge databases, from all the villages, will get stored on an on-premise 'private cloud setup' and also these modules are to be connected to the 'private and public cloud resources' with a 'hybrid cloud environment'.

Since the above said survey model demands infrastructure for a full-scale real-time survey of coastal village houses, the present research database has been generated from the 'Vulnerability Atlas of India 2006', for the housing types of non-engineered, semi-engineered and engineered for each Indian state and also for state-wise wind speed zone percentages, to group the wind speed region location of each Indian state with the expected cyclone damage level index.

(2) 'Data mining model': the database generated in the above said model is huge in size and regular data processing methods will consume a lot of time; thus, data mining technology has been proposed along with the algorithm and used here.

Data mining 'clustering analysis' has been adopted for grouping Indian states, with similar vulnerability of housing to high wind events/speed, which will be used for the location of the most vulnerable houses to cyclones and also for prioritising fund allotment to the corresponding affected Indian states. To cluster the states, damage indices corresponding to non-engineered houses, semi-engineered houses and engineered houses in various states are considered. The procedure for the evaluation of these damage indices is also highlighted.

There are a number of different methods that can be used to carry out a cluster analysis; these methods can be classified as hierarchical methods and non-hierarchical methods.

Non-hierarchical Methods (K-Means Clustering Method)

K-Means:

- K-means clustering is an unsupervised learning algorithm that tries to cluster data based on their similarity.
- In unsupervised learning, there is no outcome to be predicted, and the algorithm just tries to find patterns in the data.
- In 'k'-means clustering, the number of clusters is specified and also where the data is to be grouped into.

The algorithm randomly assigns each observation to a cluster, and finds the centroid of each cluster. Then, the algorithm iterates through two steps:

- Reassign data points to the cluster whose centroid is closest.
- Calculate the new centroid of each cluster.

These two steps are repeated till the within-cluster variation cannot be reduced any further. The within-cluster variation is calculated as the sum of the 'Euclidean distance' between the data points and their respective cluster centroids.

Results and Discussion

Open-source Integrated Development Environment (IDE) with JAVA language 'NetBeans IDE with JAVA' has been used for the present research framework web service model development, along with the services. Since SOAP (Simple Object Access Protocol) is a XML-based communication protocol for accessing a web service, this service has been used to communicate and access the web service. It is important for application development to allow Internet communication between programmes and a protocol to let applications exchange information over HTTP. A better way to communicate between applications is over HTTP, because HTTP is supported by all Internet browsers and servers. SOAP was created to accomplish this. SOAP provides a way to communicate between applications running on different operating systems, with different technologies and programming languages; hence, SOAP has been finalised for the present research and, most importantly, it is compatible with the NetBeans IDE with JAVA.

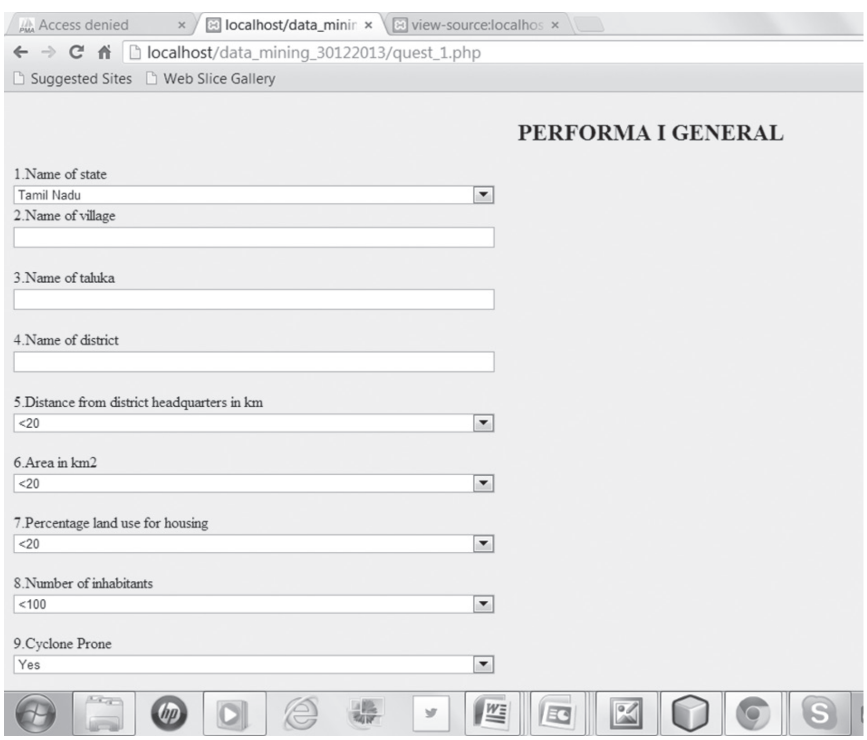

Figure 1: Output window of proforma I questionnaire in NetBeans IDE environment

Since the above said survey model demands the infrastructure, for the full scale real-time survey of coastal village houses, the present research database has been generated from the existing 'Vulnerability Atlas of India 2006', for the housing types of Non-engineered, Semi-engineered, and Engineered for each Indian state and also for state wise wind speed zone percentage (Fig. 2), to group the wind speed region location of each Indian state with expected cyclone damage level index.

The cluster diagram in Fig. 3 shows a graphical view of state-wise clusters for damage index to different types of houses, which helps in making decision towards prioritisation of mitigation efforts required for disaster preparedness. It is to be noted that clustering is done for curves; that is, each curve consists of three points of the damage index for non-engineered, semi-engineered and engineered housing.

Table 1 shows the number of clusters, state-wise for damage index to different types of houses, which helps in making decision towards prioritisation of mitigation efforts required towards disaster preparedness.

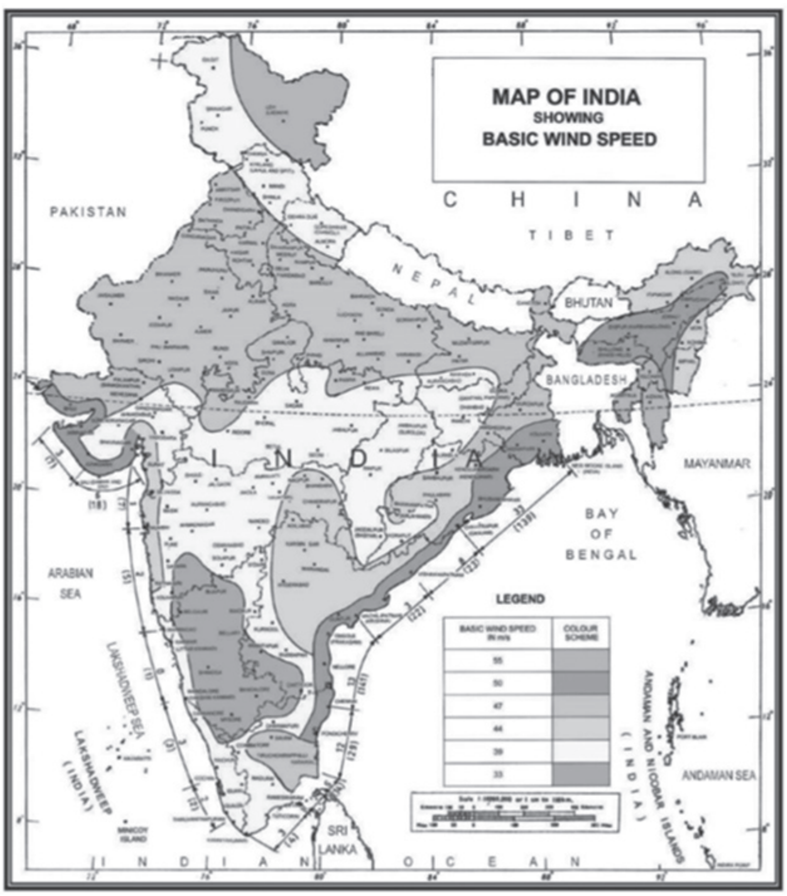

Figure 2: Indian state-wise percentage of land in different wind speed zones

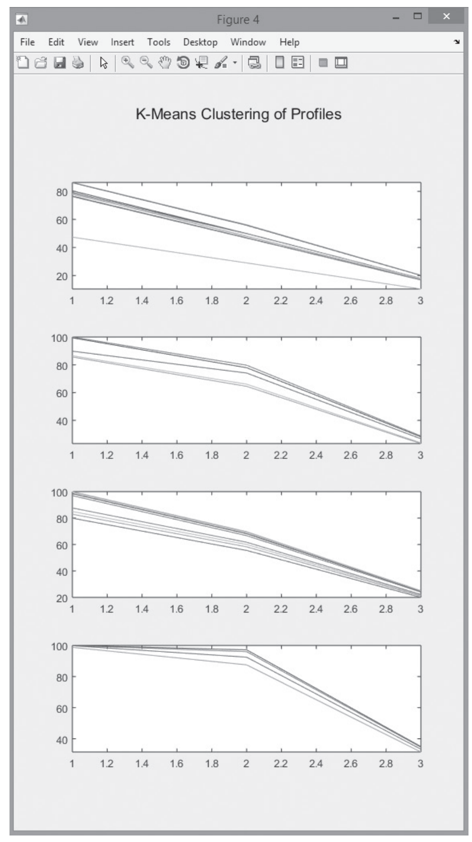

Figure 3: State-wise clusters for damage index to different types of houses

Table 1: Number of Clusters for Each Type of Houses, Non-engineered, Semi-engineered and Engineered for the Indian States

State Name	Non-engineered DNE	Semi-engineered DSE	Engineered DE	Cluster Number
Arunachal Pradesh	79.18923	49.72992	17.90509	1
Chhattisgarh	78.43443	48.00834	17.28524	1
Goa	78.43443	48.00834	17.28524	1
Himachal Pradesh	80.3322	49.94796	17.9836	1
Jharkhand	86.32743	56.1534	20.21784	1
Karnataka	47.35351	28.98425	10.43568	1
Kerala	76.60155	46.88647	16.88132	1
Madhya Pradesh	86.11177	55.7439	20.0704	1
Maharashtra	76.25058	46.67164	16.80397	1
Uttaranchal	77.82567	49.59744	17.85739	1
Andaman & Nicobar Islands	78.43443	48.00834	17.28524	1
Lakshadweep	78.43443	48.00834	17.28524	1
Jammu & Kashmir	89.88575	74.12721	26.68926	2
Nagaland	100.1	79.77479	28.72265	2
Odisha	86.59404	66.09116	23.7959	2
West Bengal	99.53339	77.97534	28.07476	2
Daman & Diu	85.68046	64.53554	23.2358	2
Andhra Pradesh	79.92409	55.50597	19.98474	3
Bihar	96.98082	66.69536	24.01344	3
Gujarat	84.96864	60.0407	21.61745	3
Haryana	100	69.73743	25.10873	3
Manipur	82.92007	58.23946	20.96892	3
Punjab	99.56869	69.30285	24.95226	3
Rajasthan	98.46884	68.19467	24.55326	3
Sikkim	100	69.73743	25.10873	3
Tamilnadu	87.63217	61.71598	22.22063	3
Uttar Pradesh	99.41773	69.15075	24.8975	3
Chandigarh	100	69.73743	25.10873	3
Dadra & Nagar Haveli	100	69.73743	25.10873	3
Delhi	100	69.73743	25.10873	3
Assam	99.8353	92.44839	33.28573	4
Meghalaya	100	96.01569	34.57013	4
Mizoram	100	97.19643	34.99525	4
Tripura	100	97.19643	34.99525	4
Pondicherry	98.77076	87.52796	31.51415	4

Conclusion

The four cluster groups of Indian states in the 'MATLAB' window will give a clear picture about the

- Number of non-engineered, semi-engineered and engineered houses available in each state's wind speed region,
- Location of each Indian state with the expected cyclone damage level index
- Which state to be given first priority for cyclone disaster relief measures according to the maximum number of non-engineered houses and semi-engineered houses located and the maximum damage level after a cyclone
- Which state to be given first priority for cyclone warning/taking precautions according to the maximum number of non-engineered houses and semi-engineered houses located and the maximum damage level expected before/during a cyclone

For example: the Indian states Assam, Meghalaya, Mizoram, Tripure and Pondicherry in Cluster 4 has the maximum number of non-engineered and semi-engineered houses and the maximum damage level expected during/after a cyclone:

- As a precautionary measure before a cyclone, the people living in non-engineered houses (huts) are moved from their houses to a cyclone shelter located near by their village to avoid loss of life through damage of houses.
- The people living in semi-engineered houses can also be similarly moved from their houses if the expected cyclone speed is higher and their houses cannot withstand the expected cyclone wind speed.

The above cluster diagram shows state-wise clusters for damage level (index) to different types of houses, which helps in making decisions towards prioritisation of disaster mitigation relief measures.

Figure 4 shows the workflow diagram of the present research. The existing database from the 'Vulnerability Atlas of India 2006' has been taken for the 'location of most vulnerable houses to cyclone'.

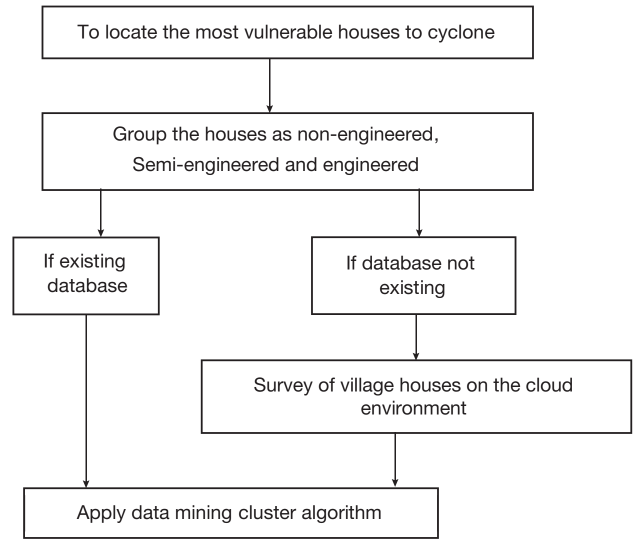

Figure 4: Workflow diagram of the present research

Bibliography

"BIS-Status Report on Standardisation Efforts in the Area of Mitigation of Natural Hazards", (2004), National Disaster Management Division, Ministry of Home Affairs, Government of India. http://www.preventionweb.net/files/2498_BIS.pdf

'Coastal Zones of India', 2012, Space Applications Centre, ISRO, Ahmedabad

Determining the Number of Clusters/Segments in Hierarchical Clustering/Segmentation Algorithms, Stan Salvador and Philip Chan, Dept. of Computer Sciences Technical Report CS-2003–18, Florida Institute of Technology, Melbourne, FL 32901, {ssalvado, pkc}@cs.fit.edu

Lakshmanan, N., and Shanmugasundaram, J. (1997) "Guidelines for Design and Construction of Buildings and Structures in Cyclone Prone Areas", SERC-UNDP Project (IND/91/011), Published by SERC Madras.

Miller, M., (2008), "Cloud Computing: Web-Based Applications That Change the Way You Work and Colloborate Online", Que Publishing, Indiana, US.

DeepDisasterNet: High-Performance Computing-Driven Rapid Disaster Response Network

Abhishek V. Potnis[a]**, Surya S. Durbha**[a]**, Rajat C. Shinde**[a] **and Pankaj D. Tarone**[a]

ABSTRACT: Natural disasters endangers life and property. They not only impact our environment but also affect the economy of a nation. Thus, there is a dire need for effective techniques to aid during disaster assessment and management. Rapid processing and analysis from very-high-resolution (VHR) satellite imagery of disaster-affected regions assists in effective management and deployment of rescue activities. In order to rapidly identify disaster-affected sites, DeepDisasterNet has been proposed, which focuses on identifying earthquake-affected regions using the Convolutional Neural Network (CNN) for multi-class classification of VHR satellite imagery. Considering the humongous volume of remote sensing data and the necessity for rapid processing, this study also discusses the performance comparison of the proposed system across various scalable and parallel platforms like High-Performance Computing (HPC). The study was performed on the GeoEye-1 imagery of the Haiti earthquake and promising classification maps were generated as a result with an accuracy of 93.5 per cent. The model, trained and tested on Nvidia GPU Cluster hardware as well as on Intel AI DevCloud, has shown to produce promising results.

KEYWORDS: earthquake, rapid assessment, deep learning, satellite imagery, high-performance computing, convolutional neural network

Introduction

Effective assessment and management of post-disaster scenarios has proved to be a complex research problem. The post-disaster assessment and management requires quick decision-making, prudent actions and most importantly reliable analytics and actionable insights. Thus, there is a dire need for effective tools and techniques to assist officials during disaster assessment and management. This work focuses on the automated rapid identification of disaster-affected regions as the disaster unfolds. During a disaster, when the area of interest on the ground is inaccessible, remote sensing platforms such as satellites, aircrafts and drones form an ideal choice to assess and monitor the situation. In recent times, with the advancements in technology, there has been a deluge of remote sensing data available for processing and interpretation. Prominent sources of geospatial data include satellite imagery, LiDAR point clouds, unmanned aerial vehicle (UAV) imagery, etc. The spatial and spectral information contained in high-resolution satellite imagery can be used for extracting geographical information about the land use/land cover over the area of interest. This technique thus forms an apt choice for the fulfillment of the research objective of this study. Rapid processing and analysis from high-resolution satellite imagery of disaster-affected regions can assist in effective management and deployment of rescue activities. However, such data is known to be humongous in terms of data size and hence conforms to the 3V's: velocity, variety and volume of Big Data.

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The pre-processing and extraction of information from high resolution satellite imagery is tedious primarily due to its demand for high computational resources and huge compute time. High-Performance Computing (HPC) with Graphics Processing Unit (GPU) infrastructure aids in performing complex computations by leveraging the power of parallel processing and thus provides a conducive environment to handle such data. In a disaster scenario, since time is of essence, rapid results are desired from the data. A High-Performance Computing infrastructure facilitates rapid processing of Big Data and the proposed deep-learning-based approach enables rapid modelling of the behaviour of such data to obtain instant results for the given dataset. The trained model is then used for inferencing and generating results in near real-time.

Related Work

Numerous approaches have been proposed to analyse and quantify the impact on earthquake-affected regions. Taskin Kaya et al. (2011) adopted pixel-based classification, a Support Vector Selection and Adaptation (SVSA) method for damage assessment using thematic maps of pre and post-earthquake scenarios. The SVSA method shows an evaluation accuracy of 81.5 per cent on QuickBird imagery of the Haiti earthquake. Myint et al. (2011) compared object-based and pixel-based classification in high-urban-density regions of Arizona and Phoenix. Maximum likelihood classifier was used for pixel classification and nearest-neighbour classification was used for object-based approach, which achieved an accuracy of 83.91 per cent and 91.25 per cent, respectively. Radial basis multilayer feedforward neural networks (RBFNN) and random forests (RF) have been used for damage detection in the earthquake-affected regions of Haiti (A.J. Cooner et. al. 2016). Moreover, their focus was primarily on textural and structural features, including entropy, dissimilarity, laplacian of Gaussian and rectangular fit for classification of the high spatial resolution. Kamilaris et al. (2017) proposed a deep learning approach for damage detection and achieved a 91 per cent accuracy on high-resolution imagery obtained from UAVs. The VGG architecture, pre-trained with ImageNet (O. Russakovsky et. al. 2015), dataset was used for the study by Kamilaris et al. The dataset contained 544 images from UAVs (images of earthquake, fire, flooding, collapsed building, non-disaster scene). The training of the model was recorded to take 20 minutes (for 444 images) and testing of the model took 5 minutes for 100 images.

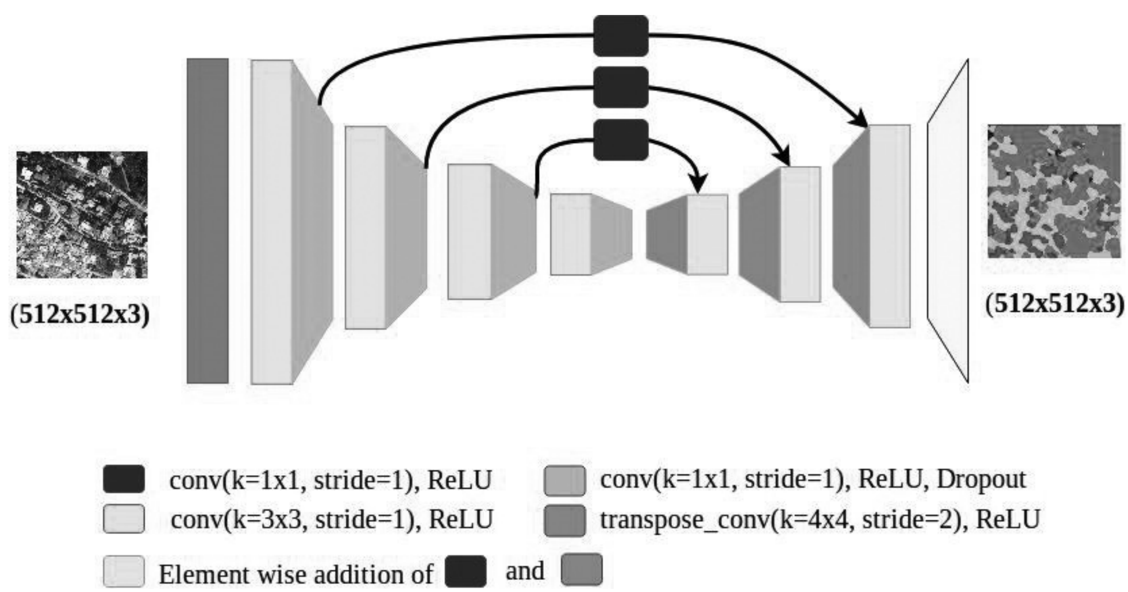


Figure 1: Proposed framework of DeepDisasterNet

Methodology

In this study, the encoder-decoder-based Convolutional Neural Network (CNN) architecture has been used. Figure 1 depicts the overview of the proposed framework.

The dataset used in the study is the RGB imagery of the Haiti earthquake which was acquired at 16:53 local time (21:53 UTC) on Tuesday, 12th January 2010.[1] The raw satellite imagery of Haiti obtained from the GeoEye-1 satellite is of 0.4 m spatial resolution. The dimension of the image is 20,001 x 20,001 pixels with four spectral channels – red, blue, green and infrared bands. The following steps describe the proposed method:

- Data preprocessing
- Training the deep learning model
- Prediction on test images and classification map generation

Data Preprocessing

The RGB patches of size 512x512x3 have been created using the QGIS[2] Retile tool:

- The patches have been segmented using the mean-shift segmentation approach.
- The segmented images of size 512x512x3 have been used to annotate buildings, damaged buildings, vegetation and shadowed region.
- Finally, 20 per cent of the annotated data was used for testing, 20 per cent for validation and the remaining 60 per cent was used for training.

Mean shift is a non-parametric clustering technique that does not require any prior knowledge and shape constraints (N. J. Gandhi et. al. 2014). The process of segmentation aided in manual annotation of satellite imagery.

Training the Deep Learning Model

Convolutional Neural Network (A. Krizhevsky et. al. 2012) is one of the popular deep learning architectures known to extract spatial features in each of the layer of the network. However, it has been observed that the classification accuracy for CNN architecture not only depends on the number of convolution layers but also on hyper-parameters like learning rate, batch size etc. (M. Janalipour et. al. 2016). We have used a nine-layer Convolutional Neural Network architecture to train the DeepDisasterNet model. The patches of size 32x32x3 for each class have been passed to the model for training. In total, there are 22,940 patches which were used for training the model. The model was trained on an Nvidia GPU Cluster as well as the on Intel AI DevCloud running the Tensorflow[3] (M. Abadi et al. 2016) and Keras[4] (F. Chollet 2017) libraries over it.

Table 1: Hardware Specifications of Nvidia GPU Cluster for Training DeepDisasterNet

Hardware Detail	Specification
CPU type	2X Intel®Xeon®CPU E5–2640v3@2.60GHz 8 core
GPU	2x Tesla K40

Table 2: DeepDisasterNet Hyper-parameters Specifications

S. No.	Parameters	Value
1	Number of layer	9
2	Activation function	ReLU, Softmax
3	Dropout	0.02
4	Input type data	HDF5
5	Input data channel	Image of three-channel RGB
6	Optimiser	Adam
7	Learning rate	0.00001
8	Number of epoch	3500
9	Beta 1	0.9
10	Beta 2	0.9999
11	Batch size	200
12	Fully connected Layer	1

Experimental Results

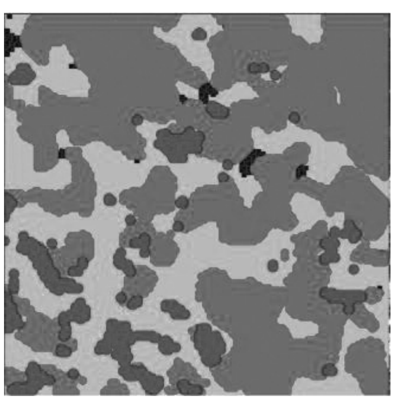
Dataset

In our study, we have used very-high-resolution (VHR) flood satellite imagery of Srinagar (India) floods. This imagery was acquired by WorldView 2 in October 2014. The imagery comprises four spectral channels — red, blue, green and near-infrared. For developing DeepDisasterNet, we used RGB tiles of size 512x512. The tiles were annotated manually for generating the training labels.

Results

After tuning different hyperparameters, the model was trained and tested for accuracy. The corresponding observations have been tabulated in Table 3.

(a)



(b)

Figure 2: (a) RGB imagery of Haiti earthquake-hit area; (b) classified map for Haiti earthquake-hit area obtained as the testing result using the DeepDisasterNet model

Table 3: Variations in Classification Accuracy with Change in Hyper-parameters

Learning	Beta1	Beta2	Accuracy
0.001	0.9	0.999	0.9145
0.001	0.8	0.9	0.8949
0.001	0.9	0.85	0.8777
0.001	0.9999	0.9999	0.617
0.00001	0.9	0.999	0.9350

To evaluate our model, we have compared the results of DeepDisasterNet with the work performed in the recent past. The compiled study is tabulated in Table 4.

Table 4: Comparison of DeepDisasterNet Results with the Work Done in the Recent Past on the Basis of Classification Accuracy

Author	Method	Accuracy
Taskin Kaya et al. (2011)	Support Vector Selection and Adaptation	81 per cent
Austin J. Cooner et al.	Artificial neural network	74.14 per cent
Austin J. Cooner et al. (2016)	Random forest	76.14 per cent
Austin J. Cooner et al. (2016)	Radial base feed forward neural network	77.26 per cent
A. Kamilaris, et al. (2017)	Convolution Neural Network	91 per cent
Proposed approach	DeepDisasterNet (deep learning)	93.50 per cent

Conclusion

We propose DeepDisasterNet – a deep-learning-based model for post-disaster analysis. In this work, the model has been trained and inferenced over the Haiti earthquake disaster. It is envisaged that this model can be extended and improved to accommodate flood and other such disasters using transfer learning approaches. We highlight the necessity of near-real-time analysis during a disaster scenario. To address this requirement, we advocate the use of High-Performance Computing platforms. In the future the proposed model can be deployed over such platforms for large-scale disaster-related classification of remote sensing imagery.

This research culminated into the development of the deep learning network – DeepDisasterNet for damaged building detection and classification for post-disaster assessment and monitoring. It was observed that the training on the segmented patches of land-use/land-cover classes gave an accuracy of 93.5 per cent, which is significantly higher than state-of-art research studies. It was also observed that the HPC computational power sped up the computation to obtain rapid results. Through an increase in the dataset, by including disaster affected imagery from different geographic locations, data augmentation approaches and appropriate tuning of hyper-parameters, the classification accuracy can be expected to fairly improve further.

Future work involving processing of multi-temporal high-resolution satellite imagery of disaster-affected areas can prove effective in monitoring disasters in real-time and also aid in improving our understanding of such natural phenomena. It is envisaged that the automatic identification of such regions in near real-time could significantly elevate the effectiveness of disaster assessment and management, and thus aid disaster response activities.

Acknowledgements

The authors are thankful to Intel for providing access to the Intel AI-Devcloud powered by Intel Xeon Scalable Processors for training and testing the DeepDisasterNet model to generate the classification results.

Notes

[1] 2010 Haiti earthquake: https://en.wikipedia.org/wiki/2010_Haiti_earthquake

[2] QGIS, Github repository: https://github.com/qgis/QGIS

[3] Tensorflow: https://www.tensorflow.org/

[4] Keras: https://keras.io/

References

Abadi, M., Barham, P., Chen, J., Chen, Z., Davis, A., Dean, J., Devin, M., Ghemawat, S., Irving, G., Isard, M., Kudlur, M., Levenberg, J., Monga, R., Moore, S., Murray, D. G., Steiner, B., Tucker, P., Vasudevan, V., Warden, P., Wicke, M., Yu, Y., Zheng, X.: TensorFlow: a system for large-scale machine learning. In *Proceedings of the 12th USENIX conference on Operating Systems Design and Implementation (OSDI'16). USENIX Association, Berkeley, CA, USA*, 265–283 (2016)

Chollet, F., Keras (2017), Github repository, https://github.com/keras-team/keras

Cooner, A.J., Shao Y., Campbell, J.B.: Detection of urban damage using remote sensing and machine learning algorithms: Revisiting the 2010 Haiti earthquake. *Remote Sensing*, 8(10), p.868 (2016)

Gandhi, N. J., Shah, V.J., Kshirsagar, R. Mean shift technique for image segmentation and modified canny edge detection algorithm for circle detection. *In Communications and Signal Processing (ICCSP), International Conference* on (pp. 246–250) (2014)

Gulati, K., Khatri, S. P.: GPU Architecture and the CUDA Programming Model. In: Hardware Acceleration of EDA Algorithms: Custom ICs, FPGAs and GPUs (pp. 23–30). Boston, MA: Springer US (2010) doi: 10.1007/978–1-4419–0944–2_3

Janalipour, M., Mohammadzadeh, A.: Building damage detection using object-based image analysis and ANFIS from high-resolution image (case study: BAM earthquake, Iran). *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 9(5), pp.1937–1945 (2016)

Kamilaris, A., Prenafeta-Boldú, F.X.: Disaster Monitoring using Unmanned Aerial Vehicles and Deep Learning. *Disaster Management for Resilience and Public Safety Workshop*, in *Proceedings of EnviroInfo (2017*)

Krizhevsky, A., Sutskever, I., Hinton, G.E.: Imagenet classification with deep convolutional neural networks. In *Advances in Neural Information Processing Systems* (pp. 1097–1105) (2012)

Myint, S.W., Gober, P., Brazel, A., Grossman-Clarke S., Weng, Q.: Per-pixel vs. object-based classification of urban land cover extraction using high spatial resolution imagery. *Remote sensing of environment*, 115(5), pp.1145–1161 (2011)

Russakovsky, O., Deng, J., Su, H., Krause, J., Satheesh, S., Ma, S., Huang, Z., Karpathy, A., Khosla, A., Bernstein, M., Berg, A. C., Li Fei-Fei: ImageNet Large Scale Visual Recognition Challenge, International Journal of Computer Vision (IJCV), vol:115–3, pp:211–252 (2015) doi: 10.1007/s11263–015–0816-y

Taskin Kaya, G., Musaoglu N., Ersoy. O.K.: Damage assessment of 2010 Haiti earthquake with post-earthquake satellite image by support vector selection and adaptation. *Photogrammetric Engineering & Remote Sensing*, 77(10), pp.1025–1035 (2011)

Ye, F., Wang, Z. J., Zhou, F. C., Wang, Y. P., Zhou, Y. C.: Cloud-Based Big Data Mining & Analyzing Services Platform Integrating R. *International Conference on Advanced Cloud and Big Data*, Nanjing, (2013), pp. 147–151. doi: 10.1109/CBD.2013.13

Social Media: A Helping Platform in Emergencies and Disaster Management – A Case Study Based on Mumbai Rains, 2017

Puja Banerjee[a]

ABSTRACT: The rapid pace of technological development has resulted in an astonishing shrinkage of our planet, in terms of relative and absolute distances, through its remarkable impact of innovations in the field of technology, especially via telecommunication. And "social media", as one of its elements which is the internet-based application, enabled people to interact and share information through media, which compressed the space-time constraints. Social media like Facebook, Twitter, YouTube, LinkedIn, and blogs has played an increasingly significant role during emergencies and disasters. Social media helps to disseminate safety information before, during, and after disasters by providing information regarding food, shelter, and transportation. It moreover allows people to exchange information and request for help as well as to inform about the disaster-affected location and population. In the present chapter the usefulness of social media, during emergencies, has been put forward through the case study based on the Mumbai rains 2017. The study shows how Mumbaikars with the aid of social media platforms like Facebook and Twitter came to support each other during a constant heavy rain which brought the finance capital of India to a standstill. The Mumbaikars who are offering shelter are using #RainHost while tweeting and shared information about their location of the shelter, which made it easily accessible to all. In addition, Facebook has incorporated a safety check option, which allows people to mark themselves safe and enable their family and friends to know about the present status. Accordingly, the study is based on the analysis of social media posts to bring forth the role of social media in an emergency situation. So, the study is crucial because in recent time digital exposure and social media platforms are growing rapidly and is equally important to gain an understanding of how society is adapting to this digital transformation, especially in emergency situations and disaster management.

KEYWORDS: social media, emergencies, Mumbai rain, digital transformation

Introduction

The advent of smart technologies, especially in the field of information and communication sectors, has revolutionised contemporary society. And social media as an Internet-based application (Lindsay, 2011; Velev & Zlateva, 2012) played a dominant role in enabling people to interact with each other and share information, which compressed the geographical space and time constraint (Green, 2002). Social media has provided a platform for the people where they can actively participate and engage in discussion, communication– which can be in one-to-one, one-to-many and many-to-many communication, comment, create content and ensures a speedy dissemination of information (Boyd & Ellison, 2008; Blank & Reisdorf, 2012; Cohen, 2012;

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Velev & Zlateva, 2012). For the last decade social media like Facebook, Twitter, blogs, YouTube and LinkedIn have played a dominant role during emergencies and disaster situations (Lindsay, 2011), where they help to disseminate safety information before, during and after disasters by providing information regarding food, shelter, and transportation (Velev & Zlateva, 2012; Herfort et al., 2014). It further allows people to exchange information and request for assistance as well as to inform about the disaster-affected location and population (Li & Goodchild, 2012; Alexander, 2014) and increases information capacity, interactivity and dependability (Jaeger et al., 2007). Accordingly, it provides an effective communication network which acts as a key component in disaster planning, recovery and response (Houston et al., 2015). As put forward by Rodriguez et al., disasters often are the "result of a crisis in communication process or a result of communication breakdown" (Rodríguez et al., 2007). For instance, in the U.S. Congress Report, Secretary of Homeland Security Michael Chertoff, during Hurricane Katrina, throws light on "the importance of having accurate, timely and reliable information about true conditions on the ground" and highlighted that the responses "were significantly hampered by lack of information from the ground" (Chertoff, 2005).

Disaster and emergency situations are a sudden accident or natural catastrophe which hinders the conventional communication process for a time interval but the social networking process remains active. And during such events, there are extensive needs for people to connect with their family and friends, and in these situations, social networking sites allow people with the resource to recover from such situations and increases awareness (Yin et al., 2012). The emergency services agencies equally use social media platforms to circulate, broadcast and amplify emergency warnings (Mathbor, 2007; Velev & Zlateva, 2012). Consequently, the social network role in emergencies and disaster management can be summarised into two categories (Lindsay, 2011):

- Social media is used for information dispersion and to acquire feedback through messages, wall posts and polls. This is also highly encouraged by the Federal Emergency Management Agency (FEMA).
- Social media used as a platform for emergency communication and circulating warning, aiding victims who require assistance and monitoring the damage level that affected the population.

In this digital transformation phase of society where society is working with the support of smart technological devices and applications, emergency and disaster-related agencies like Information Systems for Crisis, Response and Management (ISCRAM) and the Humanitarian Free and Open Source Software (FOSS) and numerous emergency and disaster-related organisations like universities, private and nonprofit sectors, and state and local governments use Facebook to disseminate information, communicate with each other, and coordinate activities like emergency planning and exercises (White et al., 2009; Lindsay, 2011). In 2009, it was found by the American Red Cross that social media sites were the fourth most popular source to access information during emergencies (The Amercian Red Cross, 2009). For example, during Fort Hood shootings in 2009, the U.S. Army used its Twitter account to provide news and updates while Facebook is used by the American Red Cross to issue an alert of foreboding disasters (Palen, 2008). So, the governmental, as well as local and private organisations, is also taking the initiative to harness the capabilities of the digital world via the use of Google, Facebook and Twitter to make it of use to public during emergencies (Lindsay, 2011). And social media electronic devices, which are mainly smartphones and tablets that are readily available with the user (Keim & Noji, 2011; Meikle & Redden, 2011; Houston, et al., 2015), are equipped with Geographical Positioning System (GPS) receivers, helping to transform the information into location-based information (Roick & Heuser, 2013; Houston et al., 2015; Beigi et al., 2016; Athanasis et al., 2018). In that way, they help to provide real-time information about the location of the disaster-affected area, which furthermore is useful in dealing with disaster situation during and after an emergency (Landwehr & Carley, 2014; De Albuquerque et al., 2015; Athanasis et al., 2018).

In the process of the request of assistance, social media seemed to have played a dominant role. Social media is turning out to become a life-supporting tool (Saleem, 2015). In March 2011, during Japanese earthquake and tsunami, people individually used Twitter for assistance as the telephonic service went down (Lindsay, 2011). And Facebook was used by engineers of Japan to develop a disaster message board to communicate for help during the 2011 Tohuku earthquake and tsunami. In addition, Facebook unleashed a safety check feature to help family and friends to locate their near and dear ones (Saleem, 2015). This feature was extremely used during the Nepal earthquake. During the 2014 Kashmir flood, Twitter was a great assistance to the officials of Indian Army to perform recovery procedure as the tweets with hashtag #kashmirflood provided information regarding the ground situation and also helped to channelise relief materials across the affected places (Saleem, 2015). Social media was well reclaimed for reducing casualties caused by the airstrike during the Syrian civil war. Hala Systems, a tech startup, uses remote sensors in detecting the aircraft over the opposition northern province of Idilb and sent an alert message via Facebook and Whatsapp to civilians and aid workers in 2016, which reduced casualties by 27 per cent (Reilly & Tantanasi, 2018). At the time of the 2018 Kerala flood as well social media has been a boon. It has helped to collect, distribute and transport relief materials under the hashtag #KeralaFlood. Infact the government of Kerala also used social media to raise disaster funds to rebuild the affected parts and help flood victims. Renowed Bollywood actors like Amitabh Bachchan and Farhan Akhtar took the help of Twitter to circulate the message of trusted relief fund donation sites. So, it is seen that social media is one of the best mediums to disseminate information during disaster or emergency situations, where individuals and communities warn others of unsafe situations and location, inform friends and family about one's safety, and raise disaster relief funds.

Objective

The objective of the study is to prove through a case study of the Mumbai rains of 2017, how the Mumbaikars with the help of social media combatted emergency situations and helped their fellow citizens.

Methodology

The study was conducted by collecting and analysing Twitter and Facebook messages for the entire period uphold the role of social media during emergency situations.

Mumbai Rains 2017

In August 2017, heavy torrential rain paralysed the financial capital of India, Mumbai, and the city was brought to a virtual standstill (Aljazeera, 2017 & The Times of India, 2017). The heavy rain jeopardised the transport system, and the railways and the roadways were in a complete hault position. In 7 hours from 8 am to 3 pm the city received more than 200 mm of rain (TheTimesOfIndia, 2017), as put forward by the Indian Meteorological Department. The train tracks and roads were flooded with heavy traffic congestion reported at the Santacruz-Chembur Link road, approach road of Eastern freeway, JVLR and Bandra-Worli sealink; the Central Railways, Harbour and Mainlines, and Western Railways were suspended. In Matunga circle, Sion circle and Jain society the water reached to a waist-high level and entered houses in Kalina and Kurla, with all the travellers being stranded (The Times of India, 2017). In this emergency situation the social media played a dominant role in alert, recovery and response processes. The moment the rain paralysed the city, the social media, mainly Twitter and Facebook, got flooded with messages from people stuck in such emergencies, alert messages to avoid certain roadways, helpline numbers, traffic updates, and places for shelter and food availability. Not only the common civilians took its aid but the Disaster Management Department, Indian government, Railway departments and Mumbai

Police too came under its umbrella for the recovery and response processes. The civilians were using hashtags to circulate important informations. Hashtags are basically used on social media sites to make it easier for the information availability of a particular theme and specific content (Taylor, 2015). It categorises the content for the audience (MacDonald, 2017). Hashtags like #MumbaiRain, #rainhost and #MumbaiHelpline were used by netizens (Hauben M, 1996; Hauben & Hauben, 1998) to convey the news to their friends, family, colleagues, associates and even other affected people.

Alert, Recovery and Responses Using Social Media

During the Mumbai rains of 2017, social media played an important role in alert, recovery and response processes. All the governmental departments took the help of social media to reach to the population and update them about the present scenario and understand the affected locations and population. The Disaster Management Department used Twitter to alert Mumbaikars through their tweet on the upcoming torrential downpour of rain. In fact the honourable Prime Minister of India, Narendra Modi, too used Twitter to communicate to people, where he urged fellow Mumbaikars to take precautionary steps in this distress situation. In addition Western Railways and Central Railways also kept updating civilians about the schedule of trains via Twitter (Usmani & Kapoor, 2017) (Fig. 1).

The whole of Mumbai came together in aiding the people in jeopardy. Twitter and Facebook served as a medium where people asked for help and they were reciprocrated with information regarding the location of shelter and food. Netizens (Hauben M., 1996; Hauben & Hauben, 1998) wisely used the social site to post an update of the traffic, waterlogging, rescue work and other sources and places where they could secure assistance from. In fact, Mumbai Police also took the help of this medium to post their helpline numbers and warn people to avoid the submerged places. Facebook initiated a safety check option where the user could mark themselves safe in such emergency situations and help their friends and family to known about their safety. Social media users used hashtag #MumbaiRains to caution people about the massive cloud break over the city and pleaded others to retweet the message so that maximum people could become aware. They notified people about the then present state of their nearby place, and flooding and water level. They not only requested people to assist the civilians stuck in rain but also the helpless animals (especially stray dogs). A few tweeted alert messages warning people who are driving to keep their windows open so that in cases of battery failure or car break down, they could escape from the window, as in 2005 Mumbai flood many people died in their car (Fig. 2).

In the recovery and response processes as well social media plays a dominant role. The local residents continuously posted updates regarding the rescue processes in social media sites. The places where tube boats are deployed by the Mumbai police and the helpline numbers to be contacted are the source of great assistance to the stranded people, as tweeted on Twitter and posted on Facebook. The hashtag #RainHost was used by fellow citizens who want to offer shelter to those stuck in the rain. Individuals, as well as corporate offices and hotels, came together in providing free shelter and food to people stuck in such an emergency situation. The users provided the locations of their houses and tweeted to help those who were stranded nearby. They kept posting about the availability of food at several places. All Mumbaikars came together for help irrespective of one's caste, creed or religion. Dargahs and gurudwaras were open for all for food. Food was also served at Chhatrapati Shivaji Railway terminus by Dawoodi Bohra to those commuters who were stranded. Social media was relied upon to spread the news. In fact hotel and transport services like OYO, Treebo, Redbus and Ola took the help of social media in circulating the messages regarding their services. OYO, Treebo, and Redbus were providing free hotel services, and Ola was providing free share rides as well (Fig. 3). So, jointly Mumbaikars came up with ways to combat such an emergency situation, for which social media sites played a significantly role.

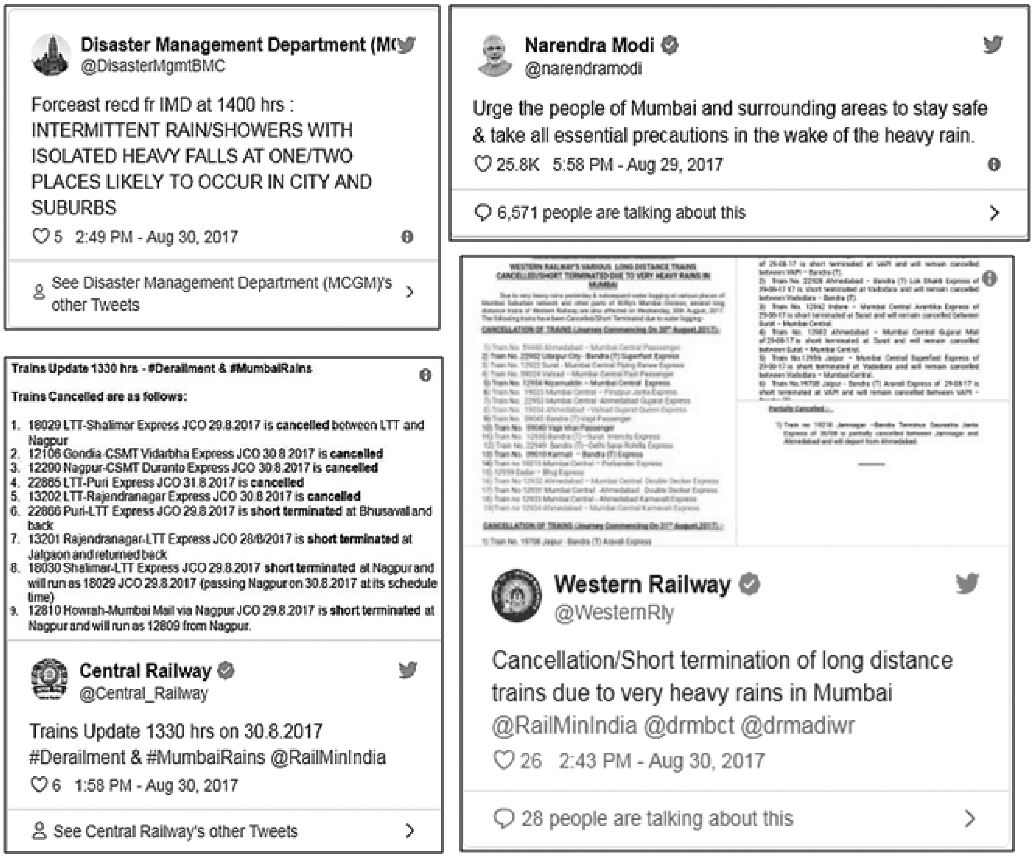

Figure 1: Alert messages by governmental department

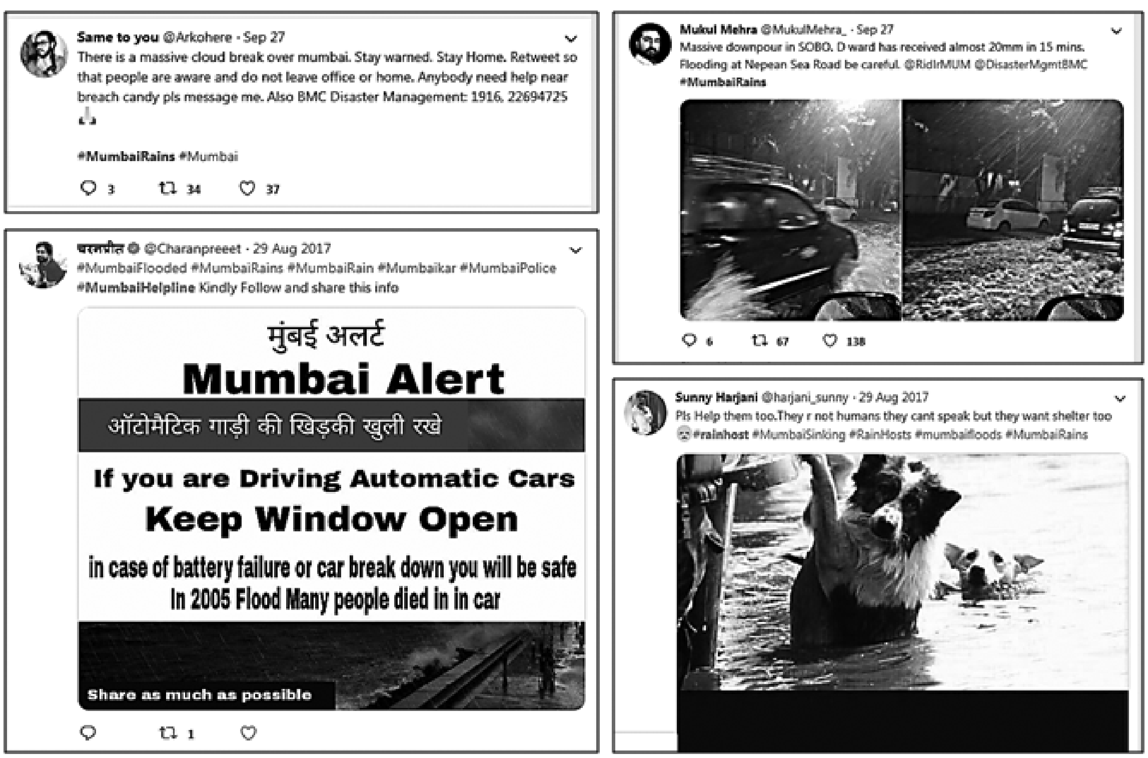

Figure 2: Alert messages by Mumbaikars

Figure 3: Rescue and response by Mumbai Police and Mumbaikars

Conclusion

Digital transformation of society through the explosion of the mobile and computer technology has reconfigured time-space constraints (Green, 2002). The widespread availability of smart technological devices and application to the people, to an extent, has minimised the life lost in emergency and disaster situations. Social media performs an integral role in managing a crisis project, as seen in the Thailand flooding disaster in 2011 (Kaewkitipong, Chen, & Ractham, 2012). In the Mumbai rains of 2017 as well it is seen how social media came into the arena of emergency management work, which is in fact encouraged by Mumbai Police as well (Fig. 4). This also throws light on how civilians are embracing digital technology into their everyday-life framework and how digital literacy is slowly gaining its place in the life of ordinary citizens. Mumbaikars have shown how effective social media can be during the time of emergency situations. In spite of such an emergency phase, social media sites acted as a ray of hope for people stuck in such a waterlogged situation. So, digital technology and social media should be encouraged and used effectively and wisely so that effective management could be done during a disaster and emergency situation.

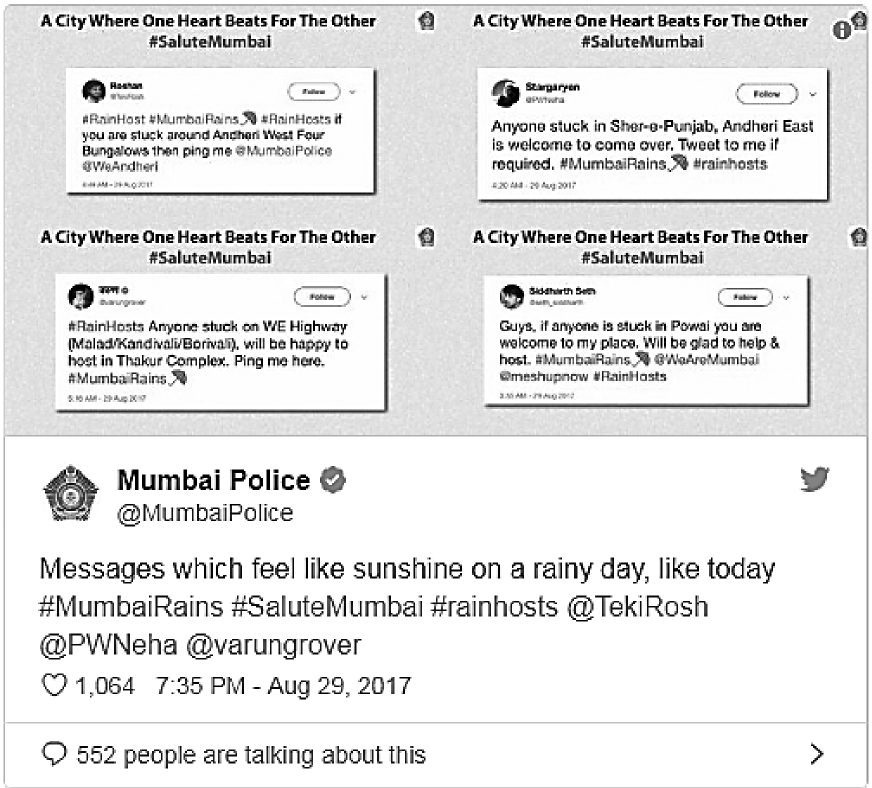

Figure 4: The spirit of Mumbaikars – social media acting as a helping hand in emergency situations

Bibliography

Alexander, D. (2014). Social media in disaster risk reduction and crisis management. *Science and engineering ethics, 20*(3), 717–733.

Aljazeera. (2017, August 30). *Monsoon rains bring Mumbai to a standstill*. Retrieved December 7, 2018, from Aljazeera: https://www.aljazeera.com/news/2017/08/monsoon-rains-bring-mumbai-standstill-170829134146264.html

Athanasis, N., Themistocleous, M., Kalabokidis, K., Papakonstantinou, A., Soulakellis, N., & Palaiologou, P. (2018, March 18–21). THE EMERGENCE OF SOCIAL MEDIA FOR NATURAL DISASTERS MANAGEMENT: A BIG DATA PERSPECTIVE. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 75–82.

Beigi, G., Hu, X., Maciejewski, R., & Liu, H. (2016). An overview of sentiment analysis in social media and its applications in disaster relief. In *In Sentiment analysis and ontology engineering* (pp. 313–340). Cham: Springer.

Blank, G., & Reisdorf, B. (2012). The participatory web. *Information, Communication and Society, 15*(4), 537–554.

Boyd, D., & Ellison, N. (2008). Social network sites: definition, history, and scholarship. *Journal of Computer-Mediated Communication., 13*(1), 210–230.

Chertoff, M. (2005). *Statement by Homeland Security Secretary Michael Chertoff before the United States House Select Committee on Hurricane Katrina.* Retrieved from Homeland Security: http://www.dhs.gov/xnews/testimony/testimony_0042.shtm

Cohen, H. (2012). *Social media definitions.* Retrieved September.

Cross, T. A. (2009, August 09). *Web Users Increasingly Rely on Social Media to Seek Help in a Disaster.* Retrieved December 27, 2018, from Press Release: http://www.redcross.org/portal/site/en/menuitem.94aae335470e233f6cf911df43181aa0/?vgnextoid = 6bb5a96d0a94a210VgnVCM10000089f0870aRCRD

De Albuquerque, J., Herfort, B., Brenning, A., & Zipf, A. (2015). A geographic approach for combining social media and authoritative data towards identifying useful information for disaster management. *International Journal of Geographical Information Science, 29*(4), 667–689.

Green, N. (2002). On the move: Technology, mobility, and the mediation of social time and space. *The information society, 18*(4), 281–292.

Hauben, M. (1996). *The net and netizens: the impact the net has on people's lives.*

Hauben, M., & Hauben, R. (1998). Netizens: On the history and impact of Usenet and the Internet. *First Monday, 3*(7).

Herfort, B., de Albuquerque, J., Schelhorn, S., & Zipf, A. (2014). Exploring the geographical relations between social media and flood phenomena to improve situational awareness. In *Connecting a digital Europe through location and place* (pp. 55–71). Cham: Springer.

Houston, J., Hawthorne, J., Perreault, M., Park, E., Goldstein Hode, M., Halliwell, M., et al. (2015). Social media and disasters: a functional framework for social media use in disaster planning, response, and research. *Disasters, 39*(1), 1–22.

Jaeger, P. T., Shneiderman, B., Fleischmann, K. R., Preece, J., Qu, Y., & Wu, P. F. (2007). Community response grids: E-government, social networks, and effective emergency management. *Telecommunications Policy, 31*(10–11), 592–604.

Kaewkitipong, L., Chen, C., & Ractham, P. (2012). LESSONS LEARNED FROM THE USE OF SOCIAL MEDIA IN COMBATING A CRISIS: A CASE STUDY OF 2011 THAILAND FLOODING DISASTER. *33rd International Conference on information System.* Orlando: Association For Information System.

Keim, M. E., & Noji, E. (2011). Emergent use of social media: a new age of opportunity for disaster resilience. *American Journal of Disaster Medicine, 6*(1), 47–54.

Landwehr, P., & Carley, K. (2014). Social media in disaster relief. *Data mining and knowledge discovery for big data* (pp. 225–257). Berlin, Heidelberg: Springer.

Li, L., & Goodchild, M. F. (2012). The role of social networks in emergency management: A research agenda. *n Managing Crises and Disasters with Emerging Technologies: Advancements*, 245–254.

Lindsay, B. R. (2011, September 9). Social media and disasters: Current uses, future options, and policy considerations. *CRS Report for Congress*, 1–10.

MacDonald, J. (2017, May 5). *The Importance of Hashtags: Know Where, Why, and How to Use Them.* Retrieved december 27, 2018, from Business 2 community: Social media: https://www.business2community.com/social-media/importance-hashtags-know-use-01837644

Mathbor, G. (2007). Enhancement of community preparedness for natural disasters: The role of social work in building social capital for sustainable disaster relief and management. *International Social Work, 50*(3), 357–369.

Meikle, G., & Redden, G. (2011). Introduction: transformation and continuity. In G. Meikle, & G. Redden (Eds.), *News Online: Transformations and Communities* (pp. 1–19). New York: Palgrave Macmillan.

Palen, L. (2008). Online Social Media in Crisis Events. *Educause Quarterly, 30*(3).

Reilly, P., & Tantanasi, I. (2018, August 23). *Social media's not all bad – it's saving lives in disaster zones.* Retrieved December 6, 2018, from Physorg: https://phys.org/news/2018–08-social-media-bad-disaster-zones.html

Rodríguez, H., Díaz, W., Santos, J., & Aguirre, B. (2007). Communicating risk and uncertainty:. (R. H., Q. E.L., & R. Dynes, Eds.) *Handbook of Disaster Research*, 476–488.

Roick, O., & Heuser, S. (2013). Location based social networks – definition, current state of the art and research Agenda. *Transactions in GIS, 17*(5), 763–784.

Saleem, V. (2015, June 7). *How people turn to social media during natural disasters.* Retrieved December 1, 2018, from DownToEarth: https://www.downtoearth.org.in/blog/how-people-turn-to-social-media-during-natural-disasters-49587

Taylor, N. (2015, June 12). *Why Are #Hashtags So Darn Important?* Retrieved December 27, 2018, from Associate Adviser: A Naylor Publication: https://www.naylor.com/associationadviser/why-are-hashtags-important/

The Times of India. (2017, August 30). *Mumbai mayhem: How heavy rains brought the city to its knees*. Retrieved December 7, 2018, from Times of India: https://timesofindia.indiatimes.com/city/mumbai/mumbai-mayhem-how-heavy-rains-brought-the-city-to-its-knees/articleshow/60287516.cms

Usmani, A., & Kapoor, M. (2017, August 30). *Mumbai Rains: Isolated Heavy Rainfall Seen At Few Places In Mumbai*. Retrieved December 7, 2018, from Bloomberg: https://www.bloombergquint.com/global-economics/live-mumbai-flooded-braces-for-high-tide

Velev, D., & Zlateva, P. (2012). Use of Social Media in Natural Disaster Management. *Intl. Proc. of Economic Development and Research, 39*, 41–45.

White, C., Plotnick, L., Kushma, J., Hiltz, S. R., & Turoff, M. (2009). An online social network for emergency management. *International Journal of Emergency Management, 6*(3–4), 369–382.

Yin, J., Lampert, A., Cameron, M., Robinson, B., & Power, R. (2012). Using social media to enhance emergency situation awareness. *IEEE Intelligent Systems, 27*(6), 52–59.

Utilising Online Social Media for Coordinating Post-disaster Relief in Indian Cities

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ABSTRACT: Cities in India have frequently been affected by natural disasters. In recent times, floods have been the most prevalent natural disasters in Indian cities. Every year due to unprecedented rainfall, coastal Indian cities like Mumbai and Chennai and cities in Kerala often suffer from floods. In any natural disasters, the key objective is to save human life by providing life-saving resources to the affected population in a timely manner. However, in the aftermath of any disaster, disaster management authorities deal with severe uncertainties in assessing the needs of different resources, and hence allocating those resources in real-time becomes difficult due to the lack of first-hand information. Hence, in this work, our specific objective is to utilise Online Social Media (OSM) to curate the requirements of several categories of critical resources in a flood-affected region of India, taking two recent floods as a case study – the Chennai floods in November–December 2015 and the Mumbai floods in August–September 2017. In this work, we have developed a semi-automatic pattern matching-based approach for finding resource needs and resource availabilities from microblogs/tweets posted on Twitter during such disaster events. We hope that the insights from our study will help disaster management authorities in assessing a broad phase-wise need of different kind of critical resources in a flood scenario and hence will help in preparedness planning of any upcoming flood specifically in Indian cities.

KEYWORDS: natural disaster, resource need, social media, first-hand information, preparedness planning

Introduction

In the past few decades, natural disasters like floods have become recurrent. During any natural disaster, the first-hand information is extremely important to coordinate the rescue and relief operation smoothly. However, developing countries like India often lack the technology and infrastructure necessary to collect such real-time data collection, especially in a disaster situation. In such scenarios, during natural disasters like floods, Online Social Media (such as Facebook, Twitter, WhatsApp) can be an attractive choice to collect data in real-time from all sorts of stakeholders. Recent flood events in India such as Chennai floods in 2015, 2016, Mumbai floods in 2017 and Kerala floods in 2017 have established the increasing use of Online Social Media (OSM) like Twitter in providing vital information during the disaster event. Since, unlike some other types of disasters, during the flood, access to the Internet mostly remains stable, people in the affected region are more inclined to post rapidly on OSM on the various aspects of the disaster. Several prior studies (mostly undertaken in the USA, Europe, Japan, Australia) have proved the crucial role of OSM like Twitter in disaster

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response. This study aims to demonstrate the utility of OSM in helping post-disaster relief operations during disaster events in India, especially during an urban flood situation. The specific goal of this study is to use microblogs (tweet) to assess the urgent requirements of various resources in a flood-affected region of India. We propose to identify two types of critical actionable information from social media – (i) what resources are needed and (ii) what resources are available in the disaster-affected area. Moreover, our motivation is to help disaster responders to coordinate the relief operations in a better way and to contribute to preparedness planning for an upcoming flood event in India, by reusing the acumen of this study. Thus, automated methodologies are essential to mine meaningful information hidden within a large amount of conversational/sarcastic contents posted on Twitter. In this context, techniques in Computer Science fields like Data Mining, Pattern Matching, Natural Language Processing, Machine Learning, etc., have to be used to extract significant information from the tweets. However, tweets are informally written using abbreviations, colloquial terms, etc. (this is mainly due to the size restriction of tweets). Hence, it is still a challenge for computer scientists to develop improved techniques for extracting meaningful information.

Literature Review

In the last decade, OSM is proven to be the most significant repository of information during any kind of natural and man-made disasters. Therefore, Online Social Media (OSM) is used in various studies allied with disaster relief operations (Varga et al. 2013; Imran et al. 2015; Rudra et al. 2015; Pandey and Natarajan 2016; Basu et al. 2017C). In any natural disaster like floods, the key task is to mobilise resources at a precise location in a timely manner. However, several prior studies on disaster (Basu et al. 2017A; Khosla et al. 2017) are focused on the identification of resource needs and availabilities in the post-disaster scenario. Though, none of the previous studies focused on the phase-wise assessment of critical resource and their availabilities. In our recent study (Basu, et al. 2017B), we analysed WhatsApp chat log of a medical group called Doctors For You (DFY) to extract the requirement of various types of resources in different phases of an earthquake and floods, respectively. Our work provided a guideline for the preparedness planning of earthquake-prone regions by mobilising vital resources phase-wise. In another recent work (Sarkar et al. 2019), we analysed tweets related to floods in Chennai (2015) to provide an insight into the phase-wise resource need during a flood disaster. Moreover, we have formed a lexicon of 936 phrases consisting of generic and event-specific phrases. Thus, in this work, we are motivated to use another dataset related to a recent flood disaster in Mumbai (2015) to establish the reusability of our lexicon and methodology and to provide a generic insight on phase-wise resource needs during a flood disaster.

In this work, we primarily focus on the Twitter social media (https://Twitter.com). Twitter is one of the extensively used microblogging platforms, where to communicate with each other, short text messages called microblog or tweets are being used by users. Moreover, for being socially connected, each user of Twitter can “follow” other users. All the tweets posted by a particular user are made available to his followers in real-time. In today’s Web, Twitter has turned into one of the well-accepted social networking sites. Every day on an average, more than 500 million tweets are being posted. In the last few years, the rapid rise in the usage of smartphones has corresponded the growth in popularity of Twitter. Smartphones have enabled users to post tweets on the move throughout the day describing various activities, actions, etc. Hence, during disaster situations also, thousands of Twitter users post tweets conveying significant information like need or availability of various resources, which is available in real-time. Moreover, as a data source, Twitter is cost-effective, a huge amount of data can be collected from Twitter at minimal cost using a set of computer programmes known as the Twitter API.

Twitter data has few limitations as well. During any mass emergency, a large volume of tweets are being posted in a rapid rate. Many of such tweets contain fake news and overstated facts. Several tweets are merely conversational/sarcastic in nature and do not contain any meaningful information. Additionally, tweets are short text (at most 140 characters) and written in an informal way with a lot of abbreviations. Moreover, in Twitter, multiple users tend to post similar tweets multiple times. Thus, a lot of duplicate tweets are found in OSM. Hence, manual process of extracting meaningful information from OSM data is infeasible; automated methods are necessary. Thus, techniques in Computer Science fields like Pattern Matching, Natural Language Processing, Machine Learning, etc., are needed to mine important information usually hidden in the deluge of conversational posts.

Dataset

For this study, we have collected large amounts of data from Twitter social media during two recent disaster events in Indian cities – the Chennai floods in November–December 2015 and the Mumbai floods in August–September 2017. We have used Twitter search API (https://dev.Twitter.com/rest/public/search) to collect the tweets corresponding to the aforementioned two flood events. We used the keywords “Chennai” and “floods” and “Mumbai” and “floods”, respectively, as filters to collect data specific to Chennai floods and Mumbai floods. However, Twitter data has a lot of duplication of content in the form of re-tweets, i.e., the duplicate or near-duplicate tweets are frequently posted by multiple users. Thus, after collecting the data, we de-duplicated and chronologically ordered the tweets using a computer programme. The final dataset corresponding to Chennai floods contains 66K tweets and the dataset of Mumbai floods consists of 94K tweets. We applied our methodologies to both the datasets. Table 1 shows some example tweets from Chennai floods dataset depicting resource needs and resource availabilities and some other tweets which contain merely conversational content. We have also reported the resource needs and availabilities posted during Mumbai floods 2017 later (Result Analyses).

Methodology for Extracting Resource Needs and Availabilities

We are developing data mining algorithms to extract resource needs and resource availabilities from the collected data. We have mainly used pattern matching-based techniques, such as regular expression matching, to identify tweets that inform about needs and availabilities of various types of resources. To this end, we used a large set of 953 generic patterns (referred to as Emergency-Terms or EMTerms in short) (Temnikova et al. 2015) for matching specific types of tweets posted during emergencies. These patterns are primarily associated with the six categories proposed by Temnikova et al. related to the need and availability of resources. Table 2 illustrates the six categories and example patterns in each category.

Table 1: Examples of tweet excerpt containing resource needs and resource availabilities posted during the 2015 Chennai floods

Resource Needs	Resource Availabilities	Others
More food packets needed for lunch. Will pick up. Rice items only. Urgent.	Daily we can distribute 2000 packets of bread from salem to Chennai, is there anyone who can distribute it there. #ChennaiFloods	surprising silence of national media on Chennai rains. https://t.co/iggfRXvd0K
My friend stranded in 219-A Engineering Avenue Sunnambukolathur, Chennai 117, need evacuation.	RT. Flood map of Chennai showing relief camps: [url] #chennairains @ChennaiConnect	Hearing about very heavy rains in Chennai. Wish the people there well.
We are 7 people struck at 219-A Engineering Avenue Sunnambukolatthur, Chennai 117, without food and shelter.	DTN Kerala: Boats continue to be the lifeline here: Over 3,000 people of two villages along Palar near Tirukaz	Chennai flooded with incessant rains bringing life to a standstill. #ChennaiRains

(*Continued*)

Table 1: (*Continued*)

Resource Needs	Resource Availabilities	Others
We are in an urgent need of refrigerated vaccines for Typhoid and TT. We are falling short of vaccines in Chennai	Oxygen cylinders available for hospitals in Chennai. Please reach Pramod at +91 94	Excerpt Firstly a Monday then it Rains in Chennai? Wow! Here's how you can make it better! #MondayMotivation

Table 2: Examples of Patterns from EMTerms That are Related to the Need/Availability of Resources

Category Code and Name	# Patterns	Example of Pattern
T06: Need of/offered supplies, such as food, water, clothing, medical supplies or blood	297	aid, bottled water, any relief goods, basic supplies
T07: Volunteer or professional services needed or offered	232	relief aid, help victims, volunteers, army deployed, canhelp
C02: Needs food, or able to provide food	40	{Number} bags of rice, distribute food, canned goods
C04: Logistics and transportation	232	{Number} trucks, helicopter, rescue boats
C05: Need for shelters, including the location and conditions of shelters and camps	92	{Number} homeless, camps, hotel, shelter, shelter kit
C06: Availability and access to water, sanitation, and hygiene	59	need clean water, no drinking water, restoring water

Retrieval with Generic and Event-Specific Patterns

We preprocessed both the pattern and tweets by case-folding to lower case. We initially experimented with Chennai floods dataset. We used an initial lexicon of 953 patterns to retrieve the tweets. However, after initial retrieval with generic patterns, through manual inspection of the retrieved tweets, some patterns (e.g., "suffering", "flood relief", "pollution", "shower") identified to be irrelevant in the context of identifying need and availability of resources. Hence, 42 such patterns retrieving a large number of false-positive (irrelevant) tweets like *("May Allah or Ur god shower his mercy upon U Guy", "It's not only Chennai but many parts in #TamilNadu are suffering*)" were excluded from the initial set of patterns. Additionally, we included 28 event-specific patterns for identifying resource needs and resource availabilities specific to a particular disaster event. Thus, our final set of patterns/lexicon consists of 939 patterns. We reused this lexicon and extended our methods on Mumbai flood dataset to observe whether the lexicon is generic and event independent and the methods are extensive. We noticed apart from a few phrases like "chappati", "voveron", "vaccine", etc., the lexicon is fairly reusable for Mumbai flood dataset. Moreover, through manual inspection, we identified a few new phrases specific to Mumbai flood. The event-specific phrases for Chennai flood dataset are described in Table 3. Our prior work (Sarkar, 2019) describes the methodology in detail. The event-specific phrases for Mumbai flood dataset are illustrated in Table 4.

Table 3: Example of Event-Specific Phrases Related to Chennai Floods 2015 (Reproduced from our prior work (Sarkar et al. 2019))

Example of Event-Specific Phrases
antibiotic, milk, bread, biscuits, water bottle, bedsheet, chappathi, chapathi, chapati, diarrhoea, diarrhea, docs, dialysis, oxygen, mosquito repellent, ventilator, neer bottles, power restored, breakfast, lunch, bleaching, tab tablet, meal, voveron, vaccine

Table 4: Example of Event-Specific Phrases Related to Mumbai Floods 2017

Example of Event-Specific Phrases
vada, tea, torchlight, candle, grocery, diaper, powerbank, maggi, pavbhaji

Grouping Patterns to Form Resource Classes

Following the guidelines of the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA), we grouped the final set of patterns to construct five resource classes. According to UNOCHA, the responding authorities mostly have to deal with need or availabilities of five classes of resources in disaster scenarios: (1) Cash, related to monetary contributions; (2) Health, related to health concerns and resources; (3) Logistics, related to transportation, storage and human resource; (4) Shelter, related to housing and shelter; and (5) Water and Sanitation. In addition to these five categories of resources, we observed many tweets associated with the need of rescue (e.g., "In Chennai Ashok Nagar Sreenivasan Rajappa American citizen stuck in his house 1st floor water 6 ft in the house needs rescue") in our datasets. Thus, we introduced one new resource class named Rescue. We ignored the "Cash" resource since we intended to focus on physical resources that need to be delivered immediately in the disaster-affected region.

Thus, we consider five classes of resources. The description of each class is as follows – (i) Food: This resource category consists mainly of food items and basic supplies essential for survival, such as water bottles, food packets, etc. (ii) Rescue: This resource category consists of need of relief and rescue and related resources such as flood maps, volunteers, etc. (iii) Shelter: This resource category consists of resources related to shelter and housing, such as shelter kits, tents, etc. (iv) Logistics: This resource category considers the availability of several types of logistic resources, ranging from trained personnel like doctors, army transport, power and electricity communication, storage, equipment, etc. (v) Health: This resource category consists of resources that are concerned with the medical items recommended by the World Health Organisation (WHO) associated with general health and hygiene of the people, such as medicines, sanitation, blood, etc. Table 5 describes the five resource classes and example patterns in each class.

Table 5: Examples of Patterns Related to Five Resource Classes Reproduced from Sarkar (2019)

Resource Group	Example Patterns
Food	food, water, breakfast, relief material, lunch, basic supplies, essential items, milk, bread, chapati, meal, relief good, truckloads, biscuits, neer bottles, chappathi, chapathi, chapati, water bottle
Rescue	flood assistance, rescue, volunteered to help, volunteers to help, flood maps, people stranded, roads closed, struggling to reach, needs rescue, stranded passengers, can contribute, bus services, stranded train, full of water, sewage water, collecting clothes
Shelter	shelter, camps, relief camp, shelter to people, to house, housing, rehabilitation, clothing, blanket, donate clothes, collecting clothes, tent, shelter kit, medical camp
Logistics	chopper, boats, hospital, airport, convoy, flights to, train, buses, copters, no flights, a vehicle, bus services, navy ship, planes, army trucks, cargo, ventilator, no power, power restored, no fuel, mosquito net
Health	blood, medicine, hospital, oxygen, medical supplies, medical kit, antibiotic, diarrhea, diarrhoea, voveron, vaccine, medical camp, tablet, vessels, ventilator, sanitation, docs, dialysis, bleaching

Phase-Wise Requirement and Availability of Resources

We used our final set of patterns/lexicon corresponding to each resource class to retrieve the tweets that match any pattern present in the lexicon. Hence, the timestamp information extracted from the tweets (containing the day, date and time at which the tweet was posted) was used to segregate the tweets day-wise. Thus, tweets were manually annotated as resource needs and resource availabilities (in aforementioned five resource classes). In our prior study with Chennai floods dataset, we considered three phases – Phase 1 (Nov 12–Nov 30) consists of 19 days, Phase 2 (Dec 1–Dec 7) consists of 7 days and Phase 3 (Dec 8–Dec 13) consists of 6 days. We have done a detailed day-wise analysis for Phase 2 since the effect of the flood was at its peak in Phase 2 (Dec 1–Dec 7) as reported by several online and offline news media sources.

We initially experimented with Chennai floods dataset, and we are presently extending our methods to the Mumbai floods dataset. We have considered similar three phases for Mumbai flood dataset. Phase 1 (Aug 20 –Aug 27), Phase 2 (Aug 28–Sep 3) and Phase 3 (Sep 4–Sep 12) and we have done a detailed day-wise analysis for Phase 2. Our methods could identify hundreds of resource needs and resource availabilities from the Twitter data collected during the 2015 Chennai floods and 2017 Mumbai floods. The analyses on the results are demonstrated in the next section.

Result Analyses

In this section, we study the phase-wise requirements and availability of the different category of resources for Mumbai floods dataset. Moreover, we compare the results of Mumbai floods dataset with the results of our prior work with Chennai floods dataset to provide a generic insight on the phase-wise resource needs during a flood event in Indian cities. We follow the same methodology as in our prior study (Sarkar et al. 2019); we counted the number of tweets requesting resource needs and availabilities corresponding to the following five resource classes – Food, Rescue, Shelter, Logistics and Health. The statistics of resource-need and resource-availability messages (tweets) are reported in Table 6 (for Chennai flood dataset) and Table 7 (Mumbai flood) dataset.

Table 6: Phase-wise count of resource needs and resource availabilities corresponding to each resource class using Chennai floods dataset (Reproduced from our prior work (Sarkar, 2019))

Timeline	Food	Rescue	Shelter	Logistics	Health
Resource needs					
Nov 12–30	5	15	2	7	7
Dec 1	86	173	9	117	14
Dec 2	345	770	18	174	63
Dec 3	377	717	22	151	82
Dec 4	233	419	8	220	200
Dec 5	183	315	18	122	59
Dec 6	79	188	15	56	44
Dec 7	30	93	11	38	52
Dec 8–13	90	304	35	111	182

(*Continued*)

Table 6: (Continued)

Timeline	Food	Rescue	Shelter	Logistics	Health
Resource availabilities					
Nov 12–30	17	29	7	11	3
Dec 1	134	591	93	109	9
Dec 2	422	1193	128	353	115
Dec 3	532	942	77	295	93
Dec 4	353	523	36	205	84
Dec 5	247	324	19	128	42
Dec 6	144	157	25	57	50
Dec 7	66	65	22	34	35
Dec 8–13	210	482	108	159	142

Table 7: Phase-wise count of resource needs and resource availabilities corresponding to each resource class using Mumbai floods dataset

	Timeline	Food	Rescue	Shelter	Logistics	Health
Resource needs	Aug 29	219	401	15	870	59
	Aug 30	33	38	1	110	4
	Aug 31	3	0	5	9	0
Resource availabilities	Aug 29	996	516	127	532	10
	Aug 30	315	324	17	27	5
	Aug 31	34	0	1	18	0

From Tables 6 and 7, it is evident that in Phase 1 for both the floods, the tweets related to resource needs and resource availabilities across all the classes of resources were very low.

However, in Phase 2, a rapid growth in the number of tweets related to both resource needs and resource availabilities can be observed across all the resource classes. It can also be noted that for both the disasters, the need for rescue and logistic-related resources was predominant, followed by the need for food items. It can also be observed specifically for Mumbai floods dataset that the availability of shelter and allied resources was higher than their requirement. In Phase 3, for both the disasters, it can be observed from the tables that the number of resource needs and resource availabilities decreased considerably. Thus, it indicates that the effect of flood gradually subsided after Phase 2. The day-wise detailed statistics of Phase 2 for both Chennai floods and Mumbai floods are diagrammatically represented by Figures a, b, c and d. We also report some tweets identified by our methods regarding the needs and availabilities of different types of resources during the Mumbai floods in Table 8.

Table 8: Excerpt from Tweets Related to Five Resource Classes

Resource Class	Excerpt from Need-Tweets and Availability-Tweets
Food	<need>: Mumbaikars please help your 4 legged friends get through this weather by providing food & shelter! #MumbaiFlooded… https://t.co/ctTYtyENxd
	<availability>: Distributed Food Packets to Traffic Police @mtptraffic working hard in #MumbaiRains @mohitkamboj_bjp @BJYM4Mumbai @BJYM @ MrChoudharyS https://t.co/qvdjdS7KdG
	<availability>: Stuck in Dadar, Matunga, Sion, Parel, move towards RamMandirWadala. 9821595432. Food & Help available. #HelpingMumbaikar #MumbaiRains
Rescue	<need>: AVM schl buses are stuck near sion hospital..pls ask ur known ones staying near sion hospital to help out. AVM bus #MumbaiRains_HELP
	<availability>: #MumbaiRains Five flood rescue teams and two diving teams ready to render assistance at different locations across Mumbai: Navy PRO (ANI)”
	<need>: So many people stucked at andheri station...need volunteers to help them #MumbaiRains #MumbaiFlooded #MumbaiDelugeů https://t.co/zJipnKGxbX
Shelter	<need>: Stuck at home with wife due to the #MumbaiRains...! Looking for a shelter near JVLR
	<availability>: Gurudwaras in Mumbai are open to serve FREE food/shelter to ANYONE stuck in #MumbaiRains#Dadar #Matunga #Sikhs… https://t.co/FPDRixecGV<||>Tue Aug 29 18:01:55 +0000 2017
	<availability>: Indian Navy sets up 4 rain shelters at Sailor Institute Sagar, Cooperage INS TrataWorli, INS HamlaMarveand MO Ghatkopar #MumbaiRains
Logistics	<need>: @Olacabs need boats in mumbai’s flooded areas immediately.
	<availability>: @Olacabs Heard Ola boats are back in action in #Mumbai. Way to go.@Uber what’s your move?
	<availability>: latest update; Train services resume on Harbour line #MumbaiRains
Health	<need>: Risk of #Leptospirosis Infection as high (moderate/low) depending on exposure of flood water #MumbaiRains #health
	<availability>: Medical camp setup bh Indian Navy at Mankhurd Station #HelpMumbaikar #Mumbaikars #MumbaiRains
	<availability>: #MumbaiRains NGO lions Club Vile Parle east Helping People stuck in water logged Vile parle Westerns express Highway with food & Medicine

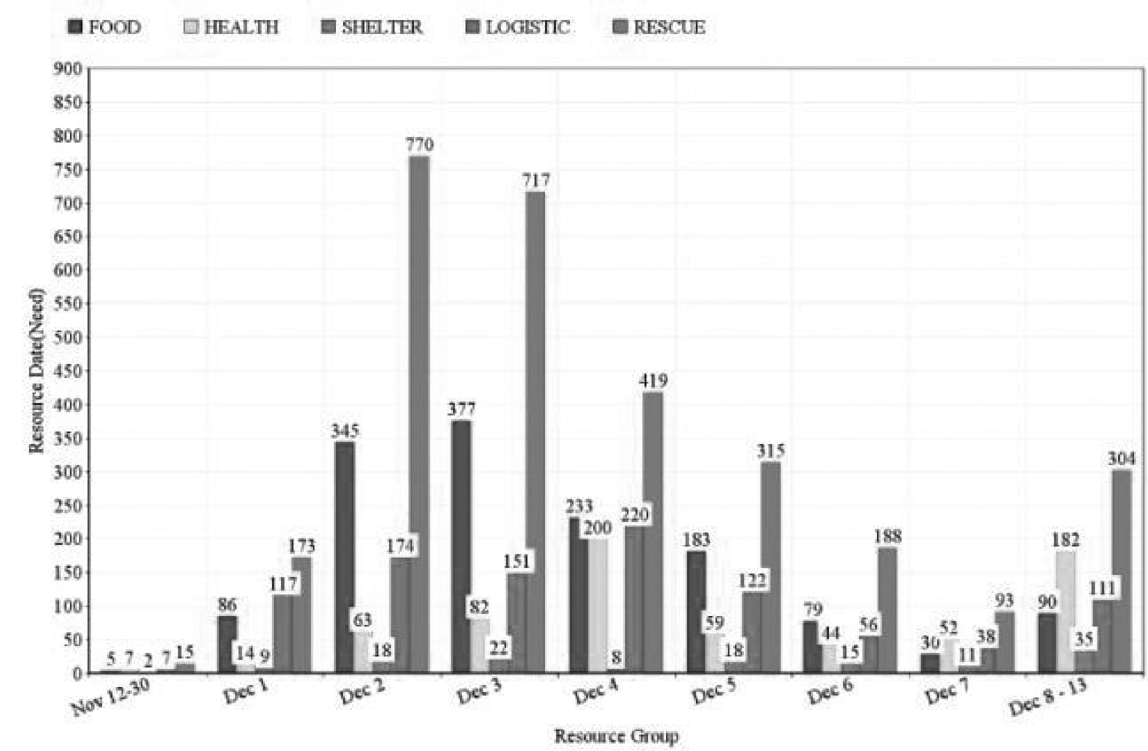

Figure a: Figure depicting day-wise need of different kind of resource needs (Chennai floods dataset)

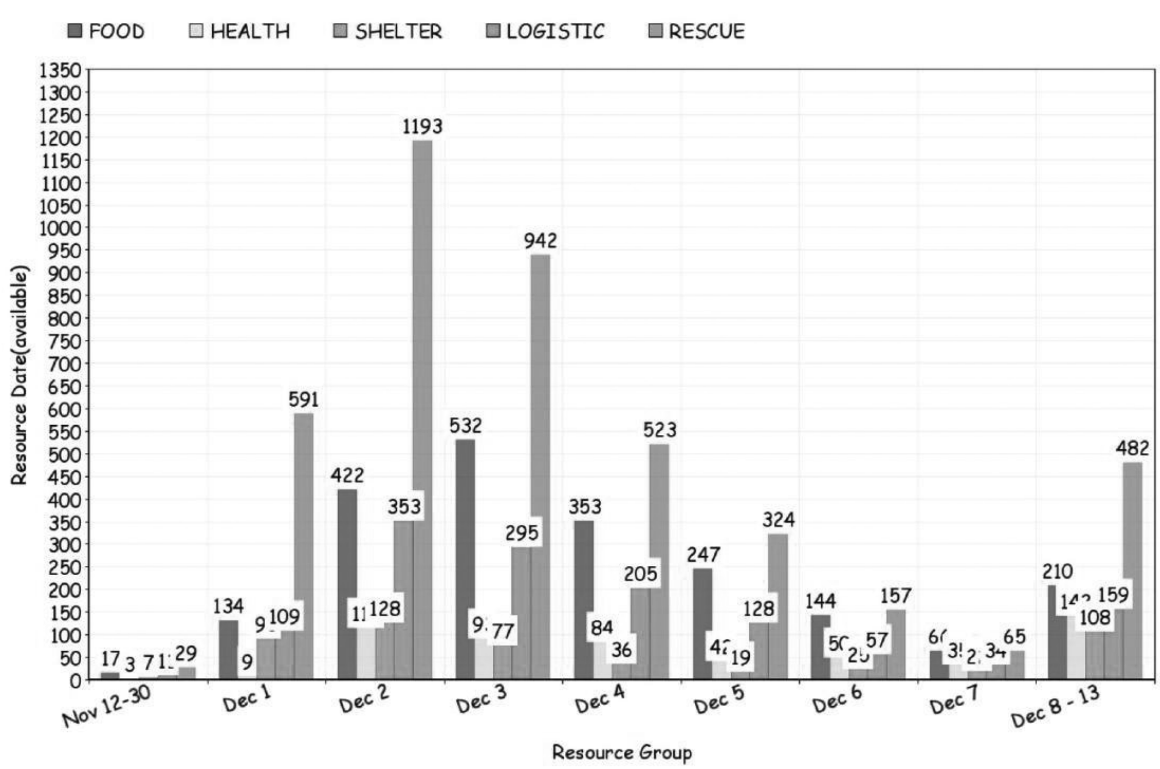

Figure b: Figure depicting day-wise availability of different kind of resources (Chennai floods dataset)

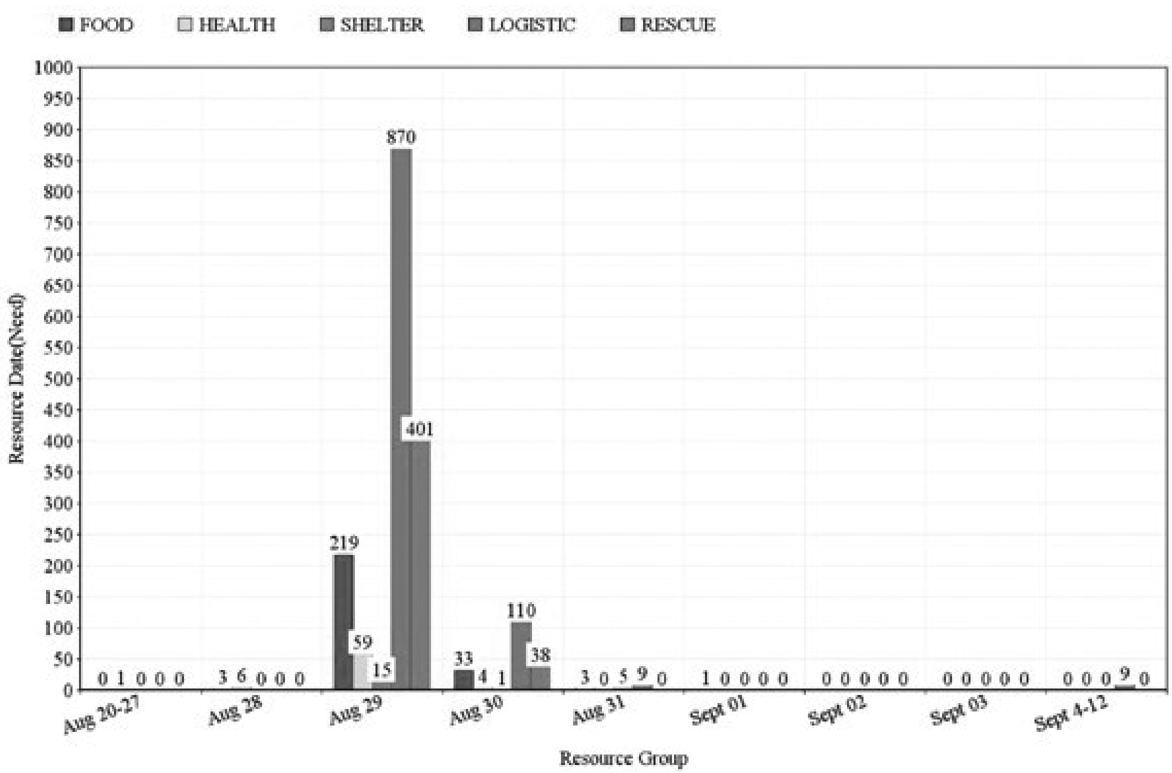

Figure c: Figure depicting day-wise need of different kind of resources (Mumbai floods dataset)

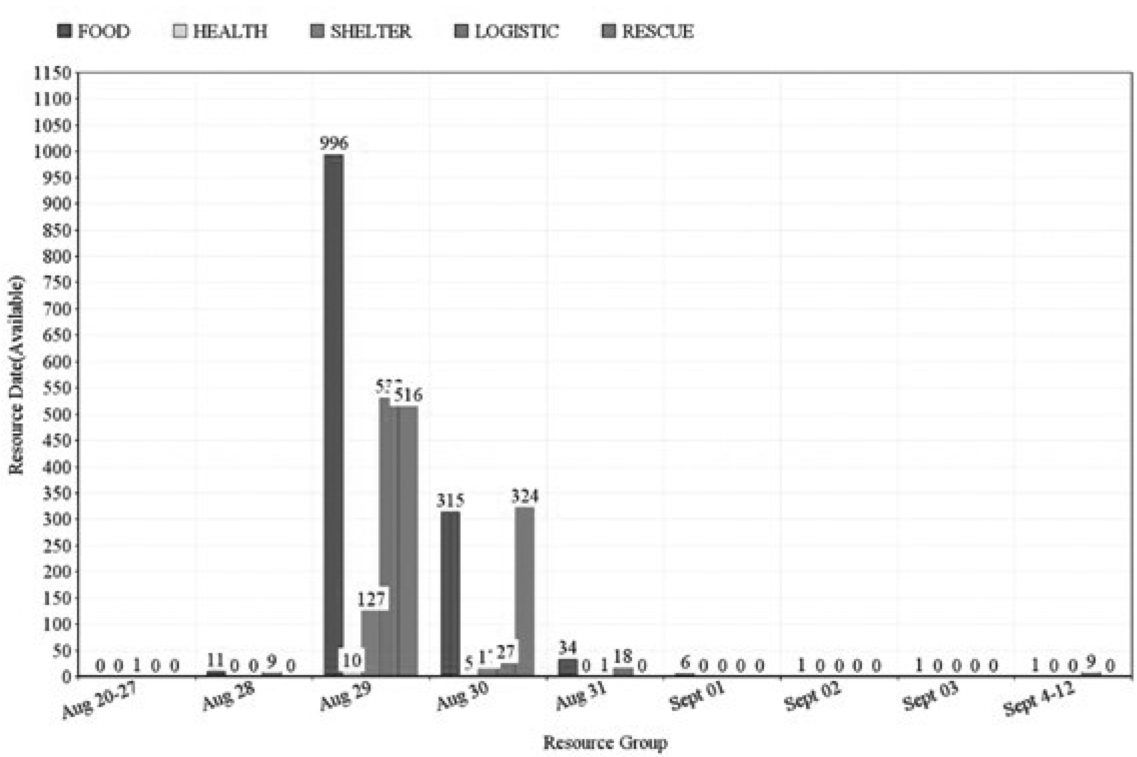

Figure d: Figure depicting day-wise availability of different kind of resources (Mumbai floods dataset)

Conclusion and Future Directions

In this work, our objective is to assist disaster responders to coordinate the rescue and relief operations in an enhanced way by procuring life-saving resources in a timelier manner. We hope the insights of our study would contribute to preparedness planning for an upcoming flood event in India. In this study, we reused our lexicon, i.e., a large set of 911 generic benchmark patterns (referred to as EMTerms) and 28 event-specific patterns included from our prior work on Chennai floods dataset on an unseen disaster (Mumbai flood dataset). We reported the reusability of event-specific patterns. We also introduced a few event-specific patterns from Mumbai floods dataset.

It is evident that if such information can be extracted and shown to the responding authorities in real-time, then the authorities will benefit a lot in coordinating the post-disaster relief operations. This work aims to develop various techniques for extracting relevant information from Online Social Media for helping to coordinate post-disaster relief operations in Indian cities.

References

(Basu et al. 2017A) Basu M, Ghosh K, Das S, Dey R, Bandyopadhyay S, and Ghosh S (2017) Identifying Post-Disaster Resource Needs and Availabilities from Microblogs. In Proc. ASONAM. DOI: 10.1145/3110025.3110036

(Basu et al. 2017B) Basu M, Ghosh S, Jana A, Bandyopadhyay S, and Singh R (2017). Resource mapping during a natural disaster: A case study on the 2015 Nepal earthquake. International Journal of Disaster Risk Reduction 24(2017), 24 - 31. https://doi.org/10.1016/j.ijdrr.2017.05.020

(Basu et al. 2017C) Basu M (2017) Utilizing Online Social Media for Disaster Relief: Practical Challenges in Retrieval. In Proceedings of the 40th International ACM SIGIR Conference on Research and Development in Information Retrieval (SIGIR '17). ACM, New York, NY, USA, 1385–1385. DOI: https://doi.org/10.1145/3077136.3084160

(Imran et al. 2015) Imran M, Castillo C, Diaz F, and Vieweg S (2015) Processing Social Media Messages in Mass Emergency: A Survey. Comput. Surveys 47, 4 (June 2015), 67:1- 67:38.

(Khosla et al. 2017) Khosla P, Basu M, Ghosh K, and Ghosh S (2017). Microblog Retrieval for Post-Disaster Relief: Applying and Comparing Neural IR Models. In SIGIR 2017 Workshop on Neural Information Retrieval (Neu-IR"17). https://arxiv.org/pdf/1707.06112.pdf

(Pandey and Natarajan 2016) Pandey N and Natarajan S (2016) How social media can contribute to disaster events? Case study of Chennai floods 2015. In Proc. International Conference on Advances in Computing, Communications and Informatics (ICACCI), Jaipur, 2016, pp. 1352–1356.doi: 10.1109/ICACCI.2016.7732236

(Rudra et al. 2015) Rudra K, Ghosh S, Goyal P, Ganguly N, and Ghosh S (2015) Extracting Situational Information from Microblogs during Disaster Events: A Classification Summarization Approach. In Proc. ACM CIKM.

(Sarkar et al. 2019) Sarkar A, Roy S, Basu M (2019) Curating Resource Needs and Availabilities from Microblog During a Natural Disaster: A Case Study on the 2015 Chennai Floods. In Proc. The ACM India Joint International Conference on Data Science & Management of Data (CoDS-COMAD 2019). DOI 10.1145/3297001.3297055

(Temnikova et al. 2015) Temnikova I., Castillo C, and Vieweg S (2015) EMTerms 1.0: A TerminologicalResource for Crisis Tweets. In Proc. International Conference on Information Systemsfor Crisis Response and Management (ISCRAM).

(Varga et al. 2013) Varga I, Sano M, Torisawa K, Hashimoto C, Ohtake K, Kawai T, Oh JH, and Saeger SD (2013) Aid is Out There: Looking for Help from Tweets during a Large Scale Disaster, in Proc. ACL, 2013.

PART II MAKING INFRASTRUCTURE RESILIENT

IV Buildings and Other Constructions

Study as per IS Code Provisions for Safe and Economical Structural Steel Sections

Prabhat Kumar Soni[a], Prakash Sangamnerkar[b] and S. K. Dubey[c]

ABSTRACT: The paper reviews illustrated designs of standard Structural Steel Sections illustrated in Indian Standard Special Publications, SP 6(1):1964; ISI Handbook for structural engineers (Part-1) – Structural Steel Sections. The paper also presents analysis of different standard steel sections to evaluate load-carrying capacity subjected to compression considering different parameters such as effective length, slenderness ratio, radius of gyration, material yielding and inelastic buckling as per the standards of IS 800: 2007 under provisions of limit state design with objective of achieving economy in the use of structural steel by rational, efficient and optimum standards for structural steel sections. The paper progresses with comparative analysis of results so obtained and load-carrying capacity as per SP 6(1):1964 to obtain optimum sections to fulfil the aspect of economic designs with safety of the structure. It demonstrates the variations in the load-carrying capacity of sections and suggests about need of improvisation in illustrated designs of SP 6(1) incorporating the provisions of design as per IS 800: 2007. This work can be useful for structural designers of a country for taking updated designs as reference. In the paper, the design procedures for columns under concentric loads as per IS 800:2007 are reviewed and applied for various steel sections to obtain safe loads for the sections in both major buckling axis and minor buckling axis.

KEYWORDS: standard steel sections, yielding, radius of gyration, inelastic buckling

Introduction

An Overview SP 6–1964

In order to reduce the work involved in design computations and to facilitate the use of the Indian Standard Code of Practice for Use of Structural Steel in General Building Construction [IS: 800–1962 (Revised)], it was proposed to make available a number of design handbooks showing typical designs of different types of structures. This revised handbook, which gives the properties of structural steel sections, was first issued in 1959. The first edition of this handbook, which had been processed by Structural Sectional Committee, SMDC 6, was approved for publication by the Structural and Metals Division Council of ISI.

The matter contained in the handbook is arranged from the point of view of maximum convenience in using the handbook in the design office.

Broadly speaking, the contents have been grouped as follows: Section (A) – Structural Shapes and Other Steel Products, Section (B) – Beams, Channels and

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Compound Sections Used as Girders, Section (C) – Angles, Single and Double, Used as Struts and Ties, and Section (D) – Beams, Channels and Other Compound Sections Used as Columns.

An Overview of IS 800:2007

The steel economy programme was initiated by Indian Standards Institution in the year 1950 with the objective of achieving economy in the use of structural steel by establishing rational, efficient and optimum standards for structural steel products and their use. IS 800:1956 was the first in the series of Indian Standards brought out under this programme. The standard was revised in 1962 and subsequently in 1984, incorporating certain very important changes.

IS 800 is the basic Code for general construction in steel structures and is the prime document for any structural design and has influence on many other codes governing the design of other special steel structures, such as towers, bridges, silos, chimneys, etc. The code was revised in the year 2007 and was made available since February 2008.

In this revision, the following major modifications have been effected:

- In view of the development and production of new varieties of medium- and high-tensile structural steels in the country, the scope of the standard has been modified permitting the use of any variety of structural steel provided the relevant provisions of the standard are satisfied.
- The standard has made reference to the Indian Standards now available for rivets, bolts and other fasteners.
- The standard is based on limit state method, reflecting the latest developments and the state of the art.

The revision of the standard was based on a review carried out and the proposals framed by the Indian Institute of Technology Madras (IIT Madras). The project was supported by Institute of Steel Development and Growth (INSDAG) Kolkata with a number of academic, research, design and contracting institutes/ organisations.

Limit State Design

The fundamental requirement of a structural design is that the elements of the structure should have adequate and reliable safety against failure, the structure should remain serviceable during its intended use, and the design is economical.

The limit states considered in the code may be grouped into the following two types:

- Ultimate (safety) limit states, which deal with strength, sway or overturning, sliding, buckling, fatigue fracture and brittle fracture.
- Serviceability limit states, which deal with discomfort to occupancy and/or malfunction, caused by excessive deflection, vibration, corrosion (and subsequent loss of durability), fire resistance, etc.

Analysis

Design considerations as per IS 800:2007 have been employed in the calculation of safe loads. Both ends are considered as hinge. Therefore, the value of effective length factor is (1.0). Different I-sections and channel sections have been considered for calculation of safe loads with the following preliminary data – Yield Stress of Material (f_y) = 250 N/mm^2, Modulus of Elasticity (E) = 2 x 10^5 N/mm^2, Effective Length Factor (K) = 1.0, y-y axis has been considered as minor buckling axis and x-x axis as major buckling axis.

Table 1: Percentage Variation in Safe Loads for ISHB 200 (y-y Axis)

Designation		ISHB 200					
Size (mm)		200			200		
Sectional area, cm^2		47.54			50.94		
Weight, kg/m		37.3			40		
Radius of gyration, cm	r_{xx}	8.71			8.55		
	r_{yy}	4.51			4.42		
	L_y	SP 6 :1964	IS 800 :2007	Variation (per cent) in comparison to IS 800:2007	SP 6 :1964	IS 800 :2007	Variation (per cent) in comparison to IS 800:2007
Effective length in metre (y-y axis)	2.0	554.2	607.6	+8.8	592.9	646.6	+8.3
	2.5	539.3	555.5	+2.9	575.9	589.3	+2.3
	3.0	518.9	500.2	–3.7	553.1	528.6	–4.6
	3.5	491.1	443.9	–10.6	521.6	467.2	–11.6
	4.0	455.4	389.7	–16.9	481.2	408.5	–17.8
	4.5	413.1	340.1	–21.5	433.7	355.4	–22.0
	5.0	367.3	296.5	–23.9	383.8	309	–24.2
	5.5	323.5	259	–24.9	336.8	269.4	–25.0
	6.0	283.7	227.2	–24.9	294.4	236	–24.7
	6.5	249.2	200.3	–24.4	258.2	207.8	–24.3
	7.0	224.8	177.5	–26.6	223.8	184	–21.6
	7.5	189.3	158.2	–19.7	194.2	163.9	–18.5
	8.0	164.3	141.8	–15.9	168.2	146.7	–14.7
	8.5	145.1	127.6	–13.7	149.2	132	–13.0
	9.0	128.4	115.5	–11.2	131.5	119.4	–10.1
	9.5	113.1	104.9	–7.8	116	108.5	–6.9
	10.0	101.0	95.7	–5.5	103.7	98.9	–4.9
	11.0	81.5	80.6	–1.1	83.4	83.2	–0.2

Table 2: Percentage Variation in Safe Loads for ISHB 150 (y-y Axis)

Designation		ISHB 150					
Size (mm)		150			150		
Sectional area, cm^2		34.48			38.98		
Weight, kg/m		27.10			30.60		
Radius of gyration, cm	r_{xx}	6.50			6.29		
	r_{yy}	3.54			3.44		
	L_y	SP 6 :1964	IS 800 :2007	Variation (per cent) w.r.t. IS 800:2007	SP 6 :1964	IS 800 :2007	Variation (per cent) w.r.t. IS 800:2007
Effective length in metre (y-y axis)	2.0	389.9	399.1	+2.3	438.5	444.6	+1.4
	2.5	370.1	347.6	–6.5	413.8	6384.4	–7.6
	3.0	339.9	296.3	–14.7	377.5	325.3	–16.0
	3.5	302.2	249.5	–21.1	332.1	272.2	–22.0
	4.0	260.2	209.5	–24.2	283.4	227.5	–24.6
	4.5	220.8	176.6	–25.0	238.7	191.2	–24.8
	5.0	186.5	150.0	–24.3	201.5	162.0	–24.4
	5.5	157.7	128.6	–22.6	167.8	138.6	–21.1
	6.0	131.8	111.1	–18.6	140.0	119.6	–17.1
	6.5	110.8	96.9	–14.3	118.4	104.2	–13.6
	7.0	95.1	85.1	–11.8	100.8	91.5	–10.2
	7.5	81.0	75.3	–7.6	85.9	80.9	–6.2
	8.0	70.4	67.1	–4.9	74.6	72.0	–3.6
	8.5	61.2	60.1	–1.8	64.9	64.5	–0.6

Observations

(Table 1): For calculations as per IS 800:2007, percentage variation of safe load in comparison to SP 6 varies from (+) 8.8 (max.) to (–) 26.6 (max.) for ISHB 200. It can be observed that most of the load values are found to be economical in case of IS 800:2007 compared to SP 6.

(Table 2): For calculations as per IS 800:2007, percentage variation of safe load in comparison to

SP 6 varies from (+) 2.3 to (–) 25 for ISHB 150. It can be observed that most of the load values are found to be economical in case of IS 800:2007 compared to SP 6.

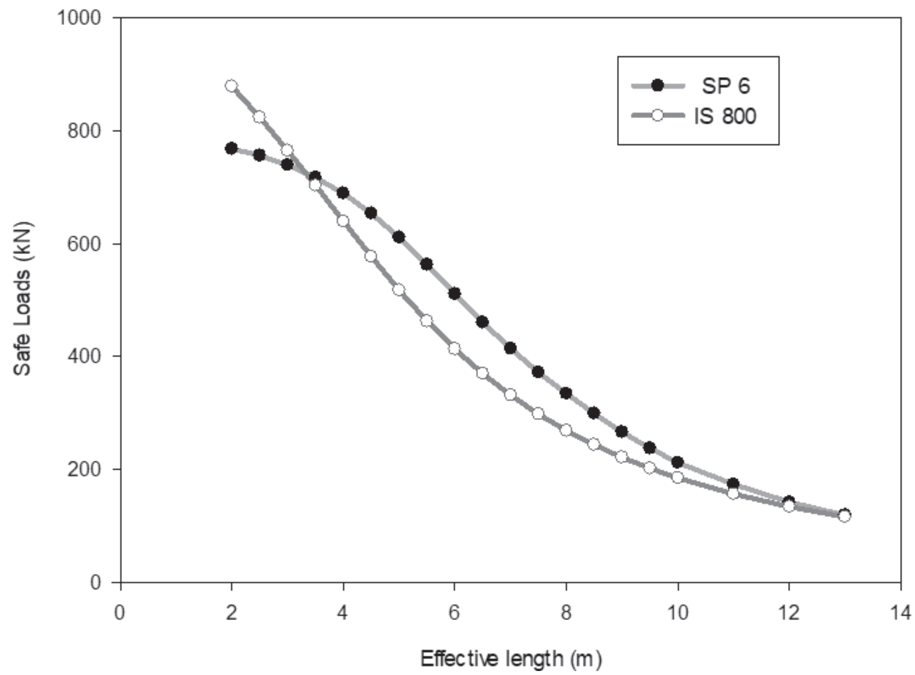

Figure 1: Comparison of safe loads for ISHB 250 (sectional area 64.96 cm^2) as per SP 6 and calculations as per IS 800:2007

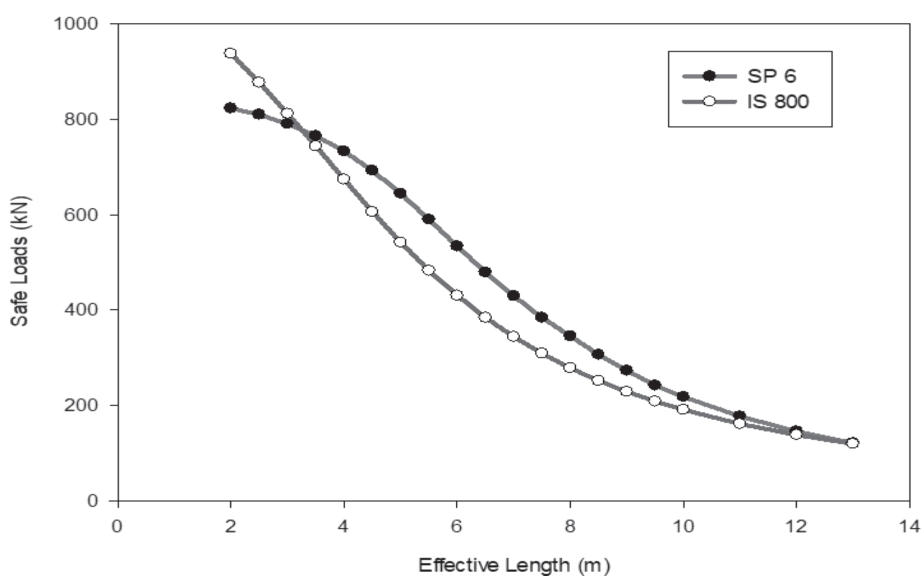

Figure 2: Comparison of safe loads for ISHB 250 (sectional area 69.71 cm^2) as per SP 6 and calculations as per IS 800:2007

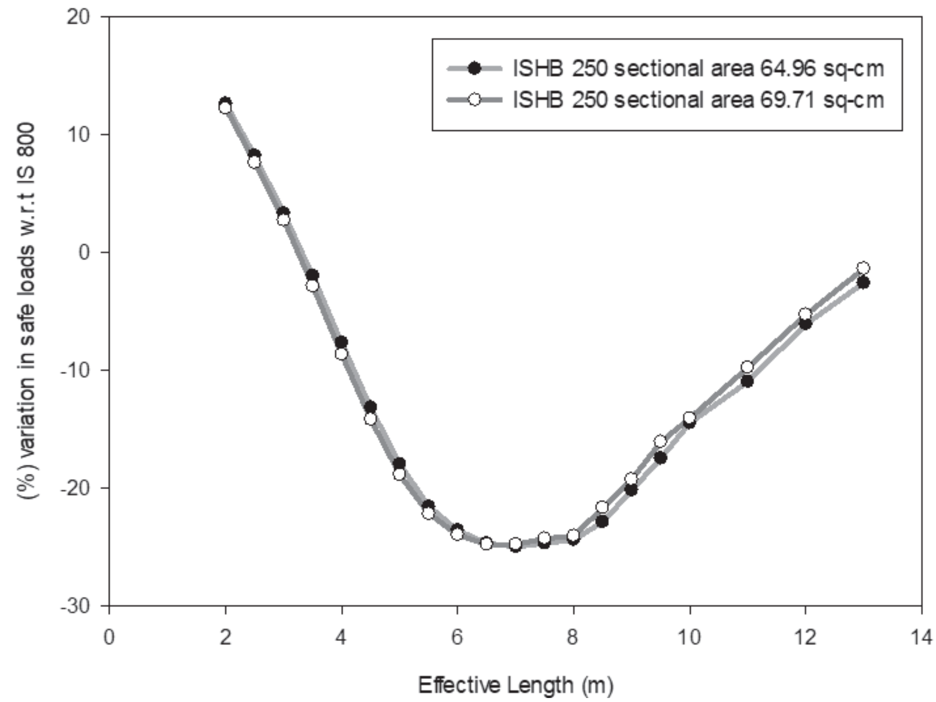

Figure 3: Percentage variation in safe loads of ISHB 250 section in comparison to calculations as per IS 800:2007

Conclusion

In the paper, column sections under concentric loads as per IS 800:2007 have been reviewed and analysed for different steel sections to obtain safe loads. The results obtained have been compared with provisions given in SP 6–1964.

It can be observed that there are large variations in load-carrying capacity of standard sections as per IS 800:2007 compared to SP: 6(1)-1964. In some of the cases, safe loads given in SP: 6(1)-1964 seem to be uneconomical; on the other hand, in some of the cases, safe loads given in SP: 6(1)-1964 are likely to be unsafe compared to IS 800:2007.

Hence, from the above observation, it can be concluded that load-carrying capacity of sections given in SP: 6(1)-1964 needs to be reviewed, and load-carrying capacity calculated as per IS 800:2007 is required to be incorporated.

Bibliography

Amendment No.1 to IS 800:2007 (2012) General Constructions in Steel- Code of Practice, Reprography Unit, BIS, New Delhi.

Bureau of Indian Standards (2007). IS 800:2007; Code of practice for general construction in steel, Bureau of Indian Standards, New Delhi.

Bureau of Indian Standards (1984). IS: 800–1984; Code of practice for general construction in steel, Bureau of Indian Standards, New Delhi.

Bureau of Indian Standards (1964). SP: 6(1)-1964, Handbook for Structural Engineers, Structural Steel Sections, Bureau of Indian Standard, New Delhi.

Kulkarni RB, Jirage RS (2011) Comparative study of steel angles as tension members designed by working stress method and limit state method. International Journal of Scientific & Engineering Research, Volume 2, Issue 11, November-2011

Subramanian N (2011) Steel structures design and practice based on limit state method of design. Oxford higher education, Chapter 5, Design of compression members.

Pre-engineered Steel-Foam Concrete Composite Panels for Seismic-Resistant Low-Rise Buildings

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ABSTRACT: In India, fast track construction technologies to meet the demand for mass housing and the occupant safety during earthquakes are the major issues that have gained prominence. For the first time in India, pre-fabricated Steel-Foam Concrete Composite (SFCC) panel made of foam concrete (FC) core sandwiched between profiled steel sheets is proposed as load-bearing wall and floor/roof elements. The use of lightweight FC in composite panel reduces the self-weight by 40 per cent compared to an equivalent brick wall. This paper collectively provides the details and results of the experimental work carried out earlier under above-mentioned loadings. The strength and deformation behavioural aspects are superior to conventional elements under axial compression, flexural and in-plane lateral loads, as observed from the experiments. SFCC panel as shear resisting elements in earthquake-prone regions (Zone-V) is verified and is recommended to be used as shear wall for G+3 buildings. Hence, these panels have a huge potential in enhancing seismic performance/retrofit strategies for buildings and can be an alternative for load-carrying brick walls and floor/roof slabs for low-rise buildings. SFCC panels can be integrated into a building system by developing appropriate connections and can be effectively used for seismic-resistant low-rise buildings and mass housing schemes during post-disaster mitigation.

KEYWORDS: steel-foam concrete composite, profiled steel sheets, foam concrete, mass housing, shear wall, seismic resistance

Introduction

Severe damages experienced during the past earthquakes and other natural disasters across the world have raised questions about the structural and occupant safety of buildings and houses. Ductility and structural integrity are essentially required for any building system to withstand the earthquake forces. Interest in sandwich panels for housing has been growing over the past few years due to its structural efficiency, insulation property, light weight and aesthetics values. Steel concrete composite construction though popular in industrial buildings for over two decades due to their strength and stiffness characteristics is yet to be explored in residential constructions. Reinforced concrete and steel plate shear walls are traditionally used as axial or low cyclic load-resisting systems in mid-rise and high-rise buildings. Double-skinned profiled steel sheet composite (DPSC) wall panel is a novel form of composite construction, which consists of a core of concrete sandwiched between relatively thin steel plates. These panels developed from the composite flooring used worldwide have the benefit of acting as bearing, retaining, partition and shear walls due to the composite action of steel and concrete. Though DPSC panels are intended for use as partition

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and shear walls in steel-framed buildings (Fig. 1), it has the potential to be used as structural elements in load-bearing construction. The conventional concrete, which makes up the inner core in composite walls, has not contributed to enhancement of strength over weight ratio.

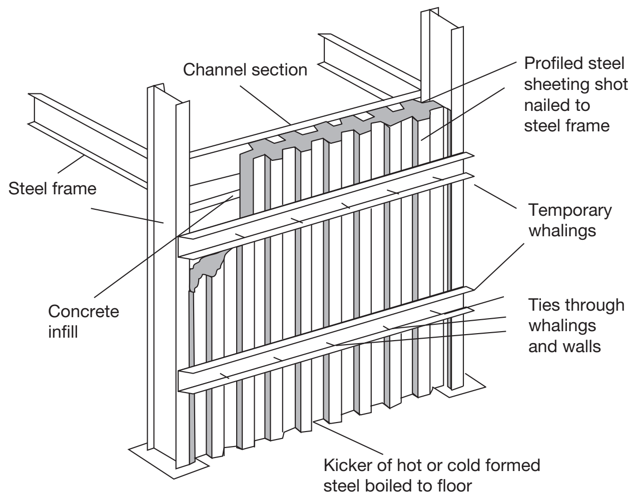


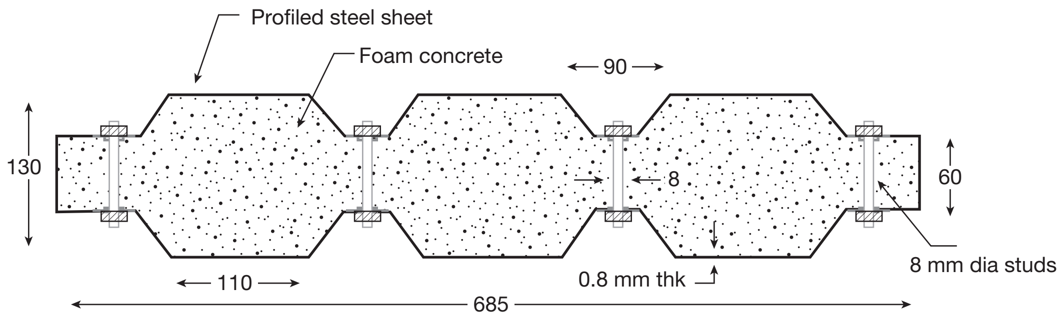
Figure 1: Application of DPSC wall panels in buildings (Wright and Gallocher 1995)

Research works were reported on the axial (Wright and Gallocher 1995; Wright 1998), flexural (Flores and Li 2012), combined axial and flexural (Uy et al. 2001; Hossain and Wright 2004) and shear load resistance (Eom et al. 2009; Rafiei et al. 2015) of DPSC panels. The effect of openings on the structural behaviour of DPSC wall panels was studied by Hossain (2000). The research work by Eom et al. (2009) proved the use of DPSC wall panels in seismic-resistant buildings, as the profiled steel sheets provide improved shear capacity and ductile resistance to low cyclic loads and concrete cracking. Many interconnection types such as headed shear studs, fastener screws, hooks, batten plates, welded C-sections, through-through bolts and tie rods are used to achieve the composite action between sheet and concrete. The self-weight of conventional elements imposes large proportion of total load on the supporting structure. Hence, usage of light weight concrete in DPSC panels would offer considerable reduction in the self-weight and overall cost of construction. Very few studies were reported on the use of normal concrete, high-strength concrete, self-consolidating concrete and the engineered cementitious composite as infill in DPSC panels. Othuman and Wang (2011) and Flores and Li (2012) reported on the behaviour of DPSC wall panel with light weight concrete as infill under compression and bending load for load-bearing construction. Foam concrete is one such alternative light weight material due to its low density, high workability and excellent thermal properties and hence recommended for structural and semi-structural applications. Foam concrete (FC) is a mixture of cement, fine sand, water and special foam. Studies reported that upto 67 per cent of cement could be replaced with ungraded and graded flyash without significant reduction in the strength (Kearsley and Wainwright 2001). The composite panel that can combine the advantage of thin profiled steel sheets and low-density foam concrete appears to be the best choice for affordable housing. There is a significant reduction in use of scarce natural resources as well. Based on the previous research, it is observed that the research on this type of light weight composite panels for load-bearing construction is inadequate, and there is ample scope for further research.

Steel-Foam Concrete Composite (SFCC) Panel

SFCC panel made of thin profiled steel sheets of thickness 0.8 mm as the outer skins and FC of density 1250 kg/m^3 as the infill is proposed for use as load-bearing wall and floor/roof elements in a building. The interaction between sheet and concrete is achieved by using 8 mm dia through-through mild steel (f_y-250 MPa) studs. The number of studs and the spacing in-between are provided appropriately such that the failure of panels is by yielding of steel sheets rather than buckling, which is the design criteria. The yield and ultimate strength of steel sheet are 261.3 and 363.8 MPa, respectively, and Young's modulus is 2x10^5 MPa. The general arrangement and geometrical details of SFCC panel are given in Fig. 2. The SFCC panel dimensions are 685 mm wide and 130 mm thick (sheet to sheet). The dimensions are kept constant and the length of the panel alone varies based on the type of loading. FC is a type of porous concrete produced by mixing the preformed foam of density around

70–80 gm/lt to the mortar composed of cement (OPC 53 grade), fine sand (<1.18 mm) and flyash matrix (Fig. 3a). A protein-based chemical is used to generate the foam. Based on the trial mixes, mix ratio for the desired density of 1250 kg/m^3 is 1:0.80:0.87:0.7:0.124 (cement:flyash:sand:water:foam). FC is poured inside the panels manually, and the cast SFCC panels are covered by polythene sheets for 28 days as shown in Fig. 4. The average compressive strength of FC cube and cylinder @ 28 days is 5.1 MPa and 4.0 MPa, respectively. The Young's modulus of FC is 4000 MPa. The use of FC of density 1250 kg/m^3 in SFCC panel reduces the self-weight by 40 per cent compared to an equivalent concrete wall. Experimental investigations were carried out to understand the structural behaviour of SFCC panel under axial compression, flexural and in-plane lateral loads. The details of the experimental work and the results are presented below.



All dimensions are in mm

Figure 2: General arrangement and geometrical details of SFCC panel

a. Adding foam to the mortar

b. FC

Figure 3: Preparation of FC

Figure 4: Casting and sealed curing of SFCC panels

Axial Compression Loading

Experimental studies are carried out by Prabha et al. (2013) to study the effect of confinement action of FC on the axial capacity and behaviour of SFCC wall panel. The SFCC wall panel dimensions are 870 mm high, 685 mm wide and 130 mm thick. A total of 32 nos. of 8 mm stepped studs are used for the interconnection. To avoid early/brittle local buckling of sheet under direct compressive loading, the load is primarily distributed over concrete surface (Fig. 5a). The specimens are tested to obtain their failure modes, ultimate load capacity, load-deformation and load-strain responses. Diagonal edge shear cracks (tension or compression shear) and vertical splitting of concrete are observed followed by crippling of steel sheet. SFCC wall panel (Fig. 6a) performed well with the capacity of 380 kN and exhibited high ductility. The axial deformation at failure is about 3–5 times that of plain profiled foam concrete specimens and the failure is not sudden. The controlled lateral deformations of confined concrete by steel sheet due to interconnecting studs exhibited ductile deformations after the post-peak behaviour.

Flexural Loading

Experimental studies are conducted on two SFCC floor/roof panels of length 1570 mm by Prabha et al. (2018) to obtain the failure mode, load-deformation and load-strain response. Four-point bending tests (Fig. 5b) have been conducted with simply supported boundary conditions. The length of constant moment region is 423 mm and centre-to-centre distance between supports is 1270 mm. The SFCC floor panel carried the maximum load of 51.32 kN at the corresponding mid-span displacement of 46.62 mm (Fig. 6b). The above-observed load is not the ultimate load as the experiment had to be terminated due to the restrictions in stroke of the actuator. The confinement of concrete by steel sheets and the studs enable the panel to carry higher loads even after the failure of concrete and with gradual increase in the load-deformation response. The span to deflection ratio is found to be 1 in 25, which represents large ductility. Using an equivalent bilinear approximation, the ductility ratio at this stage is more than 10. The estimated loading for a span of 3, 4 and 5 m floor/roof slab as encountered for residential buildings is well below the capacity of the proposed panel.

In-Plane Monotonic and Cyclic Lateral Loading

Two SFCC wall panel specimens are tested under monotonic loading and in-plane cyclic lateral loading by Prabha et al. (2017). The panels are tested by applying in-plane load on the top portion of SFCC wall panel (Fig. 5c). The results are interpreted in terms of load deformation response of the wall panel, stiffness degradation, energy dissipation, ductility, strain distributions, shear stress distributions and overall failure modes. The ultimate in-plane shear capacity and stiffness of the wall panel (Fig. 6c) under monotonic loading are 58 kN corresponding to 25 mm displacement and 2.3 kN/mm, respectively, for MWP-1. MWP-2 is the duplication of MWP-1, and with improvement to experimental set-up, MWP-2 carried the ultimate in-plane shear load of 64 kN at corresponding deflection of 13 mm and shear stiffness is 4.84 kN/mm. The failure of SFCC wall panel is associated with the tension cracks in exposed concrete portion followed by subsequent local buckling of profiled steel sheets at the fixed base of wall panel. Two SFCC wall panel specimens are tested under cyclic loading. From the experiment, the peak load for CWP-1 and CWP-2 specimen is found to be 57.5 and 56 kN, respectively (Fig. 6c). The SFCC panel failed due to tearing of profiled steel sheets and subsequent crack enlargement in FC. For cyclic loading, the SFCC wall panel is subjected to 16 cyclic loading groups (total 48 cycles). The wall stiffness is reduced from 8 kN/mm (at the first cyclic group) to 0.67 kN/mm (ultimate stage), showing a stiffness degradation of 94 per cent at the ultimate stage. The strain reading indicated that the number of intermediate fasteners along the height and width of the specimens provided sufficient composite action to prevent early elastic buckling of the profiled steel sheets and initiated failure only after the yielding of the sheet. The cyclic displacement ductility factor of 9.75 is obtained for the proposed panel.

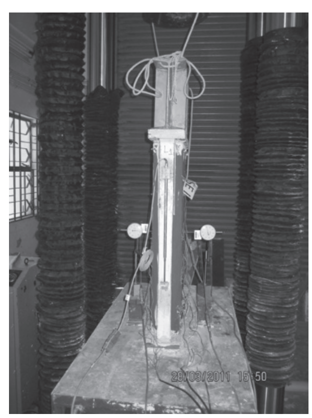


Figure 5: Experimental set-up and instrumentation: a. Axial compression load (Prabha et al. 2013)

Figure 5: Experimental set-up and instrumentation: b. Flexural load (Prabha et al. 2018)

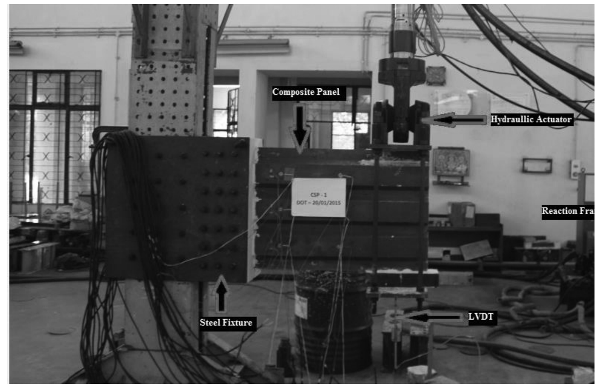
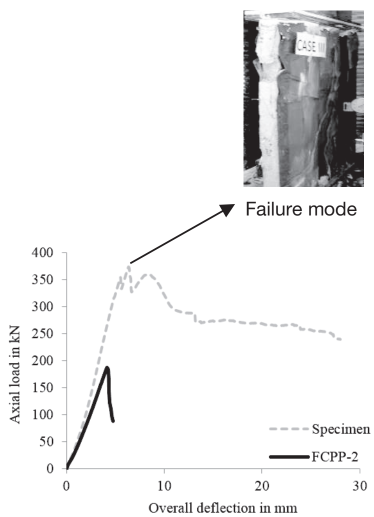
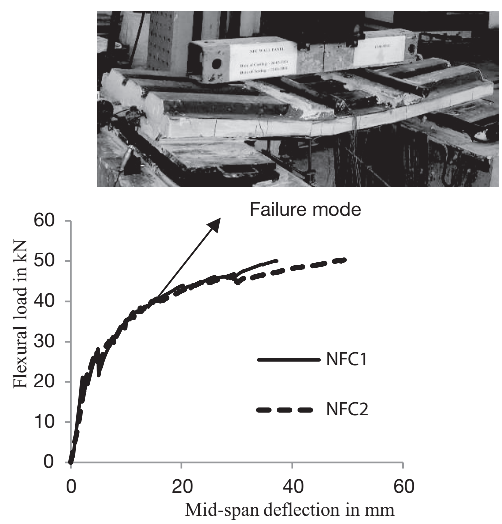


Figure 5: Experimental set-up and instrumentation: c. In-plane lateral load (Prabha et al. 2017)



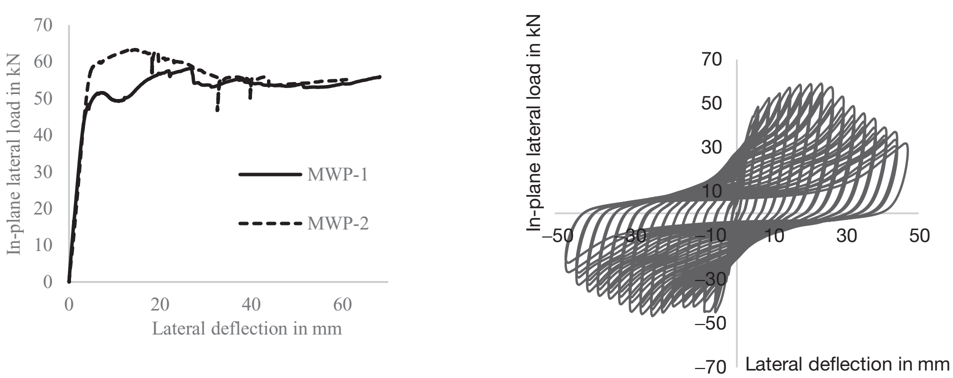
a. Axial compression load

(Prabha et al. 2013)



b. Flexural load

(Prabha et al. 2018)

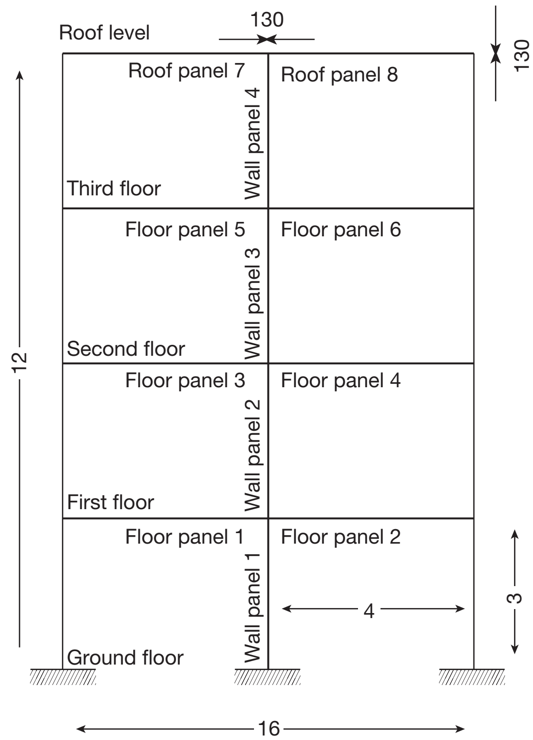


c. Monotonic and cyclic in-plane lateral load (Prabha et al. 2017)

Figure 6: Load versus deflection response and failure mode

Application of SFCC Panel for (G+3) Buildings in Earthquake-Prone Regions

The potential application of SFCC panels is for seismic-resistant low-rise residential construction in earthquake-prone regions. Hence, the suitability of the proposed SFCC panel for G+3 buildings in earthquake-prone regions is verified. It is proposed to construct all the walls, floors/roof of the building by using 130-mm-thick and 685-mm-wide SFCC wall and floor/roof panels with 0.8-mm steel sheet as tested in this research work. Fig. 7 shows the elevation section of a G+3 storey residential building of size (16 m wide x 12 m high). The floor span is 4 m and the height of each storey is 3 m. The loads on the interior wall panels (1–4) supporting different floors are summarised in Table 1. The building is assumed to be located at an area of high seismic risk (zone V). As per IS: 1893 (Part-1):2002, the design seismic base shear V_b is estimated to be around 4350 N and the corresponding factored base shear is 5220 N. The lateral force Q_i estimated for each floor level is presented in Table 2. The actual base bending moment in the building is calculated as 51.24 kNm, and the maximum shear stress due to earthquake force is 4.67 N/mm^2. In view of very low magnitude of shear stress, the element will fail under bending with strain hardening. The plastic moment capacity of SFCC panel is 53.75 kN-m, which is greater than 51.24 kN-m. The verification study clearly indicates that the 130-mm-thick SFCC panel with 0.8-mm steel sheet has sufficient lateral load-carrying capacity to act as shear wall in G+3 buildings.



(All units are in m)

Figure 7: Cross-section of G+3 storey building

Table 1: Load Calculations

Description	Weight N/m^2	Total load N
Self-weight of SFCC wall panel (685 mm x 130 mm) including facing tiles for height 3 m	2000	4110
Self-weight of SFCC floor/roof panel (685 mm x 130 mm) including floor finish for 4 m span	2350	6440
50 per cent live load	750	2050

Table 2: Base Shear Calculations

Floor no.	W_i	h_i	h_i^2	$W_ih_i^2$	Q_i	V_i
	N	m	m^2	Nm^2	N	N
1	12600	3	9	113400	190	5220
2	12600	6	36	453600	760	5030
3	12600	9	81	1020600	1710	4270
4	10540	12	144	1517760	2560	2560

Summary and Concluding Remarks

The proposed light weight steel-foam concrete composite (SFCC) panel with appropriate load transfer mechanism proposed by Prabha et al. (2013, 2018, 2017) has required axial compression, flexural, shear capacity, respectively, and ductility for use as load-bearing shear wall and floor/roof panels. Based on the verification studies, it is recommended to employ SFCC wall (axial and in-plane shear) and floor/roof panels for seismic-resistant G+3 buildings. Also SFCC panels can be integrated into complete building system by developing appropriate connections. Considering the light weight, adequate strength and ductility, seismic-resistance, thermal comfort, eco-friendliness and feasibility for prefabricated construction, it can also be effectively used for war-front housing during post-disaster mitigation.

Acknowledgements

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References

Eom TS, Park HG, Lee CH, Kim JH, Chang IH (2009) Behaviour of double skin composite wall subjected to in-plane cyclic loading. Journal of Structural Engineering 135: 1239–1249.

Flores Johnson EA, Li QM (2012) Structural behaviour of composite sandwich panels with plain and fibre-reinforced concrete cores and corrugated steel faces. Composite Structures 94(5):1555–1563.

Hossain KMA (2000) Axial load behaviour of pierced profiled composite walls. in: IPENZ Conference New Zealand.

Hossain KMA, Wright HD (2004) Flexural and shear behaviour of profiled double skin composite elements. Steel and Composite Structures 4(2):113–132.

IS1893 Part-1 (2002). Criteria for Earthquake resistant design of structures-Part 1 General provisions and buildings. Bureau of Indian Standards New Delhi.

Kearsley EP, Wainwright PJ (2001) The effect of high fly ash content on the compressive strength of foamed concrete. Cement and Concrete Research 31:105–112.

Othuman Mydin MA, Wang YC (2011) Structural performance of lightweight steel-foamed concrete–steel composite walling system under compression. Thin Walled Structures 49:66–76.

Prabha P, Marimuthu V, Saravanan M, Palani GS, Lakshmanan N, Senthil R (2013) Effect of confinement on Steel-Concrete Composite Light-Weight Load-Bearing Wall Panels under Axial Compression. International Journal of Constructional Steel Research 81:11–19.

Prabha P, Palani GS, Lakshmanan N, Senthil R (2017) Behaviour of Steel-Foam Concrete Composite Panels under In-Plane Lateral Load. Journal of Constructional Steel Research 139: 437–448.

Prabha P, Palani GS, Lakshmanan N, Senthil R (2018) Flexural Behaviour of Steel-Foam Concrete Composite Light-Weight Panels. KSCE Journal of Civil Engineering. 22(9):3534–3545. DOI 10.1007/s12205–018–0827–7.

Rafiei S, Hossain KMA, Lachemi M, Behdinan K (2015) Profiled sandwich composite wall with high performance concrete subjected to monotonic shear. Journal of Constructional Steel Research 107:124–136.

Uy B, Wright HD, Bradford MA (2001) Combined axial and flexural strength of profiled composite walls. Proc.Inst. Civ.Eng.Struct.Build.146:129–139.

Wright HD (1998) The axial load behaviour of composite walling. Journal of Constructional Steel Research 45(3):353–375.

Wright HD, Gallocher SC (1995) The behaviour of composite walling under construction and service loading. Journal of Constructional Steel Research 35:257–273.

Prevention of Liquefaction Disaster Using a Novel and Eco-friendly Approach

Aishwarya T.[a] and Ashish Juneja[a]

ABSTRACT: Over the past decades, earthquakes proved to be the deadliest of all disasters with many fatalities and huge direct economic loss. Earthquake-induced liquefaction causes severe damage to structures and accounts for major share of loss. Liquefaction is a phenomenon where soil loses its strength and starts flowing like liquid causing collapse of structures, initiating land subsidence and damaging lifeline utilities. Accurate assessments of liquefaction susceptible zones are needed to save life and mitigate the huge economic loss incurred. There are several methods to mitigate liquefaction such as densification of soil by compaction, dewatering, installing stone columns, grouting using chemicals and synthetic resins, etc. These methods are site specific and cannot be implemented under existing structure. Also they are expensive, complex and eco-destructive. Injection of chemicals such as epoxy, acrylamide, pheno-plasts and polyurethane through jet grouting for soil improvement have proved to be detrimental. Many countries have also imposed a ban on man-made synthetic resins for grouting. An interdisciplinary approach involving microbiology, geo-chemistry and civil engineering has been identified as a potential solution to the current problem. Biomineralisation is a process of forming inorganic precipitates in the soil matrix that alters the void ratio and grain size distribution, thereby changing the engineering properties. The basic principle underlying this phenomenon is the hydrolysis of urea by the bacteria or the urease enzyme in the presence of calcium ions resulting in the precipitation of calcite. This calcite improves the bonding between the soil particles, thereby strengthening it. The ability of this method to increase the fines content, reduce the void ratio and bind the particles makes it suitable for liquefaction mitigation. In this study, the likelihood of this method in improving the liquefaction resistance of soil is investigated through several laboratory tests. The potential advantage of this method for real field application is briefly discussed.

KEYWORDS: biomineralisation, calcite, cyclic resistance, liquefaction mitigation

Introduction

Liquefaction causes severe damage to lifeline utilities. There are several examples of the recent earthquakes which have resulted in soil liquefaction and have had serious implications on the structures and services. Liquefaction is more common in cohesion-less soils, when the granular particles exert contact forces on each other due to the weight of the overlying particles. This force is responsible for holding the particles intact and results in the strength of soil. But under rapid loading, the saturated soil particles lose contact with each other, and due to lack of time, the water does not find way to move out instead it is trapped inside the soil mass resulting in decrease in effective stress and lose of shear strength. The emphasis of this study

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is on applicability of biomineralisation in mitigation of liquefaction through cyclic simple shear testing. Biomineralisation is a process of forming inorganic precipitates in the soil matrix that alters the void ratio and grain size distribution, thereby changing the engineering properties. Microbial-induced calcite precipitation (MICP) and enzyme-induced calcite precipitation (EICP) are biomineralisation processes, where bacteria and enzyme catalyse the ureolysis and precipitate calcite in calcium-rich environment.

$$NH_2CONH_2 + 2H_2O \rightarrow 2NH_3 + CO_2 \quad \text{Eq 1}$$

$$2NH_3 + 2H_2O \leftrightarrow 2NH_4^+ + 2OH^- \quad \text{Eq 2}$$

$$CO_2 + 2OH^- \leftrightarrow HCO_3^- + OH^- \leftrightarrow CO_3^{2-} + H_2O \quad \text{Eq 3}$$

$$Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_3(s) \quad \text{Eq 4}$$

Ureolysis in the presence of calcium ions is the idea behind this technique governed by equations 1–4. The bacteria mainly responsible for MICP process is *Sporosarcina pasteurii.* It is an alkalophilic microbe which consumes the urea and the urease enzymes present in it, decomposes it into ammonia and carbon dioxide and diffuses it into the surrounding through the cell wall. Ammonia and carbon dioxide react with the water and forms ammonium, carbonic acid, carbonates and bicarbonate ions. These ions increase the pH of the medium and facilitate the calcium ions to form calcium carbonate.

In EICP, the urease enzyme is directly used, since it is easily available in the market and can be extracted from numerous plants and microorganisms. Due to their ultra-fine size, they can simply seep through the smallest pores in most granular media (Kavazanjian et al. 2015). Unlike bacteria, these urease crystals can be directly mixed with the reagents and used for treatment. MICP and EICP are preferred over other ground improvement techniques and have drawn attention of many researchers due to its cost-effective and environment-friendly nature. An attempt has been made to study the performance of MICP and EICP on improving the cyclic property of cohesion-less soil using cyclic simple shear testing.

Background

Many researchers have witnessed substantial improvement in the shear strength and stiffness of soil due to calcite precipitation. MICP has proved to increase the strength and stiffness of the soil from unconfined compression and bender element test results (Qabany et al 2013). The strength of the soil treated with MICP was also analysed using the triaxial testing (DeJong et al 2006; Cheng et al 2013). Mortensen and DeJong (2011) conducted a series of triaxial testing at different stress paths under both drained and undrained conditions. Feng and Montoya (2015) examined the effect of cementation level and confinement on the strength of the triaxial soil samples. Higher stiffness and strength were obtained at higher cementation levels. The ability of this method to increase the fines content, reduce the void ratio and bind the particles together brings the thought of using it as a liquefaction mitigation measure. Studies using centrifuge tests have proved the increase in liquefaction resistance using MICP. Montayo et al. 2012, who conducted centrifuge study on loose untreated sand and MICP-treated sand under seismic shaking, found that there was a considerable reduction in the pore pressure ratio and the vertical strain beneath the structure. Montayo et al. 2013 conducted simple shear test on treated as well as untreated sand and developed a relation between cyclic stress ratio and number of cycles to liquefy. In spite of being eco-friendly and economic, MICP has several limitations. The bacteria culture, fixation and transport are specific to a controlled environment and cannot withstand harsh conditions, making it impractical for real site applications. Urease enzyme derived from plants, microorganisms and several invertebrates can sustain harsh environments and bypass the tedious process of bacteria growth.

Objective

The objective of the paper is to study the applicability of biocementation in improving the cyclic resistance of cohesion-less soil. Both bacteria and enzymes were employed to precipitate calcite.

Experimental Investigation

Sand sample for the investigation was obtained from Bhuj, India. Basic characterisation study was conducted and the index properties are given in Table 1. The grain size distribution curve of the sample was found to lie in the liquefaction susceptible range as given by Tsuchida 1970, shown in Figure 1.

Table 1: Index Properties of Sand

Parameter	Value
Specific gravity	2.65
Maximum dry density	1.63
Minimum dry density	1.29
D_{50}, mm	0.28
Uniformity coefficient C_u	2.066
Coefficient of curvature C_c	0.948
Coefficient of permeability,cm/s	2 X 10^{-2}

Stress-controlled cyclic tests were conducted on medium dense sample with relative density ranging from 30–40 per cent and at cyclic stress ratio of 0.1. A Sample of diameter 71.4 mm and height up to 22 mm was prepared by dry pluviation or tamping. Figure 2 shows the sequence of sample preparation. The shear box assembly consisted of a bottom and top stainless steel plate with two pore water connections for saturation and flushing. Polished Teflon-coated rings provide reinforcement to specimen and rubber membrane. A specially designed fully automated control and data acquisition software "GEOSYS" helps to perform programmable static and cyclic stress–strain and constant volume-controlled simple shear tests with respect to complex test criteria. To maintain a constant diameter throughout the test, the sample is restrained by a series of rings. The sample is flushed with about three times the pore volume of water and then consolidated by applying vertical load followed by cyclic shearing. A constant vertical stress of 100 kPa was applied in all the tests, and cyclic stress ratio in cyclic simple shear is given by Eq 5

$$CSR = \sigma_v/\sigma_h \quad \text{Eq 5}$$

where σ_v is the vertical effective stress and σ_h is the applied horizontal stress.

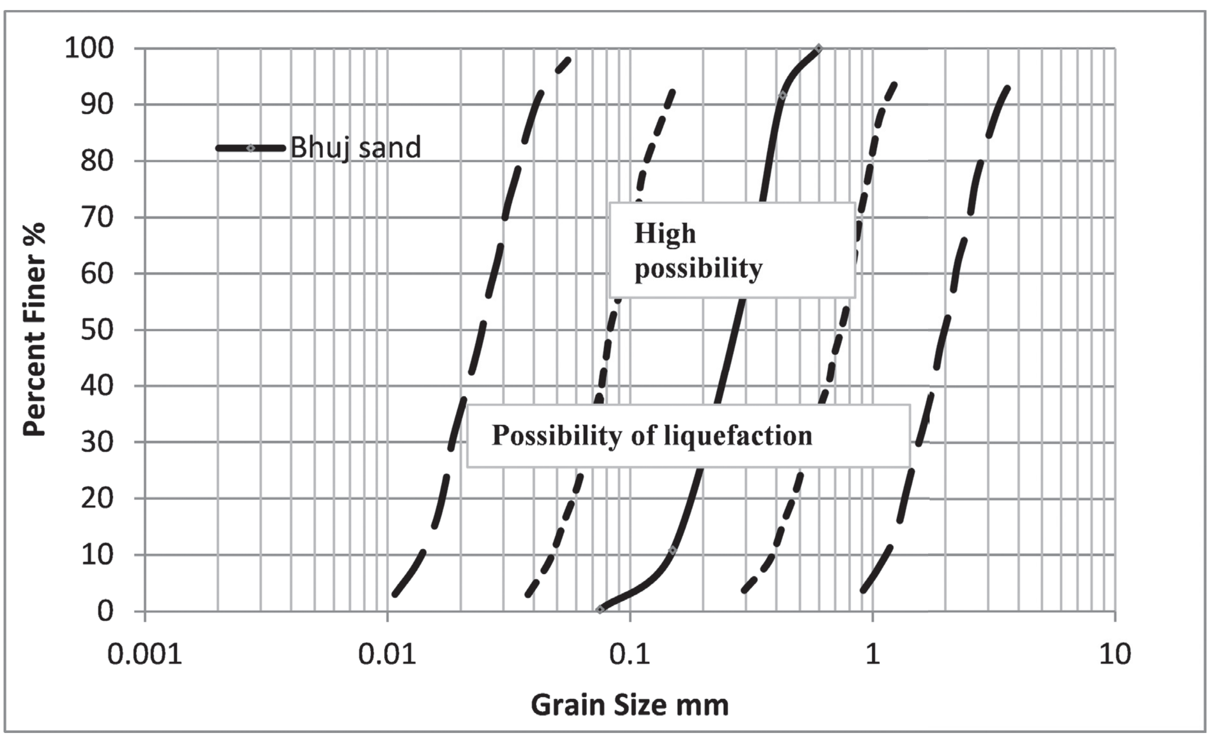
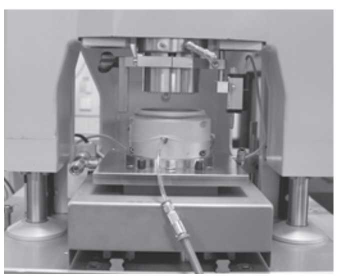


Figure 1: Grain size distribution curve with the liquefaction susceptible range given by Tsuchida 1970

(a)

(b)



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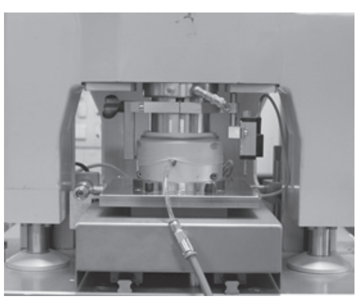


(d)

Figure 2: Sequence of sample preparation for cyclic simple shear test

Bacteria Culture Preparation

Sporosarcina pasteurii obtained from the National Collection of Industrial Microorganism, National Chemical Laboratory, Pune, was used to induce urea hydrolysis. The bacterial suspension was prepared by inoculating the bacterial strain in a nutrient media containing 10 g/l of beef extract and peptone and 5 g/l of sodium chloride and adjusting the pH to 7. This mixture was kept in a shaking incubator at 200 rpm and 30 °C temperature. This growth media was autoclaved at 121°C and 15 Psi pressure for 20 mins prior to inoculation in order to avoid the growth of other microorganisms. The culture thus obtained was centrifuged at 4000 g for 15 mins, and the supernatant was removed and suspended in a fresh nutrient media. The optical density of the bacterial solution used in the experimentation was around 1.

Urease Enzyme

Urease enzyme extracted from jack bean seed was used which is commercially available in powder form as Jack bean meal (Alpha chemika, India). The concentration of urease solution was 5 g/l and cementation solution comprised urea and calcium chloride ($CaCl_2$) of molarity 0.5 M.

Dry sand was packed into the cylindrical column of 71 mm diameter and 22 mm height made up of stainless steel. The column consisted of opening on the top and bottom plates. The bacterial culture, urease solution and cementation solutions were injected into the soil column from the bottom that eventually helped in the expulsion of air pockets from the soil matrix. In case of MICP, the bacteria solution was first injected followed by the cementation solution after 4 hours. During this period, the bacteria attaches itself to the sand particle. Urease solution and cementation solution were mixed prior to injection in case of EICP. The column was so fabricated that its size was identical to the CSS (cyclic simple shear) sample, thus enabling the sample treated in column to be extracted and subjected to cyclic loading.

Results and Discussion

Cyclic simple shear tests were done on virgin soil, MICP-treated and EICP-treated soil. Stress-controlled cyclic tests of CSR 0.1 under 100 kPa vertical stress were conducted after treatment and curing period of 1 day. Constant volume tests were conducted, where change in vertical stress is related to change in pore pressure. Hence, the ratio of change in vertical stress to the initial vertical stress was considered as the pore pressure ratio. Soil was deemed to fail when the pore pressure ratio becomes 1 or at 3.75 per cent single amplitude shear strain, whichever occurred first. Figure 3 shows the input shear stress plot with time for CSR of 0.1 at vertical stress of 100 kPa.

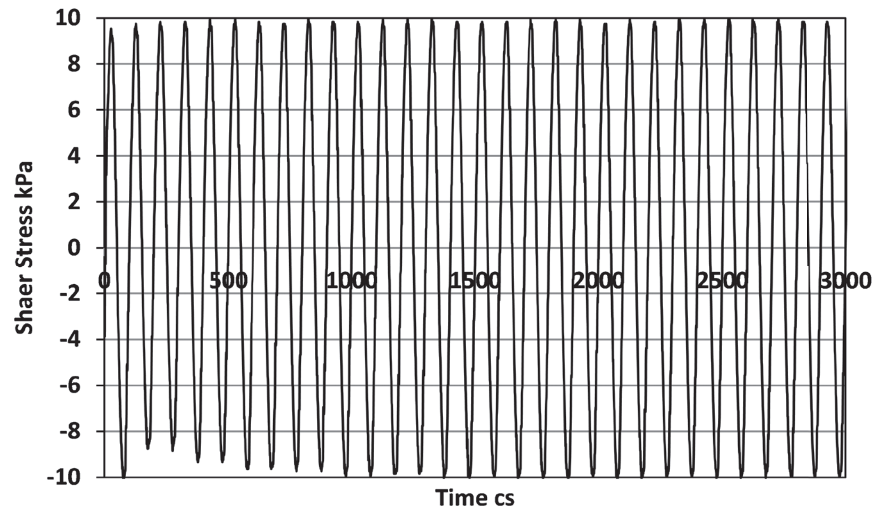


Figure 3: Input shear stress

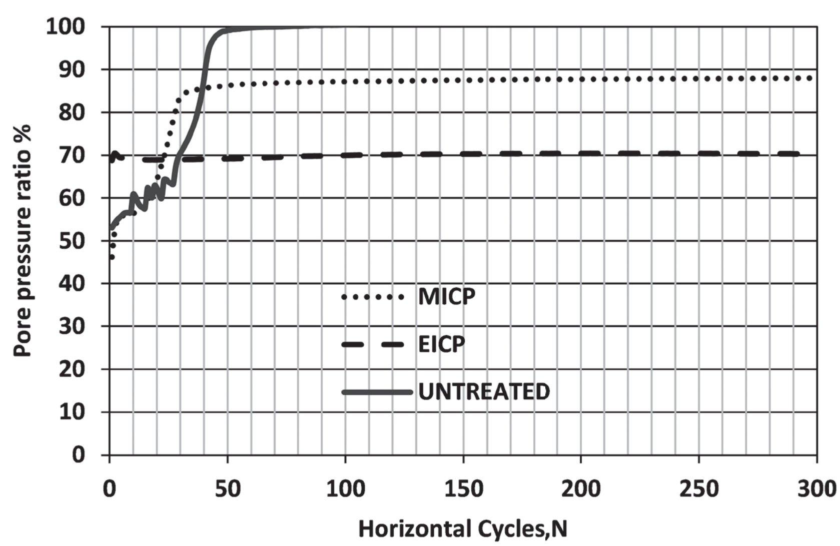
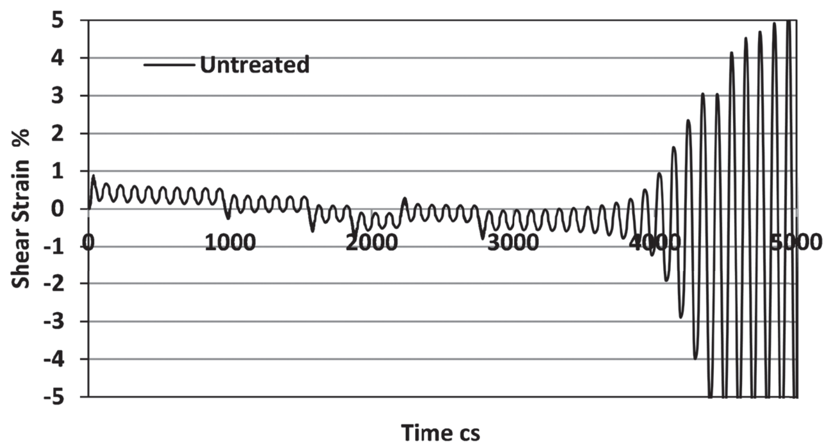
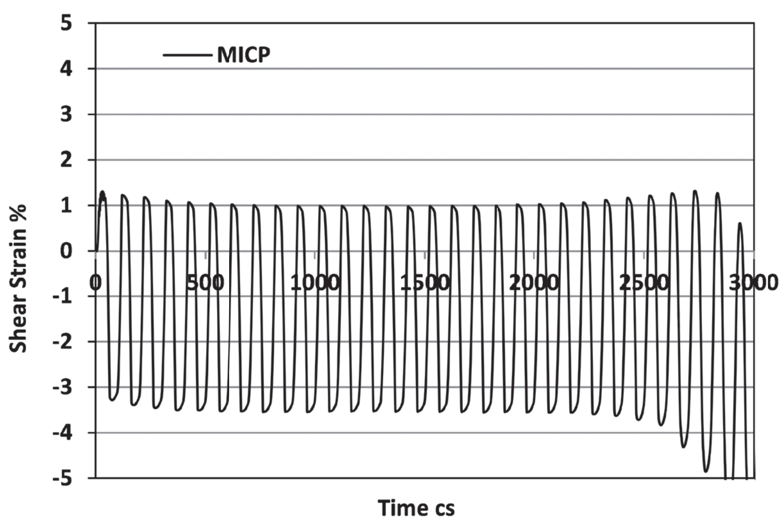


Figure 4: Variation of pore pressure ratio with time

Figure 4 shows the variation of pore pressure ratio with a number of horizontal cycles. Here, pore pressure ratio refers to the ratio of change in vertical stress to the initial vertical stress applied. Untreated soil liquefies at around 50 cycles, MICP soil reaches 85 per cent pore pressure ratio around 30 cycles and EICP soil maintains a constant trend of 70 per cent pore pressure ratio throughout. Figure 5 a, b and c shows the recorded shear strain till 3.75 per cent strain is reached with time for untreated, MICP and EICP soil, respectively. It can be inferred from the figure that EICP soil does not fail considering both the pore pressure criterion and shear strain criterion. MICP soil and untreated soil reach 3.75 per cent shear strain at around 30 and 50 cycles, respectively. MICP soil did not reach pore pressure ratio of 1, however reached 3.75 per cent shear strain in one direction at less number of cycles compared to untreated sand. The reason for this can be attributed to the insufficient precipitation in the soil matrix. It could have so happened that the bacteria could not attach to the soil matrix and was instead flushed. Additionally, the survival of the bacteria inside the soil sample is doubtful considering its delicacy to adverse surrounding. Enzyme-treated soil showed significant improvement in cyclic resistance and is also favourable for practical application as it can sustain harsh environmental conditions unlike bacteria, which otherwise require critically controlled surroundings.

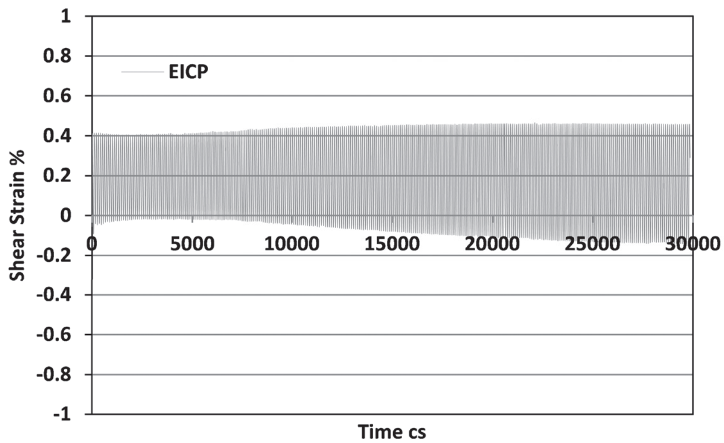


(a)



(b)

Figure 5: Recorded shear strain with time



(c)

Figure 5: (Continued)

Conclusion

Calcite formation in soil matrix induced by bacteria and enzyme was investigated. Performance of MICP- and EICP-treated sand under cyclic loading was studied through cyclic simple shear tests. EICP sand showed notable improvement in cyclic resistance in comparison to MICP sand. Inadequate precipitation due to doubtful survival of bacteria inside the sand sample might be the reason for poor performance in MICP. EICP is therefore suggested to be a potential solution to mitigate liquefaction.

References

Al Qabany A, Soga K(2013) Effect of chemical treatment used in MICP on engineering properties of cemented soils. Géotechnique, 63(4):331–339

Cheng L, Cord-Ruwisch R Shahin M A (2013)Cementation of sand soil by microbially induced calcite precipitation at various degrees of saturation. Canadian Geotechnical Journal, 50(1): 81–90.

DeJong J T, Fritzges M B Nüsslein K (2006) Microbially induced cementation to control sand response to undrained shear. Journal of Geotechnical and Geoenvironmental Engineering, 132(11): 1381–1392.

Feng K, Montoya B M (2015) Drained shear strength of MICP sand at varying cementation levels. IFCEE 2015; 2242–2251

Kavazanjian E Hamdan N (2015) Enzyme induced carbonate precipitation (EICP) columns for ground improvement. IFCEE 2015 :2252–2261

Montoya B M, DeJong J T, Boulanger R W, Wilson D W, Gerhard R, Ganchenko A, Chou J C. (2012) Liquefaction mitigation using microbial induced calcite precipitation. Proceedings of GeoCongress: 1918–1927

Montoya B M, DeJong J T, Boulanger R W(2013) Dynamic response of liquefiable sand improved by microbial-induced calcite precipitation. Géotechnique, 63(4):302–312

Mortensen B M., DeJong, J T (2011) Strength and stiffness of MICP treated sand subjected to various stress paths. Geo-Frontiers 2011 Advances in Geotechnical Engineering, ASCE : 4012–4020

Tsuchida H (1970) Evaluation of liquefaction potential of sandy deposits and measures against liquefaction induced damage. In Proceedings of the annual seminar of the Port and Harbour Research Institute: 3–1

An Improved CSMM-Based Simulation Model for Analysis of RC Panels under Cyclic Shear Loading

Vijay Kumar Polimeru[a] and Arghadeep Laskar[a]

ABSTRACT: In this study, the robustness of the cyclic softened membrane model (CSMM) has been improved by implementing state-of-the-art, Trust-Region-based Global Optimisation (TRGO) algorithm and restructuring the existing CSMM algorithm. Two RC panels (namely CA3 and CA4) tested to study their response under reversed cyclic shear loading at University of Houston have been considered for this study. The results obtained from the improved CSMM algorithm has been compared with the test results. It can be observed from the obtained results that the improved model has been able to predict the complete cyclic response without any convergence issues. In addition, the overall runtime taken for simulation of each panel is significantly lower than the runtime required using the existing CSMM. It can thus be concluded that the improved CSMM algorithm presented in this study is highly robust and more efficient to analyse the RC panels subjected to reversed cyclic shear loading.

KEYWORDS: RC shear panel, nonlinear analysis, cyclic softened membrane model, convergence, global optimisation

Introduction

Reinforced concrete (RC) members exhibit several failure modes when subjected to extensive time-varying loads during their service lives. Unlike flexure failure, shear failure of RC members is very critical (Martinelli 2008, Kim et al. 2012, Cassese et al. 2017) as it is brittle in nature involving low ductility and energy dissipation capacities along with the rapid deterioration of strength with increasing widths of the shear cracks. Hence, shear failure of RC members is not preferable in the earthquake-prone areas. Accurate simulation models which can predict the complete nonlinear behaviour (elastic, inelastic and post peak failure behaviour) of RC members are essential to study the performance of structures under seismic loads. With the development of accurate simulation models, better decisions (retrofitting or demolition) can be made during seismic assessments of existing structures, so that shear critical structures can be avoided in the earthquake-prone areas. For this reason, extensive research has been conducted to develop robust simulation models to predict the behaviour of RC shear critical structures. Over the past three decades, structural engineering researchers had been using an element-based approach to analyse RC structures. This approach involves discretizing the entire structure into substructures and then to discrete elements (also called panels) and then developing analytical models to predict the behaviour of these discrete elements. Later the developed analytical models for the elements can be incorporated in the finite element programme to

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predict the complete nonlinear response of the overall wall-type structures (Wang and Hsu 2001). Various analytical models have been developed by researchers at the University of Houston using the data obtained from the experimental studies conducted to study the behaviour of RC panel elements. These models include rotating angle softened truss model (RA-STM) (Hsu 1988), fixed angle softened truss model (FA-STM) (Pang and Hsu 1996), softened membrane model (SMM) (Zhu 2000) and cyclic softened membrane model (CSMM) (Mansour 2001). CSMM is very effective in predicting the behaviour of RC panel elements under cyclic loadings. As shown in Fig. (1), CSMM involves optimising a shear strain (γ_{12}) and a normal strain (ε_1) for each value of orthogonal normal strain (ε_2), selected from the input strain history. Even though the model is very effective in predicting the complete cyclic behaviour of shear panels, the optimisation methodology used in CSMM to predict the values of γ_{12} and ε_1 for each ε_2 is not robust enough to simulate the behaviour of RC low rise shear walls without any convergence issues. Hence, this study is aimed at addressing this drawback by improving the robustness of the CSMM using the state-of-the-art Trust-Region-based Global Optimisation (TRGO) algorithm (Conn et al., 2000). The methodology followed is thoroughly discussed in the following section.

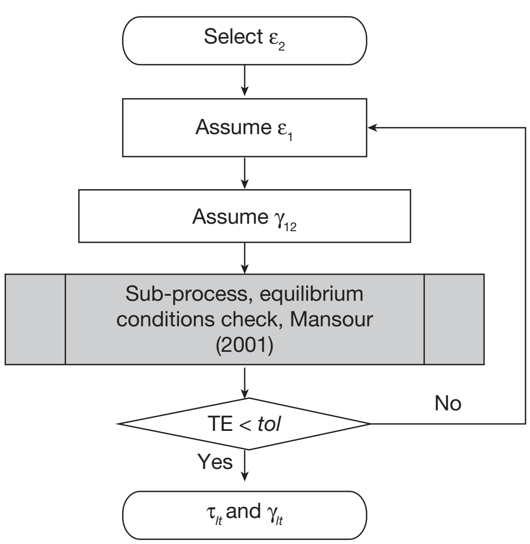


Figure 1: Flowchart of CSMM developed by Mansour (2001)

Methodology

The cyclic softened membrane model (CSMM) is developed using smeared crack concept and satisfies Navier's principles of mechanics of materials. Two RC panels (namely CA3 and CA4) tested under reversed cyclic shear loading at the University of Houston (Mansour 2001) have been considered in this study. Both panels and shear wall have two layers of steel reinforcement, oriented at an angle of 45^0 to the applied principle stress direction, as shown in Fig. (2). The material and geometric properties of specimens are given in Table 1. Two types of coordinate systems have been used in the formulation, namely, (1–2) coordinate system, oriented along the direction of applied principal stress, and (*l*-*t*) coordinate system, oriented along the direction of longitudinal and transverse reinforcements. The stresses in the longitudinal and transverse steel reinforcement (f_l and f_t) are related to the applied stresses (σ_l, σ_t and τ_{lt}) using equilibrium equations shown in Eqns. (1)–(3).

$$\rho_l f_l + \rho_t f_t = (\sigma_l + \sigma_t) - (\sigma_1^c + \sigma_2^c) \tag{1}$$

$$\rho_l f_l - \rho_t f_t = (\sigma_l - \sigma_t) - (\sigma_1^c - \sigma_2^c)\cos(2\alpha_1) + 2\tau_{12}^c \sin(2\alpha_1) \tag{2}$$

$$\tau_{lt} = (\sigma_1^c - \sigma_2^c)\sin\alpha_1 \cos\alpha_1 + \tau_{12}^c \cos(2\alpha_1) \tag{3}$$

where σ_l, σ_t and τ_{lt} are the applied stresses, f_l and f_t are the stresses in the reinforcement in longitudinal and transverse directions, respectively, σ_1^c, σ_2^c and τ_{12}^c are the stresses in the concrete along applied principal stress directions, ρ_l and ρ_t are the percentages of steel in the longitudinal and transverse directions, respectively, and α_1 is the steel reinforcement orientation or the applied principal stress angle. The compatibility between the steel strains in the (*l*-*t*) coordinate system and the concrete strains in the (1–2) coordinate system are defined using the compatibility equations shown in Eqns. (4)–(6). Biaxial stress–strain relationships of concrete and steel are required to solve the six equilibrium and compatibility equations given in Eqns. (1)–(6). The biaxial strains ($\varepsilon_l, \varepsilon_t, \varepsilon_1$ and ε_2) in the compatibility equations have to be converted to uniaxial strains ($\bar{\varepsilon}_l, \bar{\varepsilon}_t, \bar{\varepsilon}_1$ and $\bar{\varepsilon}_2$), since the stress–strain relationships obtained from the laboratory tests are uniaxial in nature. Hsu and Zhu (2002) derived four equations (Eqns. (7)–(10)) to relate uniaxial strains and biaxial strains using the Hsu/Zhu ratios (v_{12} and v_{21}).

$$\varepsilon_l = \varepsilon_1 \cos^2 \alpha_1 + \varepsilon_2 \sin^2 \alpha_1 - \frac{\gamma_{12}}{2} 2 \sin\alpha_1 \cos\alpha_1 \quad (4)$$

$$\varepsilon_t = \varepsilon_1 \sin^2 \alpha_1 + \varepsilon_2 \cos^2 \alpha_1 + \frac{\gamma_{12}}{2} 2 \sin\alpha_1 \cos\alpha_1 \quad (5)$$

$$\frac{\gamma_{lt}}{2} = \left(\varepsilon_1 - \varepsilon_2\right) \sin\alpha_1 \cos\alpha_1 + \frac{\gamma_{12}}{2} (\cos^2 \alpha_1 - \sin^2 \alpha_1) \quad (6)$$

$$\bar{\varepsilon}_1 = \frac{\varepsilon_1}{1 - v_{12} v_{21}} + \frac{v_{12} \varepsilon_2}{1 - v_{12} v_{21}} \quad (7)$$

$$\bar{\varepsilon}_2 = \frac{v_{21} \varepsilon_1}{1 - v_{12} v_{21}} + \frac{\varepsilon_2}{1 - v_{12} v_{21}} \quad (8)$$

$$\bar{\varepsilon}_l = \bar{\varepsilon}_1 \cos^2 \alpha_1 + \bar{\varepsilon}_2 \sin^2 \alpha_1 - \frac{\gamma_{12}}{2} 2 \sin\alpha_1 \cos\alpha_1 \quad (9)$$

$$\bar{\varepsilon}_t = \bar{\varepsilon}_1 \sin^2 \alpha_1 + \bar{\varepsilon}_2 \cos^2 \alpha_1 + \frac{\gamma_{12}}{2} 2 \sin\alpha_1 \cos\alpha_1 \quad (10)$$

where ε_l, ε_t, ε_1 and ε_2 are biaxial strains along 1–2 and *l-t* coordinate axes, $\bar{\varepsilon}_l$, $\bar{\varepsilon}_t$, $\bar{\varepsilon}_1$ and $\bar{\varepsilon}_2$ are uniaxial strains along 1–2 and *l-t* coordinate axes and v_{12} and v_{21} are Hsu/Zhu ratios. The equations pertaining to the cyclic constitutive relationship of concrete (Eqns. (11)–(16)) and steel (Eqns. (17)–(20)) have been summarised in Figs. (3) and (4).

(Stage 1) $\sigma^c = E_c \bar{\varepsilon}$ if $0 \le \bar{\varepsilon} < \varepsilon_{cr}$ (11)

(Stage 2) $\sigma^c = f_{cr} \left(\frac{\varepsilon_{cr}}{\bar{\varepsilon}} \right)^{0.4}$ if $\bar{\varepsilon} > \varepsilon_{cr}$ (12)

(Stage 3) $\sigma^c = D\zeta f_c' \left[2\left(\frac{\bar{\varepsilon}}{\zeta\varepsilon_0} \right) - \left(\frac{\bar{\varepsilon}}{\zeta\varepsilon_0} \right)^2 \right] 0 \le |\bar{\varepsilon}| \le |\zeta\varepsilon_0|$, (13)

(Stage 4) $\sigma^c = D\zeta f_c' \left[1 - \left(\frac{\bar{\varepsilon}/\varepsilon_0 - 1}{4/\zeta - 1} \right)^2 \right] |\bar{\varepsilon}| > |\zeta\varepsilon_0|$, (14)

(Unloading and Reloading stages) $\sigma^c = \sigma_i^c + E_{cc} \left(\bar{\varepsilon}_i - \bar{\varepsilon} \right)$

(15)

where $\zeta = \frac{5.8}{\sqrt{f_c'(Mpa)}} \frac{1}{\sqrt{1 + 400\bar{\varepsilon}_{2/1}}} \le 0.9$;

$D = 1 - 0.4 \frac{\varepsilon_c'}{\varepsilon_0} \le 1.0$; $E_{cc} = \frac{\sigma_i^c - \sigma_{i+1}^c}{\bar{\varepsilon}_i - \bar{\varepsilon}_{i+1}}$

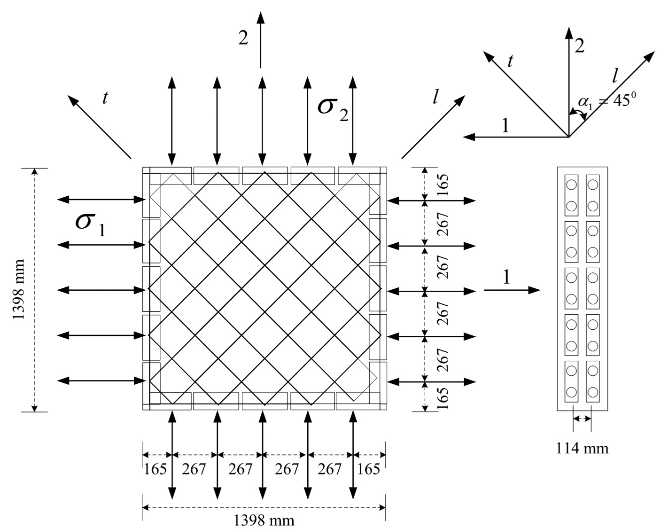


Figure 2: Dimensions of analysed RC panels

$$\tau_{12}^c = \frac{\sigma_1^c - \sigma_2^c}{2\left(\varepsilon_1 - \varepsilon_2\right)} \gamma_{12} \quad (16)$$

where E_c is the elasticity modulus of concrete, $\bar{\varepsilon}$ is uniaxial strain in concrete, σ^c is the concrete stress, ε_{cr} and f_{cr} are the cracking strain and stress of concrete respectively, D is the damage coefficient, f_c' is the compressive strength of concrete, ε_0 is the strain in concrete at f_c', ζ is the softening coefficient, E_{cc} is the slope of unloading and reloading branches, $\bar{\varepsilon}_{2/1}$ is the uniaxial orthogonal strain (i.e. along one direction, $\bar{\varepsilon}_{2/1}$ is $\bar{\varepsilon}_2$ and vice versa), ε_c' is the peak compressive strain in the previous cycle and σ_i^c, σ_{i+1}^c, $\bar{\varepsilon}_i$ and $\bar{\varepsilon}_{i+1}$ are the stresses and strains of the unloading and reloading points – the methodology to calculate these points have been reported in Mansour (2001).

(Stages 1 and 3) $f_s = E_s \bar{\varepsilon}_s$, if $(\bar{\varepsilon}_s \le \bar{\varepsilon}_n)$ (17)

(Stage 2) $f_s = f_y \left[\left(0.91 - 2B\right) + \left(0.02 + 0.25B \frac{\bar{\varepsilon}_s}{\varepsilon_y} \right) \right]$, if $(\bar{\varepsilon}_s > \bar{\varepsilon}_n)$, (18)

(Stage 4) $f_s = -f_y$, (19)

(Stages 5 and 6) $\bar{\varepsilon}_s - \bar{\varepsilon}_{si} = \frac{(f_s - f_i)}{E_s} \left[1 + A^{-R} \left| \frac{f_s - f_i}{f_y} \right|^{R-1} \right]$, (20)

where $B = \left(1/\rho\right)\left(f_{cr}/f_y\right)^{1.5}$; $\rho \ge 0.5\%$ and $\bar{\varepsilon}_n = \varepsilon_y (0.93 - 2B)$, $A = 1.9 k_P^{-0.1}$; $R = 10 k_P^{-0.2}$ and $k_P = \bar{\varepsilon}_s / \bar{\varepsilon}_n$, ρ is the percentage of steel, f_{cr} is the cracking stress of concrete, i.e.

$0.7\sqrt{f_c'}$, f_s and $\bar{\varepsilon}_s$ are trial state stress and strain in steel, respectively, E_s is the elasticity modulus of steel, B is the curve parameter, f_y and ε_y are the yield stress and strain of reinforcement steel, respectively, and $\bar{\varepsilon}_{si}$ and f_i are the unloading and reloading points – the methodology to calculate these points have been reported in Mansour (2001). The values of ε_1 and γ_{12} need to be assumed to calculate the concrete and steel stresses for each value of biaxial shear strain (γ_{lt}). Thereafter, the validity of the assumed strains ε_1 and γ_{12} is evaluated by checking the total error (TE) obtained from the error in the equilibrium conditions along orthogonal directions (Eqns. (21)–(23)).

$$Error_1 = (\rho_l f_l + \rho_t f_t) - (\sigma_l + \sigma_t) - \left(\sigma_1^c + \sigma_2^c\right) \quad (21)$$

$$Error_2 = (\rho_l f_l - \rho_t f_t) - (\sigma_l - \sigma_t) - \left(\sigma_1^c - \sigma_2^c\right)\cos(2\alpha_1) + 2\tau_{12}^c \sin(2\alpha_1) \quad (22)$$

$$\text{Total Error (TE)} = \sqrt{Error_1^2 + Error_2^2} \quad (23)$$

The evaluation of total error in Eqn. (23) is repeated with new values of ε_1 and γ_{12} until the total error is less than the tolerance, i.e. 10^{-6} (taken in this study). This process requires robust search algorithms to obtain the correct values of ε_1 and γ_{12}. In this study, the TRGO technique which is predefined in the MATLAB (Mathworks, 2011) global optimisation toolbox has been used. A brief description of the optimisation algorithm is given in the following subsection. The effectiveness of the TRGO algorithm has been further verified through the analysis of a low-rise shear wall (shown in Fig. 5) tested at the University of Ottawa (Pilette, 1988) to study its response under reversed cyclic loading. The CSMM algorithm shown in Fig. (1) has been restructured to start from γ_{lt} instead of ε_2 and thereby make the algorithm suitable for analysing the shear wall considered in this study. The value of γ_{lt} has been calculated using deflection history ($\gamma_{lt} = \delta/h$, where δ is the lateral deflection and h is the height of the wall). The shear force (P) corresponding to the applied deflection history has been calculated from the shear stress τ_{lt} ($P = \tau_{lt} L t$, where L is the length of the wall and t is the thickness of the wall) obtained from the CSMM algorithm. The complete flowchart of the improved CSMM algorithm used in this study is shown in Fig. (6). The shear strain history used for analysing the two RC panels and the deformation history used for analysing the shear wall are shown in Fig. (7). The geometric and material properties of the specimens are shown in Table 1.

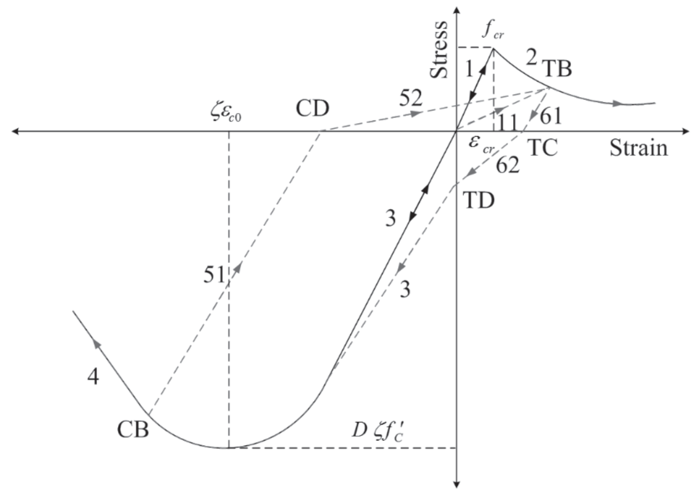


Figure 3: Cyclic constitutive relationship of concrete

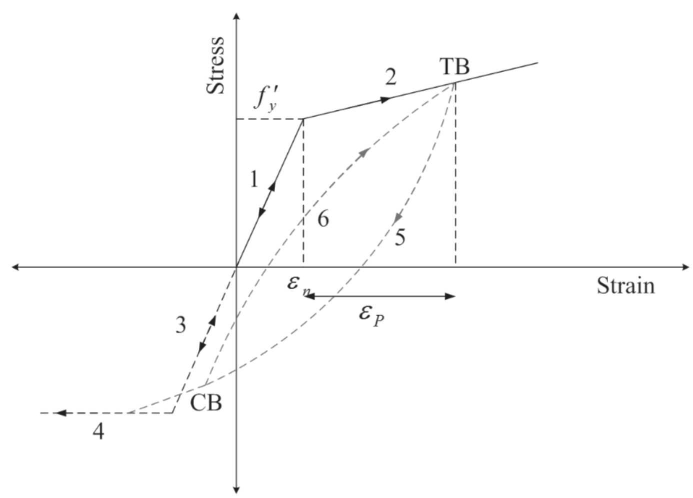


Figure 4: Cyclic constitutive relationship of steel

f_c' is the compressive strength of concrete, ε_0 is the strain in the concrete corresponding to the compressive strength f_c', ρ_l and ρ_t are the percentages of steel in the longitudinal and transverse directions, respectively, f_{ly} and f_{ty} are the yield strengths of steel reinforcements in the longitudinal and transverse directions, respectively, and α_1 is the steel reinforcement orientation or the applied principal stress angle.

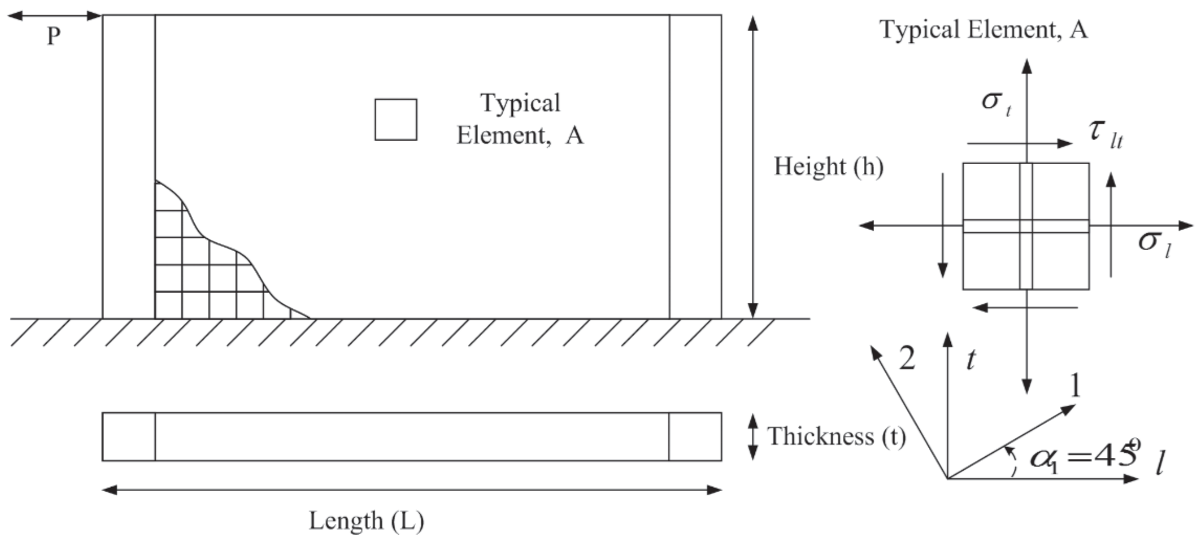
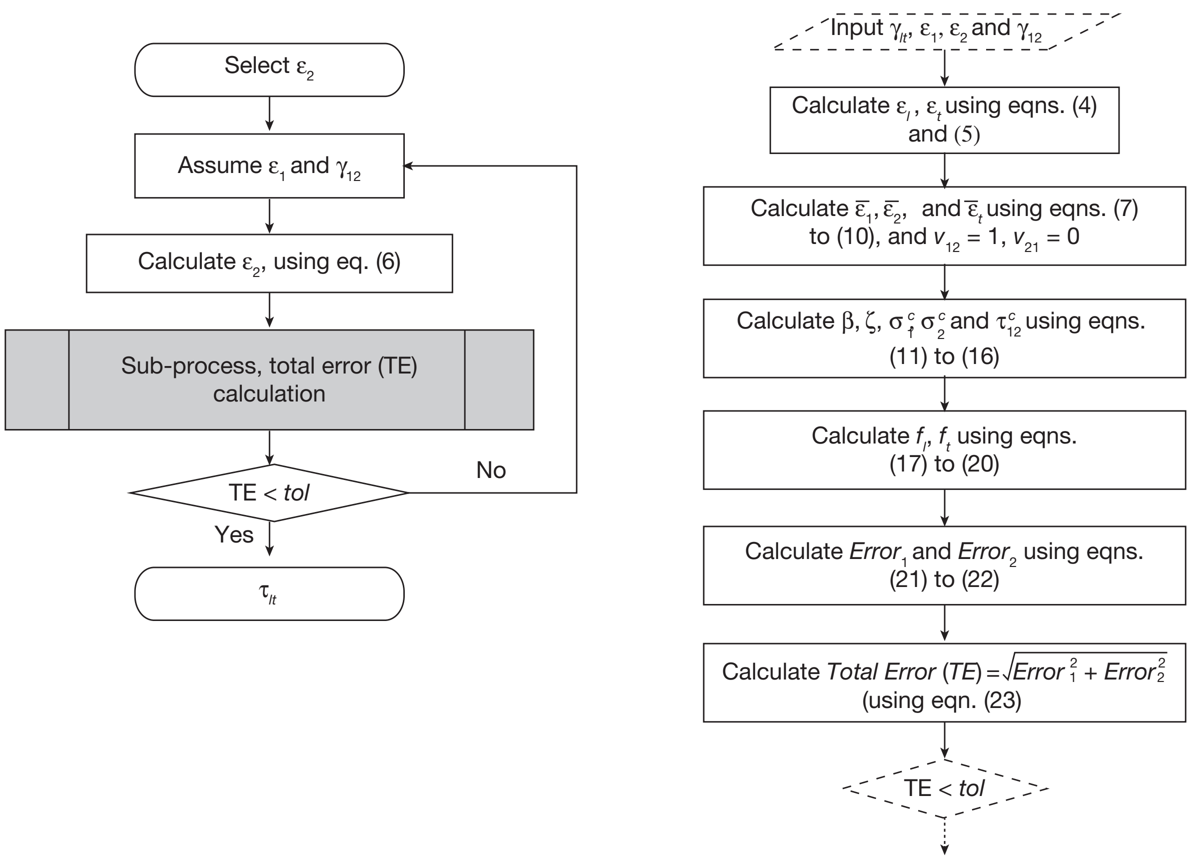


Figure 5: Dimensions of analysed low-rise RC shear wall

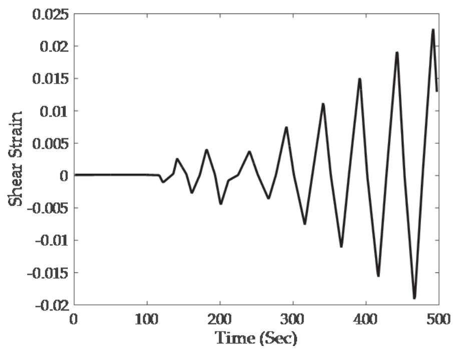


(a) (b)

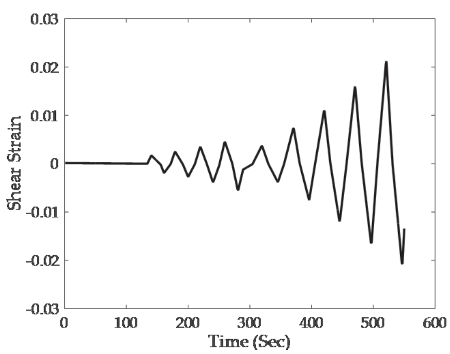
Figure 6: Flowchart of improved CSMM used in this study

Table 1 Geometric and Material Properties of RC Panels and Shear Wall

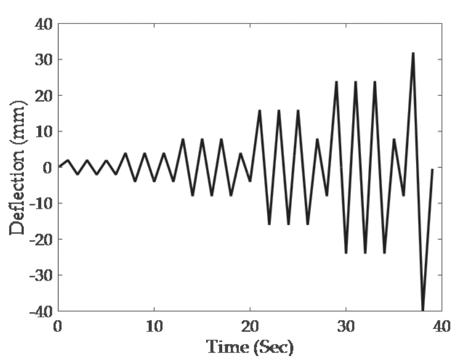
Specimen No.	Concrete		Steel in l-direction		Steel in t-direction		α_1 (degrees)
	f_c' (Mpa)	ε_0	ρ_l (per cent)	f_{ly}(Mpa)	ρ_t (per cent)	f_{ty} (Mpa)	
CA3	46	0.0024	1.70	425.4	1.70	425.4	45
CA4	44	0.0026	2.70	453.4	2.70	453.4	45
Shear wall	33	0.0024	0.80	480.0	0.80	480.0	45



(a) CA3



(b) CA4



(c) Shear Wall

Figure 7: Reversed cyclic loading used in this study

Trust-Region-Based Global Optimisation (TRGO) Algorithm

The TRGO algorithm described by Conn et al. (2000) approximates a given objective function $f(x, y)$ within a certain trust region (Δ_i) defined by its radius (R_i) in each iteration (i) to find the local minima (x_i, y_i) in that region and thereafter use this newly found local minima (x_i, y_i) as the starting point for the next iteration to ultimately obtain the global minima (x^*, y^*) of the given objective function. This process starts with assumption of a random starting guess point (x_0, y_0) and continues till the global minimum (x^*, y^*) is obtained. A schematic representation of the TRGO algorithm is shown in Fig. (8).

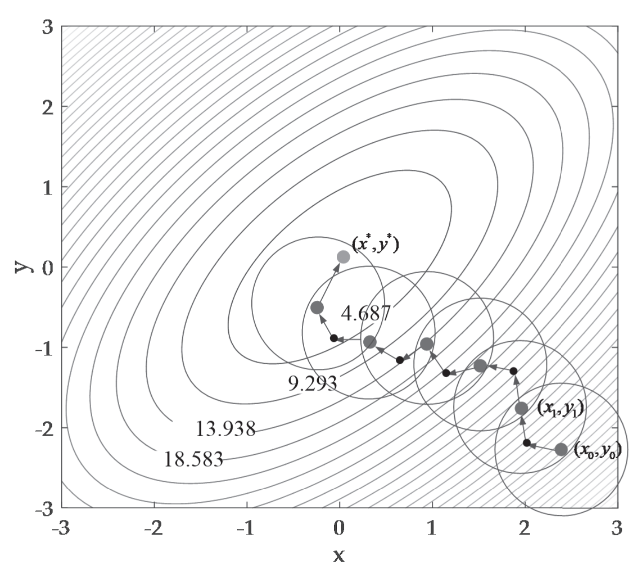


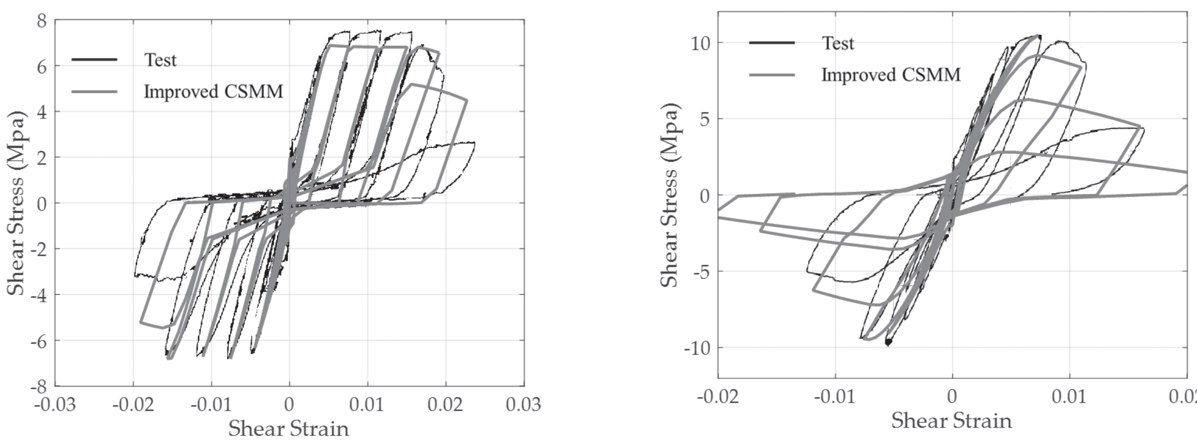
Figure 8: Schematic representation of TRGO algorithm

A critical discussion on the results obtained using the improved algorithm is presented in Section 3.

Results and Discussion

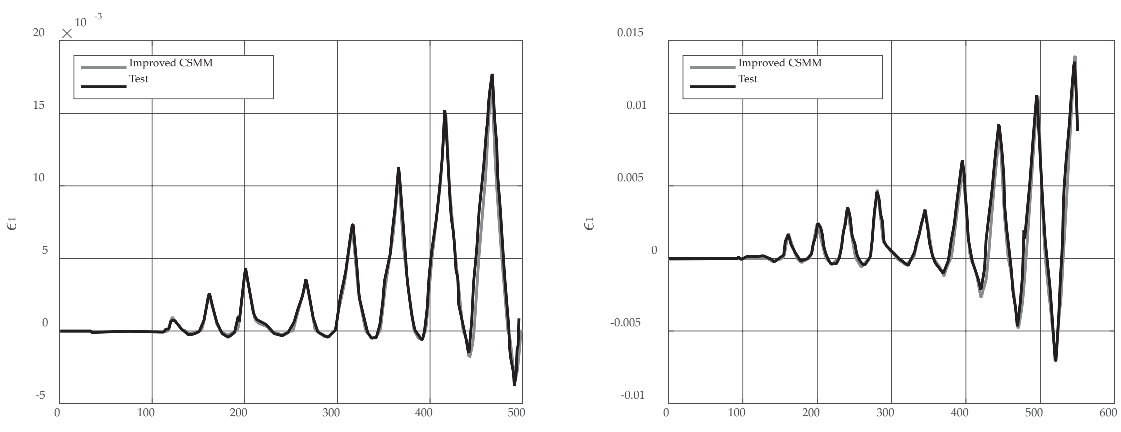
RC Panels

The cyclic shear strain vs shear stress values of panels CA3 and CA4 obtained from the improved CSMM algorithm have been compared with test results as shown in Fig. (9). It can be observed that the improved CSMM is able to predict the complete cyclic shear stress vs shear strain behaviour including the post peak shear strength degradation and pinching effects. From the results of normal strains ε_1 and ε_2 values in panels as shown in Figs. (10) and (11), it can be observed that the results obtained from the improved CSMM have been corroborated well with the experimental values. The TRGO algorithm used in the analysis is robust enough to simulate the complete nonlinear cyclic shear behaviour of the two RC panels with high accuracy ($TE < 10^{-6}$).



(a) (b)

Figure 9: Shear stress vs shear strain (a) CA3 and (b) CA4



(a) (b)

Figure 10: ε_1 variation (a) CA3 and (b) CA4

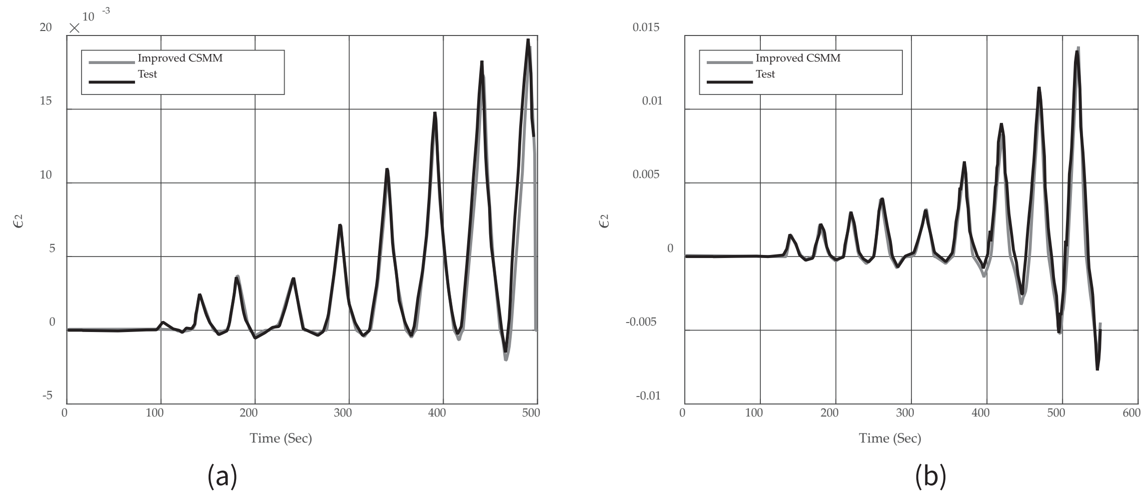


Figure 11: ε_2 variation (a) CA3 and (b) CA4

RC Shear Wall

The cyclic force deflection response of the RC shear wall tested by Pilette (1988) has been obtained from the improved CSMM algorithm and compared with the test results as shown in Fig. (12). It can be observed that the improved CSMM is able to predict the complete cyclic force deflection response of the shear wall including the post peak strength degradation and pinching effects. The TRGO algorithm used in the analysis is thus robust enough to also simulate the complete nonlinear cyclic shear behaviour of the considered low-rise shear wall with high accuracy ($TE < 10^{-6}$).

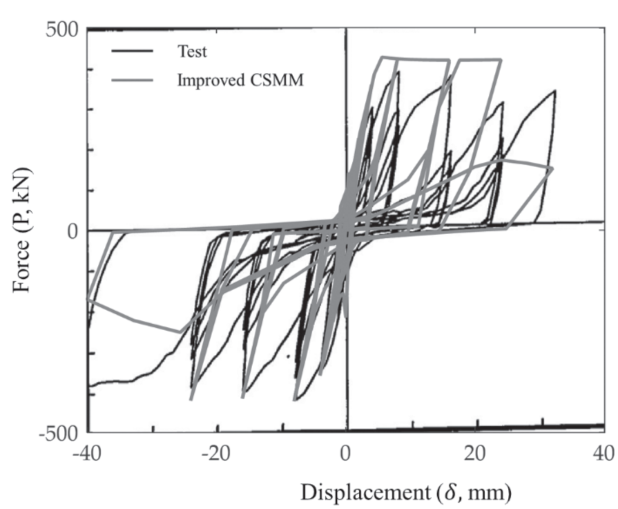


Figure 12: Force displacement curve of shear wall

Conclusion

Shear failure is very critical because it involves the sudden collapse of the structural members due to rapid strength deterioration with increasing crack widths. The CSMM has been developed at the University of Houston to study the behaviour of these shear critical wall-type structures. In this study, the robustness of the CSMM has been improved by implementing state-of-the-art, Trust-Region-based Global Optimisation (TRGO) algorithm. Two RC panels (CA3 and CA4) tested to study their response under reversed cyclic shear loading at University of Houston and one low-rise shear wall tested to study its response under reversed cyclic loading at University of Ottawa have been analysed using the improved CSMM algorithm. Comparison of the results obtained from the improved CSMM with the test results shows that the improved model is able to predict the complete shear response of the two RC panels and the complete nonlinear force deformation response of the RC shear wall, without any convergence issues. It can thus be concluded that the improved CSMM algorithm is highly robust and more efficient for analysing the RC panels and low-rise shear walls under reversed cyclic shear loading.

Acknowledgements

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References

Conn, A. R., Gould, N. I., and Toint, P. L. (2000). Trust region methods, Vol. 1, Siam.

Cassese, P., Ricci, P., and Verderame, G. M. (2017), Experimental study on the seismic performance of existing reinforced concrete bridge piers with hollow rectangular section, Engineering Structures, 144:88–106.

Hsu, T. T. C. (1988), Softened truss model theory for shear and torsion. Structural Journal of the American Concrete Institute, 85(6):624–635.

Hsu, T. T. C, and Zhu, R. R. (2002). Softened membrane model for reinforced concrete elements in shear. ACI Structural Journal, 99(4):460–469.

Kim, I. H., Sun, C. H., and Shin, M. (2012), Concrete contribution to initial shear strength of RC hollow bridge columns, Structural Engineering and Mechanics, 41(1):43–65.

Mansour, M. (2001), Behavior of reinforced concrete membrane elements under cyclic shear: experiments to theory. Ph. D. Dissertation, Department of Civil and Environmental Engineering, University of Houston, Houston, TX.

Martinelli, L. (2008), Modelling shear-flexure interaction in reinforced concrete elements subjected to cyclic lateral loading, Structural Journal of the American Concrete Institute, 105(6):675–684.

Mathworks. (2011). Global Optimisation Toolbox: User's Guide (R2015a)

Pang, X. B. D., and Hsu, T. T. C. (1996), Fixed angle softened truss model for reinforced concrete. Structural Journal of the American Concrete Institute, 93(2):196–208.

Pilette, C. F. (1988), Behavior of earthquake resistant squat shear walls, University of Ottawa (Canada).

Wang, T., and Hsu, T. T. (2001), Nonlinear finite element analysis of concrete structures using new constitutive models. Computers & structures, 79(32):2781–2791.

Zhu, R. R. H. (2000), Softened membrane model of cracked reinforced concrete considering the Poisson effect, Ph. D. Dissertation, Department of Civil and Environmental Engineering, University of Houston, Houston, TX.

Towards Sustainable Soil Stabilisation by Utilising CCR in the Treatment of Expansive Soils

Ashish Juneja[a] and Shrikant Shinde[a]

ABSTRACT: The economic loss due to damage which the expansive soils cause to civil engineering structures is comparable to the loss incurred due to flood, hurricanes or earthquake. More often than not, the cost of annual maintenance can exceed the construction cost. In India, these expansive or black cotton soils cover over 20 per cent of the central and southern parts of the Indian subcontinent. Stabilisation of these soils with lime and cement has otherwise been a common engineering practice. However, these additives are known to significantly affect the environment. To overcome this difficulty, the use of industrial by-product (waste) like calcium carbide residue (CCR), which can stabilise this expansive soil, is suggested in this study. This paper presents experimental data of CCR-blended black cotton soils which can improve the soil's engineering properties. In the first part of the experimental programme, physical and chemical properties of black cotton soils were determined and used as reference. Black cotton soils were then treated with CCR to obtain optimum CCR dosage using Atterberg's limits and pH test. The effect of CCR on compressibility and strength at curing period which varied up to 14 days was investigated using one-dimensional consolidation and unconfined compressive strength test. The alteration in mineralogical composition of the treated soil is observed by X-ray diffraction (XRD). Progress of cementitious product of calcium silicate hydrates (C-S-H) is observed after curing period. These effects were then compared to the swelling pressure tests to help replicate the in situ conditions. The results indicate that CCR helps increase strength and reduce swelling and compressibility of black cotton soils. These results help direct new applications of CCR which can otherwise reduce its impact on the environment and prevent damage to structures build over black cotton soils.

KEYWORDS: damage, calcium carbide residue, expansive soils, constitutive model

Introduction

This work addresses two major geotechnical challenges observed in the central Indian peninsula. First, the black cotton soil, which is highly problematic because of its swelling nature, and second, calcium carbide residue (CCR), which is lime-rich waste produced in the manufacture of acetylene gas. Acetylene gas is used as raw material in PVC resins and gas cutting and welding in the metal industry. The consumption of acetylene is high in most Asian countries, which primarily depends upon calcium carbide for its production (Jaturapitakkul and Roongreung 2003). China, Japan, India and some European counties are amongst the largest consumers of calcium carbide. Globally, it is estimated that over 500,000 tonnes calcium carbide is used to generate acetylene gas (Yaolin et al. 2015). This in turn generates about 1.4 million tonnes of CCR, and this by-product is expected to increase by 1

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per cent each year until 2020. In India, it is estimated that about 4.5 million tonnes of lime sludge with huge amount of CCR is generated and this is also expected to increase each year (Saldhana 2018). Due to its high alkalinity, CCR otherwise has little value, and the usual practice in this country is to dump it in landfills or slurry ponds. The main constituent of CCR is calcium oxide (CaO), which can replace lime in soil stabilisation works. Otherwise during the production of commercial lime, a lot of carbon dioxide is also emitted. This production also requires large consumption of water. Here CCR can reduce the negative impact of these other additives which have traditionally been used in soil stabilisation works.

Expansive soils are mostly found in arid and semi-arid regions of the world. The presence of smectite minerals makes this clay swell and shrink. It swells during the rainy season and shrinks during the dry season. The economic loss due to the damage caused by the expansive soils is comparable to the loss incurred due to floods, hurricanes or earthquakes (Jones and Holtz 1973). Several field observations have shown that lightly loaded structures build over these soils were uplifted due to swelling or heave during rainy season. Nelson et al. (2017) reported a few case histories of failure of structures supported on expansive soil. Figs. 1a–d show some images of the damage caused by the expansive soil to different structures.

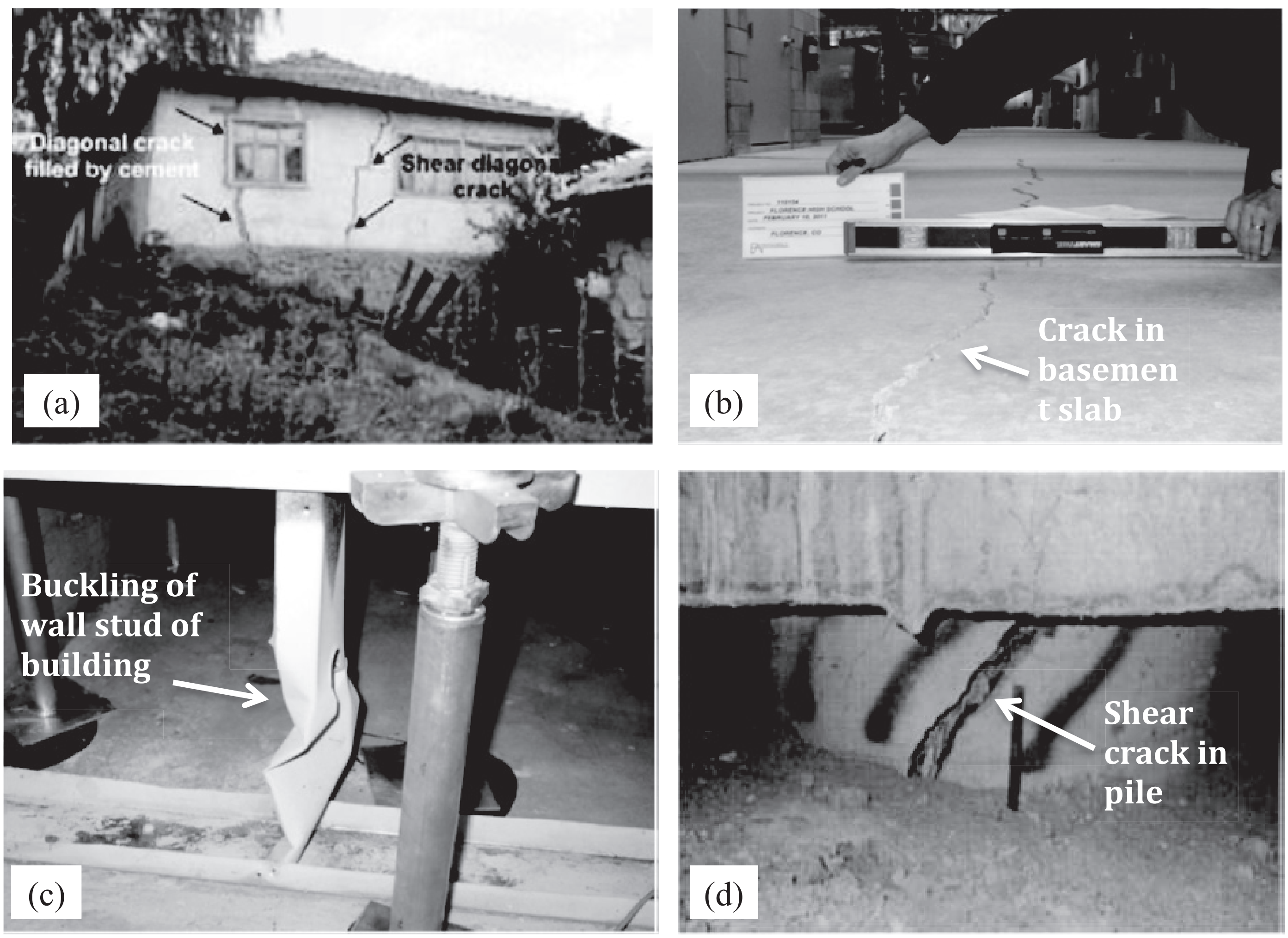

Figure 1: a–d: Damage of different structures due to change in volume of the expansive soils: (a) diagonal crack in wall; (b) horizontal crack in basement slab; (c) buckling of wall stud; and (d) shear crack in pile foundation (after Nelson et al. 2017)

Several other researchers (e.g. Rao and Thyagaraj 2003, Phanikumar and Sharma 2004, Kumar et al. 2018) have also reported similar case histories on damages observed in the Indian subcontinent. In India, these expansive or black cotton soils cover over 20 per cent of the central and southern parts of the subcontinent. The thickness of this layer varies from a few hundreds of millimetre to several metres. Although this soil is available in abundance, it is not ideal for construction. These soils are highly sensitive to the change in water content because of their high cation exchange capacity. The annual cost to maintain and repair the damage to earthwork and structures built over these soils is huge (Phanikumar and Sharma 2004), and more often than not, this cost can exceed the construction cost. To overcome this difficulty and make use of this expansive soil in the construction, there is need to first improve their properties. One of the most effective improvement method amongst several others is chemical stabilisation. These soils have historically been stabilised using either lime or cement, which has otherwise been a common engineering practice.

The use of industrial by-product in soil stabilisation is now becoming a common practice because of stringent environmental laws to utilise and curb waste. Extensive work has been done on the use of flyash in soil stabilisation works when used along with other cementing agents. Flyash is a waste material produced from thermal power plants. Phanikumar and Sharma (2004) and Al-Rawas et al. (2005) have used flyash with lime and cement slurry to stabilise these problematic black cotton soils. There is no doubt that cement is a better binding agent if short turnaround time is necessary for high strength improvement. However, the cost of stabilisation increases with the use of cement and lime, which can affect the overall cost of the project. When the budget is limited or when the project is small, it can also be impractical to use these additives. Therefore, to reduce stabilisation costs and to help the green technology, it is necessary to replace cement and lime with other low-cost binders such as CCR. This waste and other Industrial by-products are therefore the best available options to resolve the above two difficulties.

In all previous studies, efforts have been made to study the strength improvement in CCR-treated silty sand or silty clay (Consoli et al. 2001, Horpibulsuk et al. 2014) except Vichan and Rachan (2013) who studied the performance of CCR in soft Bankok clay. It has been also noted that no attention was toward CCR performance in swelling soil though this soil was abundantly spread in Indian peninsula. This paper discusses the use of CCR to stabilise black cotton soil.

Material and Experiments

The soil used for this investigation was collected from Nashik (Maharashtra, India). The soil samples were collected from pits excavated at 15 cm depth. The samples were air dried before sieving them through 4.75 mm (No.4) sieve. Calcium carbide residue (CCR) as binder material supplied by Meesha Air Products Pvt. Ltd., Mahad (Maharashtra, India), is used for this investigation. The CCR is collected directly from acetylene manufacturing plant from the above industry.

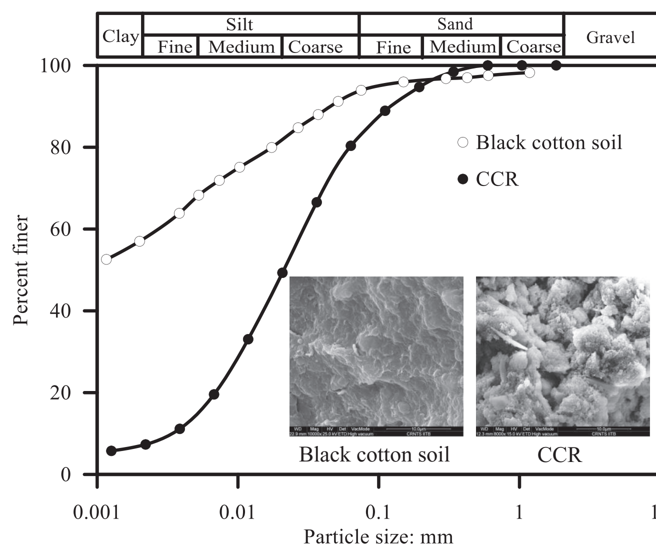

Figure 2: Particle size distribution and SEM images of black cotton soil and CCR

Figure 2 shows the particle size distribution and SEM images of soil and CCR. It is depicted from the figure that CCR is highly flocculated and porous structure compared with black cotton soil. The physical and chemical properties of base soil and CCR are as shown in Tables 1 and 2, respectively. It is observed that CCR has a high percentage of CaO (56 per cent), whereas soil has high percentage of natural pozzolanic material up to 65 per cent in the form of silica and aluminium oxide. On this basis, it is hypothesised that the blend of these two materials in the presence of water forms cementitious product of calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H). This cementitious product will increase the performance of expansive soil.

Table 1: Physical Properties of Black Cotton Soil and Calcium Carbide Residue

Sr.No.	Test	Black Cotton Soil	Calcium Carbide Residue
1	Atterberg's limits		
	Liquid limit (per cent)	75	-
	Plastic limit (per cent)	37	-
	Shrinkage limit (per cent)	8	-
2	Specific gravity, G_s	2.64	2.23
3	Free swell index (per cent)	90	-
4	Classification	CH	-
5	Particle size distribution		
	Clay (per cent)	58	5
	Silt (per cent)	38	83
6	pH	8.84	12.63

Atterberg's limit and pH test was conducted to investigate optimum percentage of CCR. The UCS test was performed on a sample prepared by static compaction at their proctor density after 7 days of curing. To evaluate settlement response, one-dimensional consolidation for different percentage of CCR was conducted. The effect of CCR on swelling pressure of black cotton soil was also studied. The specimens for consolidation and swelling tests were prepared at their proctor density. The prepared specimens were wrapped in polyethylene bag and kept in humidity chamber for required curing period. After the required curing period, the specimen was transferred to compression frame for UCS test and standard consolidation frame for consolidation test. In the consolidation test, samples were inundated with water and allowed to swell under surcharge weight of 6.25 kN/m^2. After equilibrium position reached, the one-dimensional consolidation test with load increment of unity was performed. The specimen was allowed to swell and dial gauge reading was taken. The dial gauge reading was continued for 7 days irrespective of the sample reaching equilibrium.

Table 2: Chemical Composition of Black Cotton Soil and Calcium Carbide Residue

Sr.no	Chemical Composition (per cent)	Black Cotton Soil	Calcium Carbide Residue
1	CaO	7.93	90
2	SiO_2	43.26	4.6
3	Al_2O_3	21.25	0.49
4	Fe_2O_3	15.74	0.10
5	M_nO	0.13	0.00
6	MgO	3.11	0.22
7	Na_2O	2.99	0.06

Results and Discussions

Figure 3 shows that when CCR is added to clayey soil, the liquid limit decreases and plastic limit increases. The consequences of this are reduction in plasticity index (PI). The plasticity index reduced from 40 to 18 in addition of only 2 per cent of CCR, then it becomes almost constant after 6 per cent of CCR and hence can be concluded that CCR of 6 per cent is the optimum per cent. The change in plasticity index is attributed to exchange of ions between soil and CCR. Figure 3 also shows that at 4 per cent CCR, the pH of blend reached a value more than 12.4 which confirms the pozzolanic reaction started in high alkaline environment. The pH value reached at asymptote about 6 per cent of CCR; it again confirms that 6 per cent CCR is the optimum per cent.

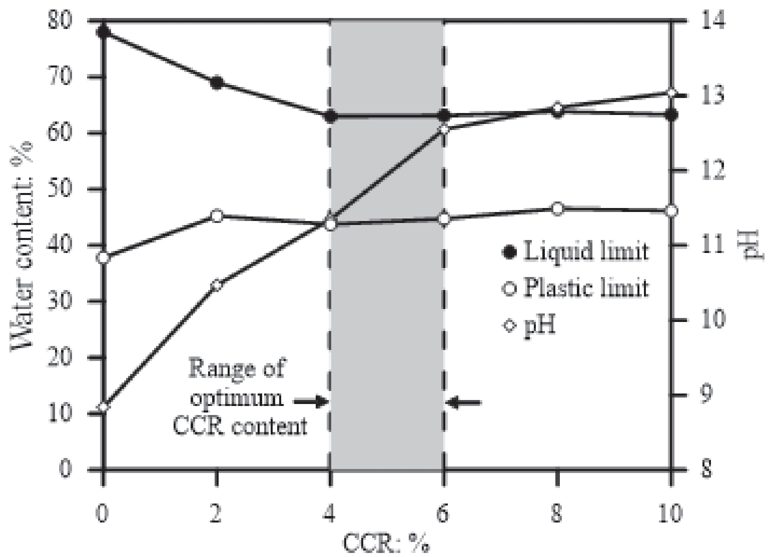

Figure 3: Atterberg's limits and pH on blend of clay and CCR

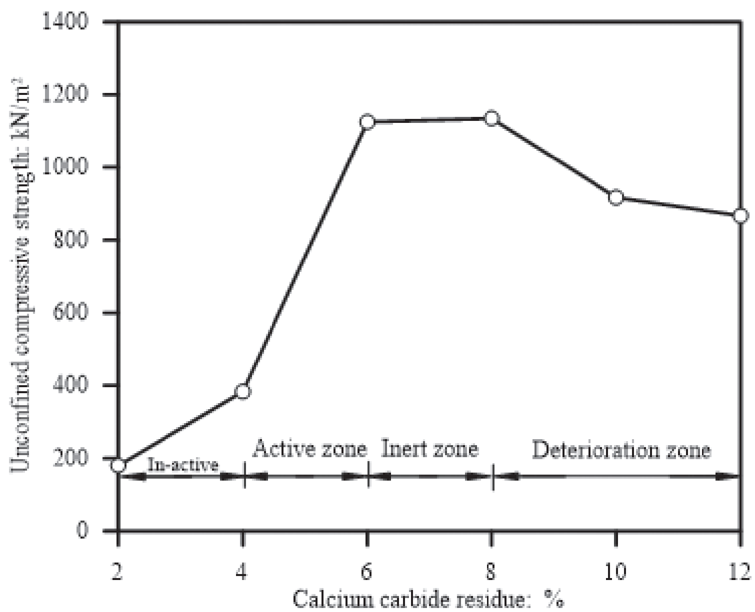

Figure 4: Unconfined compressive strength of CCR-treated black cotton soil

Figure 4 shows the results of unconfined compressive strength plotted against CCR percentage after 7 days of curing. As can be seen, the effect of CCR can be divided in different zones like inactive to deterioration which was proposed by Kampala and Horpibulsuk (2013). As shown in earlier Fig. 3, the 2 per cent CCR has not helped to develop any cementation during the curing period; hence, no strength improvement is observed. This zone is called as inactive zone. The threshold value of pH crosses when CCR increased beyond 4 per cent; hence, cementitious gel will form through pozzolanic reaction during curing period. The strength enhancement has been observed from 4 to 6 per cent of CCR and hence it is active zone.

It was noted that after active zone strength reduces rapidly. The similar observation was also reported by Vichan and Rachan (2013). Dash and Hussain (2012) also reported that excessive lime reduces shear strength of soil due to the excess formation of C-S-H gel which was highly porous in nature. This high porous structure has low shear strength and hence optimum use of lime is very important in soil stabilisation.

Compressibility of CCR-Treated Soil

Figures 5–7 show the consolidation test results of black cotton soil treated with CCR and cured for 0, 7 and 14 days, respectively. In each figure, the void ratio is noted to decrease with the increase in CCR. The change in void ratio decreased with the increase in CCR, and this change became negligible when CCR exceeded its optimum content. Figs. 5–7 also show that the curing period also affected the soil's compressibility. The compressibility seems to decrease with the increase in curing period from 0 to 14 days. Clearly, the crystallisation of cementitious gel into well-defined compound helped each mix to withstand increasingly higher stresses without compromising its compressibility. This is not surprising because CCR has more amount of free lime which will react with silica and alumina of soil to form cementitious gel during curing period.

Microstructures of CCR-Treated Soil

Figure 8 shows X-ray diffraction pattern of untreated black cotton soil. The figure shows the presence of montmorillonite [$(OH)_4Si_8Al_4O_{20}$ NH_2O] and vermiculite ($C_6H_{14}NO_2$) as the two dominant minerals. These minerals belong to the smectite group, which have huge swelling characteristics and weak expanding interlayer bonding. The range of basal spacing of montmorillonite varied from 1.54 A0 to 14.98 A0. Small peaks of quartz are also observed in black cotton soil at basal spacing of 1.37 A0 to 4.26 A0. Fig. 9 shows XRD results of black cotton soil treated with 6 per cent CCR. The new peaks in this figure are of calcium aluminium silicate or CAS and calcium magnesium silicates (Ca Mg Si2O6) or CMS, which were observed at basal spacing of 4.26 A0 and 3.34 A0, respectively. These new cementitious peaks occur because of availability of additional calcium when higher CCR was added.

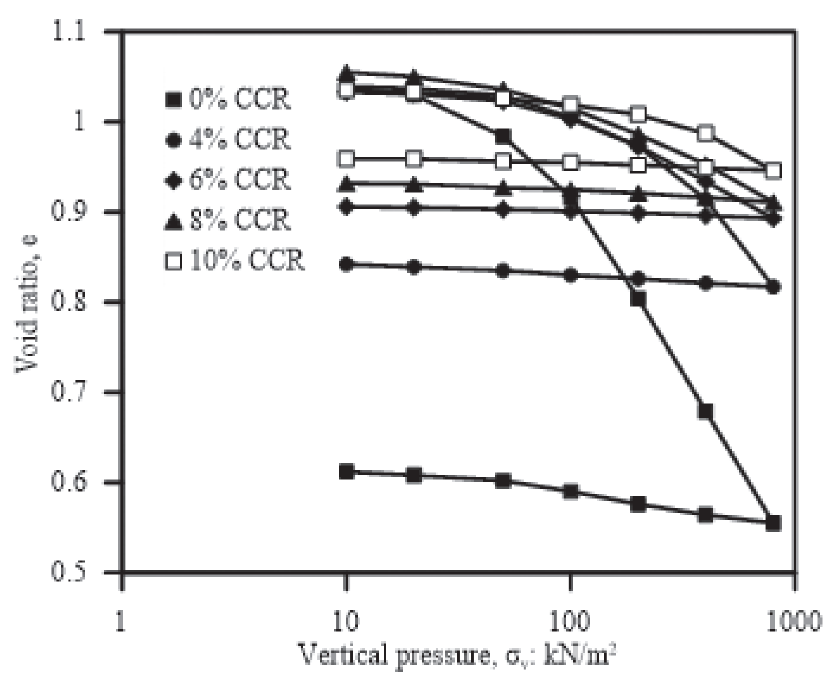

Figure 5: Void ratio versus vertical pressure of CCR-treated soil (curing 0 days)

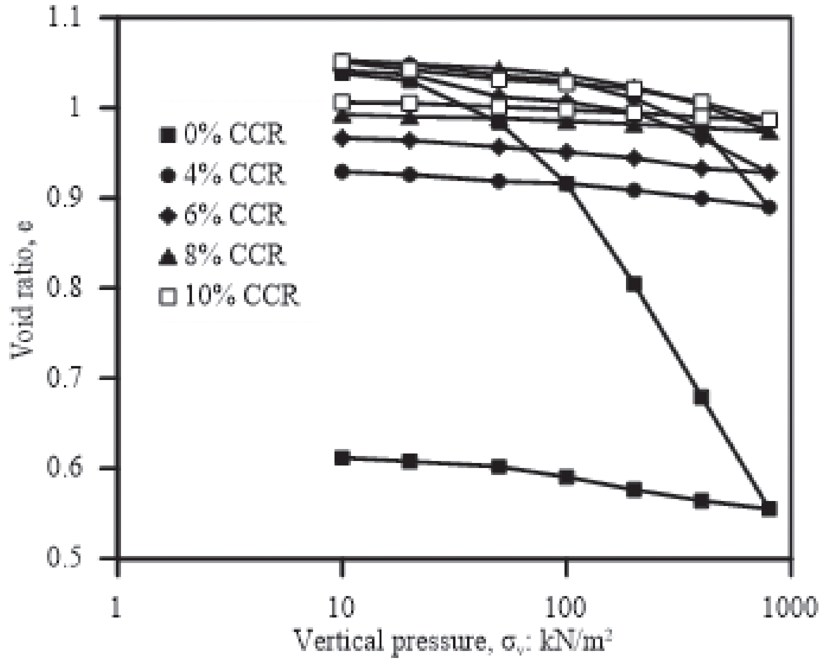

Figure 6: Void ratio versus vertical pressure of CCR-treated soil (curing 7 days)

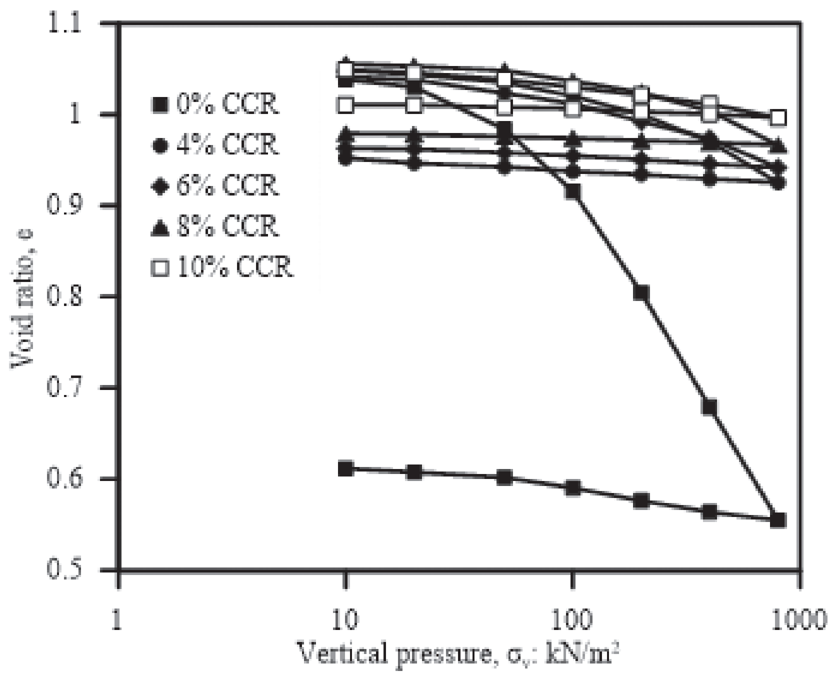

Figure 7: Void ratio versus vertical pressure of CCR-treated soil (curing 14 days)

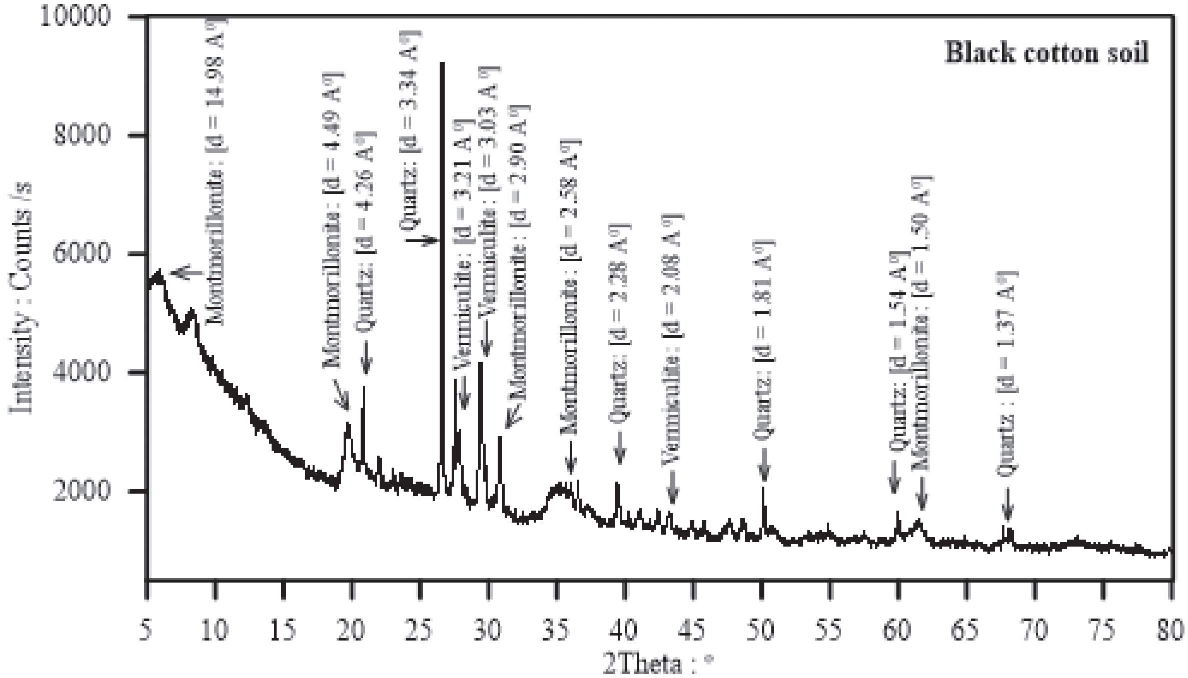

Figure 8: XRD of untreated black cotton soil

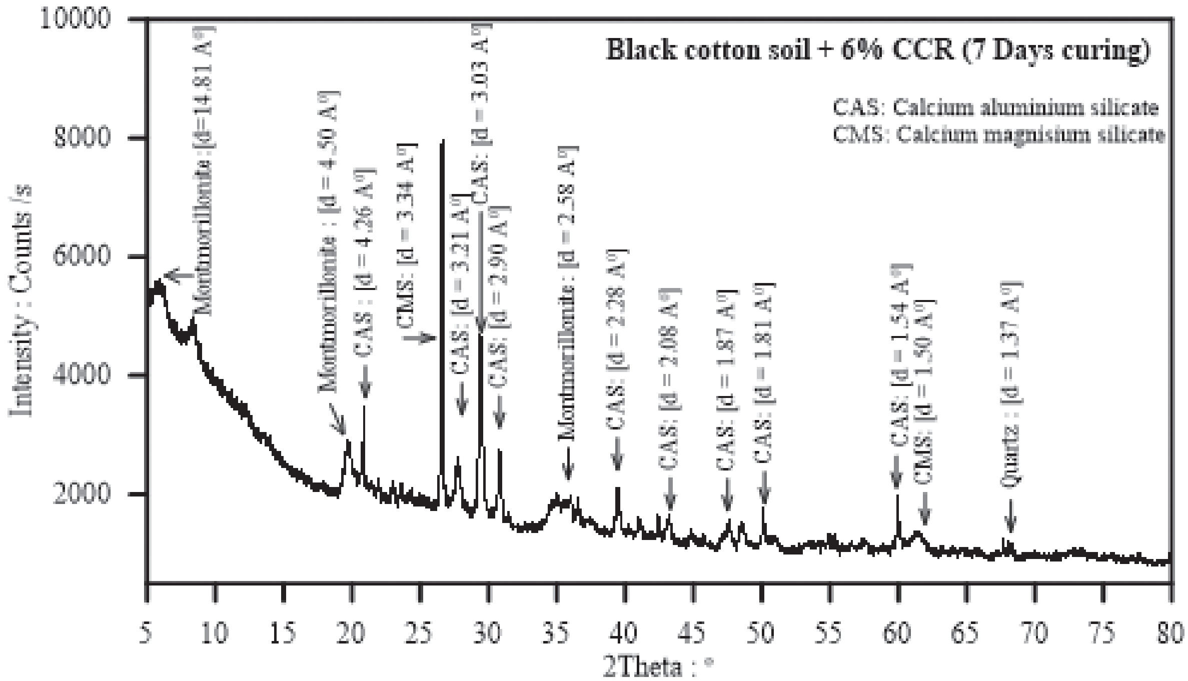

Figure 9: XRD analysis of 6 per cent CCR-treated black cotton soil

Swelling Pressure of CCR-Treated Soil

Figure 10 shows the rate of heave against time for CCR-treated and untreated soil. For all samples, heave was recorded up to 7 days of water inundation time. It was observed that, except untreated sample, all treated samples obtain equilibrium position within 15 minutes. The untreated soil took almost 7 days to stabilise heave. The untreated soil has high amount of clay particles (58 per cent), and water molecules will be strongly attracted to the soil minerals. The cation concentrations will increase due to negatively charged clay particles at the surface, which increases diffused double layer thickness. The increased double-layer will increase the thickness of the soil sample and hence maximum heave was observed for untreated soil. The diffused double layer will be supressed in CCR-treated soil due to exchange of cation that will help to stabilise heave in short period of time.

The conventional oedometer swelling pressure method is not suitable for chemically treated sample. This is true for calcium base stabilised soil due to time-dependent pozzolanic reaction. The stiffness of treated soil will increase with time hence to compress the soil to original volume will required larger pressure. This pressure may not be the swelling pressure, and hence to determine swelling pressure of CCR-treated sample, the constant volume method is used in this investigation. Swelling pressure is the ratio of maximum load shown by proving ring to keep soil sample at no volume condition to the cross-sectional area of the sample. Fig. 11 shows the effect of CCR on swelling pressure in black cotton soils.

The swelling pressure of the untreated soil sample was 192 kN/m^2; however, as CCR percentage increases, the swelling pressure decreases. During a pozzolanic reaction, calcium will react with silica and alumina of the soil and form water insoluble gel as discussed earlier. This gel will progress with time and bind the particle together and form strong matrix structure. This strong matrix structure has the ability to bind particle closely to reduce swelling. The maximum decrease in swelling pressure was observed at 6 per cent CCR; however, further increase in CCR has no significant effect on swelling pressure. This was mainly due to no further cation exchange phenomena because of complete consumption of silica and alumina from the soil.

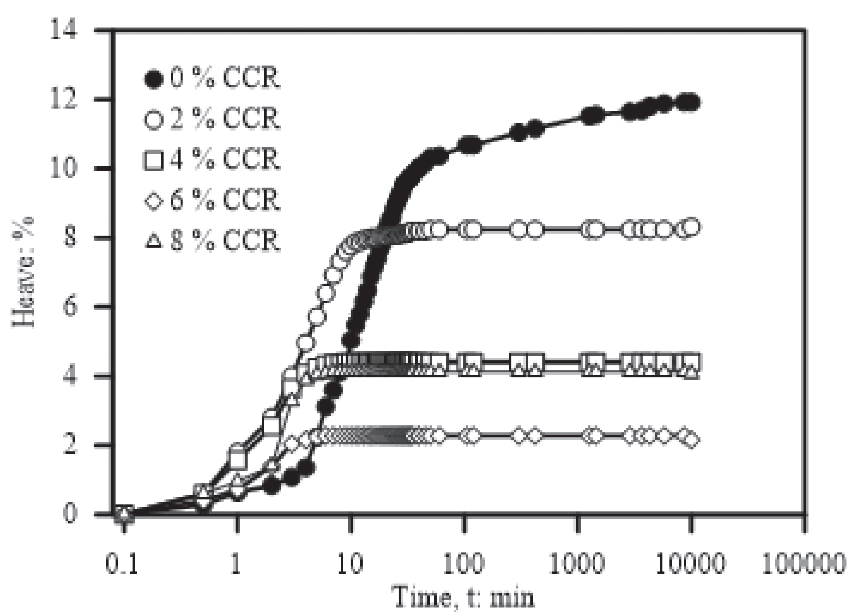

Figure 10: Heave observed in samples in CCR-treated black cotton soil

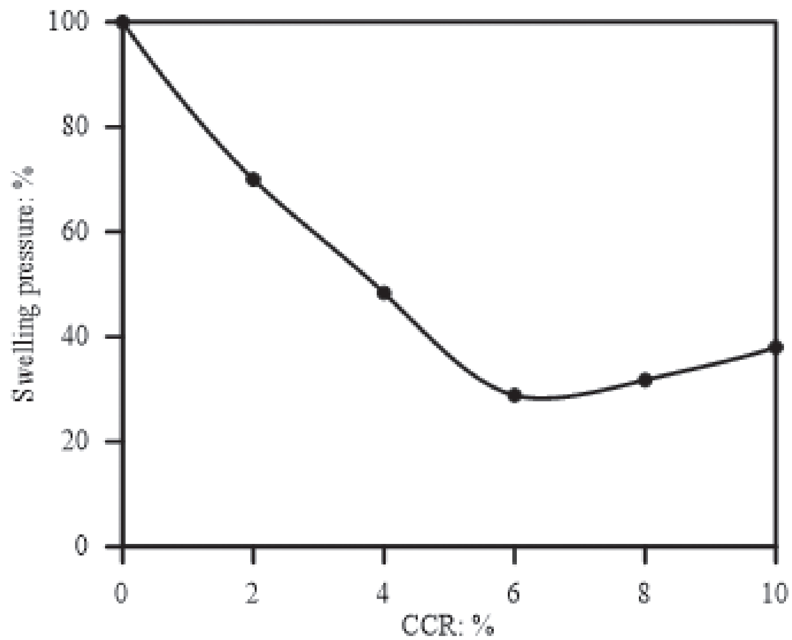

Figure 11: Effect of CCR content on swelling pressure in black cotton soil

Conclusion

A unique study of utilising calcium carbide residue (a by-product of acetylene manufacturing industry) in improving the performance of black cotton soil was carried out. The work was primarily focused on the evaluation of strength characteristics of the stabilised soil. The range of CCR dosage to bring out satisfactory stabilisation of the black cotton soil was evaluated through index properties, pH and UCS tests. Compressibility and unconfined compressive strength of CCR treated soil at 7 days curing are studied. All these results revealed that CCR could replace lime in all ground improvement technique. When soil was treated, more than the optimum percentage of CCR, the cementation gel was formed in between flocculated structure and the particles bind together. The results of UCS test showed increase in strength with CCR up to optimum percentage. UCS value decreased when CCR percentage exceeded the optimum limit. This was mainly due to excess amount of the cementitious gel, which was porous and had no strength. This conclusion was verified by using microstructural observations through XRD analysis. The XRD analysis also showed that the weak peak of clay minerals had attracted to calcium in CCR which leads to the formation of the cementitious compound. These cementitious compounds bind particles close together to increase the strength. Clay used in this study was found expansive in nature; hence, the swelling behaviour was also studied. The result showed that when soil was treated with optimum per cent CCR, both swelling potential and swelling pressure reduce drastically. All results obtained from this study help to seek new applications of CCR to reduce its impact on the environment and to stabilise problematic black cotton soil.

References

Al-Rawas, A. A., Taha, R., Nelson, J. D., Al-Shab, T. B., and Al-Siyabi, H. (2002). “A comparative evaluation of various additives used in the stabilization of expansive soils,” *Geotechnical Testing Journal*, 25(2), 199–209.

Consoli, N. C., Domingos, P., Prietto, M., Antonio, H., and Heineck, S.K. (2001). “Behavior of Compacted Soil fly-Ash carbide lime mixtures.” *Journal of Geotechnical and Geoenvironmental Engineering*, 127(9), 774–782.

Dash, S, K. and Hussain, M. (2012). “Lime Stabilization of Soils: Reappraisal.” *Journal of Materials in Civil Engineering*, 24(6), 707–714.

Horpibulsuk, S., Phetchuay, C., and Chinkulkijniwat, A. (2014). “Influence of wet-dry cycles on compressive strength of calcium carbide residue–fly ash stabilized clay.” *Journal of Materials in Civil Engineering*, 26 (4), 633–643.

Jaturapitakkul, C. and Roongreung, B. (2003).”Cementing material from calcium carbide residue-rice husk ash.” *Journal of Materials in Civil Engineering*, 15(5), 470–475.

Jones, D. E. and Holtz, W. G. (1973). “Expansive soils – the hidden disaster,” Civil Engineering-ASCE, 43(8), 49–51.

Kampala, A. and Horpibulsuk, S. (2013). “Engineering properties of silty clay stabilized with calcium carbide residue.” *Journal of Materials in Civil Engineering*, 25(5), 632–644.

Kumar, A, T., Robinson, R, G., and Thyagaraj, T. (2018). “Distress of an industrial building constructed on an expansive soil: a case study from India.” Proceedings of the Institution of Civil Engineers – Forensic Engineering, Ahead of Print.

PhaniKumar, B. R. and Sharma, R. S. (2004). “Effect of fly ash on engineering properties of expansive soils.” *Journal of Geotechnical and Geoenvironmental Engineering,* 130 (7), 764–767.

Rao, S, M., and Thyagaraj, T. (2003). “Lime slurry stabilisation of an expansive soil.” Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 156(3), 139–146.

Saldanha, B, R., Filho, H, C, S., Mallmann, F, J, E., Consoli, N, C., and Reddy, K, R. (2018). “Physical–mineralogical–chemical characterization of carbide lime: An environment-friendly chemical additive for soil stabilization.” *Journal of Materials in Civil Engineering*, 30(6), 1–6.

Nelson, E, J., Chao, K, C., Nelson, J, D., and Overton, D, D. (2017). “Lessons learned from foundation and slab failures on expansive soils.” *Journal of Performance of Constructed Facilities*, 31(3), 1–14.

Vichan, S., and Rachann, R. (2013). “Chemical stabilization of soft Bangkok clay using the blend of calcium carbide residue and biomass ash.” *Soils and Foundations*, 53(2),272–281.

Yaolin, Y., Liyang, G., Liu, S., and Puppala, A. (2015). “Carbide slag–activated ground granulated blast furnace slag for soft clay stabilization.” *Canadian geotechnical journal*, 52(1), 1–8.

Cost-Effective Base-Isolation System for Earthquake-Resilient Structures

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ABSTRACT: Earthquakes constitute one of the most damaging forms of disasters for the built infrastructure. The loss of functionality or collapse of the structures necessitates major relief and reconstruction work and puts a significant burden on the country's economy. Seismic base isolation is a well-known method to enhance the performance of structures during an earthquake. This method has been implemented in many structures worldwide and their performance during different earthquakes has reinforced the faith of the engineering community in this technique. However, the large cost of seismic isolation systems has limited their use to the critical structures or the structures with high importance. This paper discusses a frugal isolation system which is suitable for use in mid-rise residential structures which are up to 20–25 story high. An innovative concept of Seismic Isolation Platform (SIP) is proposed which can isolate a structure or a group of structures. The SIP utilises frugal isolation systems which are based on low-cost alternative materials. The proposed isolation system is based on the principle of Friction Pendulum (FP) bearing. The additional advantage of the FP bearings is the development of restoring force during an earthquake. Naturally occurring rocks are investigated as a substitute for conventional materials in isolation bearing. Rocks with large compressive strength and elastic modulus can be used as top and bottom plates in conventional isolation bearings. Polymeric overlays are examined to act as sliding surface in the bearing. A ten-story RC building with special moment resisting frame (SMRF) is analysed under fixed-base and base-isolated conditions. Four different periods of isolated structures are chosen by providing appropriate radii of curvature, *R*, for the FP bearings. Nonlinear dynamic analysis is performed by subjecting the structure to a suite of eleven ground motions. Inter-story drift ratios for different isolation periods and friction coefficients are compared.

KEYWORDS: earthquake-resilient, frugal isolation system, residential structures

Introduction

Despite the large development and advent of technology, statistics show that loss and damages from natural disasters are steadily growing. Out of different natural disasters, earthquakes have proved to be a major source of losses. Some recent major earthquakes have caused damage of the order of hundred billion dollars. In addition, in the last century earthquakes have killed more than 2.5 million people and have affected the lives of more than 100 million. Developing countries with high population are much more affected during major earthquakes. Many populous cities around the world are highly vulnerable to seismic damage. The 2015 earthquake in Nepal, where construction practices in many ways are similar to India, is a reminder to our engineering community. These all point to the necessity of a built environment that is resilient to earthquakes and other natural disasters. This paper proposes an innovative concept based on the technique of seismic base-isolation which can be implemented in most common housing

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types in Indian urban settings. In the technique of seismic isolation, a flexible layer is placed between the foundation level and the structure that elongates the fundamental period of the structure protecting it from the damaging effects of the earthquake. Alternately, sliding elements can also be placed in the place of flexible layers that undergo sliding when the lateral load on the structure increases above a predetermined level. For mass implementation, sliding systems are preferable over elastomeric systems from durability and other concerns. The interface of a sliding isolation system can be either flat or curved. Both dissipate energy by friction at sliding interface. Westermo and Udwadia (1983) and Mostaghel et al. (1983) studied the periodic response of a SDOF system isolated by a flat pure-friction system. They analysed different aspects of stick-slip motion in these studies. Mostaghel and Tanbakuchi (1983) studied response of sliding structures to earthquake support motion. Yang et al. (1990) studied response of multi-degree-of-freedom (MDOF) structures with sliding support. This study incorporated the higher mode effects in analysis of a four-story shear building. The response of pure-friction sliding structures to three components of earthquake excitation was studied by Shakib and Fuladgar (2003). The other type of sliding isolation is based on the sliding on a curved surface. The advantage with curved surface isolation is that a restoring force develops as the structure moves up the curved surface. Zayas et al. (1987) proposed Friction Pendulum System (FPS) as an innovative seismic isolation system offering improvement in strength and inherent performance benefits not available in earlier isolation systems. Experiments on building models were performed to show that FPS was a versatile isolation system using gravity and geometry to develop the restoring force (Zayas et al. 1990). Mokha et al. (1991) conducted an experimental study on six-story, quarter-scale structure isolated by Friction Pendulum System. Al-Hussaini et al. (1994) extensively investigated multi-story frame structures isolated using Friction Pendulum bearings. In a major application of FP bearings for seismic strengthening and retrofit, U.S. Court of Appeals building was isolated using these systems (Mokha et al. 1996). This landmark structure was earlier damaged during 1989 Loma Prieta earthquake and declared unsafe for further occupancy. Mosqueda et al. (2004) conducted experimental and numerical studies to examine behaviour of FP bearings to multiple components of excitation. The primary objective of this project is to propose novel seismic isolation platform (SIP) system to be implemented in a group of residential structures. This platform is suitable for a structure or a group of structures which has a common podium level. The system aims to be (1) low-cost, (2) constructed using locally available resources and (3) mass implementable. The proposed SIP consists of a low-cost isolation layer that is built below one or more buildings and decouples the structure from earthquake ground vibrations.

Methodology

The primary concept that is to be investigated is a low-cost sliding isolation layer made of readily available, durable materials. This layer is a frugal version of current advanced isolation bearings which cannot be mass implemented in India due to cost considerations. This isolation layer is placed below the slab supporting the structure as shown in Figure 1.

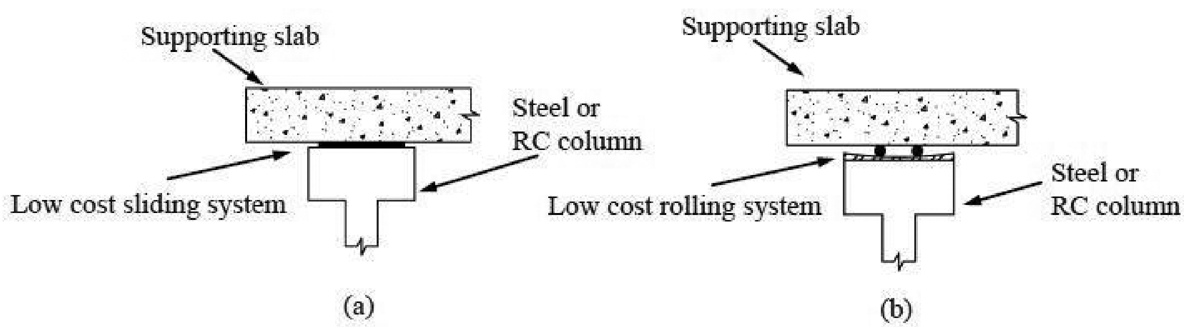

Figure 1: Proposed frugal isolation systems for SIPs (a) sliding system (b) rolling system

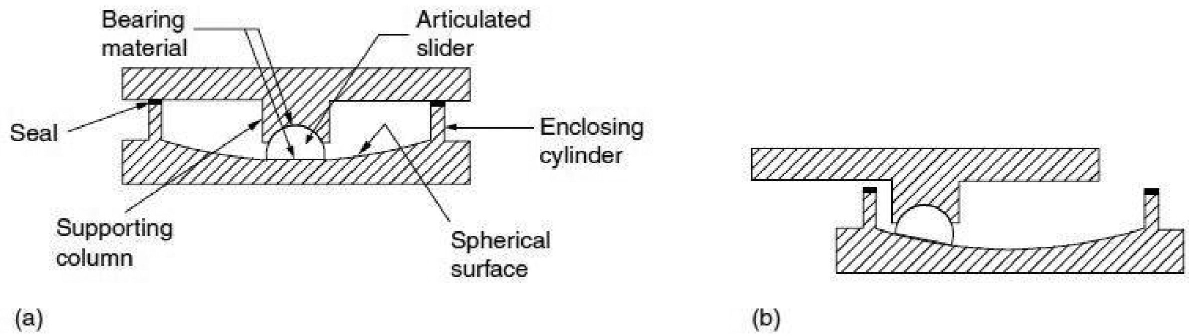

Figure 2: Sectional views of friction pendulum bearing in (a) centred and (b) displaced positions (Villaverde 2009)

The isolation unit utilises the concept of Friction Pendulum Bearings. Friction Pendulum system consists of an articulated slider sliding on a concave spherical surface under the effect of lateral ground motion. The articulated slider is coated with a low-friction and high-pressure capacity composite material. The supporting structural column rests on the articulated slider. During lateral ground motion the slider moves up along the spherical surface and causes the supported structure to rise as shown in Figure 2.

The natural period of an isolated structure is approximately equal to

$$T = 2\pi\sqrt{\frac{R}{g}} \tag{1}$$

where R is the radius of curvature of the concave surface and g is the acceleration due to gravity.

Equations of Motion

Figure 3 shows a two-degree-of-freedom model of a structure isolated with Friction Pendulum bearings. The equation of motion governing the response of the 2-DOF model can be written as

$$m_s \ddot{u}_s(t) + c_s \dot{u}_s(t) + k_s u_s(t) = -m_s\left[\ddot{u}_g(t) + \ddot{u}_b(t)\right] \tag{2}$$

$$m_b \ddot{u}_b(t) + f_b(t) + c_b \dot{u}_b(t) - c_s \dot{u}_s(t) - k_s u_s(t) = -m_b \ddot{u}_g(t) \tag{3}$$

where us denotes the displacement of superstructure relative to the isolation bearing and u_b denotes the isolator displacement relative to the ground. m_s and m_b are superstructure and base masses, respectively. k_s and c_s are stiffness and damping coefficient for the superstructure, respectively.

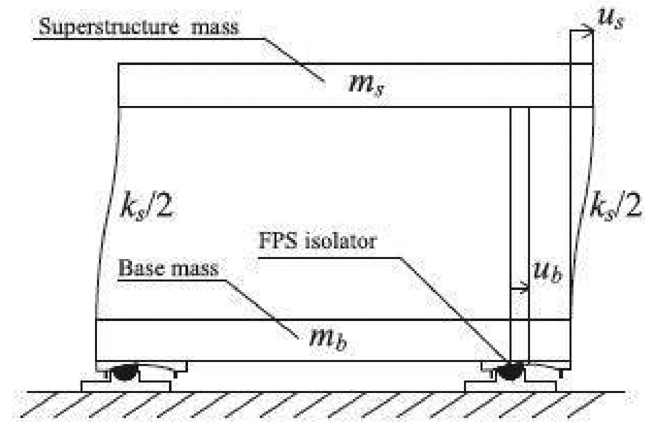

Figure 3: A two-degree-of-freedom model of structure isolated with FP bearings (Castaldo and Tubaldi 2015)

The FP bearing resisting force can be written as

$$f_b(t) = k_b u_b(t) + \mu(\dot{u}_b)(m + m_b) g Z(t) \tag{4}$$

where k_b = $(m_s+m_b)g/R$ is stiffness of FP bearing. R is the radius of curvature of the bearing and $\mu(\dot{u}_b)$ is the coefficient of sliding friction which depends on the bearing slip velocity. Also $Z(t) = sgn(\dot{u}_b(t))$, where $sgn()$ denotes the sign function.

Alternative Materials

In order to develop the cost-effective base isolation systems for mass implementation, it is imperative to make attempts to bring down the cost of the seismic isolation bearing. This can be achieved by looking for alternative materials which are low cost and/or locally available and can suitably substitute the conventional materials of the bearing components (Osorio and Augusto 2001). The bottom and top plates of the sliding isolation bearings are made up of steel castings. The cost of these components constitutes around 65–70 per cent of the total cost of the bearing. Naturally occurring rocks are reviewed as a substitute for the bottom and top plates of the bearings. Table 1 shows some physical properties of selected igneous and metamorphic rocks.

A rock surface, inherently, has large friction coefficient and an overlay needs to be put on it to provide a sliding surface suitable for isolation bearings. Different thermoplastic and thermosetting polymers used in industries and day-to-day life are reviewed for this purpose. Table 2 presents typical physical properties for some polymer-based bearing materials. Rocks with large elastic modulus and compressive strength, for example, Granite and Basalt, can be good candidates for use in the bearings. Experiments and analytical work are underway to examine the possibility of using the rock and sliding overlay system in the isolation bearings.

Table 1: Some Physical Properties of Igneous and Metamorphic Rocks (Bell 2013)

Rock	Specific Gravity	Unconfined Compressive Strength (MPa)	Shore Scleroscope Hardness	Young's Modulus (GPa)
Granite	2.68	176.4	77	60.6
Andesite	2.79	204.3	86	77
Basalt	2.91	321	86	93.6
Slate	2.67	96.4	41	31.2
Schist	2.66	82.7	47	35.5
Gneiss	2.66	162	68	46

Table 2: Typical Physical Properties of Polymer-Based Bearing Materials (Friedrich 2012)

Base Polymer	Filler	Ultimate Tensile Strength (MNm-2)	Shore Durometer	PV Limit (kNm-2ms-1)
Nylon 6 (extruded)	Nil	81.4		87.5
Nylon 6/6	PTFE, PE	72.4	86	525
Nylon 6 (cast)	MoS_2 + 5 per cent dye	82.7	85	105
UHMWPE	Silica sand	38.6		
PTFE (Nil)	Nil	6.9	52	63
Polyurethane	About 2 per cent	34.5	68	595

Example Building Description

A ten-story reinforced concrete building with special moment resisting frame (SMRF) system as shown in Figure 4 is considered for analysis. The building is assumed to be located in Mumbai. The frame has three bays with a bay-width of 5 m and the story height is 3.4 m. A tributary length of 6 m is considered for the loading on the frame. The column dimensions for the bottom two stories are 400 mm × 600 mm, for second to fourth stories are 400 mm × 500 mm and for the remaining stories are 400 mm × 400 mm. The dimensions for all the beams are 230 mm × 450 mm and the floor slabs are 200 mm thick. The dead and the live loads are applied according to IS-875 Part 2 (1987). The stiffness modifiers for columns are 0.70 and those for beams are 0.35. The earthquake load analysis for the structure is carried out according to IS-1893 Part 1 (2016). The Seismic Zone Factor Z of 0.16 for zone III is applied. The response reduction factor $R = 5$, and Importance factor $I = 1$ are chosen. Type I soil (rock or hard soil) is assumed to be underlying the structure. The dynamic analysis using Response Spectrum method is performed with a modal damping ratio of 0.05. The ductile design and detailing of the frame are done according to IS-13920 (2016).

The frame is seismically isolated using Friction Pendulum bearings. Four different values of the periods for the isolated structures are chosen for analysis. These periods are achieved by providing appropriate radii of curvature, R, for the FP bearings. The periods of isolated structures in this study are 3.5 s, 4.2 s, 5 s and 5.5 s and corresponding R values of the FP bearings are 3048 mm, 4388 mm, 6212 mm and 7524 mm, respectively.

Nonlinear Dynamic Analysis

The two-dimensional frame is modelled using Concentrated Plasticity (CP) approach. The beams and columns are modelled as elastic beam-column elements and joints are modelled as rotational hinges. The joints are modelled to capture strength and stiffness deterioration and are based on IMK model (Ibarra et al. 2005). Figure 5 shows backbone curve for IMK model. The curve is defined by elastic stiffness Ke, yield strength Fy, hardening stiffness Ks and postcapping stiffness $Kc = \alpha cKe$. The softening begins at cap deformation jc.

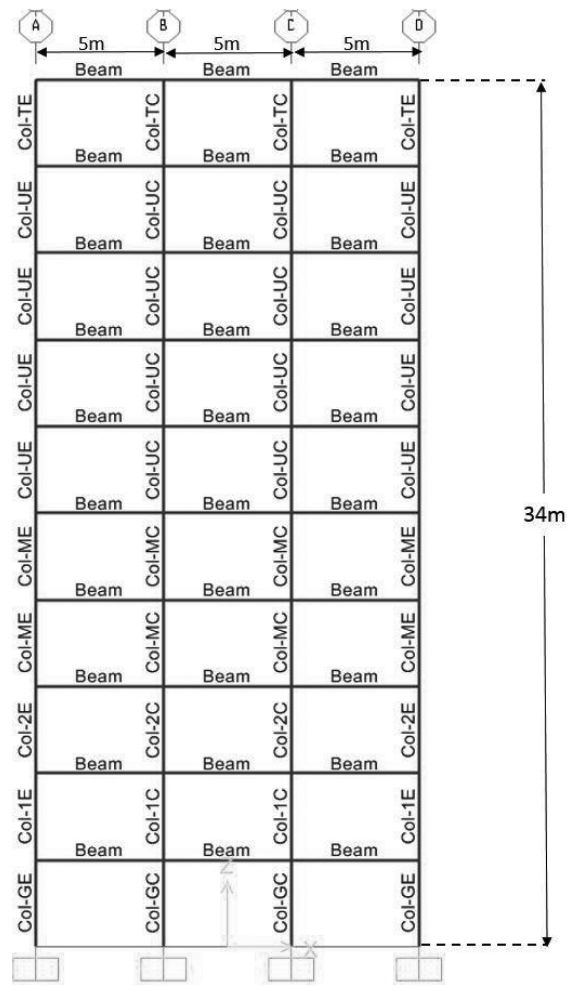

Figure 4: Model of ten-story structure with section labels in SAP2000

Figure 6 schematically shows frame portion where elastic beam-column elements are in series with rotational hinges. The nonlinear modelling is done using open source software OpenSees (McKenna et al. 2000). Friction Pendulum bearing is modelled by single FP bearing element inbuilt in the software. The first three periods of the fixed-base structure are 2.05 s, 0.68 s and 0.38 s respectively.

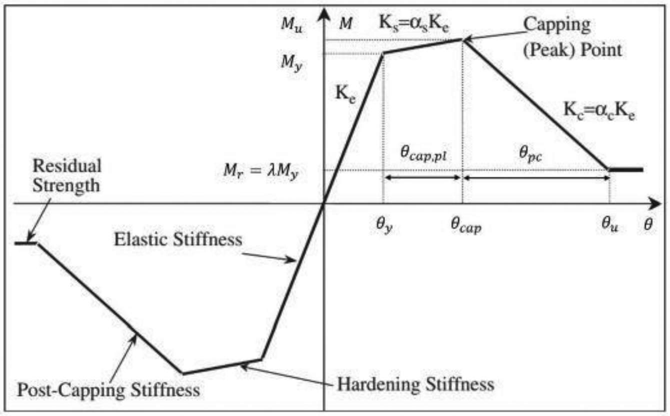

Figure 5: Backbone curve for IMK model (Ibarra et al. 2005)

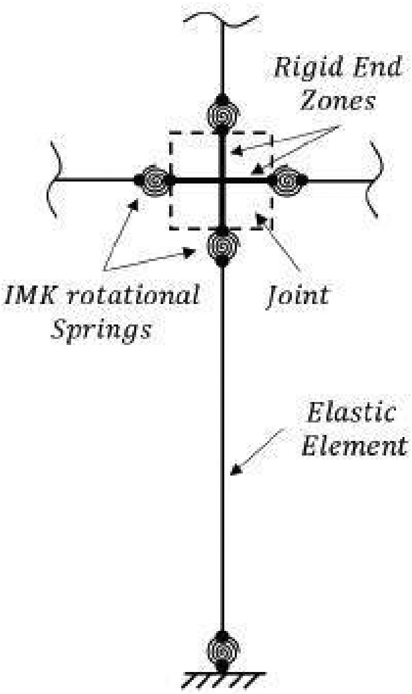

Figure 6: Elastic beam-column elements with rotational springs at joints

Ground Motion Selection

A suite of eleven ground motions is selected for the nonlinear time-history analysis of the RC frame. The ground motions representing the seismicity and tectonic setting of Mumbai are selected from PEER ground motion database. Mumbai is a part of the peninsular India which has witnessed low to moderate intensity earthquakes in the past. Koyna and Panvel source zones are two seismic zones identified around Mumbai (Sinha et al. 2010). Mumbai falls into the Panvel zone which strikes north-northwest direction along the west coast. For Mumbai region the hard-weathered rock is available at shallow depths in most parts of the city. Only for the reclaimed area, mainly in South Mumbai, soft soil is found at shallow depths. Based on the above seismicity information the input parameters as shown in Table 3 are decided for the ground motion selection.

Table 3: Input Parameters for Ground Motion Selection

Parameter	Type/Range
Fault type	Strike-Slip
Magnitude range	5.5, 6.5
R_JB (km)	10, 40
R_rup (km)	10, 40
Vs30 (m/s)	360, 760
D5–95 (sec)	15, 60
Pulse	No-pulse like records

Table 4 lists the selected ground motions with corresponding details. The ground motions record set is scaled to match the Zone III Maximum Considered Earthquake (MCE) spectral demand at T = 2.05 s. The ground motions are scaled according to the two-step process outlined in FEMA-P-695 (2009).

Table 4: Details of Selected Ground Motions with Scaling Factors

Serial no.	Event	Year	Station	Magnitude	Scaling Factor
1.	Parkfield	1966	Cholame – Shandon Array #12	6.19	2.24
2.	Livermore-01	1980	San Ramon Fire Station	5.8	4.21
3.	Morgan Hill	1984	Fremont – Mission San Jose	6.19	4.59
4.	Morgan Hill	1984	San Justo Dam (R Abut)	6.19	2.19

(*Continued*)

Table 4: (Continued)

Serial no.	Event	Year	Station	Magnitude	Scaling Factor
5.	Chalfant Valley-01	1986	Benton	5.77	6.09
6.	Chalfant Valley-02	1986	Benton	6.19	0.96
7.	Big Bear-01	1992	Snow Creek	6.46	3.92
8.	Chi-Chi, Taiwan-04	1999	CHY029	6.2	0.99
9.	Chi-Chi, Taiwan-04	1999	CHY006	6.2	0.93
10.	Parkfield-02, CA	2004	Coalinga – Priest Valley	6	3.45
11.	Joshua Tree, CA	1992	Morongo Valley Fire Station	6.1	1.80

Results and Discussion

Figure 7 shows inter-story drift ratio (IDR) values for three different sets of the coefficients of friction for the isolated structure's period of 4.2 s. For the lower stories the drift values are small and increase in the middle stories. This is because the column sizes are less in the middle stories. The lowest friction coefficient set (0.03, 0.08) causes largest IDR values for the lower stories. Figure 8 compares the IDR values for the different periods of the isolated structures. The plots show that the period of the isolated structure has negligible effect on IDR values.

Figure 9 shows variation in the IDR values along with their standard deviation along the height of the structure. This plot is for the isolated structure's period of 3.5 s. The maximum inter-story drift ratio is 0.0032 at roof level. In all cases, IDR values for the fixed-base case are much larger than those for the isolated structures.

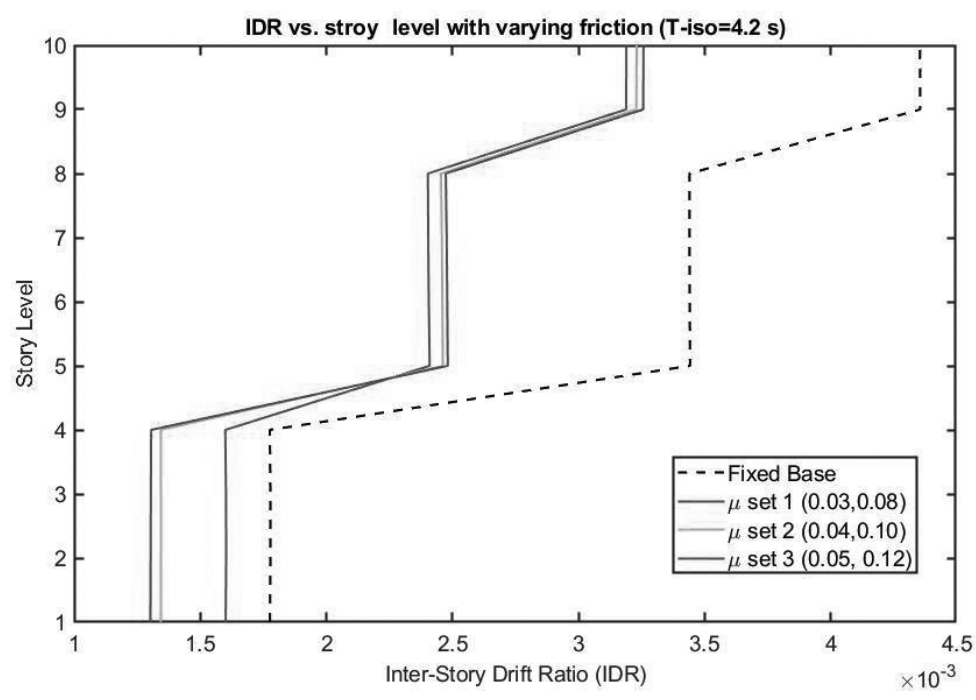

Figure 7: Inter-story drift ratios for fixed-base and isolated structures for varying coefficients of friction; isolated = 4.2 s (R = 4388 mm)

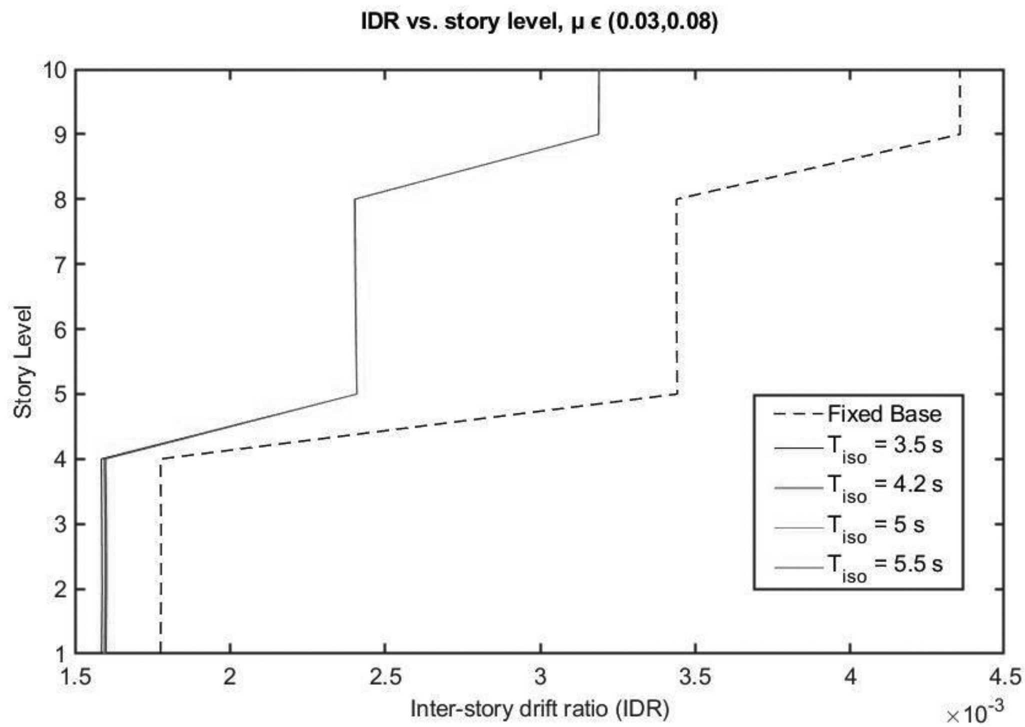

Figure 8: Inter-story drift values for different periods of isolated structure

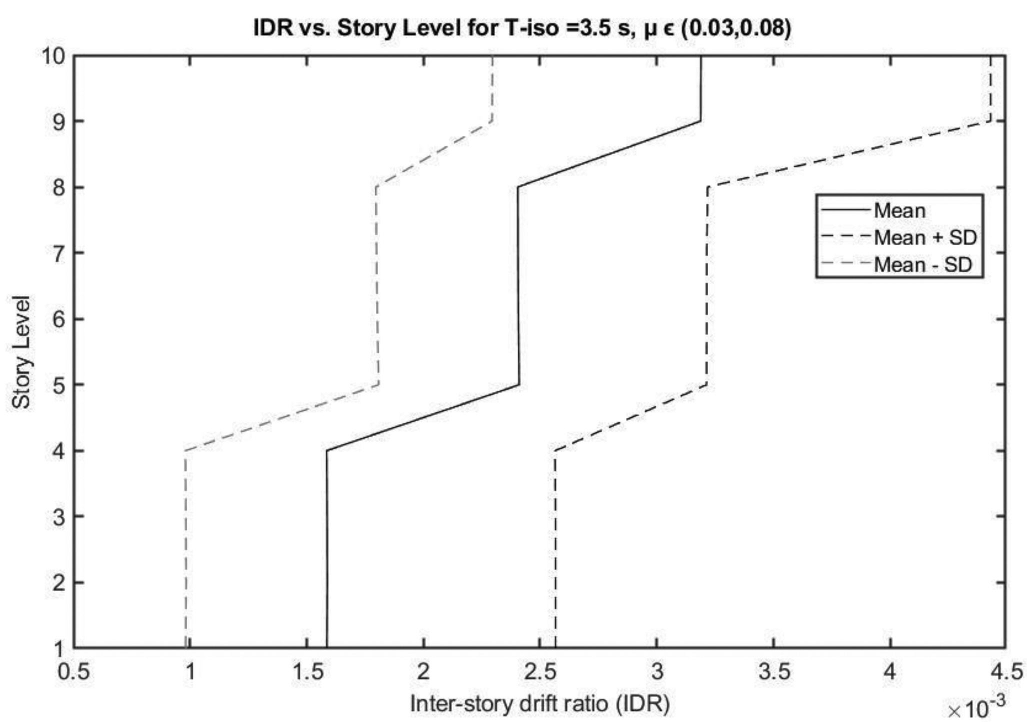

Figure 9: Variation in inter-story drift ratios; Tisolated = 3.5 s (R = 3048 mm)

Conclusion

A cost-effective methodology for the seismic base isolation is proposed which can be mass-implemented to develop an earthquake-resilient built environment. It is based on the concept of the Seismic Isolation Platform (SIP) which utilises the low-cost isolation systems. These isolation systems are chosen to be Friction Pendulum System as, apart from seismic isolation, it inherently has restoring capability resulting in smaller residual displacements. To achieve low cost of the proposed isolation system, alternative materials are investigated. Naturally occurring rocks with their high compressive strength and elastic modulus values are good candidates for this purpose. They can be used to replace the top and the bottom plates which are made up of steel castings. Also overlay materials to provide low friction coefficient for seismic isolation are examined. A ten-story RC building with the SMRF system, which is assumed to be located in Mumbai, is analysed. Four different periods of 3.5 s, 4.2 s, 5 s and 5.5 s are chosen for the isolated structures. The analysis results show that the seismic isolation significantly reduces the inter-story drift demands of the structure. Also, if friction coefficient values are very small the IDR values for the lower stories tend to increase. The proposed methodology of Seismic Isolation Platform utilising frugal isolation system seems to have potential of mass implementation and it needs to be investigated extensively for the same.

Acknowledgements

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References

Al-Hussaini, T. M., Zayas, V., and Constantinou, M. (1994). *Seismic isolation of multi-story frame structures using spherical sliding isolation systems*. National Center for Earthquake Engineering Research, Buffalo, NY.

Bell, F. G. (2013). *Engineering properties of soils and rocks*. Elsevier.

Castaldo, P., and Tubaldi, E. (2015). "Influence of FPS bearing properties on the seismic performance of base-isolated structures." *Earthquake Engineering & Structural Dynamics*, 44(15), 2817–2836.

Osorio, D., and Augusto, L. (2001). "Optimisation of base isolation systems using low-cost bearings and frictional devices." M.Eng. Thesis, Massachusetts Institute of Technology.

FEMA-P-695. (2009). *Quantification of Building Seismic Performance Factors*. Applied Technology Council, California.

Friedrich, K. (2012). *Friction and wear of polymer composites*. Elsevier.

Ibarra, L. F., Medina, R. A., and Krawinkler, H. (2005). "Hysteretic models that incorporate strength and stiffness deterioration." *Earthquake engineering & structural dynamics*, 34(12), 1489–1511.

IS-875 (Part 2). (1987). *Code of Practice for Design Loads (Other than Earthquake) for Buildings And Structures (Second Revision)*. Bureau of Indian Standards, New Delhi.

IS-1893 (Part 1). (2016). *Criteria for earthquake resistant design of structures (Part 1):*

General Provisions and Buildings (Sixth Revision). Bureau of Indian Standards, New Delhi.

IS-13920. (2016). *Ductile design and detailing of reinforced concrete structures subjected to seismic forces - Code of Practice (First Revision)*. Bureau of Indian Standards, New Delhi.

McKenna, F., Fenves, G., and Scott, M. (2000). *Open system for earthquake engineering simulation (OpenSees)*. Pacific Earthquake Engineering Research Center, University of California, Berkeley.

Mokha, A., Constantinou, M., Reinhorn, A., and Zayas, V. A. (1991). "Experimental study of friction-pendulum isolation system." *Journal of Structural Engineering*, 117(4), 1201–1217.

Mokha, A. S., Amin, N., Constantinou, M. C., and Zayas, V. (1996). "Seismic isolation retrofit of large historic building." *Journal of Structural Engineering*, 122(3), 298–308.

Mosqueda, G., Whittaker, A. S., and Fenves, G. L. (2004). "Characterization and modelling of friction pendulum bearings subjected to multiple components of excitation." *Journal of Structural Engineering*, 130(3), 433–442.

Mostaghel, N., Hejazi, M., and Tanbakuchi, J. (1983). "Response of sliding structures to harmonic support motion." *Earthquake Engineering & Structural Dynamics*, 11(3), 355–366.

Mostaghel, N., and Tanbakuchi, J. (1983). "Response of sliding structures to earthquake support motion." *Earthquake engineering & structural dynamics*, 11(6), 729–748.

Shakib and Fuladgar, H., A. (2003). "Response of pure-friction sliding structures to three components of earthquake excitation." *Computers & Structures*, 81, 189–196.

Sinha, R., Goyal, A., Shinde, R. M., and Meena, M. (2010). *Seismic Risk Assessment of Mumbai*. Indian Institue of Technology Bombay.

Villaverde, R. (2009). *Fundamental concepts of earthquake engineering*. CRC Press.

Westermo, B., and Udwadia, F. (1983). "Periodic response of a sliding oscillator system to harmonic excitation." *Earthquake engineering & structural dynamics*, 11(1), 135–146.

Yang, Y.-B., Lee, T.-Y., and Tsai, I.-C. (1990). "Response of multi-degree-of-freedom structures with sliding supports." *Earthquake Engineering & Structural Dynamics*, 19(5), 739–752.

Zayas, V. A., Low, S. A., and Mahin, S. A. (1987). *The FPS earthquake resisting system experimental report*. Earthquake Engineering Research Center.

Zayas, V. A., Low, S. S., and Mahin, S. A. (1990). "A simple pendulum technique for achieving seismic isolation." Earthquake spectra, 6(2), 317–333.

Building Design Strategies to Mitigate Flooding Disasters

Dhanashri Mirajkar[a]

ABSTRACT: Since the dawn of civilisations, humans have seen many natural disasters. Ancient civilisations always flourished on the banks of rivers. As a result, flood always played an important role in human lives. A world-destroying flood is a common legend in the ancient history of the Americans, Babylonians, Indians, Persians, Polynesians and Syrians. Archaeologists in Mesopotamia have discovered evidence of severe flooding at various levels – in particular a stratum of clay, eight feet deep, excavated by Sir Leonard Woolley at Ur, which he identified with the biblical flood. The Babylonian records say that some 4,000 years old refer to a "dark cloud" that encompassed the planet and intense fire that scorched the land – all that was bright was turned into darkness. For six days a deluge of water driven by hurricane winds swept over earth, destroying all forms of life and changing the face of the planet. Indus River changed dramatically around 1900 B.C. probably flooding many settlements along the river and disrupting the Indus valley civilisation. Floods played an important role in the decline of the Harappan civilisation. Several individual sites like Dholavira show that floods and rising sea levels leading to increased salinity made them uninhabitable. The Rann of Kutch, for example, was inhabited during the Harappan era. Floods destroyed the agricultural base of the cities. Trade and economy were disrupted. Hundreds of villages may have been destroyed by floods or by rivers. In today's context also, floods are the most common natural disasters occurring in many areas on the earth. India has a huge coastal area as well as large flood prone areas like Bihar, Assam and many other states. Loss of lives and damage of properties are the outcomes of flood. The social and economic impacts of flood are severe and cannot be avoided. Due to impact of flood, buildings get damaged directly. During or after the flood, degradation of building material takes place. Flood-borne substances cause contamination of the building. A successful flood-resistant design can overcome all these problems and buildings can resist flood loads over decades. At city-level planning stage, innovative street and public realm designs can slow and store rainwater, resulting in reduced flooding. This paper illustrates the mitigation strategies of building design for flood prone areas. Implementing mitigation strategies for flooding disasters can help to get a rede of loss due to flooding. The management and control of floodwater movement can prevent the loss of lives as well as assets. Good planning and management at building design stage can help in curbing the risks of flooding. It is therefore very important that flooding risks must be taken into account during any planning process.

KEYWORDS: amphibious, debris, disaster, flood, flood resistant, mitigation

Introduction

India lies on the banks of three oceans resulting in huge coastal areas, as well as large flood prone areas like Bihar, Assam and in many other states. These coastal areas face difficulty due to floods almost every year. The loss of lives and property takes place due to flooding disasters which affect the social and economic life of people.

There are areas that are more susceptible to flooding than others. Poor infrastructure of the drainage system contributes to even more flooding risks. This therefore

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calls for proper planning especially for any proposals of development in areas that are prone to flooding. The following is a list of major flood disasters that took place in India.

- In October 1943, Madras saw the worst flood to hit the city. Damage caused to life and property was immense however estimate figure is unknown.
- On 11 August 1979, the Machchhu-2 dam situated on the Machchhu-2 dam river burst, thus flooding the town of Morbi in the Rajkot district of Gujarat. Exact figure of loss of lives is unknown, but it is estimated between 1800 and 2500 people.
- In 1987, Bihar witnessed one of its worst floods till then. Flood occurred due to overflow of the Koshi river, which claimed lives of 1,399 humans, 302 animals and public property worth INR ₹68 billion.
- Heavy rains across the state of Maharashtra, including large areas of the metropolis Mumbai on 26 July 2005 killed at-least 5,000 people. Mumbai International Airport remained closed for 30 hours, Mumbai-Pune Expressway was closed for 24 hours with public property loss estimated at ₹550 crore .
- June 2015 Gujarat flood: Heavy rain in June 2015 resulted in widespread flood in Saurashtra region of Gujarat resulting in more than 70 deaths.
- 2015 South Indian floods: Heavy rain in Nov–Dec 2015 resulted in flooding of Adyar, Cooum River of Chennai and Tamil Nadu resulting in financial loss and human lives.
- 2016 Assam floods: Heavy rains in July–August resulted in floods affecting 1.8 million people and flooding the Kaziranga National Park killing around 200 wild animals.

What Contributes to Flooding?

Flooding is the overflow of excess water from a water body onto adjacent lands. FEMA (Federal Emergency Management Agency, USA) more specifically defines a flood as "a general and temporary condition of partial or complete inundation of normally dry land areas from the overflow of inland or tidal waters or the unusual and rapid accumulation or runoff of surface waters from any source".

One or more water bodies can contribute to flooding at a given site like a stream, a river, a bay, a pond, an ocean, a lake or storm water; depending upon local topography and hydraulic conditions.

Most Common Effects of Flooding

Floods have large social consequences for communities and individuals. As most people are well aware, the immediate impacts of flooding include loss of human life, damage to property, destruction of crops, loss of livestock and deterioration of health conditions owing to waterborne diseases as well as famine conditions.

The only way to avoid effects of flooding is to live away from flood prone zones. Coastal plains, flood plains, valley bottoms and the banks of stream channels are unsafe and may be described as areas where surface water is the prime land eroding and formatting agent. Living in these areas, for whatever reason, implies a compromise which has a concomitant increase in risk and hence vulnerability to this type of natural hazard.

In developing countries this risk is accepted as the vulnerable locations are absolutely essential for, for example, agriculture, and communications and building materials. To avoid large fertile food plains would be impossible. Hence in Bangladesh 30 per cent or more of the land is subject to regular seasonal flooding.

Following a flood incidence it is appropriate to focus on the disastrous effects by asking a series of pertinent questions concerning the interaction of the structures and building materials with the water. Following are the effects of flood on structures:

- Direct damage during a flood from inundation, high velocity flow, waves, erosion sedimentation and/or flood-borne debris as shown in Figure 1(A)
- Degradation of building materials, either during the flood or sometime after the flood as shown in Figure 1 (B)
- Contamination of the building due to flood-borne substances or mold as predicted from Figure 1 (C).

(A)

(B)

(C)

Figure 1: Direct damage of structure

Characteristics of a Successful Flood-Resist Building Design

A "successful" building will resist flood loads and other loads over a period of decades, and will exhibit the following characteristics:

- Any flood damage will be minor and easily repairable
- The foundation will remain intact and fully functional following a design flood
- Any breakaway enclosures below the DFE will break free without causing damage to the elevated building, the foundation, building access structures or utility systems
- The building envelope will remain sound
- Utility connections will be intact or easily restorable after a design flood
- The building will be accessible and usable after a design flood
- A successful flood-resistant design requires the character of flood conditions during the design flood, including source of flooding, flood depth, flood velocity, flood duration, rate of rise and fall, wave effects, flood-borne debris, scour and erosion.

How to Achieve Good Flood-Resistance Building Design?

Flooding presents a major risk role for buildings so it is an essential role to play in managing and reducing this risk. Flooding is a fact of modern life – we need to accept and learn to live with this but importantly we also need to make sure we are adequately prepared. The following are the areas of building design where utmost care can be taken to achieve a good flood proof building.

Site Development

Site development is the important aspect of flood proof design as flood affects the site at first.

Accessory Structure

A low cost and small structure (less than or equal to 100 sq. ft) made up of metal, wood or plastic, as shown in Figure 2, should be provided on site detached from main structure and should be detachable. Small accessory structures must be unfinished on the interior, constructed of flood damage-resistant materials, used only for storage, and, if provided with electricity, the service must be elevated above the BFE.

Detached Garages

Garages may be constructed under elevated buildings and enclosed with breakaway walls, as shown in Figure 3. These structures are not walled and roofed in the traditional sense, and can be designed to allow the free passage of floodwaters and waves through structures.

Figure 2: Accessory structures

Figure 3: Garage allows free way to flood waters

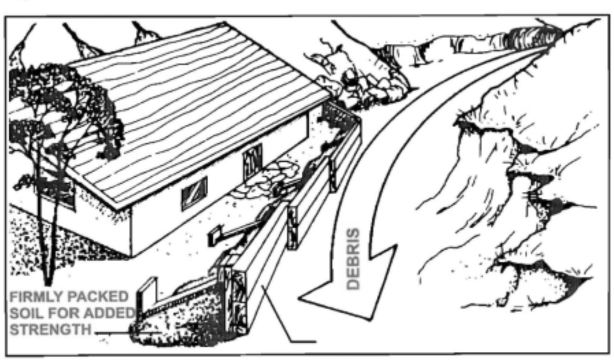


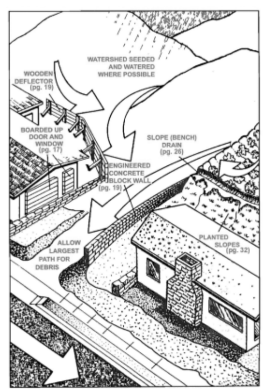
Figure 4: Fence wall diverts debri

Fences/Privacy Walls

Fences and privacy walls (including walls separating one property from another) may obstruct or divert flood flow and waves as shown in Figure 4. They must be analysed for their effects on flood conditions and the effects of debris generated by fence/wall failure during flood events.

Erosion Control Structures

Strengthening the soil to resist erosion straw or wood chips is effective in holding the soil in place. They have the added value of increasing the organic content of the soil. Either material should be worked into the top few inches of the soil. Place a covering of chips 1 inch (or less) as slope and soil conditions indicate. Woven burlap as shown in Figure 5 (C) can be laid on the slope and tied down with stakes to prevent lifting by wind or water. The burlap will decompose eventually, but will remain long enough for vegetation to become well established.



(A) Unprotected homes cause high erosion

(B) Protected homes stop erosion

(C) Burlap

Figure 5: Erosion control structures

Filling in Site

Fill placed on sites should be similar to natural soils in the area. In many coastal areas, this will be clean sand or sandy soils free of large quantities of clay, silt and organic material. Non-structural fill should not contain large rocks and debris. If the fill material is truly similar to natural soils, its behaviour under flood conditions should be similar to the behaviour of natural soils, and should not be a subject of debate.

Ground Elevations at or above the BFE

The buildings must be designed and constructed on pile or column foundations that are embedded deep into the ground. The bottoms of the lowest horizontal supporting members must be at or above the BFE. A two-feet vertical clearance between the bottom of the lowest horizontal supporting member and the ground is recommended. The soil around such buildings should be graded to drain water away from the foundations.

Septic Systems

Septic system tanks must NOT be structurally attached to building foundations. Plumbing and piping components must NOT be attached to or pass through breakaway wall panels.

Flood Proofing

Flood proofing is the process of making a building resistant to flood damage, either by taking the building out of contact with floodwaters or by making the building resistant to any potential damage resulting from contact with floodwaters. There are two types of flood proofing.

Active Flood Proofing

Active flood proofing, sometimes known as contingent (partial) or emergency (temporary) flood proofing, requires human intervention to implement actions that will protect a building and its contents from flooding. Successful use of this technique requires ample warning time to mobilise people and equipment and flood proofing materials.

Dry Active Flood Proofing:
Temporary flood shields or doors (on building openings), temporary gates or panels (on levees and floodwalls), emergency sand bagging.

Wet Active Flood Proofing:

Temporary relocation of vulnerable contents and equipment prior to a flood, in conjunction with use of flood-resistant materials for the building.

Passive Flood Proofing

Passive flood proofing, sometimes referred to as permanent flood proofing, requires no human intervention – the building (and/or its immediate surroundings) is designed and constructed to be flood proof without human intervention.

Dry Passive Flood Proofing:

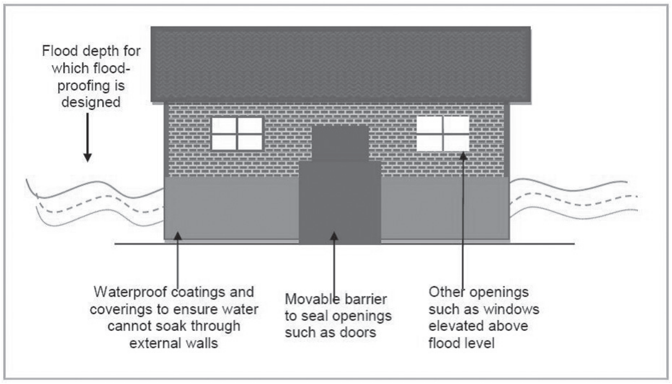
Waterproof sealants and coatings on walls and floors permanently installed automatic flood shields and doors. Installation of backflow prevention valves and sump pumps.

Wet Passive Flood Proofing

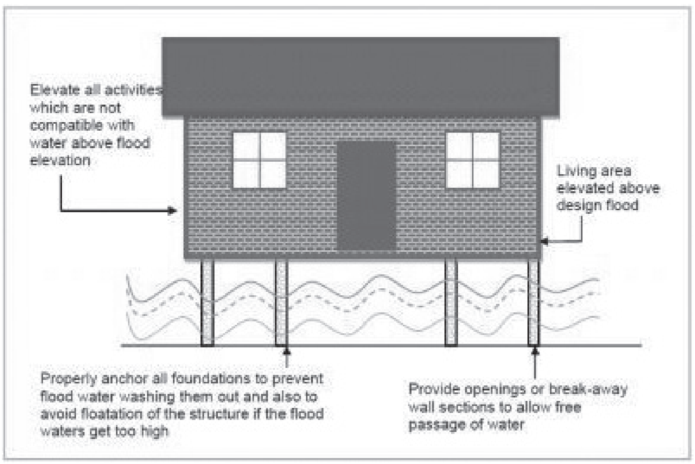
Use of flood-resistant materials below DFE Installation of flood vents to permit automatic equalisation of water level elevation of vulnerable equipment above Design Flood Elevation.

Dry-flood proofing requires use of special sealants, coatings, components and/or equipment to render the lower portion of a building watertight and substantially impermeable to the passage of water as shown in Figure 6.

Wet-flood proofing allows the uninhabited lower portion of a building to flood, but uses materials that will not be damaged by flooding as shown in Figure 7(b).



Basic dry flood-proofing measures



Basic wet flood-proofing measures

Figure 6: Flood proofing

Sealants, Flood Shields and Valves

A wide variety of materials and devices shown in Figure 7 have been developed to make building walls, floors, openings, penetrations and utilities watertight during flooding. Flood shields, panels, doors and gates are typically used to close medium to large openings in building walls. They can be temporary closures that are installed only when a flood threatens, or they can be permanent features that are closed manually or automatically. Key design parameters of these barriers are their height, their stiffness (and resistance to hydrostatic forces), their method of attachment or installation, and their seals and gaskets. As a general rule, flood shields, panels, doors and gates should not be attached to building windows, glazing or doors. Given the potential for large flood loads, they should be attached to exterior walls or the structural frame. Designers planning to incorporate flood shields, panels, doors or gates into a building design are advised to consult with engineers and vendors experienced with the design and installation of these components.

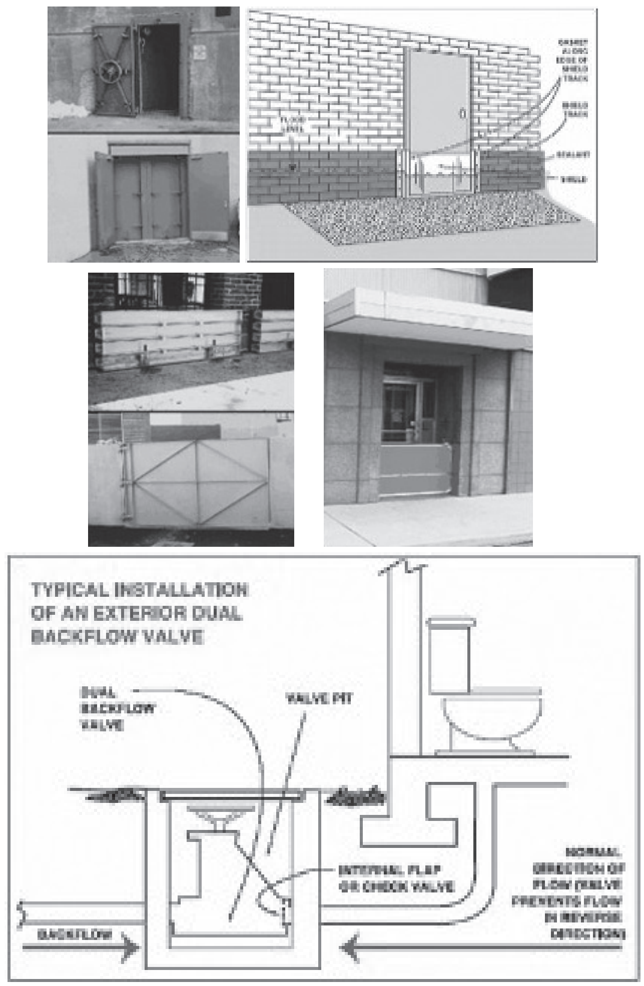


Figure 7: Sealant, shields and valves

Flood Openings

Areas below the Design Flood Elevation must be equipped with flood openings capable of equalising water levels and hydrostatic loads. Openings in Foundation Walls and Walls of Enclosures should be with special treatment. Since owners usually want to control temperature and moisture in these enclosed areas (and prevent rodents, birds and insects from entering), opening covers are often employed. These covers must not interfere with the equalisation of water levels in the event of a flood, and should be selected to minimise potential blockage by debris. There are a variety of commercially available covers, such as grates, louvers and grills that allow for control of the enclosed space and the passage of floodwaters as predicted in Figure 8.

Flood-Resistant Material

Choosing material for flood-resistant structures is an important aspect in flood proof design. The material should be able to fight against floodwater effects.

Flooring Materials

- Concrete, concrete tile and pre-cast concrete
- Latex or bituminous, ceramic, clay, terrazzo, vinyl, and rubber sheets and tiles
- Pressure-treated (PT) or decay-resistant lumber
- PT wood and cold-formed steel.

Wall and Ceiling Materials

- Brick, metal, concrete, concrete block, porcelain, slate, glass block, stone, and ceramic and clay tile
- Cement board, cold-formed steel and reinforced concrete
- Polyester epoxy paint
- Decay-resistant lumber
- Marine grade plywood
- Foam and closed-cell insulation
- Decay-resistant wood like Black Locust (*Robinia pseudoacacia*), Teak (*Tectona grandis*), Ipe (*Tabebuia spp.*), California Redwood, (*Sequoia sempervirens*), Western Redcedar (*Thuja plicata*), Loblolly Pine (*Pinus taeda*), European Larch (*Larix decidua*), Bald Cypress (*Taxodium distichum*).

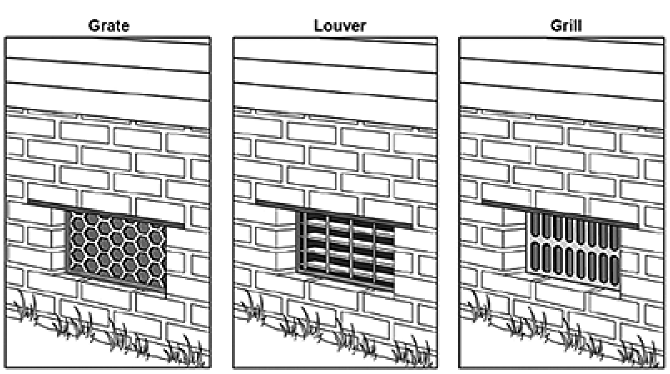


Figure 8: Flood openings

Other

Hollow metal doors, cabinets, and foam or closed-cell insulation

Base Flood Elevation Elements

The elements affected due to flood are those which are below base flood elevation as they remain in direct contact with water. So it is essential to give special attention to these elements.

Access Stairs and Ramp

Stairs and ramps required to:

- Break away during base flood conditions without causing damage to the building or its foundation,
- Resist flood loads and remain in place during the base flood.

Foundation Bracings

Elevated coastal home with timber cross-bracing, principally in the shore-perpendicular direction as predicted in Figure 9.

Figure 9: Foundation bracing

Grade Beams

Grade beams typically are made of wood or reinforced concrete; they are used to tie together the columns or foundation piles to provide additional lateral support. Grade beams must resist flood, wave and debris loads when undermined.

Floating Houses

Float house is a Canadian and American term for a house on a float (raft), a rough house may be called a shanty boat. In Western countries, houseboats tend to be either owned privately or rented out to holiday-goers, and on some canals in Europe, people dwell in houseboats all year round.

Need of Floating Houses in India

India has a huge coastal area as well as large flood prone areas like Bihar, Assam and many other states where almost every year public face difficulty due to floods and loss of lives and property takes place. In case, the principle of construction of floating houses is adopted in which the houses would rise during floods and subside down during dry conditions, loss of lives and property can be avoided. Simple techniques based on telescopic arrangements should be designed for requirements. Therefore, research and development can be taken up as model projects for developing such designs. To begin with, life line buildings in the flood prone areas can be constructed using such techniques. These buildings will function even during the period when they remain cut off due to floods and have no external electricity and water. In the islands and coastal areas, such houses will certainly be adopted sooner or later and thus Indian architects and designers should start getting expertise in this field to design such houses. Floating houses can also be built for tourists who would love to stay in such houses and India can generate considerable revenue from the same.

Basic Principle of Construction

Generally there are two basic principles for making floating houses. First is the pontoon principle, shown in Figure 10, in which one makes a solid platform, lighter than the water and the other based on the ship in which a hollow concrete box is created which is open on the top. The pontoon principle has the benefit of its use in shallow water, compared to the hollow concrete box while the concrete box has the benefit of higher space utilisation within as a part of the building. Both types of floating houses are connected with a flexible connection to the quay, so the houses can rise with the water when the tide changes. When needed the floating system can be moved elsewhere at short notice without leaving any scar to the environment. Instead a new house can be placed in to one which makes it the most sustainable and durable way to build.

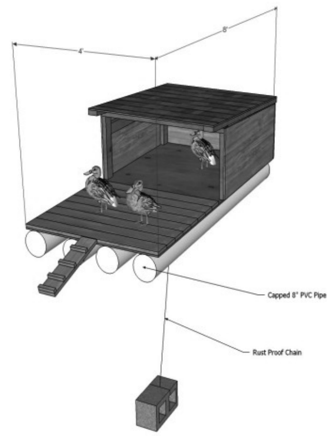


Figure 10: Pantoon principle

Services

Providing services in a floating house is a challenge which includes water supply, electricity and toilets. Therefore, the green building concept has to be followed in the floating houses which uses non-conventional resources for energy, makes use of waste products and recycles the water. Net zero energy buildings are more useful as they do not require additional energy from external source and total energy demand is met from onsite generation power. Normally solar panels are provided for the energy requirements. Due to aesthetic requirements as well as energy efficiency, roof gardens are also becoming popular. Other measures include incinolets (toilets which use electric heat) to burn waste, geothermal pond loops into the floor, and filtration unit for drinking water collected from rainstorms.

Water Gates

The water gate flood wall is designed to contain and stop heavy water flow due to severe flooding. Water gates are quick and easy to deploy to prevent heavy floodwater from reaching the property. Quick dam water gate is self-rising flood barrier that is quick and easy to use to contain large floodwaters as predicted in Figure 11.

Figure 11: Water gate

Conclusion

The occurrence of flood causes hazard to human as well as non-human communities along the river corridor. The immediate impact of flooding includes loss of human lives, damage of property, destruction of crops, loss of livestock and deterioration of health conditions owing to waterborne diseases. The loss of lives and properties affect the social and economic life of people. The only way to avoid effects of flood is to live away from flood prone zones. Due to scarcity of land in developing countries, this risk is accepted. Also vulnerable locations are absolutely essential as river basins provide fertile crescents, ease in communication and transportation and availability of many other resources.

Buildings and infrastructure are the major areas which get affected due to flooding disasters. Direct damage, degradation and contamination are the effects of flooding on building structures. Buildings can resist flood and over a period of decades only if they are designed to mitigate the flooding disasters.

The paper has illustrated the strategies for achieving good flood-resistant building design. Site development, flood proofing, sealants, flood shields, valves, flood openings, use of flood-resisting materials and base flood elevation elements are the areas which should be taken care of at design stage. These strategies can help to achieve a good flood-resistant building structure which can mitigate flooding disasters. Paper also discussed about floating houses and water gates which are useful in flood prone areas.

The paper gives direct guidelines for designing in flood prone areas. by using these guidelines and strategies it is possible to mitigate flooding disasters saving loss of lives and buildings, resulting in stable social and economic life.

Bibliography

Homeowner's guide for flood, debris, and erosion control, Riverside fire department, office of emergency management, Guided by PWD, Los Angeles

https://en.wikipedia.org/wiki/Floods_in_India

Jones, Christopher P. PE, Flood Resistance of the Building Envelope (http://www.adit.org.il/site/includes/Admin/Articles/PDF/Flood Resistance of the Building Envelope.pdf)

Linham, Matthew M., Nicholls, Robert J., Flood Proofing, University of Southampton www.climatetechwiki.org/content/flood-proofing

Technical Bulletin 5, Free of Obstructions, Federal Emergency Management Agency, USA

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Role of Civil Engineers in Disaster Mitigation

Sunil Kumar Chaudhary[a]

ABSTRACT: The natural environmental changes such as global warming, heat island phenomena in mega cities, the decrease in the number of forests, desertification and erosion of rivers, are resulting in extremely heavy rains and snows, huge typhoons and hurricanes, abnormally high temperature and high tidal waves. In addition to the change of natural environment, our social environment is also changing and it is becoming fragile against natural disasters. Those are highly congested urban areas, depopulation of rural areas, human habitation on disaster-prone lands, lack of cooperation and communication among recent urban societies, and insufficient infrastructures for disaster mitigation. The characteristics of the natural disasters are changing due to the changes of the natural and social environment. In this paper the author discusses the basic concept of the policies for the natural disaster mitigation and the roles of civil engineers.

KEYWORDS: disaster, mitigation, environment, civil engineer

Introduction

Disasters are adverse or unfortunate events or great and sudden misfortunes which have a profound effect on society and the nation. They may occur due to natural causes such as earthquakes, tsunamis, floods or cyclones or due to man-made causes such as blasts, missile attacks or fire. Generally, during a large-scale disaster, civil engineering structures like buildings, bridges, dams, roads, water supply projects, coastal structures, infrastructure facilities etc. are severely affected, causing immense inconvenience to people and disrupting routine life. Prevention of natural disasters is not possible but reduction in the undesirable effects of disasters can be the only way to cope with them. Natural disasters identify the mistakes made in the process of development of civil engineering structures in that particular locality, and teach important lessons for the future. If the learning from such undesirable events is utilised, hazardous effects can be reduced in the coming years. Civil engineers can play a major role in disaster mitigation by creating safe structures through the integrated efforts of all those involved in the construction process.

Causes of Damage

The majority of damage during natural disasters is caused due to the improper planning of cities and various infrastructure facilities, lack of site investigations, improper structural planning and design, violation of specifications, poor quality control at construction works and lack of coordination between the various departments involved in a project. A man-made disaster is generally caused due to terrorist activities or human carelessness and the severity depends on the security measures.

Basic Concepts of the Policy Against Future Disasters under the Change of Natural and Social Environments

The natural environment is changing. Those changes are global warming, heat island phenomena in urbanised

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areas, deforestation, desertification and erosion of river and seashore. The change of natural environment is increasing natural disasters. Those are extremely heavy rains and snows, huge typhoons, hurricanes and cyclones, drought, abnormally high temperature and high tidal waves due to the rising of sea water level. In addition to the change of natural environment, our social environment is also changing, becoming fragile against natural disasters.

Those are too congested urban areas, depopulation of rural area, human habitations on fragile ground, lack of cooperation and communication among the recent urban societies, budget deficit of central and rural governments and finally poverty. Poverty is the most important factor for the increase of natural disasters in Asian countries. Poverty is a major cause of increased disasters and disasters in turn result in increased poverty.

The characteristics of natural disasters are changing due to the change of natural and social environments. What is the basic policy against these kinds of natural disasters? The key point for the measures against future disasters is how to prepare unexpected natural phenomena and against external forces largely exceeding the design level. In other words, how to prepare against natural disasters with a huge scale but low probability of occurrence.

Basic concept for the measures against huge natural disasters with low probability of occurrence is a combination of hardware measures and software measures. Hardware measures mean, for an example, reinforcement of dikes against floods, and the software measures are evacuation systems during flood and the education of people. Moderate disasters with medium probability are prevented mainly by hardware measures. However, against huge disasters with low probability, the disasters are reduced both by hardware and software measures.

The problem is how to determine the rational level of the investment for disaster mitigation. One of the methods to judge the rational level of the investment is the comparison of the risk with the cost of the measures. The risk is estimated as the product of the total loss with the probability. For the estimation of the total loss, we have to take into consideration, various factors, not only loss of human lives and properties, but also probable national power decline resulting from the disaster, ruining of national landscape and furthermore, psychological damage to people. And the consensus among the people is essential to determine the rational level of disaster mitigation measures.

Roles and Responsibilities of Civil Engineers

A Civil Engineer (with or without specialisation) can work in different positions like Policy maker, Planner, Structural engineer, Geotechnical engineer, Hydrological/irrigation engineer, Environmental engineer/Public Health/Sanitary engineer, Surveyor, Transportation engineer, Marine engineer, Construction manager, Project manager, Services (Plumbing, Fire-fighting, Lift, HVAC, Electrical) consultant, Site supervisor, Site engineer Builder/Contractor Research and development, academics User of constructed facilities and many more. Policy makers and planners should prepare the development plan of an area considering the vulnerability of the area to various hazards. Specifications and guidelines for construction activities should be carefully laid down particularly for vulnerable areas.

Before sanctioning any project, all the details need to be scrutinised by the authorities. A third party check or peer review should be insisted upon at the design and supervision stages. Local authorities must check for compliance of the project with all the requirements or specifications before granting Building Use (BU) permission.

Structural engineers should be involved from the planning stage of the structures and should follow all specifications laid down by the Code of Practices. The structural engineer needs to use the latest methods of analysis and provide well-detailed structural drawings including ductile detailing. Advanced methods like Performance Based Design (PBD) must be followed for high-rise and irregular buildings rather than following simple code-based approaches. Advanced materials like High Performance Concrete, Fibre Reinforced Concrete, Self Compacting Concrete, Fibre Reinforced Polymers etc. should be used whenever required in the construction of new buildings and in the retrofitting of existing structures. Soft storeys, floating columns and other structural irregularities need to be avoided.

A geotechnical engineer should provide a detailed investigation of the subsoil, which would be particularly useful for earthquake-resistant design. The site-specific ground response and the liquefaction potential must be assessed before the planning and execution of a project. An irrigation engineer can provide hydrological data for structures like bridges and dams that have to be constructed on rivers. A hydraulic engineer can suggest flood control measures including early warning systems.

The construction manager can schedule the activities on site so that there will be enough time, material and manpower to execute the job. He must also ensure quality control of each activity. The project manager can liaise between all the agencies involved in the execution of the construction project and should monitor the progress of the project. Site supervisors or site engineers execute various construction activities. It is their responsibility to use appropriate material and appropriate construction technologies, and get the work done as per the detailed drawings and specifications. In particular, earthquake-resistant construction practices need to be followed.

If any problem occurs on site, it should be solved in consultation with the structural engineer. The materials used in construction like concrete and reinforcement (ductile steel) must be tested for quality. It is necessary to maintain documentary evidence (in the form of drawings, reports, photographs, etc.) of all construction activities that are undertaken.

After the construction work is completed, it becomes the responsibility of the users of the buildings to ensure proper maintenance. If any addition or alteration in the structure or building use is required, a structural engineer should be consulted. Civil engineers also play an important role in post-disaster conditions – in rescue operations, damage assessment and the retrofitting of structures.

Civil engineers need to keep themselves updated about the latest research and developments in construction technology, advances in construction materials and analysis or design procedures. A convenient way of achieving this goal is by attending seminars, workshops, training programmes and conferences. Civil engineers should also take support from other branches of engineering for the better planning, execution and functioning of their building and infrastructure projects.

Distraction in Performing Duty

Civil engineers face many distractions in performing their duties in various roles. Some of these hindrances are:

- Pressure from political or builders' lobbies
- Inadequate investigation and feasibility studies
- Delay in sanction of projects and in other administrative processes
- Pressure of time limit
- Builders not interested in quality
- Inadequate time for investigations
- Design conflicting interests of the agencies involved in tendering system and specifications
- Inadequate resources and adverse working conditions

The above distractions may lead to increased hazards during a disaster. Civil engineers (in every role) should try their best to overcome the above limitations and should perform their duty with utmost care.

Role of Civil Engineering Students

Students of civil engineering need to give due importance and attention to each and every subject that forms a part of their under-graduate and post-graduate studies. The course structure and syllabus is designed to impart the necessary theoretical background of all aspects of civil engineering. However, practical training is a very important aspect of the curriculum and students should take it seriously. More site visits and interaction with professionals will enable a better concept of the construction process and will familiarise students with the latest practices. Seminars and project work in advanced and interdisciplinary areas will broaden the students' knowledge about the civil engineering field. The involvement of students in on-site training strengthens their understanding of various construction activities. Students should learn about various types of disasters and about the behaviour of various structures during earthquakes, tsunamis and cyclones. Students should also be aware about the blast-resistant features of structures. A strong theoretical background and a significant amount of practical exposure will help young engineering graduates to prevent and control the adverse effects of unforeseen disasters before they occur, and to mitigate their effects afterwards.

Cooperation and Collaboration of Civil Engineers in the Asia-Pacific Region for Natural Disaster Mitigation

As mentioned previously, natural disasters are increasing, and the environments are destroyed, particularly in Asian countries. The roles and the responsibilities of civil engineers are increasing. The transfer of the technologies for natural disaster mitigation and environment protection should be strongly promoted, and furthermore, we civil engineers should work together on the education of the people for natural disaster mitigation, and should more actively participate in the technical support activities for reconstruction and restoration of the areas damaged by natural disasters. For these activities, we have to further advance the cooperation and collaboration among our civil engineers societies in the Asia-Pacific region.

JSCE is encouraging its members to participate in the technical assistance activities for the areas damaged by natural disasters and in the education for natural disaster mitigation. JSCE and its members have continued to provide assistances and aid activities in Northern Sumatra after tsunami disasters. In response to the request from the Indonesian Government, JSCE prepared technical recommendations on the plan of reconstruction of the road along the west coast of North Sumatra, most of which had been washed away by the tsunami. JSCE also proposed a regional tsunami warning system. This is the request from the state government. The student members of JSCE have been educating children in Sumatra on the earthquake and tsunami disaster mitigation.

Figure 3 illustrates the basic concept of a regional tsunami warning system for Sumatra Island, proposed by JSCE. In this warning system, the epicentre and the magnitude of the earthquake will be estimated from the seismic records at the stations along the west coast of Sumatra. The warning, which will be transmitted from the tsunami-warning centre to the regional mosques through the satellites, is conveyed to the people. One of the characteristic points of this warning system is the utilisation of mosques, which are closely associated with the regional people, and have comparatively high resistance against tsunami and earthquake motions.

Figure 1: Super-levee is an infrastructure for safety of habitants and also for urban redevelopment

Figure 2: Construction of the super-levee in low land area of Tokyo against future earthquake

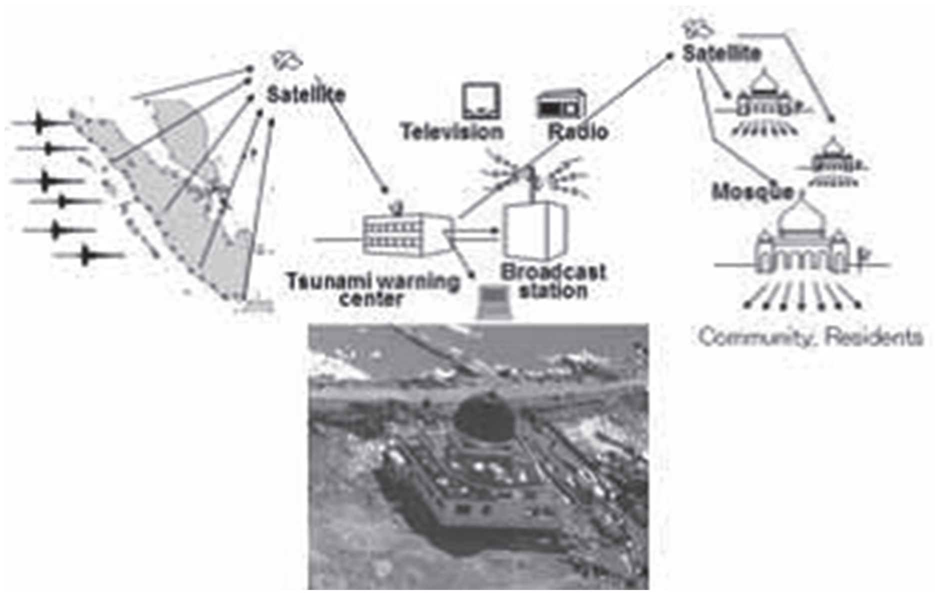

Figure 3: Plan for regional tsunami warning system by JSCE (For North Sumatra Provincial Government)

The student members of JSCE are carrying on education programmes for children of Banda Ache and other areas in Northern Sumatra. They are teaching the mechanism of the occurrence of earthquakes and tsunamis and how to save lives from future disasters. Japanese students are conducting their activities under close corporation with Indonesian student groups.

These young civil engineers' activities are expanding internationally. The technical assistances by JSCE have been carried out in Indonesia and Pakistan for the areas attacked in the recent disasters. In Nias Island, Indonesia, technical seminars for temporary restoration of bridges damaged by liquefaction have been held, while in Pakistan, the members of JSCE held conferences on the reconstruction of damaged structures, in cooperation with Pakistani engineers. In these conferences, JSCE introduced the reconstruction procedures based on the experiences gained from Kobe earthquake recently, members of JSCE and Architectural Institute of Japan established a NPO, named "Engineers without Borders, Japan". The objectives of this NPO are to provide technical support for restoration and reconstruction of the damaged areas, and to carry out education on disaster mitigation. Another important role of this NPO is the transfer of the technologies and knowledge for natural disaster mitigation. JSCE is going to strongly promote assistance and aid activities under close cooperation with this newly established organisation.

Conclusion

- Natural disasters such as earthquakes and tsunamis, and storm and flood disasters have been increasing during the last two decades, particularly in the Asian countries. Furthermore, due to the change of natural and social environments, the scale of the natural disasters is expanding.
- For mitigation of future natural disasters, the roles and the responsibilities of civil engineers are increasing. Professional discipline, sensitivity to the needs of society, an interdisciplinary approach, and integration of focused efforts towards the development of built environment, building and infrastructure projects will lead to a safer society in future.
- The role of civil engineers, whatever post they may hold in the field, is very important in reducing the risk of damage to buildings during disasters. From the planning stage to the execution of civil engineering projects, the paramount consideration is that care

should be taken by all concerned to ensure public safety in the event of a disaster.

- Furthermore, the cooperation and collaboration of civil engineers in the world are essential to accomplish these errands.
- JSCE and the other organisations of civil engineers in the world have enjoyed a good partnership for decades, and have served people for safe living and welfare.
- However, the recent natural disasters in the world taught us again that the development and application of technologies and knowledge for natural disaster mitigation is the most urgent subject for civil engineers. We have to strengthen and to further advance cooperation between two societies.

Bibliography

Cabinet Office, Government of Japan: White Paper on Disaster Prevention, 2006

Japan Meteorological Agency : A Report on Abnormal Weather 2005, 2005.10.

Japan Society of Civil Engineers : General Investigation about the Damage of Social Infrastructure Systems due to the 2004 Niigata Earthquake/Result of Investigations and Urgent Proposals, 2004.11.

Japan Society of Civil Engineers: The Damage Induced by Sumatra Earthquake and Associated Tsunami of December 26, 2004, 2005.8.

Japan Society of Civil Engineers and Architectural Institute of Japan: A Quick Report on Kashmir Earthquake, 2005.11.

V Power Infrastructure

Disaster-Resilient Infrastructure in City-Based Power Utility

Asoke Chakraborty[a] and Sukanta Basu[a]

ABSTRACT: Power generation, transmission and distribution up to last mile consumer are the prime activities of every Power utility. Electricity is the basic and vital commodity for humans and the lifeline of the present society. No agencies can provide rescue and relief to victims, in any disaster, unless electricity is available. So Power utility assumes a pivotal role in any Disaster Management across the world.

There are different challenges in maintaining electricity services during disaster and recovery phase due to geography, difficult terrain, intensity of damages, spread of areas affected, customer sector, framework of society, governance policy, etc. To ensure proactive Disaster management as per DM Act, building up disaster resilient infrastructure, intensive work on DRR with innovative approaches, application of modern science and technology for mitigation of disaster risk will be the only alternatives to Power utility for efficient management of disaster/Crisis situation in the coming future.

KEYWORDS: power utility, disaster resilient distribution system, planning, key practices, cost-effective technologies

Introduction

Power generation, transmission and distribution up to the last mile consumer are the prime activities of every Power utility. Electricity is the vital commodity for humans and the lifeline of the present society. No activities of rescue and relief operation can happen if Electricity is unavailable.

City-based power utility faces different challenges due to dense population, countless footfall in the city during commercial hours of the day, older constructions, unplanned city growth, presence of Distribution equipment in congested public places, construction bypassing municipal laws, frequent fire and electrocution hazards, water logging, managing VVIP and sensitive consumers, catering to large un- interrupted supply sector for vital utilities and services, customer sector with varying expectations, theft of electricity, space constraints and hindrances for erecting new Distribution equipment, taboos for road excavation towards repair and maintenance work of UG distribution network etc. To ensure proactive Disaster management, building up disaster resilient Electricity infrastructure, intensive work on DRR with innovative approaches, application of modern science and technology for mitigation of disaster risk are the best options to Power utility for efficient management of Disaster/Crisis situation in the city.

History of Major Disasters and Crisis in Kolkata and Howrah during This Decade

Cyclonic Storm and Nor'easter

Cyclone Aila with a wind speed of 120 kmph followed by massive rainfall ransacked the cities of Kolkata and Howrah including other districts of West Bengal on 25th May 2009. More than 30,000 consumers were without

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electricity and it took almost seven days for complete restoration of supply.

Nor'easter hit Kolkata city on 17th April 2018 around 7.30 pm with a wind speed of 95 kmph with heavy rainfall that resulted in failure of electricity distribution in many areas, caused a few deaths due to electrocution. Situation aggravated due to total failure of communication by a mobile service provider at Kolkata. We took more than 48 hrs for complete restoration.

Huge Rainfall and Inundation

Kolkata experienced massive rainfall on 13th September 2008 which inundated low lying pockets of the city. CESC over ground Distribution equipment, for example, DTR, Distribution boxes, HT and LT consumer supply installations were besieged with rain water leading to countless UG cable faults, large number of fire and electrocution incidents.

Photo No. 1: Nor'easter in 2018

Photo No. 2: Rainfall – 2008

Fire Hazards

Major fire accidents in one of our EHV S.stn in 2015 and in Bagri Market (extremely congested commercial place) in 2018 resulted in an acute crisis situation and the supply was restored from the adjacent network and mobilised generator for illumination and rescue work in affected spots.

Photo No. 3: Fire in S.stn, Kolkata

Photo No. 4: Fire in Bagri Market, Kolkata

Collapse of Bridge/Flyover/Building

Collapse of Vivekananda Flyover in 2016 and collapse of Majerhat Bridge collapse in 2018, completely damaged HV and LT Distribution system running beside the bridges, resulting in no supply in the affected and adjacent areas. We mobilised generators, temporary flood lighting systems with efficient crews to provide illumination and emergency supply to support state authorities and other agencies for conducting relief and rescue work.

Photo No. 5: Flyover collapse, Kolkata

Photo No. 6: Bridge collapse, Kolkata

Building Disaster-Resilient Distribution Infrastructure from Multi-hazard Considerations

Lt System

Conversion of bare OH wires to ABC and partially insulated conductors in congested residential areas and use of three-phase co-axial cables in theft prone pockets are made to prevent cable damages due to hooking which becomes source of accident from OH lines during natural disaster. Spacers and OH safety devices are provided in close intervals to prevent accidents from snapped OH conductors.

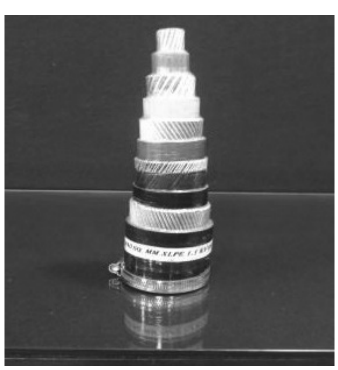


Photo No. 7: Co-axial cable

Photo No. 8: OH pole crowded with network of Cable TV

Photo No. 9: Maintenance work of OH system

Photo No. 10: OH pole after maintenance

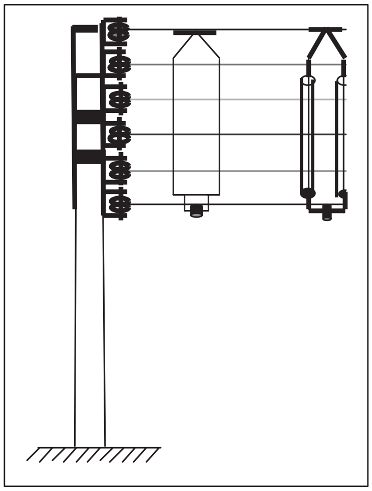


Photo No. 11: Safety devices of OH system

Photo No. 12: OH system with diamond type spacers

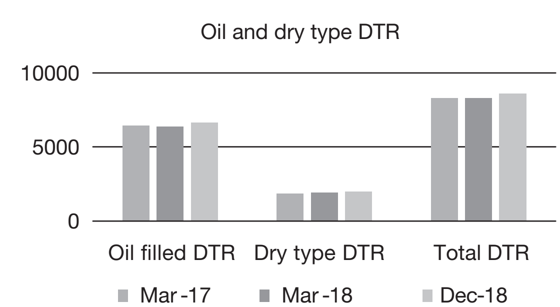
Photo No. 13: OH system with co-axial cable

Oil filled Distribution Transformers (DTR) are gradually replaced with oil free (Dry type) DTR in hospitals, markets, schools, colleges, congested places, government buildings and public places to eliminate fire accidents. Procurement of oil filled DTR is completely stopped as per our recent policy.

Fire protection is provided in unmanned Transformer Houses which still contain oil type DTR

Photo No. 14: Dry type Dist. Trf. in congested place

Photo No. 15: Unmanned Trf. house with fire protection



Period	Oil Filled DTR	Dry Type DTR	Total DTR
Mar-2017	6442	1849	8291
Mar-2018	6373	1920	8293
Dec-2018	6615	1973	8367

Dist. Transformer statistics

Measurement of Earth Resistance of Electricity poles, over ground Dist. Boxes is done at regular intervals to ensure Earth Resistance value within 1 ohm for public safety.

Plinth level of Dist. Transformer(DTR) over ground Distribution boxes in low lying areas is elevated to prevent fire and electrocution accidents due to ingress from water logging.

MCBs are placed in all LV and MV consumer's installation to prevent accidents due to overloads or faulty consumer's installation.

EHV and HV System

Protocol exists with SLDC, ERLDC and State/Central power utilities for emergency power during grid or generation failure.

SOP exists for interruption of free supply and speedy restoration due to failure of our major equipment.

Elaborate fire protection system with remote fire alarm for all manned/unmanned Substation. Remote health monitoring for fire protection at all of our major installations have been installed to closely monitor health of firefighting system and initiate action for its 100 per cent availability.

Photo No. 16: NIDS protection of power transformer

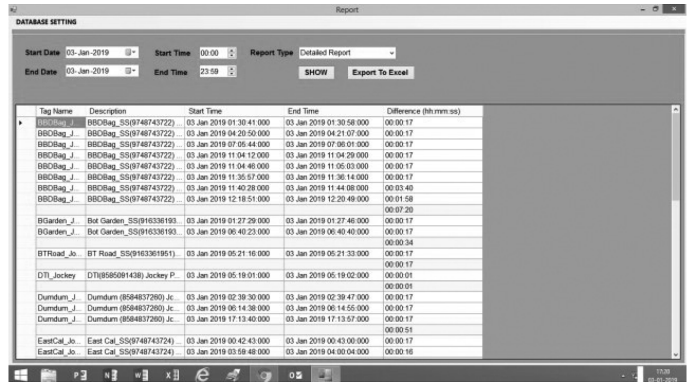


Photo No. 17: RHMS screenshot of fire protection

Protocol exists to switch off identified HV OH feeder, UG network, DTR when storm or nor'easter hit the city and due to huge water logging from rainfall. Coordination meetings are conducted with internal stakeholders before nor'easter, monsoon, etc. and even before big event in city where identified lists are validated due to network contingency/re-organisation work and changes if any, are implemented.

Standby arrangements of mobile generators, crew with vehicle, tools, materials at strategic locations are made as per departmental SOPs to handle major disaster/crisis situation in cities.

Majority outdoor S.stn have been converted to indoor GIS for system reliability and to prevent failure.

Photo No. 18: Emergency supply with mobile generator

Photo No. 19: Flood light, cables, accessories with crew mobilised at Majerhat bridge after collapse

Safety Audit and Capacity Building for Disaster Preparedness

Annual Training calendar for Training on firefighting and Mock drills for all section of employees are prepared in the beginning of every FY and are religiously followed. This has substantially improved firefighting capabilities of our employees (permanent and outsourced).

An attempt is being made to develop a Fire squadron within the organisation by providing specialised training to our Officers and Supervisors of all departments on effective firefighting with the help of WBFES at their Kolkata training centre at Behala.

Photo No. 20: Special fire training at WBFES, Behala, Kolkata

Every year, in-house training programmes for officers, supervisors, workmen and others are conducted for Disaster preparedness during peace period and included in Corporate Training calendar. Officers of Risk and Disaster Management conduct such programmes to sensitise CESC employees and outsourced manpower against all possible disaster situations and the actions they need to carry out during emergency situations.

Photo No. 21: Mock evacuation drill at one of our offices

A sample statistic of 2018–19 is given below as reference.

Sl No	Target Participants	No of Programme	Participants Covered Till 31.12.18
1	Officers	5	78
2	Supervisors and Staff	8	163
3	Workmen	3	228

Table top exercises on painted disaster scenario are conducted every year for HOD and Senior Officials of various CESC wings with the help of faculty from NIDM, NDMA, New Delhi to measure response time and access proper decision-making capacity for handling systems during major natural disasters.

Photo No. 22: In-house training on disaster management

Photo No. 23: Table top exercise on progress

Mock evacuation drills are conducted at various companies' establishments against fire accidents or disaster situations. Feedback is shared with the participants and coordinator of the building for improvements.

Routine audit system for Safety and Firefighting equipment is in place. Reports with both positive and negative feedbacks observed during audit process are communicated to the respective stakeholders for appropriate action. Such observations are archived in proper format for future reference and follow up is made with HODs for compliance. Defect is closed if it is found satisfactory after the second round of audit.

Audit and review system for Disaster preparedness is done by Officers of R&DM cell with departmental heads and their team as per prevailing SOPs. Decision is taken for amendments or correction of SOPs, necessity of new resources, capacity building exercise etc. collectively during such audit meetings.

Quarterly Report of Mock drill and training on Firefighting at our Generation plants, S.stn, Office building are sent to CEA, New Delhi as per the directive of MoP, GOI.

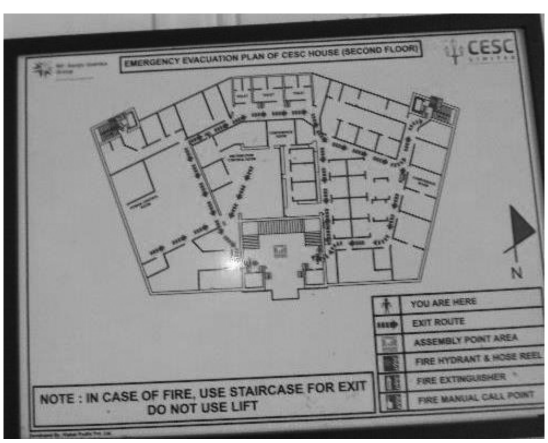


Photo No. 24

Photo No. 25: Fire safety audit at CESC office building with positive and negative observations

Photo No. 26: Safety audit at CESC work sites

Photo No. 27: Safety audit at CESC work sites

Standards of Design, Construction and Maintenance of Risk-Resistant Infrastructure

Installation of Indoor GIS is standardised for all new and upcoming EHV/HV S.stn to reduce disaster risk and failures.

Elaborate fire protection of Power Transformers using NIDS, HVWSS, Fire wall, Portable fire extinguisher (Foam & DCP) etc. is included in standard layout for all upcoming S.stn and Transformers. Special drive is taken to provide elaborate fire protection devices in all existing S.stn. within a fixed time frame. Attempts are being made to standardise the fire detection and protection system in our all EHV/HV S.stn and get NOC compliance from WBFES.

Ground wires are used in outdoor EHV yard for protection of equipment against lightening surges. Such ground wires are made of GI wires and suffer from corrosion due to atmospheric corrosion and moisture. If corroded, it may break and falls over charged S.stn equipment. This leads to total shutdown due to bus fault. Presently DSLP (Direct Stroke Lightening Protection) using earth mast replacing Ground wire in outdoor S.stn to mitigate above risk and subsequent crisis due to black out of S.stn or failure of equipment. DSLP also provides better coverage against lightening protection.

Structural Design and construction of S.stn building are being done considering the fact that the entire area is an earthquake zone and using relevant building code (IS 1983:2002 and IS 1983:2016). Emergency exit ways and additional stair case and assembly area in open air are standardised for all new constructions.

Photo No. 28: GIS

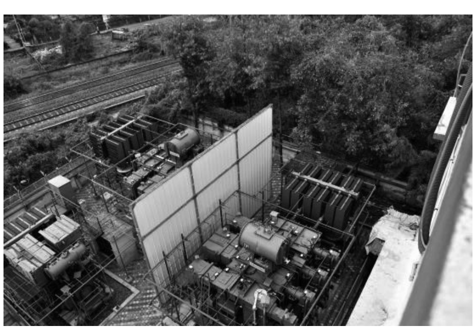


Photo No. 29: Outdoor installation

Photo No. 30: Outdoor yard with ground wire protection

Photo No. 31: Outdoor yard with DSLP

Planning and design of T&D network with (n-1) redundancy as far as possible for interruption free supply due to outage of one EHV line/Equipment during disaster or crisis situation.

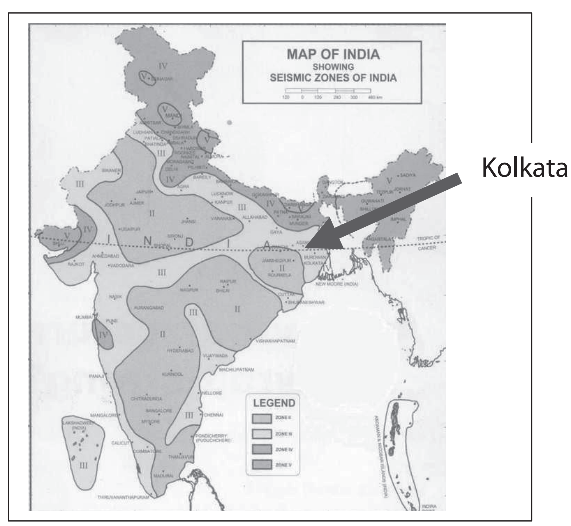


Photo No. 32: Seismic zone map of India and position of Kolkata

Photo No. 33: Construction of S.stn building

Building Resilient Communities/Consumers

Team CESC comprising Officers from Customer Relations, R& DM, Safety, as CSR initiative conduct awareness programmes at vital consumer's end for example Hospitals, Hotels, Shopping malls, Schools/Colleges on Electrical safety and Firefighting and to help them to build up capacity for handling major crisis situations due to fire or electrical accident. A snapshot of such programme already undertaken by CESC during FY 2018–19 is given below for reference. Feedback from customers on such programmes is quite encouraging.

Hospital	Hotel	Bank	Shopping Mall	Edu Institute	Total
1	2	3	1	1	8

Safety Tableau is moved round our entire licence area in pre-monsoon or prefestival periods to develop awareness on electrical safety, fire accidents with dos and don'ts during major disaster situations. Hoardings and Posters are placed at conspicuous spaces (beneath DTR and over-ground Dist boxes) or eye-catching locations (in puja pandal) for building safety consciousness against electrical and fire accidents.

CESC has taken major initiatives for Repair and rewiring of electricity installation in old and heritage buildings, market places and slums to prevent electrical and fire accidents. A snapshot of Meter board renovation in public place is given below as sample exhibit.

Photo No. 34: Meter board before and after renovation in public place

Photo No. 35: Safety tableau

Photo No. 36: Awareness programme for school children

Photo No. 37: Awareness programme on electrical safety and fire fighting for hotel employees

Cost-Effective and Cutting-Edge Technology to Fight against Disaster Situation

ERS tower is the solution for temporary and faster restoration of EHV transmission line when main transmission tower or its member collapses due to massive storm/cyclone/earthquake etc. ERS tower is a prefabricated tower which can be transported by truck to site in dismantled form and the parts can be integrated and placed in a nearby area of damaged tower within shortest possible time for restoration of Transmission lines. Assembled ERS towers can sometimes be air lifted to installation sites due to difficult terrain.

Photo No. 38: ERS tower under erection

We procured a portable inflatable balloon light tower which provides 360° glare free illumination and runs on Petrol or Diesel Generator for use in disaster sites where electricity is not available/suspended. It is very useful for rescue and recovery work where the electricity service is cutoff. We use Aska Model AIT- 4500 fitted with 400 W Metal halide lamp with 42000 lumen brightness. Its tower height is 4.5 m long and weighing around 45 kg.

Photo No. 39: DG set driven inflatable balloon light

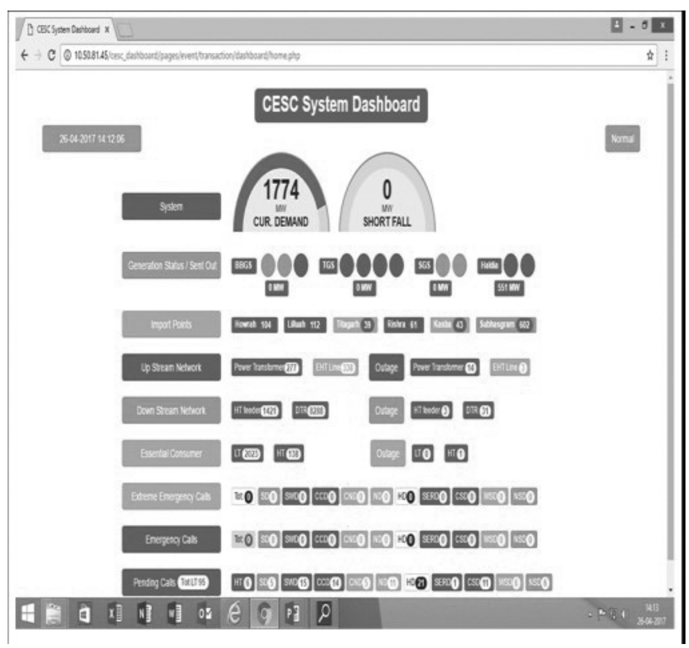


Photo No. 40: CESC system dashboard

IT enabled Disaster dashboard, DRRS (Disaster Response and Recovery System) and Fire incident management system are developed in-house and are 24 hrs available in company intranet for use within organisations to track pending complaints, fire and electrocution calls, outages of T&D network etc. during crisis and emergency situations. The same service is available in temporary EOC (opened during disaster/crisis situation) at one of our operation centres.

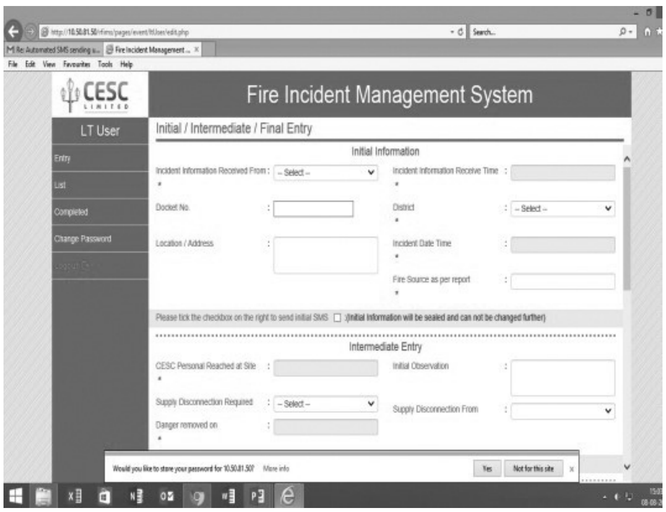


Photo No. 41: Fire incident management system

We use Drone services fitted with high resolution camera to patrol over EHV OH corridor and take pictures for health checking of HV insulators, conductors at tower top where manual intervention is difficult due to site conditions.

Our practice for Health checkup of T&D equipment - Thermography, PD, PID (Punctured Insulator detector) for online monitoring for proactive maintenance helps us to avert major and sudden breakdown.

We use automated RMU and HV Switch gear for remote control and operation of Drainage pumping stations and vital installations during disaster or emergency situations to maintain interruption free supply at all vital installations in the city.

SCADA is commissioned in all of our EHV and HV substations for better monitoring and control of network and system, remote and faster operation of T and D equipment. We use DMS (Distribution Management system) in HV network for safe and efficient operation, speedy restoration maintaining safety of operator and system at large during normal as well as in crisis situation.

Smart metres with communication facility are installed at VIP supply installations for instant supply for outage information of VVIP and vital consumers to our call centres. Crews are accordingly deputed, proactively for restoration of supply to VVIP consumer and vital installations even during major disaster situations. In addition, remote LT supply changeover facility is also installed for a few selected VVIP consumers to restore supply instantly in case of unfortunate outage.

24x 7 LT control room has been set up manned by operating Engineers to monitor outage of LT supply, electrocution and fire hazards and take appropriate actions in case of any delay. LT control room is equipped with GIS-based crew tracking system and big screen display to depute nearest crew for any emergency calls.

Photo No. 42: Drone in use

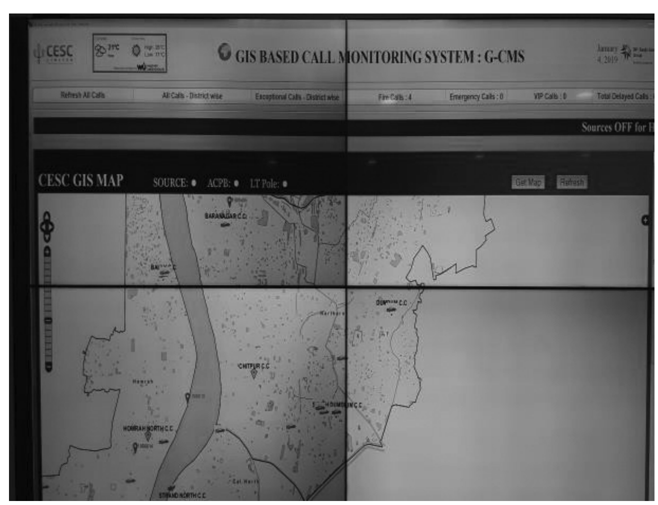


Photo No. 43: GIS-based crew tracking system

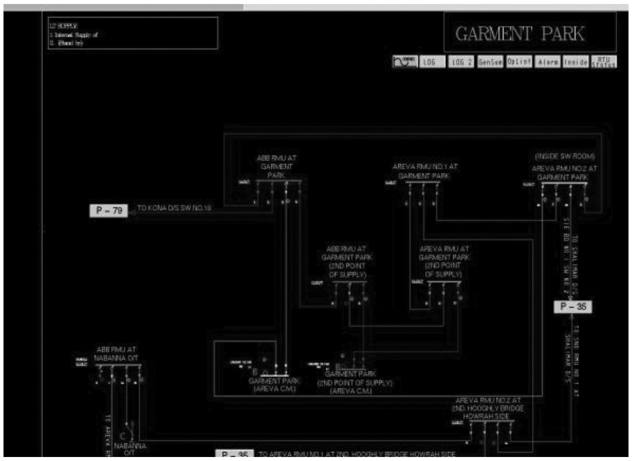


Photo No. 44: DMS screen

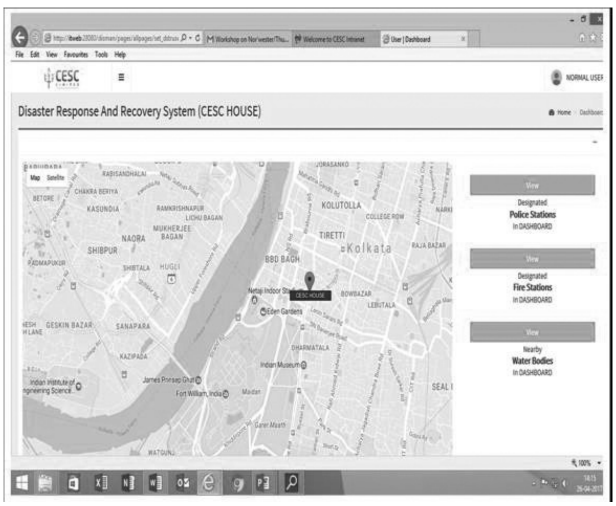


Photo No. 45: DRRS screen

Risk Management Strategies with Inter Connected Infrastructure

As per IEGC (Indian Electricity Grid Code) Special Protection System (SPS) is mandatory for every Power system to maintain its integrity by initiating automatic measures – tripping, isolating, sending inter trip signal to associated network etc. during extreme credible contingencies. Examples are under frequency, overloads, grid voltage collapse etc. In CESC SPS in the form of under frequency, Generator lock out, Line and Transformer overload Relays etc. are in place. Necessary coordination with State and Central transmission utilities is done for quick islanding during grid disturbance. This has saved our system on a number of occasions in the past including blackout of ER grid in July 2012.

Bilateral agreement for startup and emergency power with neighbouring utilities is already in place during major Disaster or shutdown in our system and even for big events in the city (Durga puja).

Coordination with other service providers/agencies to avert inadvertent damage of our T&D network and fatal accidents during activities on common space/ road/passage way of cities.

Response and Recovery – Coordination with External Stakeholders

We have a system for close monitoring of IMD and other weather sites, routine communication with IMD control room for latest weather updates. Emergency numbers of CESC Control Room and Network operation centres are recorded in IMD system for auto sms and email information on weather updates. We keep close coordination with Senior Officers of IMD/Kolkata and attend various coordination meetings arranged by IMD, Kolkata. This has helped us to get weather alerts in advance and take various preparatory measures for example load forecast, day ahead scheduling etc. besides making emergency arrangement to fight disaster/crisis situations.

We maintain close liaison with SDMA, Officials of state administration, KMC, WBFES etc. throughout the year and attend various coordination meetings arranged by them for networking, communication, exchanging support and services as and when required. Our designated ADMG (Apex disaster management group) members update our action plans to SDMA while handling disaster or crisis situations.

We depute our operating Engineer in Kolkata Police headquarters control room during major disasters or big events in the city etc. for close coordination with Kolkata Police in connection to our restoration and breakdown activities. Similarly we keep close liaison with KMC control room, WBFES control room during emergency for faster response and recovery.

CESC control room (load dispatch centre) regularly interacts with SLDC, ERLDC, parallel utilities as per our protocol for import/export scheduling and requirement of excess power during emergency or crisis situations.

We open EOC and members of CDMG (Central Disaster Management group of CESC comprising HODs of different department and R and DM cell) meet at one of our centrally located network operation centres after receipt of major weather alerts for strategic decision and internal coordination for appropriate disaster preparedness.

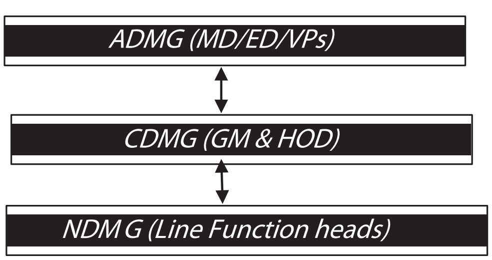
CESC has a Backup control room setup at one of our establishments in South Kolkata for operation of the system in case CESC Main Control Room at Central Kolkata fails due to any serious contingency or disaster. Usually the mirror image of main control room SCADA system is available in Backup control room and is kept on hot stand-by after receipt of major weather alert. The backup control room is equipped with Diesel Generator with auto start, UPS, communication facility along with SCDA, DMS for operation of the system.

Photo No. 46: Backup control room

Planning and Practices for Fighting Disaster/ Crisis Situation, Effectively

We have a SOP driven DM plan with actionable points in Pre, During and Post Disaster periods with responsibility matrix, template for disaster data archival. Standard communication protocol is followed for handling vulnerabilities due to disaster. Each one of us is aware about SOP and responsibilities.

We have a three tier Disaster Management Group with mapped responsibility in respective SOPs.



We build up reliable communication installing Radio communication at System control, Power plants control rooms, network operation centres, Regional depots, call centres, consumer service vans etc. and are providing dual sim from different service providers to all our operating heads, operating Engineers and Supervisors, Breakdown crews, Call centres etc. Regular audit is carried out to check healthiness and use of the communication system. We experienced a very bad situation in April 2018 during Nor'easter when our only mobile service provider was completely collapsed for 45 mnts immediately after Nor'easter hit the city in April 2018.

We visit parallel Power utilities to crisscross and exchange ideas, practices, experiences in handling disasters for learning and adoption of good practices to strengthen our Disaster Management activities.

Photo No. 47: Use of radio communication by breakdown crews

Photo No. 48: Benchmarking meeting on DM with APEPDCL

We are planning to build up fire marshal and self-disaster response force within departments by providing specialised training from WBFES – already elaborated under " Capacity building exercises for DM".

We arranged one coordination workshop within all external stakeholders to understand individual capabilities, to build up networking and relation for managing difficult Disaster and Crisis situation. MIC, Power and NES, Govt. of WB inaugurated the workshop. It helped us to understand each other resources and the key person to be contacted for necessary support during crisis situations.

Photo No. 49: Coordination workshop with our stakeholders

De-centralised operation, Incident commander, stand-by material, transport, manpower arrangement and crew management techniques, staging areas for fighting disaster or crisis situation are already defined in CESC DM Plan.

Inventory for flood lights, wires, fast moving spares, vital raw materials etc. with proper skilled manpower to meet emergency requirement within our licenced areas are also included in SOPs.

Sensitivity to Nature, Environment

It needs no mention that massive use of fossil fuel, deforesting, removing water bodies, industrialisation etc. abnormally increase pollution levels in the air, emit greenhouse gases depleting environment, jeopardise natural ecosystem and pose threat to the entire living world in the form of frequent major disasters. Statistics clearly shows that intensity of disasters is increasing manifold w.r.t. past few decades. CESC being an environment sensitive corporate entity has taken many initiatives that manifest in saving of greeneries and nature, controlling emission, use of NES etc. Few of these are narrated below.

Use of various energy saving programmes, planning to convert companies' building to green building Promoting NES through Solar panels for reducing carbon emission

Massive use of energy efficient LED lights in S.stn

Educating School children and community about saving and optimum use of energy Tree and sapling plantation in and around S.stn and many more.

Photo No. 50: Use of LED lights in S.stn

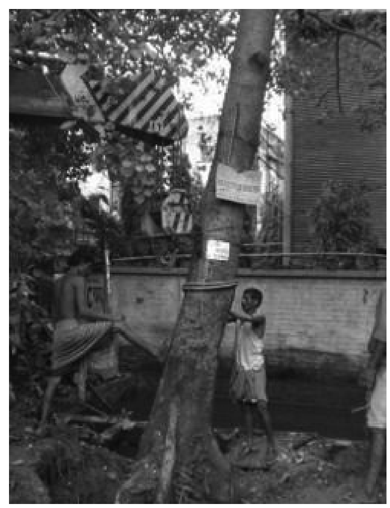


Photo No. 51: Tree plantation in S.stn

Conclusion

The above practices helped CESC in building up a reliable T&D system with negligible system downtime during disaster and crisis situations. This has institutionalised our proactive approach in managing both natural and man-made disaster situations, effectively and enabled us to maintain a failsafe T& D system for the cities of Kolkata and Howrah even in disaster situations.

A Grid-Connected PV Module with MPPT and VSC

Umakant Tivari[a] and Joyashree Das[a]

ABSTRACT: PV array is used with MPPT to attain maximum power while the radiation is changed frequently. MPPT is controlled via incremental conductance method Algorithm. A 3-phase voltage source converter is used to convert DC from MPPT to AC which is connected to the Grid through Transformers. The inverter is controlled using vector control schemes to have an independent control on active and reactive power. Capacitive Banks have also been installed prior to Grid to provide reactive power supply and improve Active power performance. The proposed system is analysed with the help of MATLAB/SIMULINK.

KEYWORDS: voltage source inverter (VSI), photovoltaic (PV), maximum power point tracking (MPPT), grid-connected

Introduction

With the increase in environmental pollution and gradual depletion of fossil fuels, people incrementally turn their concentration to non-conventional energy generation. In future times large-scale solar plants will be gaining recognition as huge capability of energy sources. Due to the increasing demand and environmental issues, renewable energy sources have attracted the attention of researchers and investors. Among the available renewable energy sources, the photovoltaic (PV) system is considered to be the most promising technology, because of its suitability in distributed generation, satellite systems and transportation. The main benefits of solar energy are that it can be easily utilised by both home and commercial users as it does not require any huge set-up as much as wind and geothermal power stations. The generation and control of electrical power supplied to the grid have changed drastically due to improvement in power electronics and development of new technologies. Therefore, solar photovoltaic cells are used for powering the grid connected inverters. The role of inverters in a grid connected systems not only result in integration of renewable energy sources to ac grid but also provides power factor correction, reducing harmonics drawn from grid and improving quality of voltage at load terminals. While an inverter performs above functions, it also injects switching frequency ripples in the grid, therefore it must be insured that frequency ripples injected in the grid are within specified safety limits of the grid. For this a properly designed filter is required at the output of the inverter. Further a grid-connected inverter is expected to undergo common grid disturbances like voltage sags, voltage swells, which require control mechanism to ensure operation under these excursions. Also the operating power of solar power plants has elevated from few KWs to MWs, so to assure the seemly performance of grid connected to such plants we require good control of active and reactive power generated by the inverter. The PV system operates in two different modes: grid-connected mode and island mode. In the grid-connected mode, maximum power is extracted from the PV system to supply maximum available power into the grid. Grid-connected PV systems have become very favourable because they do not require battery back-ups to assure MPPT.

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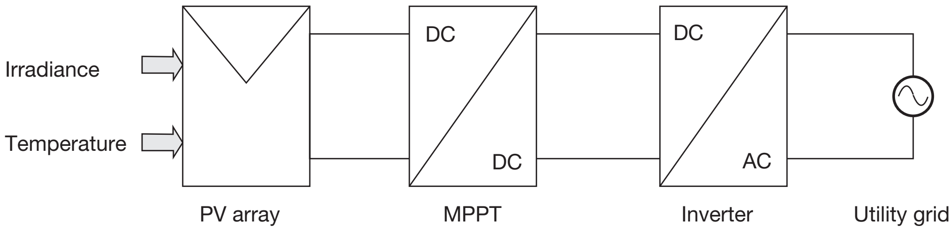

Figure 1: The block diagram of grid-connected PV system

Stand-alone systems can also attain MPPT, but it requires suitable battery back-ups for this purpose. Grid-connected PV systems usually employ two stages systems and single stage systems. The foremost stage is used for Maximum Power Point Tracking (MPPT) and boosting the PV voltage. The next stage is inverts, the first stage DC output to AC at grid frequency. The first stage consists of a boost or buck-boost converter (DC-DC) and the second stage consists of the inverter (DC-AC). The block diagram of the grid-connected PV system is shown in Figure (1).

Modelling of Grid-Connected Photovoltaic System

Photovoltaic Array

A single diode equivalent circuit of a PV cell is shown in Figure 2. by applying KCL for ideal photovoltaic cell, the generated output current of the cell is difference of photon current and diode current and is given in equation (1). The practical PV cell is represented by adding series and shunt resistance to the ideal cell. A PV array mathematical model is formed by equation (2) -(4) considering the number of parallel and series cells and its corresponding losses in terms of resistances. Where Id-diode current, Iphthe photon current, Icell-individual cell current, Is-the saturation current Np-number of modules connected in parallel, Ns- number of cells connected in series, q- electrical charge, N-ideality factor, k - Boltzmann constant, VA - terminal voltage of the array and IA- PV array current, Rs -series resistance, Rsh-shunt resistance. A practical PV array configured by series parallel combination of PV module and each module is constructed by number of PV cells connected in series.

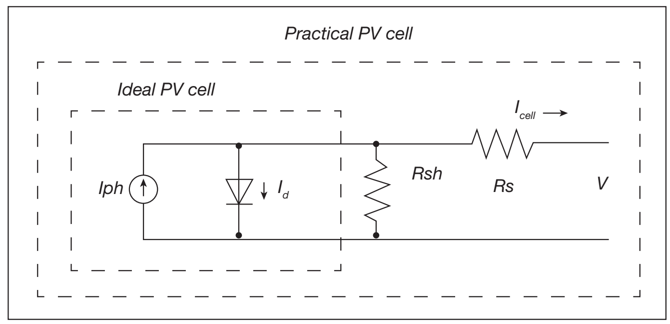

Figure 2: Equivalent circuit of PV cell

$$I_{cell} = I_{ph} - I_d \tag{1}$$

$$I_d = I_s\left(e^{\frac{qV}{NKT}} - 1\right) \tag{2}$$

$$I_{cell} = I_{ph} - I_d - I_{sh} \tag{3}$$

$$I_A = I_{ph}N_p - N_p\left[I_s\left(e^{\frac{\left(V_A + I_A R_S \frac{N_S}{N_p}\right)}{N_S V_t}} - 1\right)\right] - \frac{\left(V_A + I_A R_S \frac{N_S}{N_p}\right)}{R_{sh}\frac{N_S}{N_p}} \tag{4}$$

Maximum Power Point Tracker

In practice, the PV array is connected to the MPPT in order to allow the PV array to produce maximum power. It is capable of varying the electrical operating point of the PV array. The converter changes the operating voltage level of the PV array to operate at *Vmp* in order to produce maximum power. The operating voltage level is controlled by changing the duty cycle of the converter. A pulse width modulation (PWM) control signal is applied to the gate of the transistor in the DC-DC converter. The generation of the PWM control signal is controlled automatically by an algorithm. The photovoltaic power characteristics are nonlinear, which vary with the level of solar irradiation and temperature, which make the extraction of maximum power a difficult task during the load variations. To overcome this problem, several algorithms for extracting the maximum power have been proposed, however in this work the incremental conductance method has been used.

Converter

Inverters are the power electronic circuit, which converts the DC voltage into AC voltage. The output voltage can be controlled with the help of drives of the switches. The pulse width modulation techniques are most commonly used to control the output voltage of inverter. However, the output voltage of the inverter contains harmonics whenever it is not sinusoidal. Harmonics can be reduced using proper control scheme. Inverters can be broadly classified into two types:

- Voltage Source Inverter (VSI)
- Current Source Inverter (CSI)

In voltage inverter (VSI) or voltage fed inverter (VFI), the DC voltage remains constant. In the current source inverter (CSI) or current fed inverter (CFI), input current is maintained constant occasionally. The DC input voltage to the inverter is controlled to adjust the output. These types of inverters are called variable DC link inverters. Inverters can have single-phase or three-phase output.

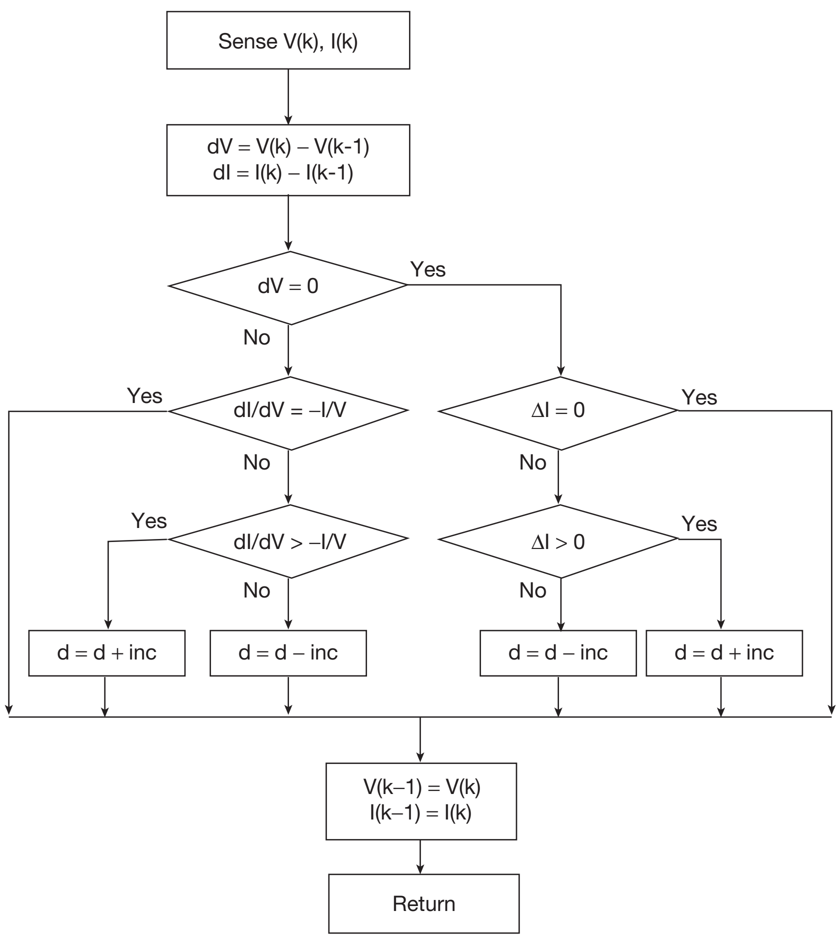

Figure 3: Flowchart of incremental conductance algorithm

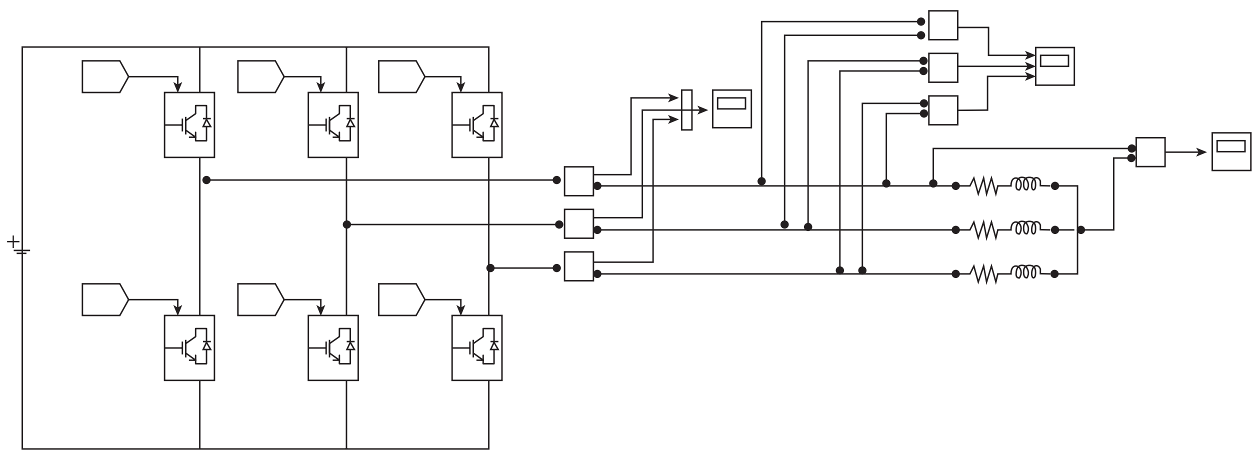

Figure 4: Simulation of two-level inverter

Control Strategy

Vector control is a popular method known for converting the three-phase quantities into synchronously rotating reference frame. The basic idea of vector control is to control the flux producing component (direct axis current) and the torque producing component (quadrature axis current) in a decoupled manner, keeping analogy with the above convention, in this work, the grid current is separated into direct and quadrature axis currents and the vector control scheme is implemented in a decoupled manner in the synchronously rotating reference frame.

Clarke Transformation

Using Clarke transformation, the balanced three-phase quantities are transformed from the three-phase reference frame to the balanced two-axis orthogonal stationary reference frame. The Clarke transformation can be expressed as follows:

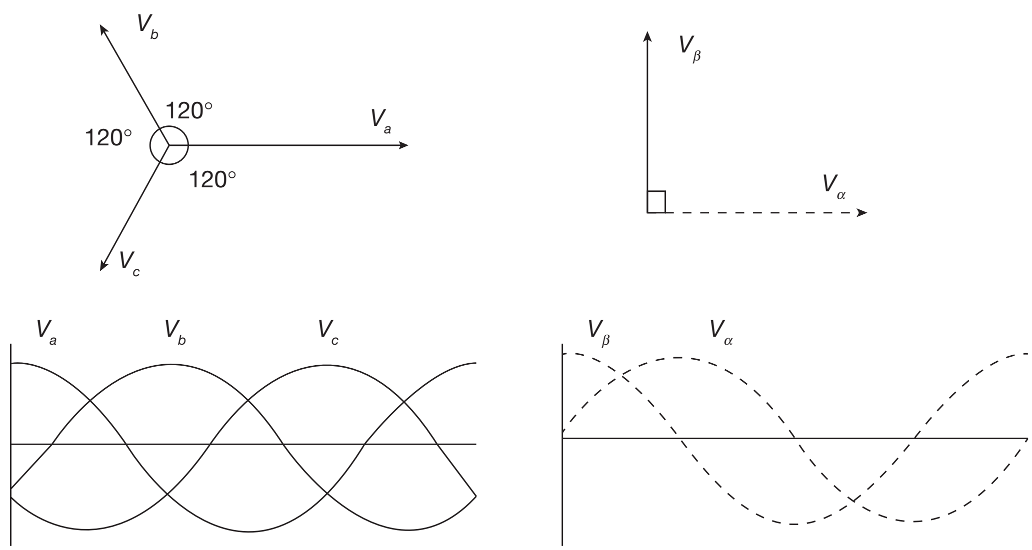

Figure 5: Different reference frames for three-phase and two-phase

$$\begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} = \begin{pmatrix} 1 & 0 & 1 \\ -\dfrac{1}{2} & \dfrac{\sqrt{3}}{2} & 1 \\ -\dfrac{1}{2} & -\dfrac{\sqrt{3}}{2} & 1 \end{pmatrix} \begin{pmatrix} V_\alpha \\ V_\beta \\ V_o \end{pmatrix}$$

Vector Control Scheme

The overall block diagram of a vector control scheme is shown in Figure (6). The grid voltages and the line currents are transformed into *dq* reference frame, and are used as feedback variables for the controller. The control calculations are performed in the *dq* reference frame. After performing all such calculations, these quantities are again converted back to *abc* reference from the *dq* reference frame and which will be used in the PWM stage for the three-level inverter switches. In this project the active and reactive power flow from the inverter to the grid is controlled in decoupled manner by implementing the vector control approach. The overall control scheme consists of the following stages:

- Grid Synchronisation with PLL
- Current Control
- Decoupling
- PWM Scheme

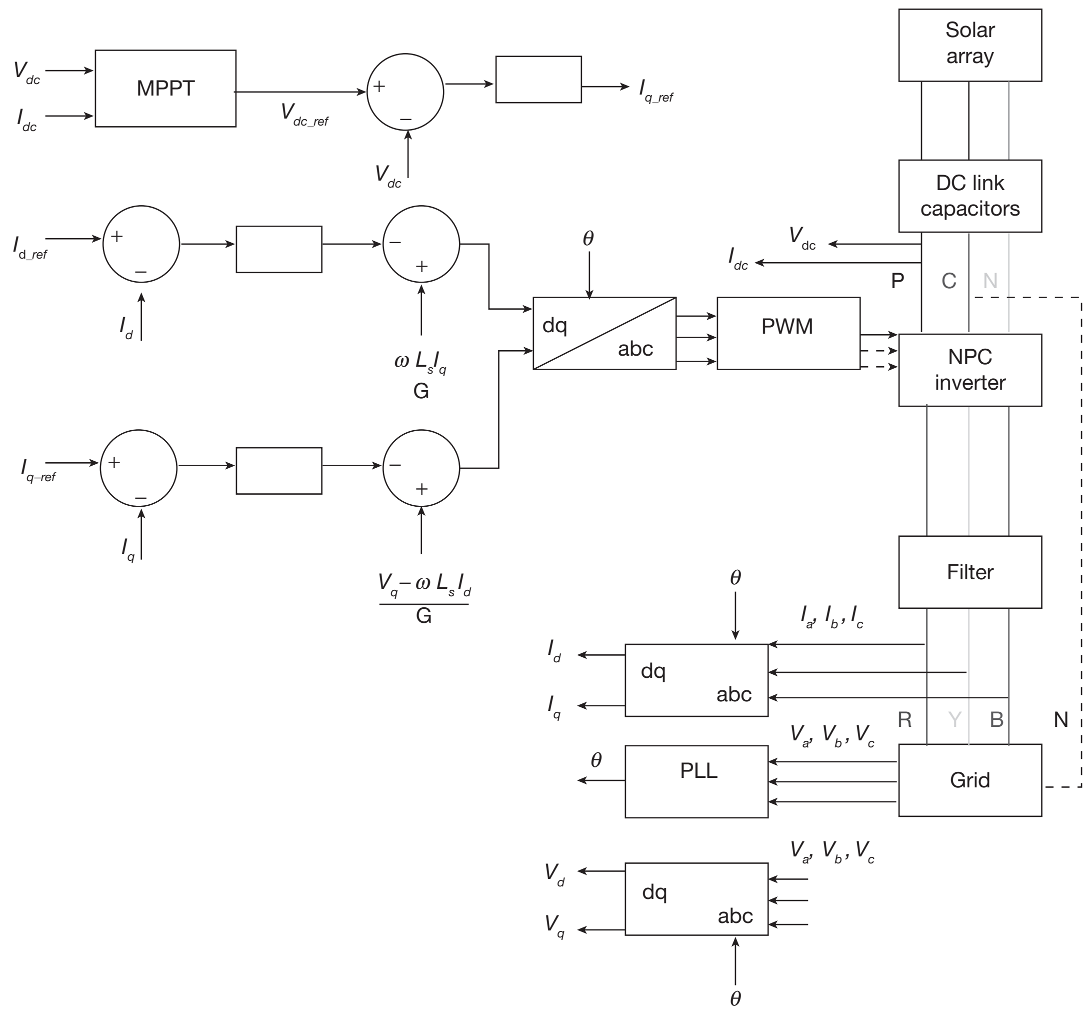

Figure 6: Structure of vector control scheme

Modelling of Inverter

The single-phase equivalent circuit of a three-phase three-level grid connected inverter is shown in Figure 7.

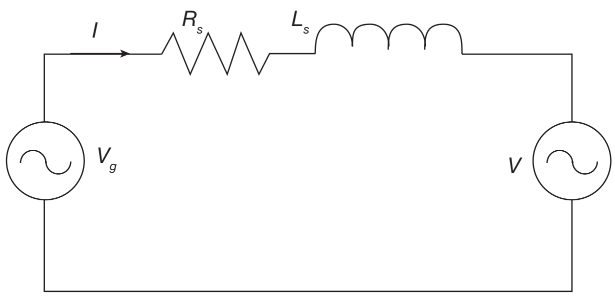

Figure 7: Single-phase equivalent circuit of grid connected inverter

Where V is the inverter pole voltage and V_g is the grid voltage. R_s and L_s are resistance and inductance of the line. The differential equations for the above system can be expressed as,

$$\begin{pmatrix} V_{ga} \\ V_{gb} \\ V_{gc} \end{pmatrix} = R_s \begin{pmatrix} I_a \\ I_b \\ I_c \end{pmatrix} + L_s \frac{d}{dt} \begin{pmatrix} I_a \\ I_b \\ I_c \end{pmatrix} + \begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} \quad (5)$$

$$L_s \frac{dI_{abc}}{dt} + R_s I_{abc} = \Delta U_{abc} \quad (6)$$

Where $\Delta U_{abc} = V_{gabc} - V_{abc}$

The grid currents in synchronously rotating reference frame can be expressed as equations (7) and (8) respectively

$$I_d = \frac{2}{3}\left[I_a \cos\omega t + I_b \cos\left(\omega t - \frac{2\pi}{3}\right) + I_c \cos\left(\omega t + \frac{2\pi}{3}\right)\right]$$
$$I_q = -\frac{2}{3}\left[I_a \sin\omega t + I_b \sin\left(\omega t - \frac{2\pi}{3}\right) + I_c \sin\left(\omega t + \frac{2\pi}{3}\right)\right] \quad (7)$$

In a similar way the voltages can be expressed as follows,

$$\Delta U_d = \frac{2}{3}\left[\begin{matrix} \Delta U_a \cos\omega t + \Delta U_b \cos\left(\omega t - \frac{2\pi}{3}\right) \\ + \Delta U_c \cos\left(\omega t + \frac{2\pi}{3}\right) \end{matrix}\right]$$

$$\Delta U_q = -\frac{2}{3}\left[\begin{matrix} \Delta U_a \sin\omega t + \Delta U_b \sin\left(\omega t - \frac{2\pi}{3}\right) \\ + \Delta U_c \sin\left(\omega t + \frac{2\pi}{3}\right) \end{matrix}\right] \quad (8)$$

On differentiating equations *(7)* and *(8)*,

$$\frac{dI_a}{dt} = \frac{\Delta U_a}{L_s} - \frac{R_s}{L_s} I_a \quad (9)$$

$$\frac{dI_b}{dt} = \frac{\Delta U_b}{L_s} - \frac{R_s}{L_s} I_b \quad (10)$$

$$\frac{dI_c}{dt} = \frac{\Delta U_c}{L_s} - \frac{R_s}{L_s} I_c \quad (11)$$

On substituting equations *(9)*, *(10)* and *(11)* $\frac{dI_q}{dt}$ and $\frac{dI_d}{dt}$

$$\frac{dI_d}{dt} = \frac{\Delta U_d}{L_s} - \frac{R_s}{L_s} I_d + \omega I_q \quad (12)$$

$$\frac{dI_q}{dt} = \frac{\Delta U_q}{L_s} - \frac{R_s}{L_s} I_q - \omega I_d \quad (13)$$

$$\Delta U_d = V_{gd} - V_d \quad (14)$$

$$\Delta U_q = V_{gq} - V_q \quad (15)$$

Which can be further arranged as,

$$V_d = V_{gd} - (R_s I_d + L_s \frac{dI_d}{dt} - \omega L_s I_q) \quad (16)$$

$$V_q = V_{gq} - (R_s I_q + L_s \frac{dI_q}{dt} + \omega L_s I_d) \quad (17)$$

Equations *(16)* and *(17)* reveal that a cross coupling exists between the direct and quadrature axis quantities. To separate the direct and quadrature axis quantities decoupling terms have to be added in both direct and quadrature axis. The decoupled control can be ensured by adding two feed forward terms V_{dff} and V_{qff} to the output of the direct and quadrature axis current controllers respectively.

$$V_{dff} = \frac{\omega L_s I_q}{G} \quad (18)$$

$$V_{qff} = \frac{V_q - \omega L_s I_d}{G} \quad (19)$$

Thus after implementing the decoupled control as mentioned the active and reactive power in the *dq* - reference frame is given by *(18)* and *(19)*.

$$P = \frac{2}{3}\left(V_d I_d + V_q I_q\right) = \frac{2}{3}\left(V_q I_q\right) \tag{20}$$

$$Q = \frac{2}{3}(V_q I_d - V_d I_q) = \frac{2}{3}(V_q I_d) \tag{21}$$

Where P is the active power and Q is the reactive power.

Simulation Validation

In this paper, the PV array of three-phase grid connected 100kWp PV system is discussed. The given model when implemented using MATLAB Simulink gives the following waveforms of different entities. The theoretical and simulated waveforms of the output voltages, current, power etc. are showing good matching. As the solar irradiance changes output power delivered by the PV array also changes. Output voltage of PV array is boosted by boost converter. The proposed MPPT scheme will help the system to operate at that voltage where the power output will be the maximum depending upon the solar irradiance changing throughout the day time. Inverter is connected to a transformer and transformer connected to the utility grid.

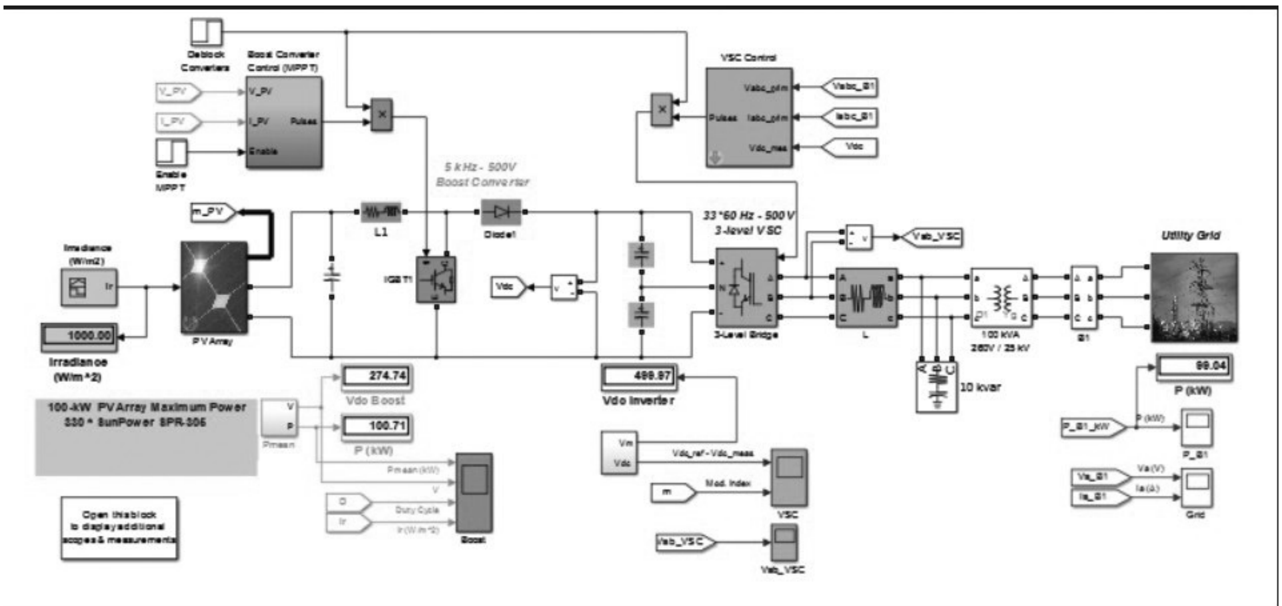

Figure 8: MATLAB/SIMULINK grid connected PV system

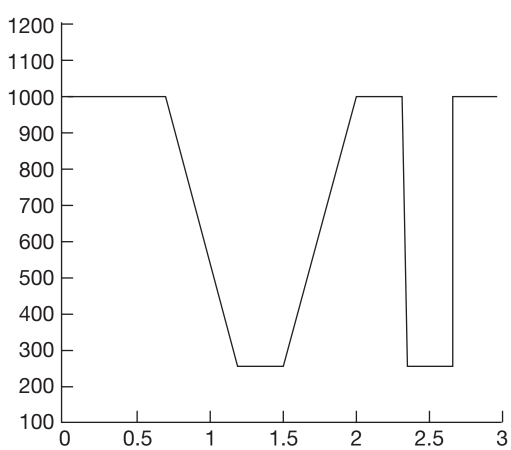

Figure 9: Irradiance delivered to PV array

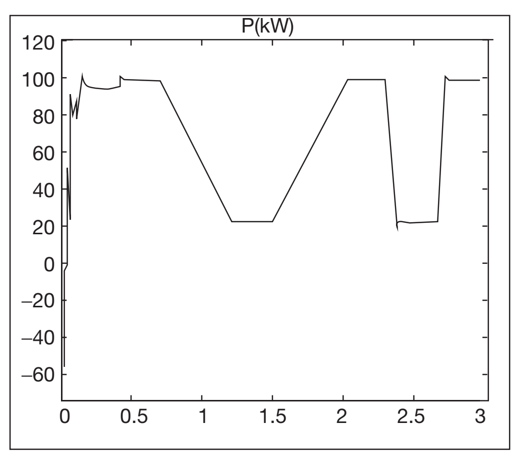

Figure 10: Power delivered by PV array to the grid

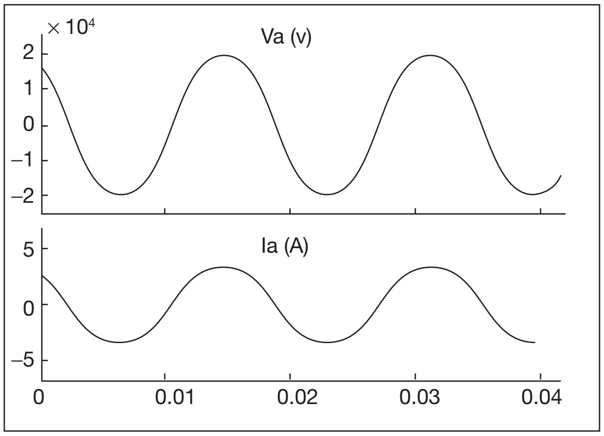

Figure 11: Line voltage and currents at the input to grid

Conclusion

In this paper the complete circuit-based grid connected PV system simulation model is discussed. The output power is varying linearly with solar irradiance of PV array. With the help of MPPT the maximum power is extracted from the given solar irradiance. Output characteristics of the inverter show good agreement with the grid characteristics. The PV array model is developed in MATLAB/Simulink Environment.

Bibliography

Atiqah Hamizah Mohd Nordin, Ahmad Maliki Omar "Modelling and Simulation of Photovoltaic (PV) Array and Maximum Power Point Tracker (MPPT) for Grid-Connected PV System" International Symposium & Exhibition in Sustainable Energy & Environment, 1–3 June 2011, Melaka, Malaysia 3rd 2011.

K. Jong-Yul, J. Jin-Hong, K. Seul-Ki, C. Changhee, P. June Ho, K. Hak-Man, and N. Kee-Young, "Cooperative control strategy of energy storage system and micro sources for stabilising the micro-grid during islanded operation," *IEEE Trans. Power Electron.*, vol. 25, no. 12, pp. 3037–3048, Dec. 2010.

M. G. Villalva, J. R. Gazoli, and E. R. Filho, "Comprehensive approach to modelling and simulation of photovoltaic arrays," *IEEE Trans. Power Electron.*, vol. 24, no. 5, pp. 1198–1208, May 2009.

Savitha PB, Shashikala MS, Putta Buddhi KL "Modelling of Photovoltaic Array and Control of Grid Connected Photovoltaic System to Provide Quality Power to Grid" International Conference on Electrical, Electronics, Communication, Computer and Optimisation Techniques (ICEECCOT) 2016.

Y. Bo, L.Wuhua, Z. Yi, and H. Xiangning, "Design and analysis of a grid connected photovoltaic power system," *IEEE Trans. Power Electron.*, vol. 25, no. 4, pp. 992–1000, Apr. 2010. [6] W. Tsai-Fu, C. Chih-Hao, L. Li-Chiun, and K. Chia-Ling, "Power loss comparison of single- and two-stage grid-connected photovoltaic systems," *IEEE Trans. Energy Convers.*, vol. 26, no. 2, pp. 707- 715, Jun.2011.

VI Dams and Reservoirs

Hydrologic Considerations in the Safety of Dams

U. C. Chaube[a], C. Garg[a] and A. Babu[a]

ABSTRACT: Many of the older dams are now characterised by increased hazard potential due to developments in flood plain and increased risk due to structural deterioration or inadequate spillway capacity of the dams. Guidelines issued by Dam Safety Organisation of Central Water Commission are reviewed in the context of safety of dams based on hydrologic considerations (design storm, design flood, spillway capacity).

India ranks third in the world in dam building with 5254 large dams (completed) and 447 dams under construction. Out of these 213 dams are over 100 years old. There have been 36 dam failures in India since the first failure in 1917 (Tigra dam in Madhya Pradesh). Most of the dam failures have been with respect to earth dam.

Literature review of flood estimates of 62 large dam shows that reassessed design floods are significantly larger than earlier estimates. With occurrence of more severe events in a large sample, earlier estimates of design flood are bound to be revised upward as illustrated through review of flood estimates of dams in India. Subjectivity in estimation of PMP and PMF should be minimised by evolving consensus and codifying the criteria, and procedures for estimation of design flood.

When various storms are considered for development of Unit Hydrograph for the same catchment, a marked variation is observed in the peak flood as well as the time of occurrence of the peak. Therefore average Unit Hydrograph needs to be derived giving higher weightage for the Unit Hydrograph derived from severe storms. Further, different unit hydrographs should be identified for the various conditions which have major influence on formation and time distribution of the runoff. These unit hydrographs may then be judiciously applied under different conditions.

Recent flood hydrographs should be used for derivation of Unit Hydrograph. Expected changes in land use, land cover in the catchment area and over the design life of the dam should be duly considered in the estimation of flood. Errors in forecasting floods in terms of estimation of peak discharge and time to peak due to use of different Unit Hydeographs when rainfall is not uniform and when rainfall is assumed to be uniform over the catchment are significant.

The effect of various factors on design flood estimation is analysed through case study of floods at Bhakra dam site on river Sutlej in India. Different probability distributions provide significantly different estimates. For example, using 1909–1992 data series of Bhakra dam, 10,000-year estimate by EVI is 21,036.26 m^3/s and by Pearson Type III, it was 26,154.53 m^3/s (24.33 per cent higher) (Bawono 2010). Using same probability distribution but different samples from same population also results in significantly different estimates.

KEYWORDS: dam failures, underestimate of design flood, inadequate spillway capacity

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Introduction

For centuries, dams have provided mankind with such essential benefits as water supply, flood control, recreation, hydropower and irrigation. They are an integral part of society's infrastructure. However in the last few decades, several major dam failures have increased public awareness of the potential hazards caused by dams. In the world of science, failure of dam is considered as events of "low-probability, high-loss". There are very large numbers of dams all over the world that are 50 or more years old. Many of the older dams are now characterised by increased hazard potential due to development in flood plain in downstream and increased risk due to structural deterioration or inadequate spillway capacity of the dam. Several of the old dams were designed with inadequate hydrological investigations.

In developing countries such as in Indonesia, India, Bangladesh, there is pressure to live and work in flood-prone areas, which typically feature attractive rich soils, sources of abundant water supplies and ease of transport. At present about 1 billion people – the majority of them among the world's poorest inhabitants – are estimated to live in the potential path of a 100-year flood and, unless preventative efforts are stepped up worldwide, that number could double or more in two-generation period. Due to various factors like deforestation, climate change, rising sea levels and growth of population in flood-prone areas, the number of people at risk by devastating flood can be predicted to be 2 billion by 2050.

Significant Dam Failures in India

India ranks third in the world in dam building with 5254 large dams (completed) and 447 dams under construction. Out of these 213 dams are over 100 years old. There have been 36 dam failures in India since the first failure in 1917 (Tigra dam in Madhya Pradesh). Most of the dam failures have been with respect to earth dams. There have been 36 dam failures in India up to the year 2010. Table 1 provides details of these 36 dam failures (year of construction, year of failure, cause of failure).

Table 1: Reported Failure of Dams in India (Year-wise)

SL	State	Name of	Type	Max Height	Year of completion	Year of Failure	Causes of Failure
1	Madhya Pradesh	Tigra	Masonry	24.03	1914–17	1917	Overtopping followed by slide
2	Maharashtra	Ashti	Earth	17.70	1883	1933	Slope failure
3	Madhya Pradesh	Pagara	Composite	27.03	1911–27	1943	Overtopping followed by breach
4	Madhya Pradesh	Palakmati	Earth	14.60	1942	1953	Sliding failure
5	Rajasthan	Dakhya	Earth	N.A	1953	1953	Breaching
6	Uttar Pradesh	Ahrura	Earth	22.80	1953	1953	Breaching
7	Rajasthan	Girinanda	Earth	12.20	1954	1955	Overtopping followed by breaching
8	Rajasthan	Anwar	Earth	12.50	1956	1957	Breaching
9	Rajasthan	Gudah	Earth	28.30	1956	1957	Breached due to bad workmanship

(*Continued*)

Table 1: (Continued)

SL	State	Name of	Type	Max Height	Year of completion	Year of Failure	Causes of Failure
10	Rajasthan	Sukri	Earth	N.A	N.A	1958	Breached by leakage through foundation
11	Madhya Pradesh	Nawagaon	Earth	16.00	1958	1959	Overtopping leading to breach
12	Rajasthan	Dervakheda	Earth	N.A	N.A	1959	Breaching
13	Gujarat	Kaila	Earth	23.08	1955	1959	Embankment collapsed due to weak foundation
14	Maharashtra	Panshet	Earth	53.80	1961	1961	Piping failure leading to breach
15	Maharashtra	Khadakwasla	Masonry	60.00	1875	1961	Overtopping
16	Rajasthan	Galwania	Earth	N.A.	1960	1961	Breaching
17	Rajasthan	Nawagaza	Earth	N.A.	1955	1961	Breaching
18	Madhya Pradesh	Sampna	Earth	21.30	1956	1964	Slope failure on account of inappropriate materials
19	Madhya Pradesh	Kedarnala	Earth	20.00	1964	1964	Breaching
20	UttaraKhand	Nanaksagar	Earth	16.00	1962	1967	Breached due to foundation piping
21	Gujarat	Dantiwada	Earth	60.96	1965	1973	Breach on account of floods
22	Tamil Nadu	Kodaganar	Earth	12.75	1977	1977	Breached on account of floods
23	Gujarat	Machhu-II	Composite	20.00	1972	1979	Overtopping due to floods
24	Gujarat	Mitti	Earth	16.02	1982	1988	Overtopping leading to breach
25	Madhya Pradesh	Chandora	Earth	27.30	1986	1991	Breaching
26	Andhra Pradesh	Kadam	Composite	22.50	1958	1995	Overtopping leading to breach
27	Rajasthan	Bhimlot	Masonry	17.00	1958	N.A.	Breached due to inadequate spillway capacity
28	Gujarat	Pratappur	Earth	10.67	1891	2001	Breached on account of floods
29	Madhya Pradesh	Jamunia	Earth	15.40	1921	2002	Piping leading to breaching

(*Continued*)

Table 1: (Continued)

SL	State	Name of	Type	Max Height	Year of completion	Year of Failure	Causes of Failure
30	Orissa	Gurilijoremip	Earth	12.19	1954–55	2004	The abutment structure along with wing and return walls got undermined with foundation scouring
31	Maharashtra	Nandgavan	Earth	22.51	1998	2005	Excessive rain causing water flow over the waste weir to a depth beyond the design flood lift
32	Madhya Pradesh	Piplai	Earth	16.73	1998	2005	Breaching
33	Rajasthan	Jaswant Sagar	Earth	43.38	1889	2007	Piping leading to breaching
34	Andhra Pradesh	Palemvagu dam	Earth	13.00	U/C	2008	Flash flood resulting in overtopping of the earth dam
35	Madhya Pradesh	Chandiya	Earth	22.50	1926	2008	Breaching
36	Rajasthan	Gararda	Earth	31.76	2010	2010	Breaching

Source: Dam Safety organisation, Central Water Commission, Government of India

Causes of Failure

Dams may fail due to a variety of reasons as given in Table 1. Analysis of 36 dams failures in India shows that major causes are foundation failure (40 per cent) and inadequate spillway capacity (31 per cent) as shown in Table 2. "Inadequate spillway capacity" implies that the flood passing over the spillway is sufficiently higher than the flood for which the spillway has been designed and thus the flood level rises and overtops the non-overflow section (usually made of earth and composite material). Underestimation of design flood becomes the main cause. Estimation of design flood is an important component of dam safety analysis.

Table 2: Cause of Dams Failure in India

No.	Cause	Per cent of Failure	No.	Cause	Per cent of Failure
1	Foundation Failure	40	4	Structural failure	20
2	Inadequate Spillway	31	5	Embankment Slips	3
3	Poor Construction	3	6	Defective Materials	3

Factors Affecting Accuracy of Flood Estimation

Absolute safety of dams from flood is unrealistic. A rational hydrologic design must therefore take into consideration the risk of flooding and consequent damages. The risk of damage is equivalent to the probability of occurrence of flood larger than the design flood (WMO, 1986). Design flood criteria are often specified in terms of flood corresponding to a return period T or Exceedance probability P (P = 1/T). Flood frequency analysis is used to estimate a flood corresponding to certain return period. Several factors influence the reliability of estimate of T year flood. These are:

- Length of data that is number of years record of annual maximum floods. Sufficiently long data length is necessary to allow reliable estimation of population parameters from the sample data
- Frequency analysis yields only the flood magnitudes and not volume or shape of the hydrograph.
- Choice of plotting position formulae out of several formulae given in literature (Hazen, Weibull, Gringorten, etc.) could be subjective.
- Choice of theoretical probability distribution considered for application could be subjective. Different probability distributions fitted to same data result in different estimated values especially in the extrapolated range.
- Difficulties exist in having homogenous data due to developments in catchment such as construction of new storage structures.
- Occurrence of an extreme rare event in the data series. Whether it is rejected as an outlier or included as an important rarely observed value.

Elements of risk and uncertainty are inherent in any flood frequency analysis as discussed below.

Probability of T year floods being exceeded in a period of r-years is given by

$$P(X > X_T) = 1 - \left(1 - \frac{1}{T}\right)^r$$

Using this formula, for example, it can be seen that the probability of a 100-year flood being exceeded in a project life of 100 years is 63.4 per cent, which is too high to be accepted in general. This is contrary to the popular notion that a 100-year flood has very little chance of being exceeded in 100 years. Conversely, the return period which is to be used for design of a structure can be decided, if the acceptable degree of risk and the expected life of the project are known.

$$T = \frac{1}{1 - (1 - P)^{1/r}}$$

Where, P represents the acceptable risk, in a project life of “r” years. For example, it can be seen that the return period to be adopted for a structure having life of 100 years for an acceptable risk of 1 per cent will be 9950 years (and not 100 years). There is need for better appreciation of these basic principles by designers. In the above derivations, sampling errors are ignored. Since, this is not normally the case, there are further risks associated with estimation from limited samples.

Effect of various factors on design flood estimation using flood frequency approach is analysed through case study of annual maximum floods at Bhakra dam site on river Sutlej in India.

Design Flood Estimation: Case Study of Bhakra Dam

Bhakra Nangal Dam is across the Sutlej River (Figure 1), near the border between Punjab and Himachal Pradesh in northern India.

It is considered as the highest gravity dam (225.55 m) in the world. The span of the dam is 518.25 m. Its reservoir, known as the “Gobind Sagar”, stores up to 9340 million m^3 of water, enough to flood the whole of Chandigarh, parts of Haryana, Punjab and Delhi. A Reservoir of 90 km length, formed by the Bhakra Nangal Dam is spread over an area of 168.35 km^2. It is a part of the multipurpose Bhakra Nangal Project constructed to to prevent floods in the Sutlej-Beas river valley, meet the required irrigation demands, along with production of hydropower generation.

Annual Flood Series at the Bhakra Dam Site

Observed annual flood peak data of 84 years (from 1909 to 1992) covers 51 years pre-construction period (1909 to 1959) and 33 years post-construction period

(1960 to 1992) Handri Alun Bawono(2010) under the guidance of first author carried out following analysis using the observed data:

- Randomness of data series is checked using peak and trough analysis.
- Effect of length of data is analysed by considering following three different series:
  - Pre-construction flood series (1909 to 1959)
  - Post-construction flood series (1960 to 1992)
  - Entire flood series (1909 to 1992)
- Choice of plotting position formulae. Probability of Exceedance of observed flood peaks has been computed using:
  - Hazen formula
  - Weibull formula and
  - Gringorten formula
- Presence of Jump and Trends has been checked by applying moving average method applied to mean and standard deviation.
  - Including highest observed peak and
  - Excluding the highest observed peak in the series.
- Outlier test for the highest and lowest observed series.
- Changes in statistical properties due to:
  - Different length of data
  - Inclusion/exclusion of highest observed value as outlier
- Choice of probabilities distribution:
  - Log normal
  - Extreme value type I
  - Pearson type III

Highest observed flood is 17,227 m^3/s in the year 1971 which pertains to post-construction period. The flood frequency analysis in post-construction period is influenced by choice for inclusion/exclusion of this rare event in the data series. The plot of the annual peak flood data is shown in Figure 2. The visual inspection of the data indicates a certain degree of variation in the average value of the peak flood in the later years of observation. The plot exhibits, in general, a slightly rising trend. However, with a view to examine the possibility of variations in the characteristics of the data in the pre-construction and the post-construction periods, the data series has been bifurcated in two parts – one for the period from 1909 to 1959 and the other for the period from 1960 to 1992.

Figure 1: Bhakra dam site at Sutlej River

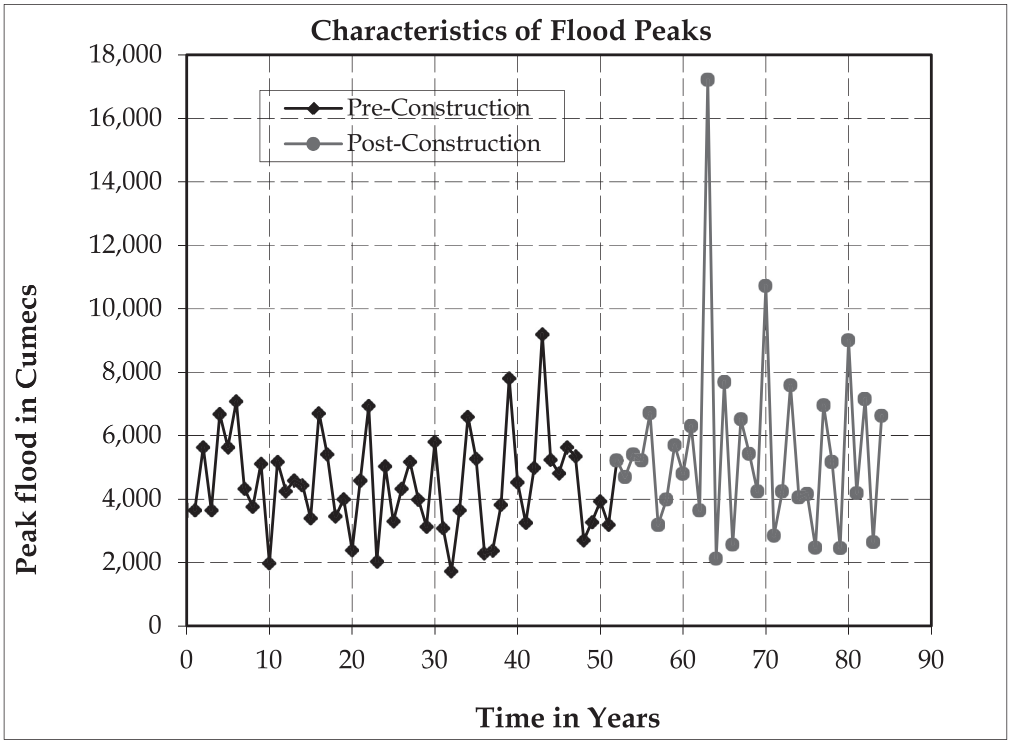

Figure 2: Observed flood peaks at Bhakra dam site

In order to examine the possibility of the specific annual flood peak data of 17,227 m^3/s being erroneous, the corresponding values of the rainfall record were scanned. The peak value has been reported to be observed on 6 August 1971. The flood hydrograph for the period from 03:00 Hrs of 6.8.71 to 24:00 Hrs of 7.8.71 indicates a total volume of 99.93 mm of runoff against the average value of 250.00 mm of the rainfall recorded at the various stations in the basin. Thus the runoff during the specific extraordinary flood event is only about 40 per cent of the rainfall falling over the basin suggesting that reported value of the annual peak flood of 17,227 m^3/s cannot be considered to be erroneous even though Test of Outliers indicates this flood to be outlier.

As the flow data series has a relatively high value of skewness (+2.234), the normal distribution which is symmetrical in nature will not be applicable.

Statistical parameters of the original series are used in Normal, EV Type I and Pearson Type III distributions whereas for log Normal distribution the parameters of log transformed are used. Post-construction series is highly skewed. Log transformation helps in significant reduction in series.

Floods for Different Return Period

If peak flood of about 17,227 m^3/s observed in the year 1971 is taken as real event and taken as a part of the sample of 84 annual maximum, the estimated value of 1,000 year return period and of 10,000 year return period appears to be on lower side on its face value. However, the analysis for the outliers suggests the 1971 flood peak value to be a higher outlier which in general means that it may be equivalent to a flood of a return period of more than 100 years.

Pearson Type III provides higher estimates of return year floods compared to other probability distributions. Pre-construction period estimate of 1,000-year floods 10,745.44 cumecs whereas post-construction period estimate is 24,073.76 cumec which is 224.04 per cent of the pre-construction estimate.

Choice of probability distribution has significant affect on flood estimate, 1,000-year flood by EV Type I probability distribution is 16,736.01 cumec whereas Pearson Type III provides estimate of 19,503.04 cumec which is 1.17 times more.

For the same data series, different probability distributions provide significantly different estimates for example using 1909–1992 data series, 10,000-year estimate by EV Type I is 21,036.26 m^3/s and by Pearson Type III is 26,154.53 m^3/s (24.33 per cent higher).

Using same probability distribution but different samples from the same population also results in significantly different estimates; 10,000-year flood estimates using Log Normal II probability distribution are 18,732.75 cumec (1909–92 data series), 15,064.06 cumec (1909–59 data series) and 24,588.81 m^3/s (1960–92 data series).

Conclusion and Recommendations

Based on the above-mentioned case study, author's experience in CWC and study of literature (mainly documents of Central Water Commission as in reference list) following recommendations is made regarding design flood estimation-

- For the safety of dam and other hydraulic structures, it is very important to understand the limitations of the flood frequency approach due to following factors influencing the flood estimate.
  - For the same data series, different probability distributions provide significantly different estimates.
  - Using the same probability distribution but different samples from same population also results in significantly different estimates.
  - An extreme rare flood data should not be considered as outlier on the basis of theoretical outlier test only.
- It would be worthwhile to adopt multiple storm durations to produce multiple inflow design flood hydrographs to arrive at the most severe inflow design flood hydrograph (CWC2015).
- Use of revised PMS Atlas for design flood reviews is recommended (CWC 2015).
- As hydrology is a dynamic process, the hydrological parameters such as design flood, should be reviewed periodically, particularly when a significant hydrometeorological event occurs in the catchment of the project (CWC 2015).
- There is urgent need for assessing the impact of climate change on PMF to be used for taking appropriate dam safety measures in the country (CWC 2016)
- Volume and duration of flood events should also be considered along with the peak discharge rates using multivariate modelling to assess the risk of flood events in its entirety (CWC 2016).
- Because of the availability of DEMs, it is now possible to estimate response of catchment using Geomorphoclimatic Instantaneous Unit Hydrograph (GIUH). The methodology may be attempted in many gauged and ungauged catchments to develop confidence for application of the same for design flood estimation (CWC 2017).
- CWC should analyse Dam Safety Review Panel (DSRP) reports of 1,000 dams to bring out design, construction, and maintenance deficiencies and identify dams with manifestation of distress that may lead to failure, and dams with enhanced hazard due to revised design flood and seismic activity, to implement appropriate and timely measures (CWC 2017).

References

Bawono, A.L. (2010). "Hydrologic Considerations in Safety of Dam" Master's Thesis, Department of Water Resources Development and Management, IIT Roorkee, India.

World Meteorological Organisation (1986). Manual for estimation of probable maximum precipitation, 2nd edition. Operational Hydrology Report, Vol. 1. WMO No. 332.

CWC (1993): “Recommendations-Workshop on Rationalization of Design Storm Parameters” Hydrology Organisation, Central Water Commission New Delhi 1993.

CWC (1986): “Report of Dam Safety Procedure”, Central Water Commission 1986.

CWC (1987): “Guidelines for Safety Inspection of Dams”, Ministry of Water Resources, Central Water Commission Government of India, June 1987 (Revised).

CWC (1979): “Dam Safety Service”, Ministry of Agriculture and Irrigation (Department of Irrigation), Central Water Commission, New Delhi, 1979.

CWC (2015): Recommendations given in the Compendium of Technical Papers of the First National Dam Safety Conference organised by Central Water Commission (CWC) during 24 and 25 March 2015, IITM, Chennai

CWC (2016): Recommendations given in the Compendium of Technical Papers of the Second National Dam Safety Conference organised by Central Water Commission (CWC) during 12 and 13 January 2016, IISc. Bengaluru

CWC (2017): Recommendations given in the Compendium of Technical Papers of the Third National Dam Safety Conference organised by Central Water Commission (CWC) during 18 & 19 February 2017.

Deep Tunnelling for Underground Storage in Jointed Rock Mass

Ashish Juneja[a] **and Kota Vijay Kiran**[a]

ABSTRACT: Tunnel failure remains a severe problem in practice, as many deep tunnels may need to often pass through large-scale jointed rock masses. Many reported failures of underground openings during excavation and in operation are closely related to joints. The stability of the tunnel is mainly affected by the attributes of the joints, namely, their orientations relative to the tunnel, their spacing and their shear strengths. In this study, the applicability of the discrete element modelling and discrete fracture networks to analyse underground openings was examined, and tunnel behaviour is evaluated by investigating the resulted deformations of the potential failure wedges, displacements and induced stresses in jointed rock. The obtained numerical results are analysed and discussed displaying the importance to consider the factors affecting the behaviour of tunnels constructed in jointed rock.

KEYWORDS: deep tunnelling, jointed rock mass, discrete element modelling

Introduction

The demand for underground storage for isolating nuclear waste, ammunition and explosives and many other hazardous wastes has been developed in recent years because of more stringent environmental protection standards. Rock tunnels have been found to be suitable for creating such storage. For planning, design and construction of underground storage caverns, engineering geological assessment of the selected proposed site forms a key input. As many underground excavations constructed often pass through jointed rock mass, the effect of joints on underground openings is to be understood precisely. Joints are the discontinuities in an intact rock, typically parallel and regularly spaced, which form in the rock mass to be blocky. Due to their low shear and tensile strengths, the rock mass is subjected to shear failure causing rupture and sliding along the structural plane during unloading by excavation. The high-stress concentrations during deep excavations lead to brittle failure in jointed rock masses which results in spalling and strain bursting (Diederichs, 2007). Spalling is sometimes a time-dependent phenomenon, which is the result of visible extensile fracturing under high compressive stresses, commonly encountered in crystalline rocks at low confinements around underground openings under high stresses. During spalling, the formation of thin parallel slabs leads to a sudden release of stored strain energy (Diederichs, 2007, 2014).

On the contrary, in deep tunnelling, complex stress paths within the vicinity of the excavation, as the tunnel advances, result in strain bursting (Kaiser et al., 1995) at the walls and the face of the excavation, with or without structural control (Diederichs et al., 2013). Phenomena such as this in tunnelling operations, which involve stress changes, energy storage and release mechanisms, are of a more local nature and are usually coincident with the excavation boundary (Diederichs, 2014, 2018). Rock burst in highly jointed rock masses can be triggered as a result of rapid release of strain energy followed by rock mass failure or often caused due to the propagation of strain waves at the surrounding major rock mass structural features (e.g. faults). In Figs. 1, 2 and 3, a few examples of wedge fall due to shear failure, spalling and strain burst phenomena are illustrated.

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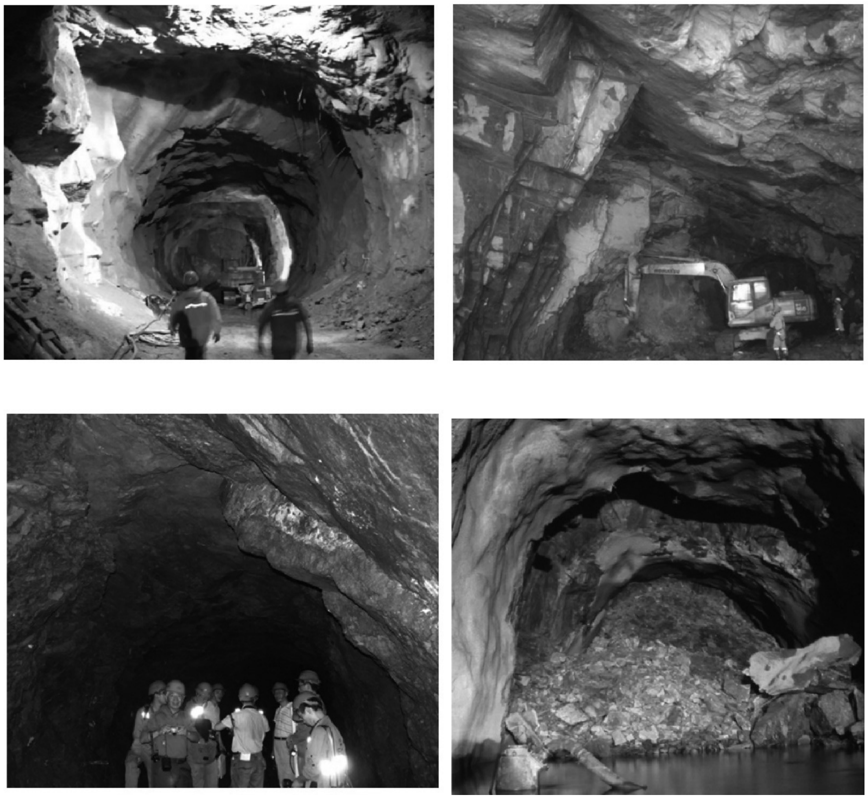


Figure 1: Examples of wedge fall due to shear failure

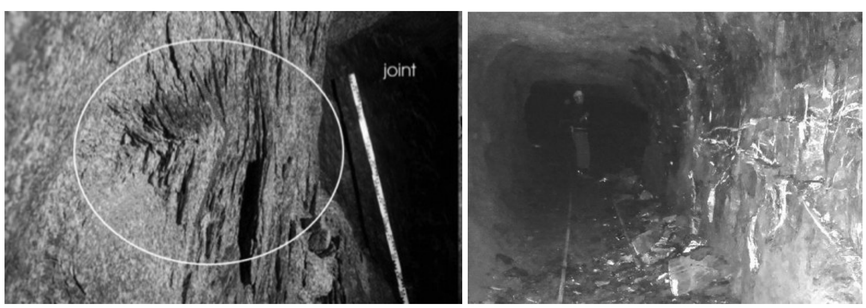


Figure 2: Examples of spalling

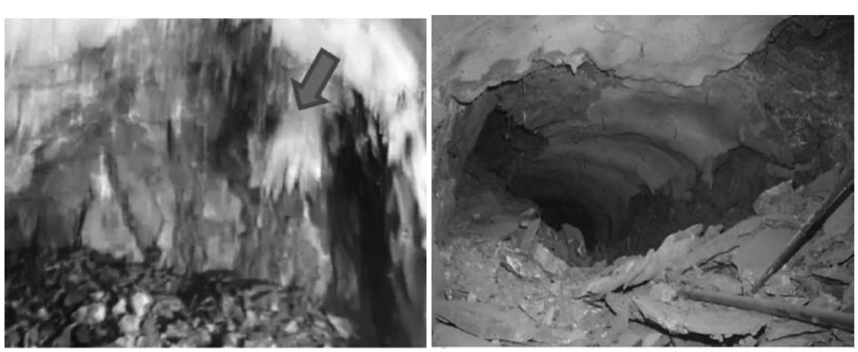


Figure 3: Examples of rock bursts

Table 1: A Few Case Studies on Tunnel Failures

Tunnel	Nature and Type of Failure	Possible Cause of Failure	Lessons Learnt
Penmanshiel Tunnel, Scotland, UK, March 1979	• Ground failure during reconstruction • Fall of rock over a length of some 20m	• The degeneration of the rock within the anticlinal structure built up heavy loading on the arch ring and side walls • Additional excavation in the tunnel increased the stresses in the already overstressed rock in the side walls	• The consequences of adjusting the profile of a working tunnel without stress analysis and appropriate support • The importance of understanding the geological conditions of the site and the need for analysis
Oslofjord Subsea Tunnel, Norway, 28 December 2003	• Service failure • About 20 m^3 of crushed and weathered rock involving with clay, which came down from the crown • Second failure involved about 3 m^3 of heavily weathered rock, which came down from the spring line and fell down to the invert • Third failure involved 2–3 m^3 of completely weathered rock, which fell down from the crown and rested on top of the water shielding vault	• The humidity behind the vault constructed for frost insulated water shielding was high, and the high content of swelling clay in the weathered rock started sucking water and expanded gradually over a long period of time	• The importance of proper geological mapping and rock mass classification • The need to identify swelling minerals and the potential of deterioration of strength in weathered rock • The importance of adequate support design for long-term stability in weathered rock
Oslo Metro Tunnel, Norway, 17 June 2004	• Construction failure • At the junction where the two tunnels met in an acute angle, tunnel caved in after removal of most part of the rock pillar between the tunnels	• Unfavourable direction of the bedding planes in relation to the geometry and span of the tunnels • Over-excavation of the rock pillar before the planned concrete pillar was constructed	• The importance of adequate ground investigation • The need to follow the sequence of rock support installation in accordance with the design plans during construction
Lane Cove Tunnel, Australia, 2 November 2005	• Construction failure • Collapse occurred during breakout for a ventilation tunnel from the running tunnel	• Possible "rock slippage" • Under-designed rock bolts due to increased effective span at the intersection of adit and tunnel	• Lack of qualified engineering geologist at the site to carry out mapping and design

(*Continued*)

Table 1: (Continued)

Tunnel	Nature and Type of Failure	Possible Cause of Failure	Lessons Learnt
Hanekleiv Road Tunnel, Norway, 25 December 2006	• Service failure • A section of tunnel caved in 10–11 years after excavation	• Unfavourable geometry with joints almost parallel to the tunnel axis • The rock bolts installed mainly parallel to the rock joints and with limited influence on the stability	• The importance of proper geological mapping and influence of tunnel orientation with respect to joints
São Paulo Metro Station, Brazil, 12 January 2007	• Construction failure • Collapse of the station cavern/ tunnel and partial damage to the station/access shaft • The rate of settlement at the tunnel crown increased rapidly and reached 15mm to 20mm 2–3 days before the failure	• Failed to account for the geology of the site • The existence of the curved top ridge-of-rock has added to the dead weight above the cavern/tunnel and might have prevented arching action, causing overstress	• Sub-urban tunnelling with thin rock cover should be avoided if possible due to the unpredictable degree of rock weathering

Many failures discussed above are due to lack of qualified engineering geologists at the site to carry out mapping and design during the tunnel construction. It is very important to understand the geological conditions of the site and analyse the potential failure mechanisms at varying grounds. So, in the following sections, an attempt has been made highlighting the limitations of simple techniques that are being followed by many engineers from the past succeeded by numerical modelling of an underground opening in jointed rock mass using discrete element modelling.

Simple Empirical and Graphical Methods and Their Limitations

Favourability of Tunnel Axis with Joint Orientation

Francis (1990) presented a simple method to classify the favourability of joint orientations with respect to tunnel drive direction. As joint populations are generally plotted stereographically, an overlay was prepared with sectors defining favourability in terms of the geomechanics classification. Superimposition of the favourability overlay on a joint pole counter plot allows easy assessment of the effects of joint set orientations while using Bieniawski's geomechanics classification system. The overlay presented in Figure 4a may be prepared using transparent plastic of equal diameter to the stereograph base. It is centred on the contoured joint pole plot, orientated correctly with respect to tunnel drive direction and the favourability class read off for each pole cluster as shown in Figure 4b.

Modes of Failure and Risk Hazard Assessment

Hoek and Brown (1980) introduced a stress-to-strength ratio as an index for tunnel stability in hard brittle rocks. Their stability index ranges from 0.1 through 0.5 and can be briefly described as follows: the rock mass response was elastic if $\sigma_1/\sigma_{ci} > 0.15$, minor to moderate instability occurred if σ_1/σ_{ci} falls between 0.15 and 0.35, and severe instability encountered when $\sigma_1/\sigma_{ci} > 0.4$; that is, heavy support required to stabilise the opening. In these approaches, the stress level is typically defined in terms of the overburden stress σ_v or σ1 the major far-field in situ principal stress. Figure 5 illustrates these modes of failure and the possible outcome. In order to make the risk/hazard assessment the designer must know the strength of the rock mass and the in-situ stress state.

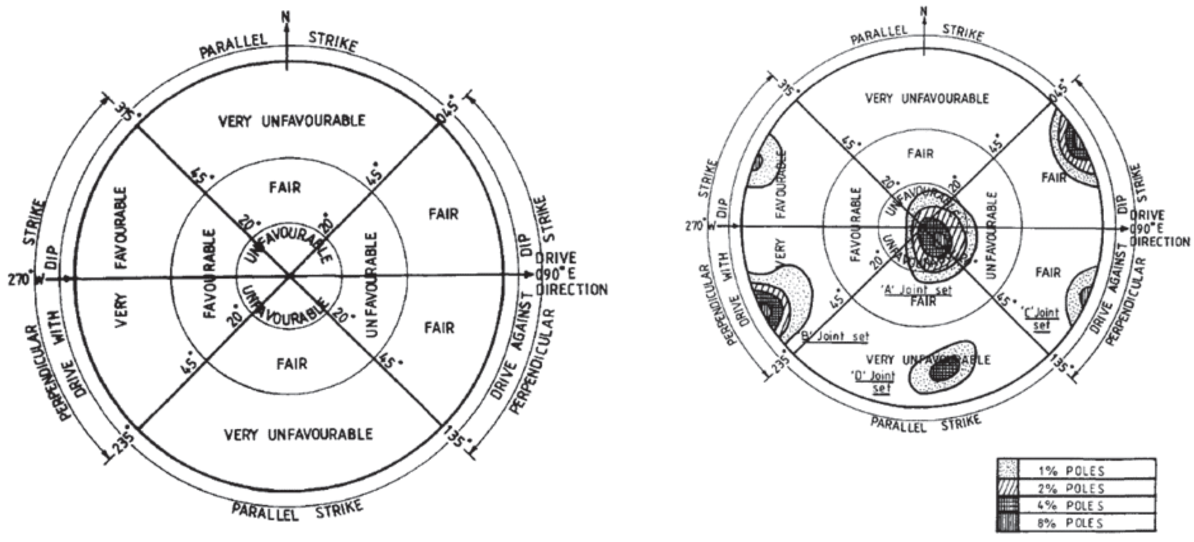


Figure 4: (a) Favourability of joint orientation for geomechanics classification (b) Superimposition of pole plot and favourability overlay (after Francis, 1990)

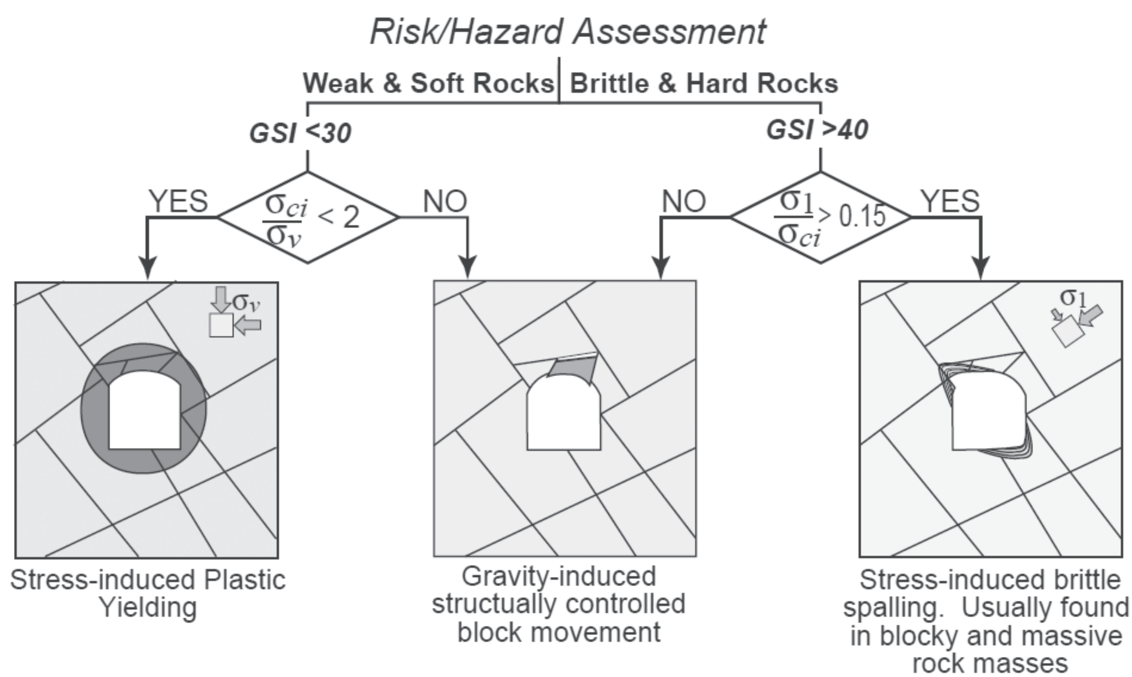


Figure 5: Modes of tunnel failures (After Hoek-Brown, 1980)

Sliding and Bending Zones

Goodman (1976) has suggested a graphical method to judge the sliding zones and bending zones of the tunnel. The process follows; draw a normal line of joints OO' and two lines OA and OB with an angle of Φ_j (Φ_j is the internal friction angle) besides the normal. Upon drawing the tangent lines of tunnel periphery, which are parallel to OA and OB, within the zone enclosed by these four tangents, two sliding zones can be judged by measuring whether the angle between the tangent lines of the tunnel and the normal is bigger than Φj. The limitations of this method were raised from numerical simulations, which showed that for low lateral pressure coefficient (e.g. k = 0.5), the failure zones around tunnel are very similar to that judged by the graphical method. But for high lateral pressure coefficients (e.g. k = 1.2 and 1.5), the failure zones change due to the effect of lateral pressure. Goodman's graphical method seems more suitable for low lateral pressure coefficient.

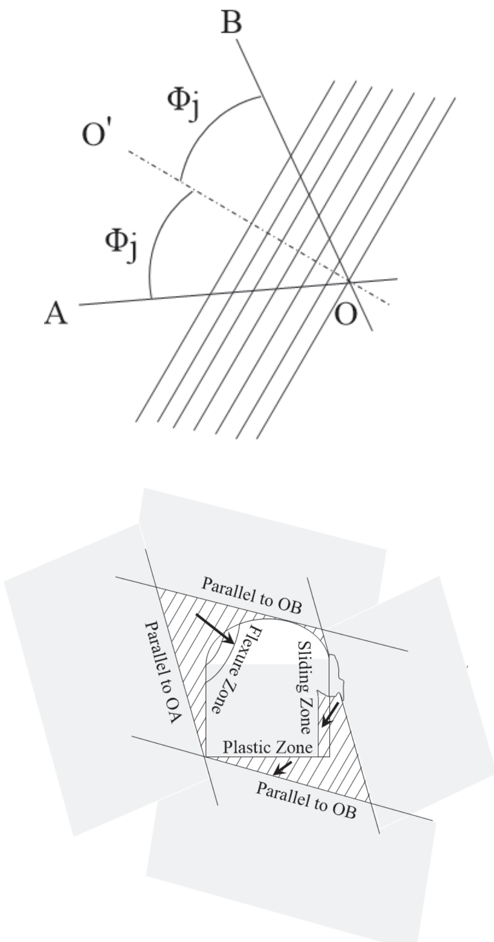


Figure 6: Graphical method to distinguish the sliding zone and bending zone (After Goodman, 1976)

Key Block Theory for Potential Failure Wedges

For underground excavations in sparsely jointed rock masses with large joint spacing, stability is governed by key blocks whose shapes permit free kinematic movement into the opening. Failure involves either sliding or falling of key blocks. The engineer can identify key blocks from rock joint surveys and secure them using pre-tensioned rock bolts.

Mauldon (1993) studied the effect of joint orientation on the variation of joint pyramids. Goodman and Shi (1985) introduced a key block theory to identify potential failure wedges around an underground opening. Classification of the blocks around the opening has been made, based on its potential to move.

- Type I - being moveable.
- Type II - having key potential to move.
- Type III - has no movement because of its position in basement.
- Type IV - has no movement because of blocking with around blocks.
- Type V - a jointed block without any free space in rock mass (Hammett and Hoek, 1981).

The key blocks (I and II) described as unstable block in rock mass should be taken into great consideration. These blocks are evaluated by the kinematic method.

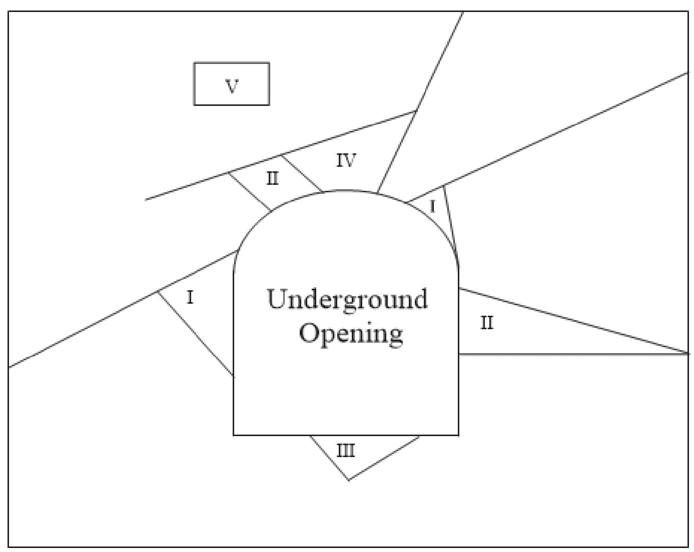


Figure 7: Types of blocks around the excavation section (After Goodman and Shi, 1985)

However, designs based on key blocks are not suitable for underground excavations in moderately to heavily jointed rock masses as a typical failure involves ravelling and loosening of rock mass material that pops into the excavation opening. The failed material usually consists of numerous rock blocks. This complexity led engineers to develop rock mass classification systems such as the RMR system (Bieniawski, 1993) and the Q-system (Barton et al., 1974), based on large field data from the past.

Numerical Modelling of Tunnels in Jointed Rock Mass

Many underground facilities are associated with ramp or shaft system, comprising complex geometries. In addition, most of these facilities often pass through geological features such as joints or faults. Due to these complexities, closed-form solutions and graphical methods are of limited value in studying the behaviour of tunnels in jointed rock conditions. In recent years, numerical methods like Boundary Element Methods (BEM), Finite Element Methods (FEM), Finite Difference Methods (FDM) were employed to analyse the complex tunnel geometries. All these methods treat the rock mass as a continuum, and user can input interface elements that enable them to model a jointed rock to some extent. However, their formulation is usually restricted to small displacements and rotation, and even the logic breaks down upon incorporating many interface elements. Also, these continuum methods would not allow recognising new contacts.

Discrete Element Modelling

Distinct Element Method

In discrete element method, finite displacements and rotation of discrete bodies are allowed, including complete detachment and automatic recognition of new joints. The term "Distinct Element Method (DEM)" was introduced by Cundall and Strack (1979) to refer to discrete element scheme that uses deformable contacts and explicit time-domain solution of the equations of motion. In DEM, each block is a unique free body which interacts with adjacent blocks at contact locations. The contacts are identified and represented by the adjacent blocks that overlap each other, avoiding the need to define unique joint elements. This is why DEMs take advantage of having large relative displacements at the contact, which is not possible in any finite element codes.

Further, the joints can be incorporated into the model using discrete fracture networks (DFNs) technique, which enables quick generation of randomly intersecting joints with the input parameters of joint orientation, intensity and fracture size (Itasca, 2008).

Development of the Numerical Model

To understand the effect of joints on tunnel behaviour in jointed rock, three cases have been considered with various models. In each case direction has been altered, which would reflect on the tunnel response to excavation. The numerical model is a cuboid of dimensions 15 m x 10 m x 15 m with gravity acting along the negative z-axis. The model has its origin at the centre of the tunnel such that the x-coordinate axis ranges from -15 to 15 m, y-coordinate axis ranges from -10 to 10 m and the z-coordinate axis ranges from -15 to 15 m. The shape of the tunnel considered is D-shaped, with dimensions 6m x 6m height. The tunnel is assumed to be at a depth of about 500 m from the surface, and the model dimensions have been selected to ensure that there is sufficient material around the tunnel. This is essential to ensure that the model boundary is farther than the area of influence. As a general guideline, the horizontal and vertical dimensions of the model should be at least five times the horizontal and vertical dimensions of the tunnel. In the current set-up, the cross-section dimensions of 15 m x 15 m sufficiently satisfy this guideline.

The physical and mechanical properties of intact rock used in the model are given in Table 2. The used rock constitutive model is the Hoek-Brown model. The vertical stress at 500 m has been estimated as a function of depth using a constant average overburden density of 2700 kg/m^3, to be 13.5 MPa. The model is bounded at the base by fixities which prevent vertical movement, and stress boundaries have been used along the other five faces, with magnitudes equal to the in-situ stresses and gradients along the respective directions. The discrete fracture networks technique was used to incorporate the joints with the joint intensity and size as uniformly distributed and varying the joint orientations as tabulated in Table 3.

Table 2: Properties of the Material Model and Joints Considered for Numerical Simulation

Rock Properties:	
Density (kg/m³)	2700
Young's modulus (MPa)	45000
Poisson's ratio	0.18
Intact comp. strength (MPa)	100
mb Parameter (peak)	1
s Parameter (peak)	0.001
a Parameter (peak)	0.5

Joint Properties:	
Normal stiffness, Jn	10 GPa
Shear stiffness, Jks	2 GPa
Joint cohesion, Jcoh	0.1 kPa
Joint friction, Jfric	25

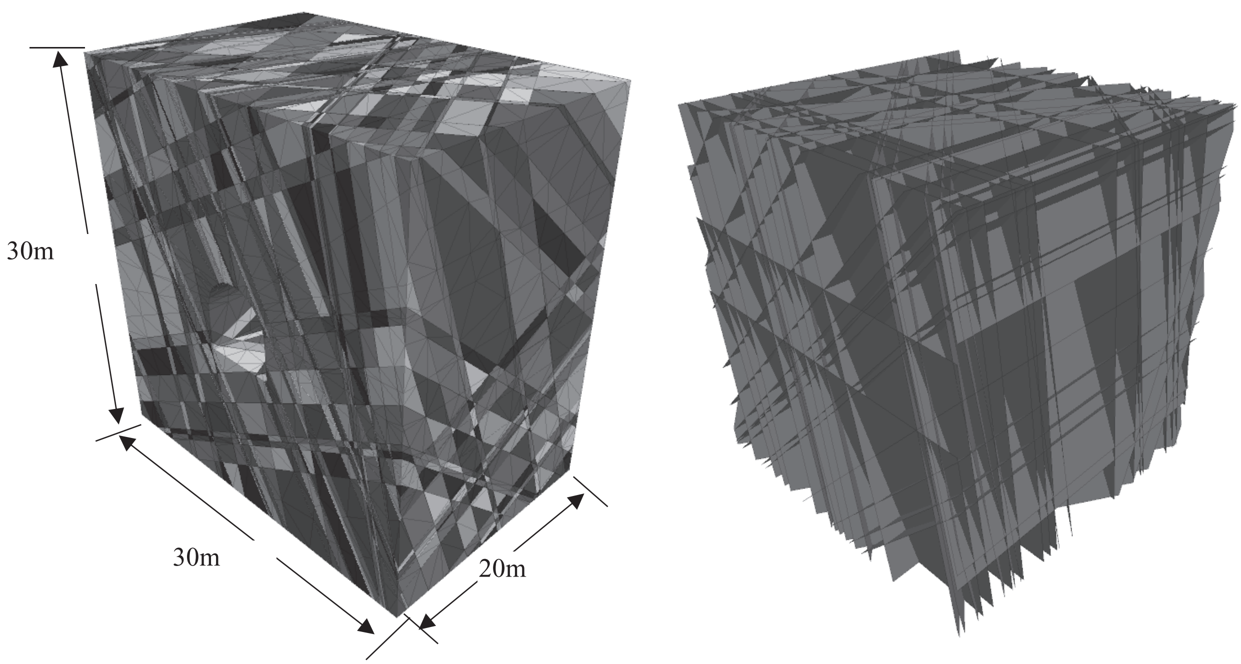


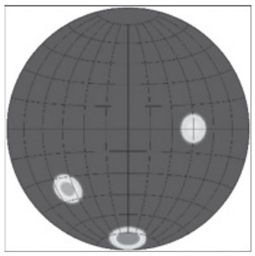
Figure 8: Model geometry and DFN model

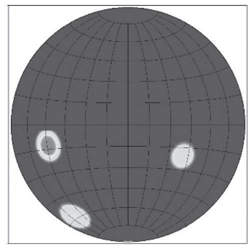
Table 3: Results of the Considered Cases with Different Joint Orientations

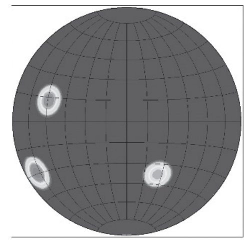
Joint set data

	Case-1			Case-2			Case-3		
	S. No.	Dip	DD	S. No.	Dip	DD	S. No.	Dip	DD
	1	80	0	1	80	30	1	80	60
	2	45	270	2	45	300	2	45	330
	3	60	45	3	60	75	3	60	105

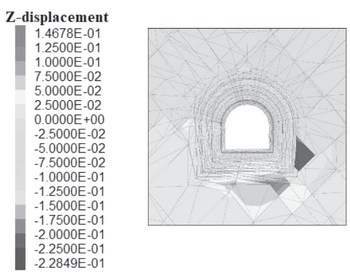
Stereonet

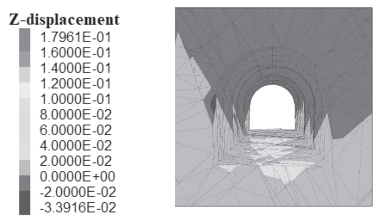
Case-1


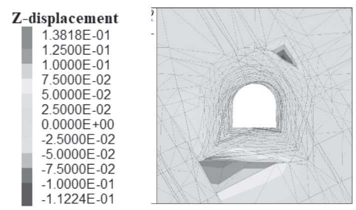
Case-2


Case-3


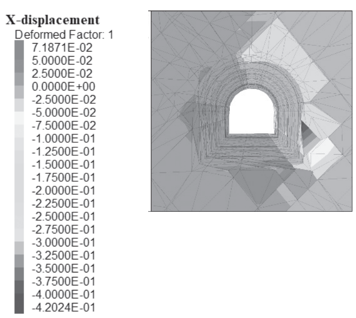
Z-Displacement (m)

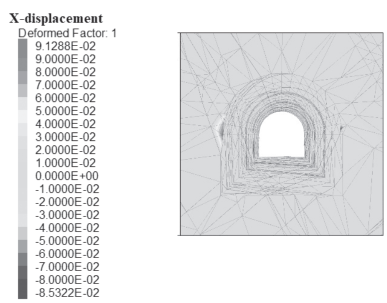
Case-1


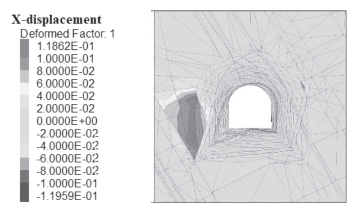
Case-2


Case-3


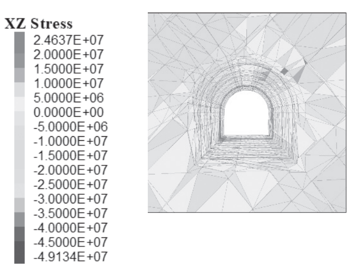
X-Displacement (m)

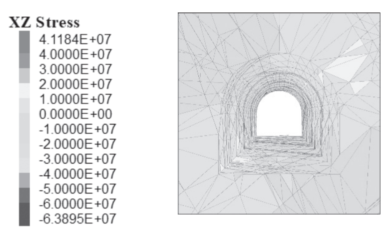
Case-1


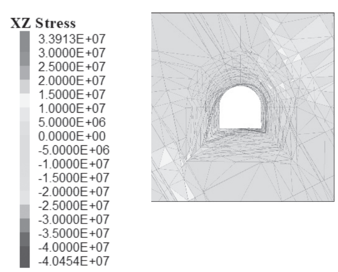
Case-2


Case-3


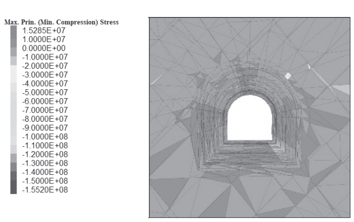
XZ-Stress (N/m^2)

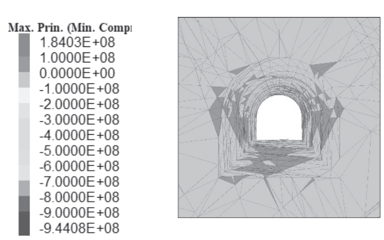
Case-1


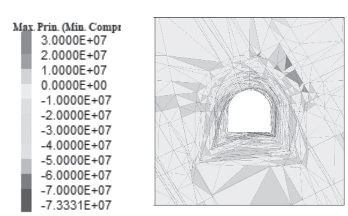
Case-2


Case-3


Max. Principal Stress (Min. Compressive stress) (N/m^2)

Case-1


Case-2


Case-3


Note: It may be noted that 3DEC recognises the compressive stresses/forces and downward displacements as being negative.

Results and Discussion

A model was created without joints for validation, as the presence of joints cutting across an excavation can analyse the stress fields around the excavation, a confusing or complicated task. Once the validity of this model was established, the joints planes were incorporated using DFN technique into the model. Table 3 shows the deformation distributions where significant deformations can be distinctly observed around the walls, sagging roof and some degree of floor heaving around the tunnels. The maximum floor heaving was observed in case-2 and maximum displacement at the crown was observed for case-1 with values 179 and 228mm respectively. The high values of displacement are noticed due to detachment of the blocks, which has the potential to fall into the opening. The minor-major principal stresses are the tensile stresses around the vicinity of the opening, which need to be accounted for the design for tensile support. Shear stresses and maximum principal stresses were on a relatively higher range for case-2 as compared to other two cases. From the computed results, it can be noted that cases-1 and 3 are most preferable joint set directions than case-2 having relatively low displacements and stresses around the vicinity of the excavation.

Conclusion

Deep tunnels in the jointed rock mass, under a high in situ stress field, have been modelled using the distinct element method and discrete fracture networks. This is preceded by the study of failure patterns for unsupported openings in a rock mass intersected by three independent sets of joints. The results from the simulations show that a qualitative description of the failure patterns can be attained for efficient design of supports for tunnel excavation. Potential failure wedges, stress distributions around the vicinity of the opening and the favourable cases for the joint sets considered were identified based on the computed results.

References

Barton, N., Lien, R., & Lunde, J. (1974). Engineering classification of rock masses for the design of tunnel support. *Rock mechanics*, *6*(4), 189–236.

Bieniawski, Z. T. (1993). Classification of rock masses for engineering: the RMR system and future trends. In *Rock Testing and Site Characterization* (pp. 553–573). Pergamon.

Cundall, P. A., & Strack, O. D. (1979). A discrete numerical model for granular assemblies. *geotechnique*, 29(1), 47–65.

Diederichs, M. S. (2007). The 2003 Canadian Geotechnical Colloquium: Mechanistic interpretation and practical application of damage and spalling prediction criteria for deep tunnelling. *Canadian Geotechnical Journal*, *44*(9), 1082–1116.

Diederichs, M. S. (2018). Early assessment of dynamic rupture hazard for rockburst risk management in deep tunnel projects. *Journal of the Southern African Institute of Mining and Metallurgy*, *118*(3), 193–204.

Diederichs MS, Eberhardt E, Fisher B. Consideration of stress and structural influence on high stress response in deep tunnelling e the Olmos Tunnel, Peru. In: Anagnostou G, Ehrbar H, editors. Proceedings of the world tunnel congress. CRC Press; 2013.

Francis, T. E. (1991). Determination of the influence of joint orientation on rock mass classification for tunnelling using a stereographic overlay. *Quarterly Journal of Engineering Geology and Hydrogeology*, 24(3), 267–273.

Goodman RE, Shi G (1985). Block theory and its application to rock engineering, *Englewood Cliffs. NJ: P-H*: 338.

Hammett RD, Hoek E (1981). Design of large underground caverns for hydroelectric projects, with reference to structurally controlled failure mechanisms. *Proc. American Soc. Civil Engineers. Int. Conf. on Recent Developments in Geotechnical Engineering for Hydro Projects. New York:* ASCE: 92–296.

Hoek E and Brown ET. (1980) Underground excavations in rock. London: *The Institution of Mining and Metallurgy*.

Hoerger SF, Young DS (1990). Probabilistic prediction of key block occurrences. *Proc., 31st U.S. Symp. Rock Mech*., 229–236.

Itasca (2008) 3DEC user's guide*. Itasca Consulting Group Inc.*, Minnesota

Mauldon M (1993). Variation of joint orientation in block theory analysis. *Int. J. Rock Mech. Mining Sci.,* 30: 1585–1590.

Kaiser PK, McCreath DR, Tannant DD. (1995) Canadian rockburst support handbook. *Geomechanics Research Centre and CAMIRO*

VII Other Infrastructure

Post-flooding Infrastructure Resiliency: An Endless Fight

Nurashikin Mohammed[a,b] and Rodger Edwards[a]

ABSTRACT: Floods are the most repeated disasters among Asian countries. Infrastructures that are involved with floods could cause further damage to the existing emergency situation, imposing the adverse impacts on the community, organisation, business, the government and also the country. It is possible to say that those infrastructural damages may create more severe condition than the first flooding events that occurred. Therefore, all vulnerable infrastructures need to be satisfactorily managed by the liable parties. Concocting a follow-up action plan for post-flooding recovery and resiliency efforts is one of a great approach. The aim of this paper is to help clarify the possible management steps in handling the institutional arrangements towards the vulnerable infrastructures during the post-flooding situation. Problems arise when comprehensive management is lacking in few aspects in aiming for the resiliency of infrastructures, lessening of flooding after-effects, or maintaining those efforts to last. These issues require rethinking and embedding the collective approach through lessons learned and review from the previous literature. The primary outcome shows that there is no best practice available for all, but different insights and solutions could fit into the situation depending on which type of measures are carried out by the stakeholders.

KEYWORDS: disaster, flood, infrastructure, resiliency, risk, sustainability

Introduction

Floods can cause direct and indirect impacts on the surroundings and usually the indirect impacts imposed on the larger area. A flooding can cause a serious impact on businesses and organisations whether big or small and could cause direct and indirect impacts, including the infrastructure. As for the last 15 years the emergency management has been involved in preparedness and response, now the focus has been changed to recovery efforts. According to John (2008), managing disaster in has grown where attention has been extended from response and recovery to public survival. Resiliency and survival ability are two features that are sharing the same notion, which is attaining persistent development concerning ecosystems, built environment, and humanity. For many years, many patrons surprisingly neglected resiliency phenomenon. For the past two decades, the move had been changed from defending against floods known as resistance towards adapting to them that is known as resilience (Jong et al., 2017). Resiliency in future flood management requires the people involved to resolve the challenges that arise at the same time making strategies to make things better (Islam and Walkerden, 2017). Resiliency would not only providing green infrastructure, but also provide multifunctionality in improving the performance of the assets (Hoang et al., 2016). The scope of post-flooding recovery would assimilate the long-term hazard mitigation, public safety, and at the same time targeting resilience (Rani et al., 2017). The works involved range from assisting economic improvement to building repair and reconstruction, infrastructure and environment restoration, sustainable and better land use, including other long-term recovery concerns acknowledged by the community involved (Tyas,

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2016). Recovery includes re-establishing the social fabric and relationships embedded in communal institutions such as workplaces, places of play and recreation, and retail shops (Vale and Campanella, 2005; Campanella, 2006). The projects in post-flooding recovery and control should be assessed starting from the earliest stage to ensure a resiliency impact (Islam and Walkerden, 2017).

Materials and Methods

This paper involves literature review and discussions to shepherding disaster risk reduction (DRR) approaches that concern on the resilient, sustainable development, flooding, including the best efforts towards the surrounding infrastructure. It is also concerned with the DRR, with a focus on resilient infrastructure towards post-flooding recovery issues. This paper consists of a literature review and discussions part. Literature reviews were gathered from reference materials extracted from sources such as journals, articles, and websites. The combination of evaluation of the literature-gathered risk assessment and knowledge gathered was used to identify ways to reduce possible flooding impacts. An effective handling of post-flooding recovery requires a multidisciplinary approach, the search covered major disciplines such as disaster preparedness, risk management, facilities management, and emergency operations were identified.

Literature Review

An Endless "Fight": Transformation and Worthy Efforts

It is expected that the post-flooding management adapted by the urban development will include social, economic, and environmental aspects while taking care of the land use, human environment, and the natural resources (Jong et al., 2017; Zevenbergen et al., 2010). The development of post-flooding recovery should be able to upkeep and lead the long-term recovery resiliency (Rani et al., 2017). Resiliency in post-flooding recovery also means that the overall recovery process should be holistically planned for two or three decades ahead to ensure it is still relevant concerning the ongoing demands and sustainable approaches along the way (Nicholas, 2014). However, delivering those approaches requires identification on where it could be delivered, where could it be applied, and to whom would they benefit (Hoang et al., 2016). The monitoring and evaluation of the post-flooding recovery process could be significantly enhanced by applying the principles and practices of auditing and assessment to provide objective assurance for governance system, including risk management, operational performance, and financial control (John, 2008). There should be a transformation of policies and strategies. The transformation is needed to provide fresh ideas and more in-depth views on how to conduct and perform best for future use (Islam and Walkerden, 2017). The government and authorities always deal with climate change and disaster policies, and less consideration is given to public initiatives (Hagelsteen and Burke, 2016). The government structure in the implementation of disaster policies at the local level is restricted. Filling the gap in the recovery phase can improve further approach (Islam and Walkerden, 2017). The bottom-up and top-down approaches are used in creating the policies. These approaches are the key to the resilience management within the community (Fraser et al., 2006). Within the national- and local-level organisations, partnership is essential to strengthen the disaster management policy and programme (Islam and Walkerden, 2017).

Concerns need to be addressed about the tangible or intangible losses (Vu and Ranzi, 2017), including both structural and nonstructural measures in handling disaster (Vu and Ranzi, 2017). It is essential to put investment on structural and non-structural measures (Vu and Ranzi, 2017). Post-flooding recovery impacts have to be evaluated to ensure right approach after the decision is made (Vu and Ranzi, 2017). Rebuilding or reconstruction after flooding requires provisions and knowledge to ensure the buildings are less vulnerable in future (Rautela, 2016). The complex process involves dealing with stakeholders at the same time making sure the plans and main concerns are not left behind (Hagelsteen and Burke, 2016). It is always good to increase public awareness of risks involved and engage with people at risk to reassure them and their surrounding infrastructure to become more resilient (Defra, 2011). Somehow the unprecedented floods happen, and organisations are not prepared for them (Wedawatta et al., 2014). The property owners and stakeholders are responsible for providing flood protection to the involved infrastructure (Wedawatta et al., 2014). Safety and regulations have to be updated from time to time together with the appropriate follow-up including the technical guidelines (Sakurai et al., 2017). Population areas affected by the flood need to be identified (Vu and Ranzi, 2017), including damage to the building functions, roads, and infrastructure. This would help for flood risk assessment to the other areas with comparable conditions for the future use (Vu and Ranzi, 2017).

A conceptual framework for the post-flooding recovery has always been important as this can help in identifying and handling challenges. The framework should be tested, and its approach is made clear. The generalisation of disaster management should be avoided unless the aspects that are being looked into are vast (Rivera et al., 2015). Exchange the know-how among selected countries and therefore help formulate best strategy and policy to mitigate the flood risk in the region (Osti and Nakasu, 2016). On the other hand, proper water management is vital to tackle the issues of flooding. Water management can carry out the technical volumes of levees and come with an improvement for the channel in regard to the floodplain management (Jong et al., 2017). When handling the flood disaster, relevant data should be appropriately recorded to facilitate the management process if the same floods occur in the future (Abulnour, 2014).

Risk Perception and Communication Approach

Risk perception is related to emotions, behaviours, and communication about the disaster (Birkholz et al., 2014). Perception and understanding will lead to the people actions in planning for and responding to flood events (Raaijmakers et al., 2008). Each of the flood risks happened should be well communicated based on the flooding situation (Jong et al., 2017). The understanding of resilience should be developing further along with the understanding of flood risk perception (Birkholz et al., 2014). The risk perceptions could improve the resilience of the societies (Burns and Slovic, 2012). In managing the disaster, considering about risk communication should be further explained (Birkholz et al., 2014). For example, a study is done towards the UK Environment Agency's Indicative Floodplain Maps, and it is about the possible flooding. It has been argued that the map provided given misleading information and lack of information being received by the public, as they cannot interpret the map in a right way (Brown and Damery, 2002). Risk communication will be able to help in understanding the impacts of flooding and help to develop more appropriate strategies. However, studies related to risk communication should cover wider apprehensions (Birkholz et al., 2014). Improved flood risk communication raises the awareness of citizens and the business community of the limited capabilities of authorities in terms of available staff and resources before, during, and after a flood, plus the need to act themselves to protect their property and to save their lives (Brinke et al., 2017). Flood risk communication could improve public awareness during the hardness in facing flooding events (Brinke et al., 2017). Somehow there are limited capabilities during the post-flood recovery. Still, the public could reduce social disruption by protecting their self and their property in the best possible way (Brinke et al., 2017). Large-scale flooding might have affected a few neighbouring countries (Brinke et al., 2017), which requires learning and helping one another in different kinds of aspects. Failure to communicate in the right way will lead to failure of the disaster management (Lin, 2017). These failures could add up to the extent of hazard or threat results in social disruption (Brinke et al., 2017). Different countries can share common knowledge. However, each flood is different, and direct comparison may not be relevant (Brinke et al., 2017). The perception of flood risk and safety including current risk communication methods needs to be enhanced for both the present and future generations.

It is always good to increase public awareness of the risks and engage with people at risk to reassure them more resilient (Defra, 2011, p. 14). Primary and secondary effects need to be known earlier by the administration by making the ranking of seriousness and effect perceived or predictable ME. For example, flood events could cause other adverse effects such as losses in electric supply and other utilities (Zevenbergen et al., 2015). Hence, professionals and stakeholders involved should provide the initiative to reconsider the likely flooding impacts and come out with relevant practices and services to overcome the issues (Zevenbergen et al., 2015). This rethinking is being included in new policies that embrace an integrated approach to flood risk management (Zevenbergen et al., 2015). If necessary, the new approach in dealing with the primary or secondary effects of flooding is included in the institutional policies and disaster risk management plans (Zevenbergen et al., 2015). Management of risk involves risk assessment, which is the understanding of the magnitude of the loss and the distribution of the loss among three components, which are social losses, physical losses, and economic losses. Thus, there are plans to reduce risk potential to each of these components. These plans include the following (Wenzel, 2006): i) Preparedness actions aimed at institutionalising knowledge on understanding disasters and preparing the population and the institutions in order to reduce losses; ii) response and recovery actions aimed at planning the process of responding and recovering from a disaster, and proactively putting the resources and processes in place to respond to such a disaster; iii) mitigation actions aimed at reducing losses through physical intervention on the built environment mainly by strengthening the infrastructure and urban planning; and iv) knowledge acquisition actions aimed at acquiring the technical and scientific knowledge as well as the tools required for disaster assessment (Wenzel, 2006).

Critical Infrastructure

Critical infrastructure involved in floods can cause secondary adverse effects to many other occasions (Bach et al., 2013). The impacts involved may be more serious than primary events. Protection against critical infrastructure can help further development towards emergency relief and recovery (Van Herk et al., 2014). If critical infrastructure is disturbed and damaged, this will impose negative impacts on public, operation and business of the organisation, the nearby areas, state, or government (Van Ree et al., 2011) (Escarameia et al., 2012) (CIRIA, 2010). At the present time there is a lack of insight into the vulnerability of critical infrastructure assets, what the severity of flood impacts could be, and what type of protective measures would be feasible and effective. This specifically holds true for these assets within cities. This leads to the scarce information to help in making related decisions (Zevenbergen et al., 2015). Relevant information is necessary to identify and rate the critical infrastructure assets that may be at risk from flooding. Furthermore, this would help to develop feasible and effective measures to minimise the damage to the infrastructure during flooding (Zevenbergen et al., 2015). As for the critical infrastructure and assets, the best practice of flood proofing is limited as there is limited practice towards this method (Zevenbergen et al., 2015).

Business Continuity Management (BCM) Approach

Early preparation on post-flooding recovery can ensure business sustainability in the future (Josephson et al., 2017). A business organisation could be affected by flooding in terms of the affected areas, markets, logistics, premises, people, processes, and finances (Metcalf et al., 2010). Therefore, it is good for the organisation to put concerns towards investing in improving the flood safety measures including post-flooding recovery process (Wedawatta et al., 2014). Growing knowledge in business could guide the organisation to be able to reduce the impact of flooding by coming out with flood-protection measures (Wedawatta et al., 2014). The policy and decision makers of the organisation would be able to use the flooding knowledge to provide more guidance for the business (Wedawatta et al., 2014). There are a few main things that could be learned in the flood-related in business. These are as follows: indirect impacts of flooding could often be extensive, impacts of flooding are complicated, inability to rely solely on insurance in the future, and also the significance of protection measures in addition to insurance (Wedawatta et al., 2014).

Worse things could happen if the planning towards flooding was treated as less important and when the stakeholders react only when actual flooding happens. The stakeholders' preparation to face flooding should be made clear, and the business and location characteristics, the changes in policies, and previous works need to be known (Josephson et al., 2017). Business-focused recommendations could be conceptually grouped into four broad areas: 1) planning, defined as the assessment of risk and planning specific strategies to minimise it; 2) transfer of risk, defined as the purchase of insurance; 3) reinforcement of structures; and 4) protection of tangible business assets, business processes, and operations (Josephson et al., 2017). The past disaster experience will help a lot, by knowing the financial resources, the seriousness of damage to the organisation, and damage to lifelines (Josephson et al., 2017).

A good BCM will have a few important aspects (Kotulová, 2010). First it is imperative to understand the institution. The second is to define the BCM strategy. The third is to obtain a BCM response. Fourth is by implementing, upholding, and revising the BCM. BCM needs to be consistent with the purpose and objective of an organisation (Hana and Alena, 2016). This BCM includes strategies to reduce the risk. According to Hana and Alena (2016), the management of the crisis should include some step-by-step measures needed to mitigate the material and human resources of the organisation involved. Business continuity management is a big area. The business continuity plan is the output of the BCM itself. This BCM includes all the steps and procedures to ensure that business operations can run properly.

Business continuity can be said to be one of the branches under risk management (Asgary, 2016). All the efforts or approaches used to repair recovery after the disaster can be planned in tandem and can meet the standards set by the authorities (Asgary, 2016). To ensure this is a success, professionals need to come out with relevant knowledge and skills in both areas. More important is to align the course and curriculum in the knowledge to be applied well. Large institutions require leaders who are experts in managing matters relating to decision-making. The specialist includes skills and has a full understanding of the concept of disaster risk management (DRM) and business continuity issue (Asgary, 2016).

Conclusion

Safe and resilient communities are people who clearly know what are the future disasters they are likely to be facing, know how to monitor it, and could at least lessen the impacts towards them. Community will be able to continue their life as usual and function like normal despite the impact of flood. They will have an ability to build back after flooding while being able to reduce vulnerability towards the future. However, people comprehend that building safety and resilience is a long-term process along with big responsibilities. Literature reviews show that there is much that the community could do to reduce the flooding issues and difficulties by expanding on their present education and learning. Having the community safe and resilient also provides greater success to achieve a better development with and an added factor to wellbeing and flexibility. There may be other characteristics that we should add particularly in a regional or national context, but these are offered as a general set of characteristics that help to define community safety and resilience in many communities globally. There might be different attributes in terms of a local or national setting; however, these are considered as an assistance towards the community resilience around the world. It is important to implement and emphasise the DRR at the community level as it will help the safety of the community. The future will be bringing them to the attention of the international community at regional and global levels, thus mobilising support to enable us to achieve an improved resilience in the future. Framework is a necessary mechanism for the delivery of DRR; it will use the framework as its planning and programming guideline, along with all other programmes supporting an improvement in the DRR work. The built back better is best supported by good access to the basic services and needs. All those achievements derive from better awareness of risks and hazards, better response actions, and a great support for maintaining safe environments.

References

Abulnour, A. H., 2014, Towards efficient disaster management in Egypt: HBRC Journal, v. 10, p. 117–126.

Asgary, A. (2016) BUSINESS CONTINUITY AND DISASTER RISK MANAGEMENT IN BUSINESS EDUCATION: CASE OF YORK UNIVERSITY/CONTINUIDAD DE NEGOCIO Y GESTIÓN DEL RIESGO DE DESASTRES EN LA EDUCACIÓN DE NEGOCIOS: EL CASO YORK UNIVERSITY. Ad-Minister, (28), 49–72. https://doi.org/10.17230/ad-minister.28.3

Bach, C., S. Bouchon2, A. Fekete, J. Birkmann, D. Serre, E. Duchemin, B. Barroca, D. Serre, B. Barroca, D. Serre, E. Duchemin, and G. Mainguy, 2013, Adding value to critical infrastructure research and disaster risk management: the resilience concept: S.A.P.I.EN.S.

Birkholz, S., M. Muro, P. Jeffrey, and H. M. Smith, 2014, Rethinking the relationship between flood risk perception and flood management: Science of The Total Environment, v. 478, p. 12–20.

Brinke, Knoop, H. Muilwijk, and W. Ligtvoet, 2017, Social disruption by flooding, a European perspective: International Journal of Disaster Risk Reduction, v. 21, p. 312–322.

Brown, J. D., and S. L. Damery, 2002, Managing Flood Risk in the UK: Towards an Integration of Social and Technical Perspectives: Transactions of the Institute of British Geographers, v. 27, p. 412–426.

Burns, W. J., and P. Slovic, 2012, Risk Perception and Behaviors: Anticipating and Responding to Crises: Risk Analysis, v. 32, p. 579–582.

Campanella TJ. Longer view: urban resilience and the recovery of New Orleans. J Am Plann Assoc 2006;72(2):141–6.

CIRIA. Flood resilience and resistance for critical infrastructure. CIRIA C688, London, p. 111, 2010.

Defra. Understanding the risks, empowering communities, building resilience: the national flood and coastal erosion risk management strategy for England. London: The Stationery Office, 2011.

Defra. Understanding the risks, empowering communities, building resilience: the national flood and coastal erosion risk management strategy for England. London: The Stationery Office,2011.

Escarameia M., Tagg A.F., Walliman N., Zevenbergen C. & Anvarifar F. The role of building materials in improved flood resilience and routes for implementation. FloodRisk 2012 Conference.

Fraser, E. D. G., A. J. Dougill, W. E. Mabee, M. Reed, and P. McAlpine, 2006, Bottom up and top down: Analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management: Journal of Environmental Management, v. 78, p. 114–127.

Hagelsteen, M., and J. Burke, 2016, Practical aspects of capacity development in the context of disaster risk reduction: International Journal of Disaster Risk Reduction, v. 16, p. 43–52.

Hana Malachová, & Alena Oulehlová. (2016). APPLICATION OF BUSINESS CONTINUITY MANAGEMENT SYSTEM INTO THE CRISIS MANAGEMENT FIELD. Transactions of the VŠB: Technical University of Ostrava, Safety Engineering Series, 11(2), 43–50. https://doi.org/10.1515/tvsbses-2016–0016

Hoang, Fenner, and Skenderian, 2016, A conceptual approach for evaluating the multiple benefits of urban flood management practices: Journal of Flood Risk Management, p. n/a–n/a.

Islam, R., and G. Walkerden, 2017, Social networks and challenges in government disaster policies: A case study from Bangladesh: International Journal of Disaster Risk Reduction, v. 22, p. 325–334.

John R. Labadie, (2008) "Auditing of post-disaster recovery and reconstruction activities", Disaster Prevention and Management: An International Journal, Vol. 17 Issue: 5, pp. 575–586, https://doi.org/10.1108/09653560810918612

Jong, Pieter, and B. M. v. den, 2017, Between tradition and innovation: developing Flood Risk Management Plans in the Netherlands: Journal of Flood Risk Management, v. 10, p. 155–163.

Josephson, A., H. Schrank, and M. Marshall, 2017, Assessing preparedness of small businesses for hurricane disasters: Analysis of pre-disaster owner, business and location characteristics: International Journal of Disaster Risk Reduction, v. 23, p. 25–35.

Kotulová, H. (2010).: Business continuity plans and their apply to industrial accident. In Fire Protection. Ostrava: VSB–Technical University of Ostrava, pp. 139–141. ISBN 978–80–7385–087–6.

Lin, L., 2017, Integrating a national risk assessment into a disaster risk management system: Process and practice: International Journal of Disaster Risk Reduction.

Metcalf G., Jenkinson K. & Johnstone K. A changing climate for business, 3rd edn. Oxford: UK Climate Impacts Programme, 2010.

Nicholas O., 2014. Durham University https://www.dur.ac.uk/news/newsitem/?itemno = 20098

Osti, and Nakasu, 2016, Lessons learned from southern and eastern Asian urban floods: from a local perspective: Journal of Flood Risk Management, v. 9, p. 22–35.

Raaijmakers, R., J. Krywkow, and A. van der Veen, 2008, Flood risk perceptions and spatial multi-criteria analysis: an exploratory research for hazard mitigation: Natural Hazards, v. 46, p. 307–322.

Rani,. Nifa, M. N. Ismail, and K. N. Khalid, 2017, Planning for post-disaster recovery: Lesson learnt from flood events in Kelantan Malaysia.

Rautela, P., 2016, Lack of scientific recordkeeping of disaster incidences: A big hurdle in disaster risk reduction in India: International Journal of Disaster Risk Reduction, v. 15, p. 73–79.

Rivera, C., HenrikTehler, and ChristineWamsler, 2015, Fragmentation in disaster risk management systems: A barrier for integrated planning: International Journal of Disaster Risk Reduction, v. 14, p. 445–456.

Sakurai, A., M. B. F. Bisri, T. Oda, R. S. Oktari, Y. Murayama, Nizammudin, and M. A. f. an, 2017, Exploring minimum essentials for sustainable school disaster preparedness: A case of elementary schools in Banda Aceh City, Indonesia: International Journal of Disaster Risk Reduction.

Tyas, W. P. (2016). Home-based Enterprises Approach for Post Disaster Housing: Learnt from Post Disaster Redevelopment Programme in Developing Countries. Procedia–Social and Behavioral Sciences, 227, 139–145. doi:http://dx.doi.org/10.1016/j.sbspro.2016.06.054

Vale LJ, Campanella TJ. The resilient city: how modern cities recover from disaster. New York: Oxford University Press; 2005.

Van Herk S., Zevenbergen C., Gersonius B., Waals H. & Kelder E.T.G. Process design and management for integrated flood risk management: exploring the multi level safety approach for Dordrecht, the Netherlands. J Water Clim Change 2014, 5, (1), 100–115. doi: 10.2166/wcc.2013.171.

Van Ree C.C.D.F., Heilemann K., Morris M.W., Royet P. & Zevenbergen C. FLOODPROBE: technologies for improved safety of the built environment in relation to flood events. Environ Sci Policy 2011, 14, (7), 874–883.

Vu, T. T., and R. Ranzi, 2017, Flood risk assessment and coping capacity of floods in central Vietnam: Journal of Hydro-environment Research, v. 14, p. 44–60.

Wedawatta, G., I. B., and P. D., 2014, Small businesses and flood impacts: the case of the 2009 flood event in Cockermouth: Journal of Flood Risk Management, v. 7, p. 42–53.

Wenzel, F. (2006). Earthquake risk reduction obstacles and opportunities. European Review, 14(2), 221–231. https://doi.org/10.1017/S1062798706000214

Zevenbergen C., K. Kolaka, S. van Herk, M. Escarameia, B. Gersonius, D. Serre, N. Walliman. Assessing quick wins to protect critical urban infrastructure from floods: a case study in Bangkok, Thailand: Journal of Flood Risk Management. (2015)

Zevenbergen C. et.al (2010). Urban Flood Management, CRC Press, Taylor and Francis Group.

Amphibious Construction in Kerala: Translational Engineering Perspective

Nanma Gireesh[a] and Suja R.[a]

ABSTRACT: Flooding has happened more frequently in the past few decades than before. Partial or complete destruction of buildings and other structures, economic hardships and psychological damages are some of the effects that flood can create. It will be a huge challenge for authorities to rebuild lives and infrastructure. The recent flood in Kerala was the worst in almost a century. Nearly one-sixth of the total population was affected by the floods, according to the officials.

This project is a study in response to the issues of the flood, considering a resilient technology that can reduce the negative consequences and pave way for water instead of fighting against it. Amphibious construction is a type of flood mitigation strategy adopted all over the world especially in the Netherlands, which has been taken as an example. A reconnaissance study was done by visiting the amphibious houses built in Maasbommel, Netherlands.

Theoretical research about its foundation and superstructure, multiple criteria analysis according to the location and analysis of a scaled model, have been included in this study for strengthening the reasons for its adaptation in Kerala. Translational engineering perspective ensures that this study will bridge the gap between theory and practice by implementing it.

KEYWORDS: amphibious house, flood, resilient structure, buoyant foundation, floating house, aquatecture

Introduction

The recent flood in Kerala, which caused one-sixth of the total population to suffer, also created large devastation in the sinking Munroethuruthu (Munroe islands). The cluster of islands formed at the confluence of Ashtamudi Lake and Kallada River, in Kollam District of Kerala, is sinking due to rising sea level and erosion. After the Tsunami of 2004, buildings started to settle, and water logging problems and frequent flooding started. Later on multiple natural disasters followed and have visible effects in the area. Earlier known as 'Prawns Village of Kerala' is no more breeding prawns or any other fishes for that matter in large scale. Due to low income generation, lack of a proper shelter and reduced quality of living, mass emigration affected the population scenario in these islands.

Meanwhile, from areas of land reclaimed from water, the Dutch built the Holland, now called the Netherlands. Many parts of the land are below sea level, and hence the Dutch researchers are trying to find a way to live in harmony with the rising water. The concept of 'amphibious houses' was developed as a solution to it, as a means to not fight against the water but to live on it.

The aim of the study is to introduce the concept of amphibious building construction in Kerala and design an amphibious house with lightweight superstructure according to the site conditions and vernacular design principles.

Study Area

Translational engineering focuses on bridging the gap between theory and practice. This ensures that existing

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technologies can be adopted from labs to solve the problems in the society-field. Therefore a problem area is first identified, studied and analysed, and it is ensured that a practical technology is adopted for it and implemented.

The total area of Munroethuruthu is 13.37sq. km. The eight islands were formed amidst the waters through gradual sedimentation of silt and fertile soil deposited by the flooding waters from Kallada River.

The area is divided into 12 Wards and of which Wards 1, 2 and 12 are the most affected. A land-use map (Figure 1) of Ward 12 is also plotted showing the affected houses. Most of the highly affected houses are clustered together in this ward alone. A railway line separating the affected region and unaffected region of Munroethuruthu can also be observed.

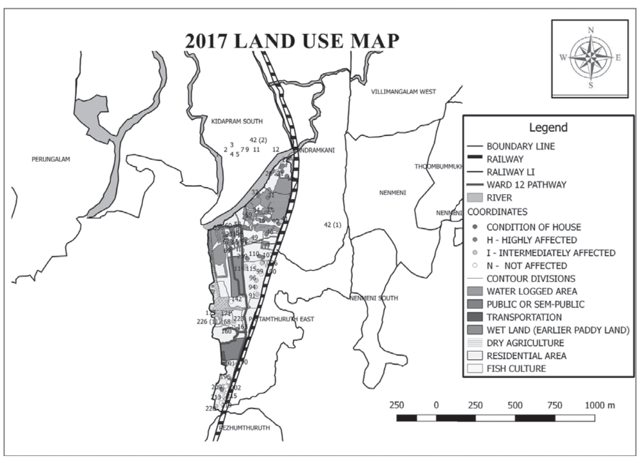


Figure 1: Land-use map of Ward 12

The area was surveyed for identifying pertaining problems. Connectivity, water logging and sinking are found to be the major problems (Figure 2). The study focused on water logging and sinking issues of Munroethuruthu.

Lack of hard underground stratum is a serious cause that makes the structures in Munroe island settle. The study by National Centre for Earth Science Studies (Table 1) shows that even beyond the depth of 14m, medium to fine sand is found. There is an absence of hard strata which makes it difficult for piling constructions too.

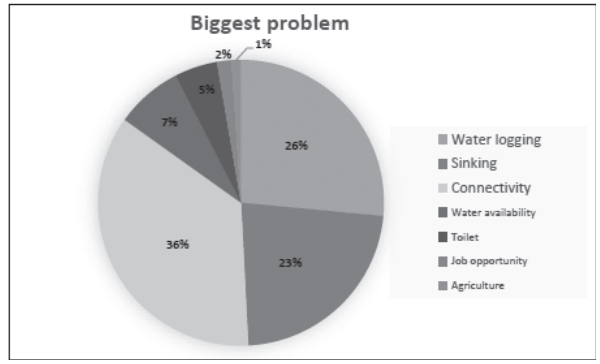


Figure 2: Pie chart showing the major problems faced by the inhabitants of Munroethuruthu

Table 1: Soil Strata Study Done by NCESS

Reports from the National Centre for Earth Science Studies (NCESS)	Details of Soil Strata of Munroethuruthu	
Depth(m)	**Lithology**	**Thickness(m)**
0–2	Clayey mud (organic rich)	2
2–6	Medium to fine sand	4
6–14	Silty clay (organic rich)	8
>14	Medium to fine sand	

Traditional houses of Munroethuruthu required only localised techniques of piling. This piling was not needed beyond a depth of 2 m.

Like most of Kerala architecture, structures in Munroethuruthu are also characterised by long steeply sloping roofs, as a main prominent visual form. It is built to withstand heavy monsoons and also as a constructional wall protection. Another main feature is the lightweight nature of the house with wooden side walls and thatched roofs. Superstructure was made of wooden planks before, and now they use clay and hollow bricks for building.

Amphibious House and Aquatecture

In aquatecture, flood resilient constructions have advanced in time. Flood avoidance by relocating and raising buildings are a few measures still followed in various regions. Statically elevated houses are subjected to more wind pressure from the top and wave pressure at the poles raising the building. In flood resistant strategy, water exclusion and dry proofing the house are to keep the building out of contact with the flood waters. Wet proofing and water entry strategy allows water into the building in a controlled way and use water resilient materials to prevent damage.

Figure 3: Elevated house by John Pardey Architects

Floating buildings permanently float on water enabling them to move in vertical direction with the flood water. Amphibious buildings, also known as Can-Float, are fixed to a buoyant foundation that rests on the ground and is designed to float only when the flood waters rise, temporarily creating a floating structure.

Buoyant foundations are made using concrete caissons, steel pontoons, polystyrene foam blocks or plastic barrels that have air-filled cavities and work according to the Archimedes principle.

Figure 4: Floating house of Maasbommel, the Netherlands

The superstructure can be made using glass fibre reinforced gypsum panels, expanded poly styrene panels or autoclaved cellular concrete (ACC). The cables, electricity in this case, need to have extendable cables. As the house lifts up these cables extend from the ground and prevent cut off. This will safeguard the supply, and the residents get power even when flooding happens.

Renewable energy like solar energy can be acquired to light bulbs, tubes, etc., and solar panels can be put for good use to create the amphibious house a self-sustaining structure.

Drinking water can be obtained from public supply lines using extendable cables and also using rainwater harvesting methods.

Reconnaissance Survey and Case Studies

Amphibious Housing in the Philippines

The daily life of inhabitants of Hagonoy, the Philippines, was affected by tidal and fluvial floods. Ground subsidence is the main cause of a worsening trend of these floods. Excessive uncontrolled groundwater subtraction creates a ground-level decrease up to 5 cm per year. In the interview with Ir. Pieter H. Ham, Asst. Professor in TU Delft, a project in Philippines which has similar situations like that in Munroethuruthu was discussed. His study basically included the design of buoyant foundation, and using vernacular principles, they are creating an amphibious house using recycled barrels in Hagonoy, Philippines.

Figures 5 and 6: Amphibious house and its barrel foundation designed for Philippines by Ir. Pieter H. Ham

By creating a parametric visualisation and calculation model, a first insight in dimensions, width and length of the amphibious foundation are determined. Two case-studies, one being a foundation with a single building and the second being a foundation with a configuration of eight buildings, are tested by an SCIA engineer.

Amphibious Housing in Maasbommel, the Netherlands

On the banks of Maas River in the Municipality of West, Maas, en Waal, there are nearly 30 amphibious houses and 14 permanently floating houses. A field visit was done to study the structure and functions of these houses in reality. Adri van Ooijen, the Director of Watersportcentrum of Maasbommel, is the initiator of the plan of the project of amphibious houses and floating houses in Maasbommel. An interview with him resulted in the study of the whole construction procedure of the amphibious house.

One of the owners of the house, Mr. Jan Leder, explained about every components of the house. He also explained how it felt when it floated during the 2011 flooding of Maas River.

Amphibious house model in Maasbommel has a concrete pontoon on top of which lightweight superstructure has been built. This pontoon floats when the Maas River overflows and the water depth is nearly 7 m NAP (Amsterdam Ordnance Datum). The inside part of the pontoons is used as living area. There are two vertical guidance poles that help the floating house to stay in position and also to safely guide the house back into its position.

Figure 7: Amphibious house of Maasbommel, the Netherlands, before and during flood

Figure 8: Amphibious houses of Maasbommel, the Netherlands, during the reconnaissance study

Multiple Criteria Analysis for Foundation

Multiple Criteria Analysis (MCA) helps to find out the best possible outcome, here type of foundation, from alternatives. Many options are chosen at the start of the process but ideally, list selected for analysis has 10–15 options maximum. Therefore, the options given are as follows:

	Option Title
Option 1	Bamboo structure
Option 2	EPS foundation
Option 3	Steel pontoon
Option 4	Concrete pontoon
Option 5	Plastone pontoon
Option 6	Recycled barrels
Option 7	Plastic bottle foundation

The options include the possible alternatives for building the buoyant foundation for the amphibious structure in Munroethuruthu.

Option scores

Option	Weighted Score
Bamboo structure	53.5
EPS foundation	20.5
Steel pontoon	15.0
Concrete pontoon	54.2
Plastone pontoon	21.8
Recycled barrels	93.3
Plastic bottle foundation	84.2

Ranking of options

Rank	Option	Weighted Score
1	Recycled barrels	93.3
2	Plastic bottle foundation	84.2
3	Concrete pontoon	54.2
4	Bamboo structure	53.5
5	Plastone pontoon	21.8
6	EPS foundation	20.5
7	Steel pontoon	15.0

Option Criterion	Transportable	Recyclable	Environmentally Healthy	Innovative	Rigid Body	Floatable	Wide Pontoon	Manufacturable	Affordable	Durable	Locally
Units	**92**	**98**	**99**	**90**	**95**	**100**	**94**	**93**	**96**	**97**	**91**
Preferred value	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**
Bamboo structure	3	5	5	3	2	4	2	3	4	4	2
EPS foundation	3	2	2	3	4	4	3	2	2	3	2
Steel pontoon	3	3	2	1	4	2	4	2	2	3	2
Concrete pontoon	4	3	2	2	5	3	4	4	4	3	4
Plastone pontoon	3	4	3	2	3	2	4	2	2	3	3
Recycled barrels	5	5	4	4	4	5	4	4	5	4	4
Plastic bottle foundation	5	5	4	4	3	5	3	4	4	4	4

Options	Criteria	Transportable	Recyclable	Environmentally Healthy	Innovative	Rigid Body	Floatable	Wide Pontoon	Manufacturable	Affordable	Durable	Locally Available	Weigted Scores
	Units	**92**	**98**	**99**	**90**	**95**	**100**	**94**	**93**	**96**	**97**	**91**	
	Preferred value	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	
	Weight	**11 per cent**	**10 per cent**	**10 per cent**	**3 per cent**	**10 per cent**	**14 per cent**	**5 per cent**	**13 per cent**	**10 per cent**	**9 per cent**	**5 per cent**	
Bamboo structure		0.00	100.00	100.00	66.67	0.00	66.67	0.00	50.00	66.67	100.00	0.00	53.50
EPS foundation		0.00	0.00	0.00	66.67	66.67	66.67	50.00	0.00	0.00	0.00	0.00	20.50
Steel pontoon		0.00	33.33	0.00	0.00	66.67	0.00	100.00	0.00	0.00	0.00	0.00	15.00
Concrete pontoon		50.00	33.33	0.00	33.33	100.00	33.33	100.00	100.00	66.67	0.00	100.00	54.17
Plastone pontoon		0.00	66.67	33.33	33.33	33.33	0.00	100.00	0.00	0.00	0.00	50.00	21.83
Recycled barrels		100.00	100.00	66.67	100.00	66.67	100.00	100.00	100.00	100.00	100.00	100.00	93.33
Plastic bottle foundation		100.00	100.00	66.67	100.00	33.33	100.00	50.00	100.00	66.67	100.00	100.00	84.17

Criteria for selection of the best foundation system were as follows:

- Transportable
- Recyclable
- Environmentally healthy
- Innovative
- Rigid body
- Floatable
- Wide pontoon
- Manufacturable
- Affordable
- Durable
- Locally available

Scores are calculated from the analysis, and the final output shows that recycled barrels is the best suitable option with the plastic bottles foundation and concrete pontoon following. The scores put were completely based on the prevailing conditions of Munroethuruthu and information collected and calculated from the area. Therefore, recycled barrels, being the buoyant foundation material, accomplish the needs of most of the criteria listed above and is selected as best for the case of Munroethuruthu.

Results and Discussion

According to the theoretical study and information collected, a model was made of an amphibious floating structure using steel framework and recycled barrels. In place of barrels of 200 L in prototype, 5 L plastic tins were used for the model.

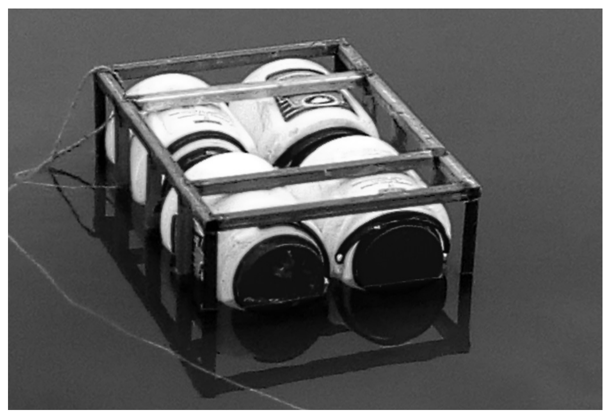


Figure 9: One model unit of foundation module with recycled cans

Three more modules were created and welded together to form one foundation unit and with three cans per module.

A house framework structure with a hip roof, according to the climatic conditions and vernacular architecture of the area, was built and kept on top of the foundation. The ratio of the outline of the house to the outline of buoyant foundation was taken as 1:2.5 ratio as in the studies of Ir. Pieter H. Ham. The house and the foundation were made to float in an artificially created tank of size 2 m x 1.5 m.

All dimensions are in cm
Scale: 1:8

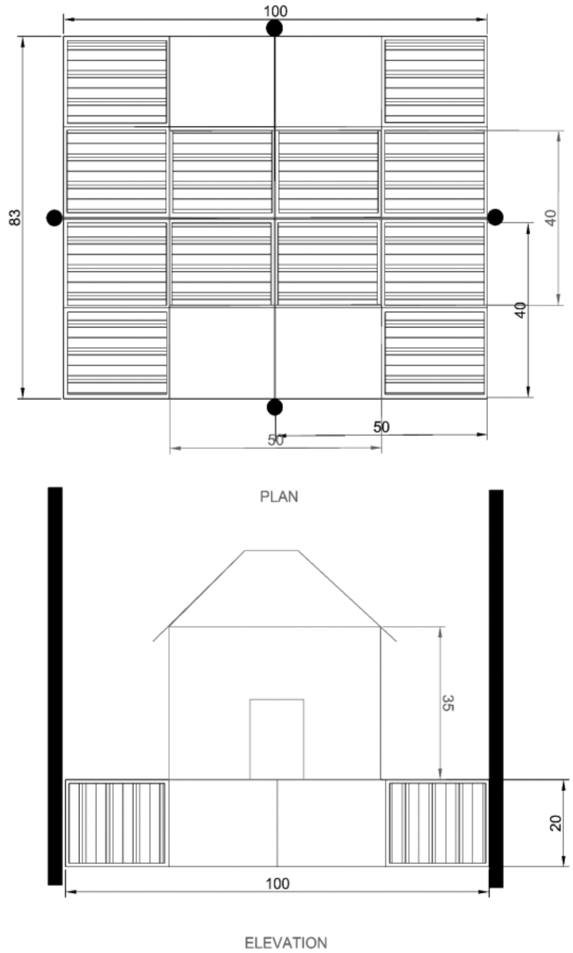
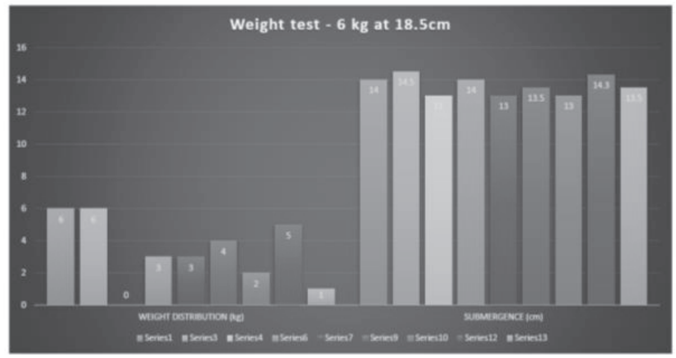
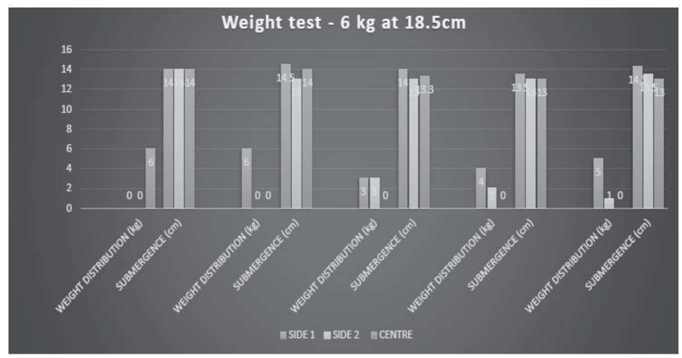
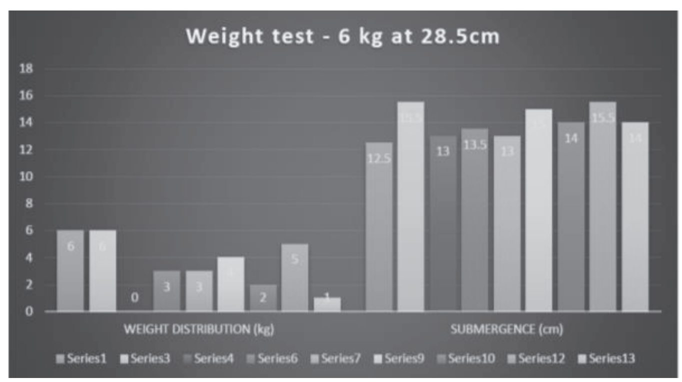


Figure 10: Finished model of amphibious house

Tests were conducted to find the behaviour of the model amphibious house during loading and tilting.







Graph 1–3: Weight tests conducted at different submergence level

From the above results, it can be seen that even if the water level increases, submergence level can remain similar. As the weight is increased during the floating phase, submergence level is also increased.

Table 2: About-to-Float Situation and Different Submergence and Surface Levels

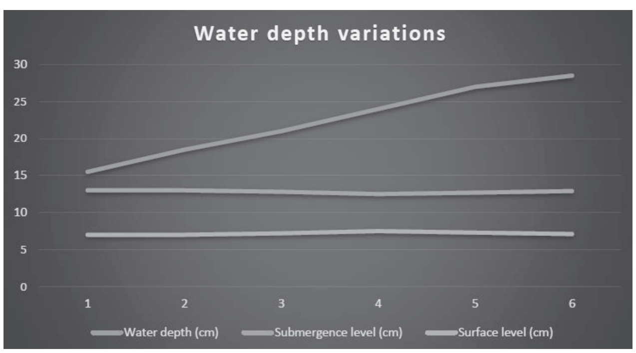
About-to-float situation

Water Level	Depth (cm)
Initial	0
About to float	15.5
Submergence level	13

Floating situation

S. No.	Water Depth (cm)	Submergence Level (cm)	Surface Level (cm)
1	15.5	13	7
2	18.5	13	7
3	21	12.8	7.2
4	24	12.5	7.5
5	27	12.7	7.3
6	28.5	12.9	7.1

About-to-float situation of the model was attained at 15.5 cm. Nearly half portion of barrel was below water level when the foundation floated.



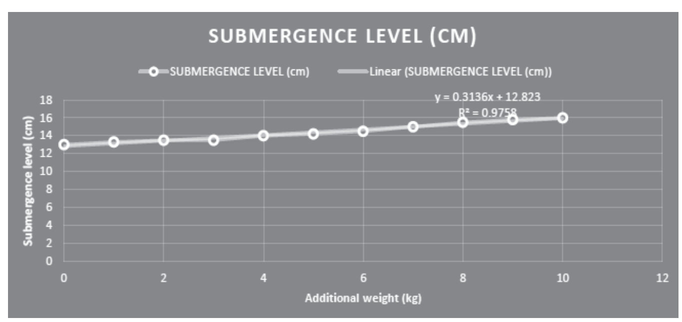
Graph 4: The relation between water depth, submergence level and surface level

As water depth increases, submergence level remains the same. Also the surface level remains the same as the water depth increases. Therefore, it is assured that water will not enter into the superstructure at any given height or water depth.

Weight test
Initial water level = 0 cm
Water level at about-to-float situation = 15.5 cm
Initial water level before testing = 18.5 cm
Weight of the house structure on buoyant foundation = 5.7 kg + 1.35 kg = 7.05 kg

Water Level	Weight Added (kg)	Submergence Level (cm)	
1	0	13	Initial depth of submergence
2	1	13.3	
3	2	13.5	
4	3	13.5	
5	4	14	
6	5	14.2	
7	6	14.5	
8	7	15	
9	8	15.5	
10	9	15.8	
11	10	16	

Height of the buoyant foundation = 20 cm
Fully submerged when y = 20 cm
$y = 0.3136x + 12.823$
$20 = 0.3136x + 12.823$
$x = 22.89$ kg
Foundation will be fully submerged by adding nearly 23 kg of weight.

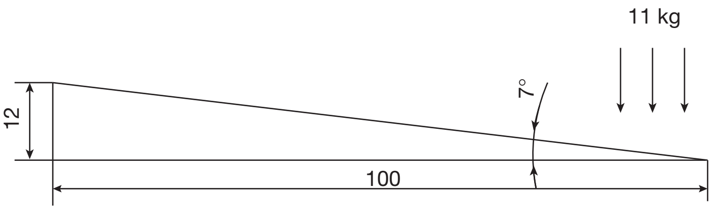


Graph 5: Relation between additional weight on foundation and submergence level

From the data obtained, an equation was derived as y = 0.3136x+12.823, and the weight at which the model would submerge is found to be nearly 23 kg.

The building will sink if the total weight of the superstructure and other loads exceeds nearly three times the weight of the foundation.

All dimensions are in cm.



The structure experienced tilt when 11 kg of weight has been added to one side. Surface level was 12 cm on one side and 0 cm on the other side, where 11 kg was applied. Therefore the angle of tilt is 7°. Considering a factor of safety, if the house tilts more than 5°, immediate evacuation is needed.

Barrel	Diameter (cm)	Height (cm)	Volume (L)	
	52	93	200	01:03.5
	48	82	120	01:03
	31	56	50	01:02
	16	20	5	01:01
				Scale

Design for a family of five members

Total weight of the family members = 300 kg (considering 60 kg/person)
Weight of food for one month = 200 kg
Weight of agricultural products = 100 kg
Weight of stored drinking water = 50 kg
Weight of furniture, utensils, clothes and others = 200 kg
Self weight of the structure = 1500 kg (GFRG panels assumed)
Total weight = (300 + 200 + 100 + 50 + 200 + 1500) kg = 2350 kg

	Model	Proto-type			
Fluid type	Water	Salt water			
Fluid density (r) **kg/m3**	1000	1025			
	Volume (L)				
	5	**5**	**50**	**120**	**200**
Buoyant force (N) (F_B = rgV)	49.05	50.28	502.76	1206.63	2011.05
No. of barrels (required)	12	459	46	19	11

No. of barrels (required) = (Total weight from the structure *9.81/net buoyant force developed by a drum)

A model is made to float inside a tank with water with usual fluid density 1000 kg/m^3. The actual prototype will be in water with 30ppt, and therefore density is taken to be 1025 kg/m^3. Thus the buoyant force is calculated and also the number of barrels required for the assumed structure.

The total weight on to the prototype structure was calculated in a practical way, and it resulted to be 2350 kg for an assumed five-member family.

Therefore, from the Archimedes principle,

$$U = G/(A \times P)$$

For Munroethuruthu condition, a scaled-up prototype (1:8 for the building) is considered.

U is the vertical drop below the water line (m) = 0.5 m (assumed).

G is the dead load of the total building construction (kN).

A is the area of the floating body (of scaled-up prototype (m^2) is 53.12 m^2

P is the density of water (kN/m^3) = 1025 kg/m^3.

Hence, from the equation, maximum dead load of the building = 27,224 kg = 267 kN.

The practical load calculated was 2350 kg, and adding the dead weight of the foundation, the total dead load results to be approximately 3000kg, which is safe as the limit = 27,224 kg.

Therefore, the vertical drop of the building below the water line is approximately 0.5m, and the house is capable of carrying a maximum load of 267 kN.

Total weight = (300 + 200 + 100 + 50 + 200 + 1500) kg = 2350 kg

30 per cent of drum diameter was maintained as free board water surface

The metacentre height was calculated for a single drum, and then using the equation developed by House, F. et al., the same is calculated for the structure. The value resulted was positive, and thus stable equilibrium can be assured.

	50 L Barrel	120 L Barrel	200 L Barrel
70 per cent under water (cm) (0.7*D)	21.7	33.6	36.4
Distance of centre of buoyancy (cm) (CB) (0.7*D/2)	10.85	16.8	18.2
Distance of centre of gravity from C(cm) (diameter/2) (CG)	15.5	24	26
BG = CG - CB (cm)	4.65	7.2	7.8
Moment of inertia I1 = MOI of plan of the body about y-y = (1/12* b^3* h) (cm^4)	453674.6667	2205472	3485547
∀ = L*B*H(cm^3)	37671.2	132249.6	176030.4
I_1/∀ (cm)	12.04	16.68	19.8
Metacentric height GM GM = (I_1/∀) (cm) -BG	7.39	9.48	12
Stability	+ve, stable equilibrium	+ve, stable equilibrium	+ve, stable equilibrium
For total foundation (equation referred from Design and Estimation of Low Cost Floating House, F. Ishaque, M.S Ahamed, and M.N. Hoque)			
1 = 1_1 + 4.5^2 *(actual diameter of drum* length of drum)	488828.6667	2285176	3583476
I/∀ (cm)	12.98	17.28	20.36
Metacentric height GM GM = (I/∀)-BG	8.33	10.08	12.56
Stability	+ve, stable equilibrium	+ve, stable equilibrium	+ve, stable equilibrium

Conclusion

Reasons for reinforcing the idea of amphibious project in Munroethuruthu were

- Residents didn't want to abandon their land and property.
- Technology that can ensure structural safety from flood and settlement.
- Providing quality of living for the inhabitants without compromising the space for Kallada River and Ashtamudi Lake ensuring double land use.
- Examples to illustrate how we should adapt our buildings to the rising sea level.

From literature study and on field survey, these reasons strengthened the need for amphibious technology, which is also an adaptation strategy. Theories related to the technology starting from the history of aquatecture are explained for analysing the differences between amphibious technology and earlier flood mitigation/ resilient strategies.

Multiple Criteria Analysis helped in analysing different possible foundations for the different criteria and conditions of Munroethuruthu. Barrel foundation was the best possible outcome. This provides the idea of recycling of plastic high-density polyethylene (HDPE) barrels. Thus the construction can be made economical without compromising the structural integrity and safety.

The model study shows that this technology works even if it is scaled up to a real-life situation. Also it shows even if the water depth increases, there will be no increase in submergence and surface level, which makes the structure safe at high flood levels too. These results infer that even if the prototype structure rises beyond a certain limit, submergence level will not alter subjected to the same or less amount of load inside the house as compared to about-to-float situation.

The maximum angle of tilt for the house must be less than 7°. For safety, it is recommended that if the structure tilts beyond 5 °, either the live load inside the house must be reduced or it must be evacuated.

If the vertical drop of the building below the water line is approximately 0.5 metres, based on the Archimedes Principle, the house is capable of carrying a maximum load of 267kN for a floating area of 53 m^2 of the structure. Beyond this limit, if the vertical drop increases, the structure will sink. The floating area of the buoyant structure can be increased to improve stability and the maximum carrying capacity. Depending on location and available area, the floating foundation must be designed to carry a load with safety factor and to maintain an equilibrium position.

The studies including structural analysis by considering varying ground conditions is still undergoing.

Bibliography

Archimedes Principles; Available:www.britannica.com,www.science360.net/archimedes-principle.htm

Hind House/John Pardey Architects; Available: https://www.archdaily.com/24363/hind-house-john-pardey-architects, June 2009

House, F. Ishaque, M. S. Ahamed, and M. N. Hoque, (June, 2014), Design and Estimation of Low Cost Floating House, International Journal of Innovation and Applied Studies, Volume 7, Issue 1, July 2014, Pages 49–57, ISSN: 2028–9324

Ir. Pieter H. Ham, (2016), The design of a modular, amphibious structure for a flood and typhoon-prone municipality: Hagonoy, the Philippines; Master thesis report, TU Delft repository, Available: uuid:cd8fce02–5a6c-4d87-b52f-c820438b9684

Project report on “Planning strategies for the development of Munroe Island with special focus on environmental issues”, School of Architecture, Government Engineering College, Thrissur, Kerala 2015

Project Review: Floating Homes ‘De Gouden Kust’ Maasbommel, the Netherlands, 1998–2005, Available: https://climate-adapt.eea.europa.eu/metadata/case-studies/amphibioushousing-in-maasbommel-the-netherlands/11310092.pdf

Richard Coutts, Robert Barker (2016), UK's first amphibious house: Can-float Amphibious Building, Baca Architects, Shortlisted – President's awards for research, 2016, Available:https://www.architecture.com//media/gathercontent/riba-presidents-awardsforresearch/additionaldocuments/106895uksfirstamphibioushousedd2pdf.pdf

Re-locatable Aerostat System for Swift Deployment of Communication Equipment in Disaster-Struck Zones

Chetan Dusane[a] and Rajkumar S. Pant[a]

ABSTRACT: Disaster situations usually affect the communication infrastructure in the affected zone, many a time rendering it useless. This hinders communication during rescue operations, hence endangering many more lives. One recent disaster situation prompted the state of Uttarakhand to fund the authors and their team to develop technology enabling rapid communication infrastructure establishment in a portable and re-locatable manner.

This work describes an aerostat (balloon) system thus developed, lessons learned from field trials and the current work, which is a step forward towards fine-tuning of the existing system based on the learnings to make it further compliant to the actual field requirements in disaster situations.

KEYWORDS: LTA systems, aerostat, post-disaster communication, balloon systems

Introduction

July 16, 2013, Kedarnath, Uttarakhand, India, a pilgrimage town nestled in the Himalayas, bustling with activity, was just about to end its tourist season when one of the deadliest tragedies struck. Flash floods completely flattened the town within minutes with thousands stuck in the debris and mud, battling for life. Most of the victims could not be saved as the first responder rescue teams could not establish timely contact with the base teams for reinforcements because of the complete breakdown of communication infrastructure.

First responders from the government of the state of Uttarakhand contacted our laboratory requesting for an intervention in the form of a portable, quickly deployable and height-adjustable aerial platforms to raise communication equipment as quickly as possible to establish contact in disaster and dark communication zones. This led to the development of an aerostat (balloon-based) system with self-stabilising capability, which can be deployed with communication payload. Design, fabrication and trials of the system were accomplished successfully, with 2G, 3G, 4G, calling and internet signal establishment on a proof-of-concept basis. A typical aerostat system is shown in Fig. I.

Aerostats are an outcome of lighter-than-air (LTA) technology, where static lift production mechanism is based on the archimedes principle wherein the density difference between an LTA gas (usually helium or hydrogen) and the ambient air results in a buoyant lift that overcomes gravity. Aerostats are aerial platforms with LTA gas filled inside a suitably sized and shaped envelope to lift themselves as well as any onboard mounted payload. They are tethered to the ground using a winching system, which can reel in or out the tether, depending on the desired deployment height. A ground stand (balloon stand as in Fig. I) is required for secure mooring and ground handling of the system. Aerostat systems find a wide range of applications as

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relocatable and height-adjustable aerial platforms with exceptionally high endurance and low operating costs since they do not consume any fuel to remain afloat in the air. The fuel or energy consumption for any other system would be very high if it is to accomplish the same task.

There are four major types of aerostat systems as shown in Fig. II. With regard to stability, maintaining both height and least rotation in high winds is one of the most desired features in an aerostat system; fig. II also gives a representational idea about how these four types of systems fare in high winds. As could be seen, literature qualitatively mentions a kite-based aerostat to be the most stable of all aerostat designs (Alsopp 2010; Rogers 2001; Verhoeven and Loenders 2009), but for this project, it was decided to go with a sailed system because it was the best possible system that could be fabricated in the given amount of time in terms of stability, fabrication complexity and time.

Even though the trials of the developed sailed aerostat proved the efficacy of balloon systems for the said application, some inadequacies were noted after analysing the system behaviour in different weather conditions and its ease of operation. Many points of improvement were noted namely, oversizing of the balloon envelope, more-than-expected loss in altitude in severe wind conditions (> 40 kph) and laborious operation of allied equipment like winching and mooring system, which proved to be cognitively heavier than expected. All these issues affected the overall system stability in windy conditions and resulted in slower-than-desired system deployment time, which can prove quite crucial during disasters. Although the system was functional, it suffered the aforementioned operational complexities that put limitations to its usability, leaving wide scope for improvement. Data related to all the concerned parameters causing the aforementioned issues have been obtained and conclusively analysed. Modifications in the existing system for enhancing the overall stability and usability and hence better signal connectivity have been envisaged to exploit the full potential of the system.

In this paper, we present the basic details of the system developed. However, the emphasis is on the trials and the observations made during them. The section thereafter focuses on the improvements that have been planned to make this system a robust solution. The ultimate goal of this work is to identify the problems with the current system and find ways of improving it so that it better fits the application at hand.

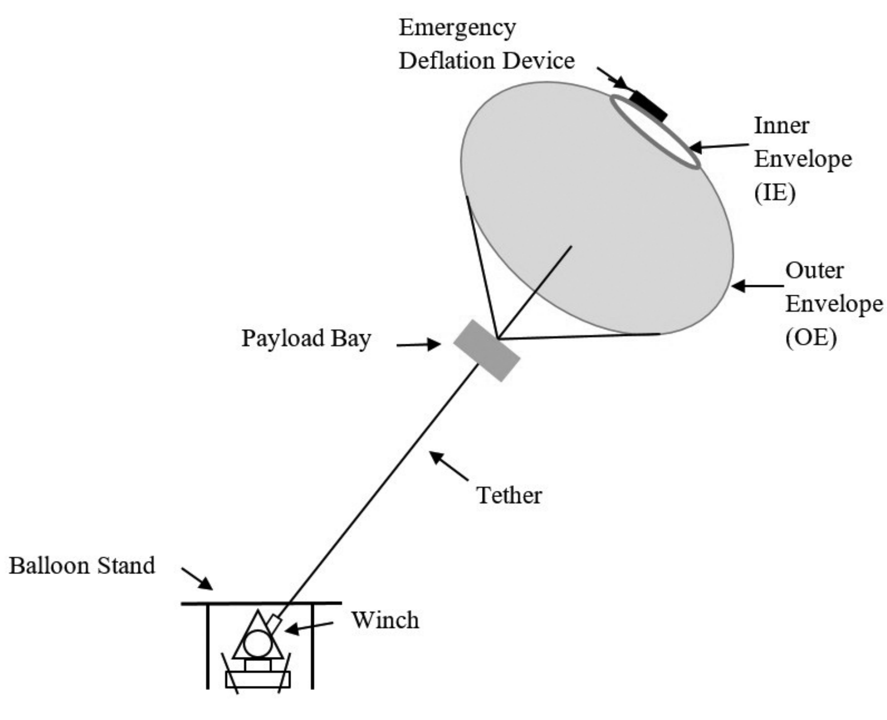

Figure I: A typical aerostat system

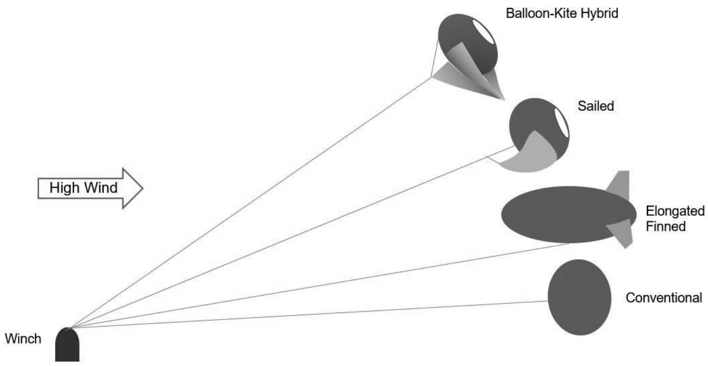

Figure II: Types of aerostats with their representational stability in high winds

The System

As mentioned in the preceding section, the two field trials of the system were carried out on POC basis to test the system performance and to understand its efficacy for the said application. This section will elaborate upon some basic details of the system that was ultimately used in the second and the final trial.

The system was designed to be twin-chambered so that the inner envelope which has very good gas retention properties will have to carry out only that task without the additional burden of bearing the stresses that come on it. Inner envelope material was not capable of handling these stresses. The outer envelope, however, was not designed for gas retention but was suitable for bearing various stresses that an envelope experiences. The outer envelope is where the payload bay (which holds the payload, for example, RF antenna) was connected to the aerostat system. Two other types of antennas namely, Sector Antennae and Police Wireless VHF Antenna were also successfully tested on the aerostat along with an RF antenna. The antennas were connected to a custom-designed payload carrying bay. This payload bay also had a provision to connect the RF cable, which connected the RF antenna and the telecom equipment backend (cell on wheels) on the ground.

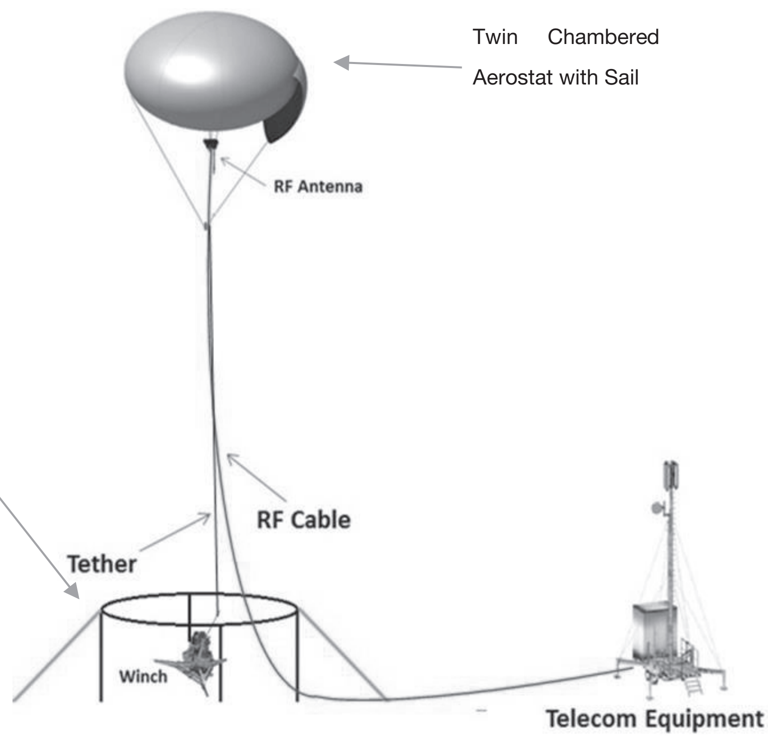

Figure III: Illustration of the complete system used during this project

The following table provides the details of the system.

Table I: System Details	
a. Inner Envelope	
Parameters	**Specifications**
Inflated height (m)	3.8
Inflated width (m)	6
Volume (m^3)	70.6
Material	Linear low-density polyethylene
Gas	Hydrogen
b. Outer Envelope	
Height (m)	3.5
Width (m)	5.6
Material	Rip-Stop Nylon
c. Ground Handling Stand	
Max. height (m)	2
Min. height (m)	1.25
Diameter (m)	2
d. Winch	
Height (m)	0.79
Width (m)	1.1
Material	Aluminium

Figure IV: Actual system deployed

Figure V: System close-up

Field Trial and Results

Objectives

- Deploy the system for a long time with the required payload to assess concept feasibility and behaviour
  - A need to test the methods of integration of sub-components like the inner envelope, outer ribbon structure, payload bay, payload, and the ground handling system was felt.
- Observe the behaviour of various components and systems involved in the deployment
  - This was the first time that the authors and their team had used a ground-handling stand. Moreover, the winch used was also new. Further, the sail-based system was also being tried out for the first time. Hence, the team felt that it was imperative to test these components and their integration with one another.
- Test the range and connectivity of the telecommunication payload
  - Testing the overall feasibility of the concept through various telecom equipment connectivity tests like drive by test formed the core of this trial.

Observations

- Communication ranges obtained:
  - RF Omni Antenna: > 2 km radius
  - Sector Antenna: > 1 km radius
  - Wireless VHF Antenna: > 40 km
- Deployment results:
  - System deployment duration: 72 hr
  - Max. wind speed: 40 kph
  - Max. deployment height: 90 m
  - Refill required: None
- System handling performance:
  - Time from unpacking to deployment: 90 min
  - Deflation time: 180 min
  - Dismantling and packing time: 60 min
  - Personnel required: 6
- Design inadequacies:
  - The envelopes were over-sized. This led to a bigger size and thus more gas to be filled in to make the envelope taut. This, in turn, increased the surface area, which increased the aerodynamic drag affecting system stability and overall stresses experienced by various components of the system.
  - The motorised winch was under-designed. It did not provide enough torque to hold the system at one height. External constraint had to be employed.
  - Power source had to be externally connected to the winch motor. This led to an increase in time required to deploy the system.
  - Winch had to be constrained using lugs hammered into the ground. Hammering in and taking out took a lot of effort and time.
  - Ground handling stand though dismountable was still difficult to transport in terms of both weight and size.
  - Wireless emergency deflation device though was not needed malfunctioned.

Overall, it was noted that the system was quite detached and not compact. This led to the system being cognitively heavy and time-consuming to operate and difficult to transport aspects which are very crucial during times of disaster.

Discussion and Future Work

During the trial, system was observed to be disorganised. Currently, re-design of the entire ground handling equipment is underway. As mentioned in earlier sections, the system developed proved to be cognitively heavy on the operators and the required number of operators (six) than desired (two). Also, the operation was time-consuming, and portability was also affected. For this, a trailer mounted system is being conceptualised, which will house the gas cylinders, winch and ground handling stand within.

The trailer is being designed in a manner which will make it easy to attach it to an SUV to take it to difficult terrains like in Uttarakhand and deploy the aerostat in emergency situations. A battery pack to operate will also be provided onboard the trailer to reduce dependency on any external power source. This source is also planned to power the ground support electronics equipment. Winch and balloon stand are also planned to be one sub-unit to decrease the part count and hence the complexity. Deflation strategy for quick packing of the system is also being thought of. A gyro-operated payload bay is also being conceptualised to keep the payload stable even if the envelope shakes locally.

A balloon-kite hybrid-type envelope is proposed, as in authors' experience and as per literature it is the most stable type of aerostat. In the near future, the task of comparing different types of aerostats for their ability to remain stable in high winds will be compared via ANSYS Fluent™ simulations to theoretically analyse this observation.

The ultimate aim will be to make full use of the potential of the aerostat systems for post-disaster scenarios, which demand a robust, quickly deployable and easily transportable emergency communication establishment system.

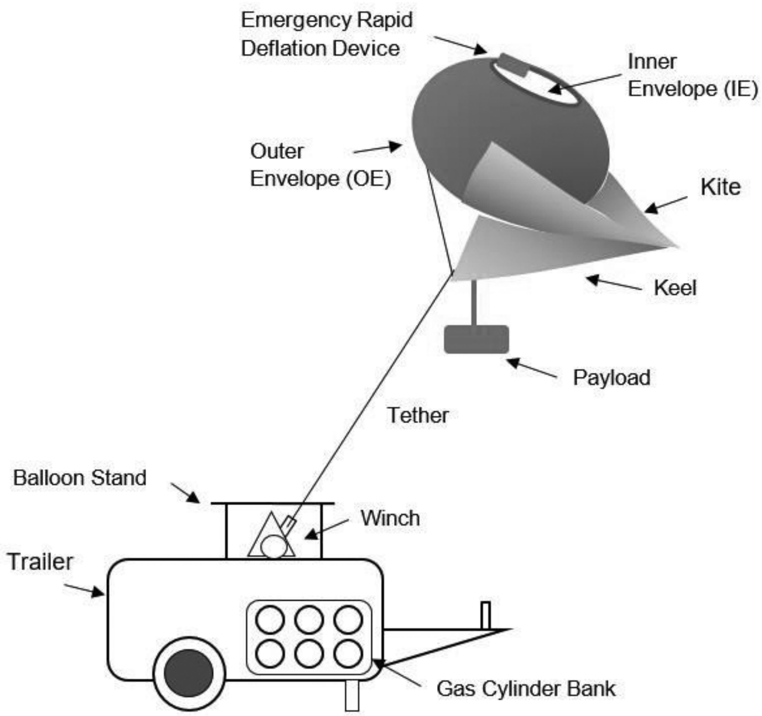

Figure VI: Proposed concept: a trailer mounted balloon-kite hybrid system

Conclusion

In summary, this project quite clearly proved that balloon-based systems could be used for establishing communication in a post-disaster scenario. The observations made during the trials have given confidence that this is an endeavour worth pursuing, and the inadequacies noted during the trials were found to be correctable through slight re-design and of the system. The proposed system in the preceding section shall prove to be a useful equipment for disaster management teams all across the country not just in communication establishment but other applications like disaster zone assessment, crowd/traffic management and surveillance.

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References

Allsopp, S., 'Helikites for High-Altitude Radio-Relay' (White Paper), Allsopp Helikites Ltd, Damerham, Fordingbridge, Hampshire, SP6 3HW, England, December 2010

Dusane, C., Wani, A., Chakraborty, D. C., Chakravarthy, B.K., Pant, R. S., "An Elevated Balloon-Kite Hybrid platform for Surveillance", Proceedings of '17th AIAA Aviation Technology, Integration, and Operations Conference', 5–9 June 2017, Sheraton Denver Downtown Hotel, Denver, Colorado, USA

Rogers, M. E., 'Helikite Elevated Platform (Final Report HEP Phase I)', Topic A00–134, Small Business Innovative Research (SBIR), Carolina Unmanned Vehicles Inc., 4105 Graham- Newton Road, Raleigh, NC 27606, 2001

Verhoeven, G., Loenders, J., 'Looking through Black-Tinted Glasses - A Remotely Controlled Infrared Eye in the Sky', For The Fund for Scientific Research - Flanders (FWO), Department of Archaeology and Ancient History of Europe, Blandijnberg 2, B-9000 Ghent, Belgium, December 2006

Verhoeven, G., J., Loenders, J., Vermeulen, F., Docter, R., ‘Helikite Aerial Photography : A Versatile Means of Unmanned, Radio Controlled, Low-Altitude Aerial Archaeology’, Archaeological Prospection, DOI: 10.1002/arp.353, Ghent University, Department of Archaeology and Ancient History of Europe, Blandijnberg 2, B-9000 Ghent, Belgium, 2009

Technological Interventions to Make Urban Transport Reliable Evacuation Transport in Case of Natural Disaster

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ABSTRACT: India is presently going through a phase of rapid urbanisation due to enhanced economic growth especially at around urban centres leading to the development of urban agglomerate and multi-fold increase in the number of vehicles plying in these cities, that is owing to transport-related risk and crisis in these cities. Unplanned road network, deteriorating air quality, reduced areas under green space, no space for hawkers and pedestrian pathway, poor parking system are some of the risks facing transport sector as a result of rapid unplanned urbanisation. It is estimated that in 2007, the transport sector contributed emissions to the tune of 142.04 Mt CO_2 eq in India alone. It accounted for approximately 13 per cent of total energy-related CO_2 emissions (MoEF, 2010), of which majority of emissions were from the road transport. The conditions in developing countries pose additional challenges on transportation systems – demand far exceeds supply, particularly for the growing number of urban poor getting pushed in urban centre for better livelihood opportunity. Thus, to minimise this gap of demand and supply in transport sector an integration between land use and transportation system is mandatory to enhance resilience and ensuring sustainable planned urban development.

The urban population in India grew from 25.8 million in 1901 to 377.1 million in 2011. According to the *Handbook of Urban Statistics* (2016) of Ministry of Urban Development, the urban population is projected to grow to about 600 million (40 per cent) by 2031 and 850 million (50 per cent) by 2051. Apart from population growth, urbanisation is viewed as socio-economic growth of any region. According to 15th Census of India, 91.4 per cent of urban households had access to drinking water. The electricity coverage of urban households in 2012 (97.9 per cent) increased over 6 per cent from 2002 (91.6 per cent). Literacy rate had also shown increase from 79.9 per cent in 2001 to 84.1 per cent in 2011. Urban households having drainage facility surge to 82 per cent in 2011 as compared to 78 per cent in 2001. These few indicators offer evidences of socio-economic growth of cities.

However, in addition to the opportunities, increasing urbanisation invites several challenges. Escalating urban population demands dedicated key urban infrastructures and services viz. transportation, solid waste management, integrated urban water resources management, low-income housing, education, sanitation and health. These basic needs of communities put further pressure on available natural resources such as land, water and energy. In order to achieve sustainable urbanisation and built resilience of cities, a wide spectrum of interventions are required. These all problems will enhance the risk in case of natural disaster. Do we have a transport for mass evacuation in case of natural disaster?

KEYWORDS: urban agglomerate, integrated transport, risk resilience, transport for evacuation, safe transport

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Introduction

This paper focuses on the current stocks of means of transport available for mass evacuation in case of disaster. On emergency warning of cyclone Phailin in 2013, the largest pre-disaster evacuation ever undertaken in the country, close to a million people were evacuated to safe shelters. As the largest evacuation efforts helped to keep casualties to minimum, reports said that only 23 people died. Most of casualties were caused due to walls collapsing, uprooted trees and flooding. Problems in evacuation transport were reported from all types of media.

Over 2,22,000 people were evacuated from low-lying and vulnerable areas to 310 relief camps in response of Hudhud. In addition, 1688 medical camps were opened, and about 2.9 million food packets and 6.5 million water packets were distributed over a period of 15 days. This was made possible with the efforts of the Govt. of Andhra Pradesh in close collaboration with district authorities, local self government, National Disaster Response Force (NDRF), Indian Army and Navy. Transportation was found to be problematic in this case also. The exact location and availability of vehicles could not be ascertained, which hampered mobilisation of vehicles. The status of the transport industry and its evolution over time from an inefficient and uncontrolled industry to a competitive and optimised one highlight how addition of technologically and operationally sound bus networks will add up to the productivity of road transport. Generally, the economic development of any economy is followed by a commensurate growth rate of transport requirement. For example, in India the road traffic increased by almost 15 times from 1950 to 2015 with the development of the economy. Over the years the daily fleet of passengers increased and so the demand for more and better modes of commute. In recent times, private players have entered the industry and have attempted to provide better services and utilisation of resources to the daily commuters using technology. The same resources and technologies can be leveraged in making urban transport into reliable evacuation transport.

Commuting in India

According to data released by the Registrar General of India, 2015, around 140 million workers commute daily for work among the working population of 200 million. Over a fifth of the non-agricultural workers commute on foot, followed by modes like bicycles, two wheelers, cars, buses and trains. With bicycles, two wheelers and buses being the most common form, a lesser percentage of commuters prefer private cars (Census 2011). Nearly a third of these people do not commute, and just 55 per cent of women commute for work, higher in urban than in rural areas.

Mode of Transport	Percentage Users
1. On footers/pedestrians	30 per cent
2. Bicycle	13.1 per cent
3. Scooter/motorcycle	12.7 per cent
4. Bus	11.4 per cent
5. Train	3.5 per cent
6. Car, jeep, van	2.7 per cent

The transport priorities in India are skewed depending on the length of commute and the commuter's propensity to pay, which filters out the net demand and the preferences of an average commuter. As the commuting distance increases, people switch to other modes rather than travelling on foot. Around one-fourth of the daily commuters travel less than 1 km and prefer walking or bicycling. Around one-third of commuters travel between 2 and 5 km primarily using two wheelers, private cars and buses. Close to 30 million commuters travel more than 10km opting for buses, metro and cars frequently, and around 17 million travel over 20km using metro and cars as their preferred mode of commute. It is also observed that women travel shorter distances than men in the country and use public transport as the most preferred mode of transport as not many know how to drive.

In order to cater the demands of the daily commuters, metro cities have invested heavily in the development of transport infrastructure. Metro rails and bus transport turn out to be the best way to commute. Although both are economical for commuters, the capital cost of setting up a metro rail system far exceeds that of a bus. Both the systems have their own benefits and thus act complementary to each other. While metro helps in ensuring smooth congestion-free movement over its corridors, buses can easily stitch the medium- and low-demand routes that cannot be covered by metro. Buses are more flexible and convenient requiring shorter walking distance to the pick-up and drop points. The presence of buses on roads will not only complement the metro rail network but also help enhance the overall connectivity of transport intra-cities, which cannot be substituted by any other means of transport. If lakhs of people travel by metro rails every day, a greater number of operationally sustainable buses will be required, not only to connect them to parts of the city where metro is not reachable but also to act as feeder network to provide last mile connectivity. In order to meet the service and technology standards of metro rails, new start-ups are coming up with tech-based solutions for integrated mobility and getting recognition in the market.

Another mode of commute that occupies most of the road space available are cars, which actually comprises a very low percentage of total commuters. It accounts for fewer than 3 per cent of the total trips. They hugely contribute to the air pollution and take up an unjustifiable amount of road space creating traffic jams. It has also been observed that people generally prefer buses for travelling shorter- and medium-distance trips, which constitutes the majority of the urban trips and therefore offers an opportunity to the private and public bus service providers to increase their market and compete to cater to a larger set of commuters inclusive of those who, at present, prefer cars and cabs over public transport. The switch would be possible only when offered the best services at par with the comfort of a car. Features such as reserved seats, conditioned buses and closeness of pick-up and drop points to their destination will play a significant role in incentivising commuters to switch to public commute and thus move towards a more sustainable future. It is obvious whenever you require transport for evacuation, only the above-said mode will be utilised. In case of Phailin and Hudhud mostly trucks and jeeps of Armed forces, NDRF and local administration were used, which is certainly not a scientific method of evacuation. Even this method is not cost effective. It is also found that services hired during emergencies are very heavy on government coffers.

Cost of Evacuation

Data on the costs of hurricane evacuation is sparse—costs fluctuate by distance travelled—but a widely circulated study from 2003 estimates that the aggregate evacuation costs to individuals in coastal counties range from $1 million to $50 million depending on storm intensity and emergency management policy (the study used data from North Carolina residents, who experienced Hurricane Bonnie in 1998). In that paper, it was modelled the evacuation decision of households during a hurricane threat and predicted future household evacuation behaviour using revealed and stated preference data methods. These methods allow the assessment of hurricane evacuation behaviour beyond the range of historical experience in revealed behaviour data. They used household evacuation costs and various measures of hurricane risks and found that households respond to risk and other factors as expected. They found that hurricane evacuation costs for ocean counties in North Carolina range from about $1 million to $50 million depending on storm intensity and emergency management policy. Considering that North Carolina has much more than 50 miles of coastline, “one million dollars per mile” is a gross overestimate of the opportunity costs of evacuation.

If emergency managers use the “one million dollars per mile” figure when balancing the benefits and costs of evacuation orders, our results suggest that they are issuing too few evacuation orders by using an upward biased cost estimate. Popular opinion of emergency management decisions is often the opposite. Emergency managers are perceived as issuing evacuation orders too often and too quickly. Perhaps then evacuation costs of “one million dollars per mile” are not used in emergency managers’ decision-making. Whatever the case, using evacuation cost estimates based on behavioural models will improve the efficiency of emergency management.

We perform an ex-post breakeven analysis of the number of statistical lives saved that would justify a mandatory evacuation order relative to a voluntary evacuation order. In the event of an extreme or catastrophic hurricane, the mandatory evacuation order appears to be an efficient policy since the breakeven number of lives saved appears low. Of course, this is speculation since little data exists to suggest how many lives would be lost without mandatory evacuation orders in a modern-day storm. Of course, when mandatory evacuation orders are issued, and a hurricane does not threaten the area, the “false alarm” evacuation order is an inefficient policy’s ex-post.

An ex ante benefit cost analysis should incorporate the probabilities of a hurricane strike when estimating the expected benefits and costs of evacuation orders. Based on casual observation of the National Hurricane Center’s website during the 1999 Hurricane season, these ex ante probabilities tend to range from 20 to 33 per cent in the areas most likely to suffer hurricane landfall. This suggests that in an ex ante benefit cost analysis, the breakeven number of lives saved must be three to five times greater than in the ex post analysis to justify mandatory evacuation orders. Future research concerning these issues should improve the efficiency of emergency management. This research should be increasingly important in the light of the largest peacetime evacuation in the US history during Hurricane Floyd and predictions of increases in the number of land falling major hurricanes.

Transport in Delhi

There are 16.6 million registered vehicles in the city as of 30 June 2014, which is the highest in the world among all cities most of which do not follow any pollution emission norm (within municipal limits), while the Delhi metropolitan region (NCR Delhi) has 11.2 million vehicles. The findings of a study commissioned by the Urban Ministry, 2012, state that the availability of public transport in Delhi is shockingly low at 0.504 per 1000 commuters. That indicates a scope for improvement in terms of both increasing supply and capacity utilisation of existing fleet in the transport facility. There is another transport means: Delhi Metro is carrying approximately 35 lakh passengers per day. The total network of metro is 277km. it is also found that development of new metro network is money and time intensive. Similarly, Delhi has internal railway lines also known as Ring Railway. The network is now utilised as a freight corridor, and limited passenger train services are available during peak hours. Altogether transport is a necessary evil for Delhi and NCR, where average speed of best quality car is 2.5 min per km in peak time. In fact, in Delhi every hour is peak hour for traffic.

Some Big Evacuation around the World

In September 1999, Hurricane Floyd was the biggest evacuation in US history in which 3 million people fled the hurricane. Most evacuees used their private car, and hence the exit express way choked up bumper to bumper. After the announcement of mandatory evacuation, fuel became unavailable. This is known as the Great Carolina Exodus fleeing the coasts. Obviously, no supply can support fuel if all vehicles in the city start their trips. Similarly roads and highway have their limitations.

In April 2001, the 1.1m (3.6ft)-long bomb, weighing 225kg (500lb), was found on Fano’s seafront, Vicenza, Italy, during the construction of a drain. Approximately 77,000 inhabitants (around two-thirds of the population were evacuated for several hours so that bomb originally dropped in World War II could be safely disarmed. The stories repeated. There was a total chaos, no transport was available and there were a massive traffic jam on the highway.

In September 2001, there were evacuations from high-rise buildings across the United States. This included more than 3200 survivors of the World Trade Center disaster and inhabitants of downtown Manhattan, New York City. Numerous other evacuations of high-rises in Chicago, Illinois, included the Sears Tower and the Thompson Building. The evacuation of New York included the largest sea evacuation in recorded history, with over 500,000 being evacuated in 9 hours by hundreds of boats. Same problem found. Evacuees were waiting for their turn and transport. Long line and chaos.

In January 2002, in the eruption of the Mount Nyiragongo, 300,000 residents of the city of Goma, Democratic Republic of the Congo, were evacuated in three days. Lots of complaints registered regarding non-availability and overcrowded transport. Similar problem was noted during European floods, Hurricane Frances and many more evacuations afterwards. In Hurricane Katrina 80 per cent of city population, approximately 484,000 people, were evacuated. The problem during evacuation was highlighted by most of world media. Katrina evacuation was the flag raiser. Most of emergency managers of world noted the Katrina evacuation. As per emergency managers, availability of transport in that sort of time is the biggest problem. In most cases the city transport vehicles are used for the evacuation.

Travel demand has grown significantly in all metro cities. The mode and type of commute people choose to travel will decide the severity of pollution and congestion caused by traffic and, ultimately, liveability of the city. If people choose to use more cars and two wheelers, the scary trend in pollution and congestion will become irreversible. Public transport provision has been improving, but in many places, it is overcrowded, unsafe or simply unavailable. There is great need for reliable, affordable and safe forms of public transport to connect many parts of the city not reached by the current network.

More than 55 per cent of rides in Delhi NCR are for daily office commute (same office, home, time of travel). Taking a cab to office every day is expensive in most cases, and car-pooling/sharing is marred with dynamic routing issues (longer travel time) leading to poor adoption. It has been estimated that most passengers spend 3 hours a day commuting, and reliability, comfort and affordability are the primary factors for the selection of travel mode. This leaves a huge space and potential for innovation in daily office commute space. The city transport of most cities especially Delhi is not enough for peacetime, then how could it will support in case of emergency.

Best Practice in Delhi NCR

Gurugram-based Shuttl is a technology-enabled seat-based demand-adaptive bus mobility innovator with a demonstrated ability to directly address the dual challenge of congestion and pollution. Shuttl provides a safe, reliable, comfortable and affordable daily office commute option for commuters. by using high-capacity vehicles to solve daily commute problems, Shuttl helps cities reduce congestion, pollution and save fuel, thereby contribution to solving the urban mobility deadlock cities are currently facing. Shuttl provides its users a dignified commute option by providing an assured seat and comfort levels comparable to cars.

Since buses are more road-space and carbon efficient than cars, Shuttl model reduces congestion and pollution with a single solution. In cities, where Shuttl's service exists, it has successfully induced a shift from personal cars to bus-based mobility. This shift from cars to smart buses has the potential to transform India's car-dependent transport sector to a more sustainable one based on shared mobility. The company operates close to 150 routes with 800 vehicles connecting metro stations, residences, universities and business hubs offering around 65,000 rides per day. The average waiting time for commuters is 5–10 minutes. Within 100 days of its operations, the company has crossed 1 million rides, saving INR 5 million worth of fuel every day and a reduction in carbon emission by 53,460 tonnes so far. With females comprising more than 35 per cent of ridership, the service has turned out to be a safe and preferred option for women. Around 375 operators are aligned with the company at present. In its effort, Shuttl has successfully gained the confidence of its commuters by providing them with a credible alternative, changing their perceptions of the public transport in the city.

Working Details

Citizen's two-way commute needs (source, destination, departure time) are sourced through various online channels (consumer mobile application, website, surveys, etc.) and offline channels (BTL promotions, kiosk, etc.) and overlaid on city's digital map to obtain demand heat map. Demand heat maps are translated into stops, routes, and an optimal route network is designed accounting for origin and destination and available time of buses. Using the route network design and demand heat map, the schedules, frequencies, size of buses and number of buses are deduced with an objective to fulfil maximum demand with minimal buses (assured seat for each passenger). The routes and itinerary are made visible to consumers for booking available seats in the bus. Based on deduced bus size and number, Shuttl hires buses having Contract Carriage permit (issued by Govt.) under an agreement for a pre-defined time and for a fixed monthly sum. After enabling the buses with GPS Device and Driver Mobile Application, the drivers are trained to follow the itinerary digitally shared by Shuttl on their Driver App. Through live-tracking dashboards, the entire operation of Shuttl is monitored, and deviations are flagged to make product, process and people interventions at right stages. Shuttl being an office commute solution needs to score high on reliability matrix. On-time performance, right stopping, driver behaviour, driving quality, bus quality, etc. are rigorously supervised.

The consumer app allows users to view schedules, reserve seats, navigate to stops and live-track buses. Once reserved, customers are guaranteed a seat on the bus. Shuttl's customers are largely young daily office commuters. They purchase a monthly, quarterly or six-monthly pass. Payment is cashless and upfront. On an average, a Shuttl ride costs $1.50 for a 20-mile journey. An encrypted audio authentication system ensures only customers who have booked a seat can board the bus. Drivers use the Driver App to report to service, start/update/end trips, navigate route/stops, authenticate boarding passengers and raise SOS. With constant GPS tracking through the driver's application, the ETA (Estimated Time of Arrival) is calculated and communicated to the commuters.

Conclusion

India has the second largest road network in the world with a length of about 137,712km. Buses not just provides the best and the most feasible means of commute but also complements the metro rail network in terms of first mile and last mile connectivity. Adoption of bus service plays a crucial role in the success of public transport. The more the number of commuters switching to bus, the lesser is the congestion. This results in improved occupancy and better scheduling of bus timings. All public transport vehicles should be linked with GPS system at the time of registration so that they could be tracked, located and called at the earliest for deployment during disasters. All these vehicles can be aggregated on a platform. The aggregator can be pre-identified, and a rate contract can be signed as for different services is being signed for disaster.

Buses do not just provide a feasible means of commute but also complement the metro rail network in the cities. In order to expand the capacity utilisation, new technology should be brought in to meet the growing expectations and should raise the standards of commuting. Private players should be encouraged to offer a cost-effective, eco-friendly, reasonable and safer rides to the public, ensuring every customer gets to travel in a comfortable and dignified way. Offering such a service to the commuters adds to their productivity, by giving them comfort and time to relax.

With the increasing gap between demand and supply, there is a need to modernise the transport infrastructure by upgrading technology and skills and enhance connectivity and efficiency of the overall system. As bus transport is the most cost-effective and convenient mode of commute, new ideas to promote and improve the bus service should be encouraged. Sustainable means of commutes such as electric and hybrid vehicles and vehicles based on alternate fuel should be promoted to move towards sustainable development. In order to evolve the system to the next level, it is important to create an operationally and technologically sound environment, which simultaneously incentivises both public and private players to challenge the existing norms and raise the bar.

Bibliography

Gray WM, Christopher WL, Paul Jr WM, Kenneth JB. Extended range forecast of Atlantic seasonal hurricane activity and US landfall strike probability for 2000, Department of Atmospheric Science, Colorado State University, http://typhoon.atmos.colostate.edu/forecasts/2000/fcst2000; 1999.

http://delhigovt.nic.in/newdelhi/dept/economic/empweb/emp1.htm

http://ind-transport.blogspot.in/2008/09/traditional-means.html

http://libres.uncg.edu/ir/asu/f/Whitehead_John_2003_One_Million_Dollars.pdf http://rise.mahindra.com/the-evolution-of-india%E2%80%99s-transportation-needs/

http://timesofindia.indiatimes.com/city/delhi/No-new-buses-DTC-struggles-to-carry-45-lakh-Delhiites/articleshow/47044842.cms

http://timesofindia.indiatimes.com/city/delhi/No-new-buses-DTC-struggles-to-carry-45-lakh-Delhiites/articleshow/47044842.cms

http://www.academia.edu/10223903/Understanding_Regional_Commuting_from_N.C.R._to_Delhi_for_work

http://www.delhimetrorail.com/press_reldetails.aspx?id = D56csDWRltIlld

http://www.thehindu.com/data/india-walks-to-work-census/article7874521.ece

https://owl.english.purdue.edu/owl/resource/560/05/

https://www.hindustantimes.com/delhi-news/every-hour-is-peak-hour-in-delhi-traffic-crawling-50–60-slower-says-cse-study/story-imggLneVZQuFhnmQFl5OjJ.htmll

PaschRJ, Todd BK, Stacy RS. Preliminary Report: Hurricane Floyd, National Hurricane Center, 7–17 September 1999. http://www.nhc.noaa.gov/1999floyd text.html; 2000.

Traffic snarl snaps 42 Cr man-hour from Delhi, NCR workers Archived 10 January 2008 at the Wayback Machine.

"Hurricane Floyd – A Night to Remember, A Day Of Evacuation Frustration To Forget". Federal Emergency Management Agency. September 9, 2000. Retrieved 2018–11–15.

PART III RESILIENT URBAN SYSTEMS

VIII Making Cities Resilient

Assessment of Life Satisfaction in Slum Rehabilitation Housing in Developing Countries

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ABSTRACT: Urbanisation is a big challenge, especially for the developing world. At least one-third of the world population lives in slums and squatter settlements without essential amenities. The sustainable development goals of the UN aim at eradicating poverty, improving the health and well-being of the population, making inclusive, resilient and sustainable cities. Mumbai is the fourth largest megacity and first among Indian cities with over 41.3 per cent of its population living in slums which are identified as vulnerable by the city government. As the city is prone to multiple hazards including floods, rehabilitation of the people is considered as a right step towards making a sustainable, resilient world-class city. This paper aims to assess the life satisfaction of residents of slum rehabilitation housing for the project-affected people in Mumbai. Data on socio-economic profile of household, life satisfaction and satisfaction with access to various public amenities were collected from 242 adult individuals from different households living in a rehabilitation housing near the Kanjurmarg railway station in Mumbai during October 2018. The results show moderate level of satisfaction with life and neighbourhood facilities. Improving satisfaction with four variables - distance to shopping centre, distance to workplace, quality of bus service and quality of health service (private) – can enhance the life satisfaction among residents of slum rehabilitation housing. So the study may be useful for urban policymakers and other stakeholders in improving the quality of life of the urban poor.

KEYWORDS: life satisfaction, slum rehabilitation, neighbourhood, urbanisation, quality of life

Introduction

This paper aims to assess the life satisfaction of residents of slum rehabilitation housing for the project-affected people in Mumbai. Slum rehabilitation in developing countries aims at improving the quality of lives of the people through improved housing resulting in the well-being of the residents (Vaid & Evans, 2017). This will reduces vulnerability to natural disasters. However, the literature indicates that public housing schemes for the poor have been unable to meet the need of the people regarding quality and quantity (El-Masri & Tipple, 2002). So, the study examines life satisfaction and satisfaction with neighbourhood facilities among residents of one public housing for the poor – slum rehabilitation housing – in Mumbai that rehabilitates vulnerable poor people who were residing along the railway lines. According to the Mumbai disaster management plans (DMPs), slums considered vulnerable and risky are especially those located on "hilltops, slopes, nallahs, low-lying areas (with tendency to flood during high tides), coastal locations, under high tension wires, along highways, along railway lines, within industrial zones, pavements, along

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water mains, and along open drainage" (Parthasarathy, 2009). Minimising population displacement due to the redevelopment of the unplanned human settlement or slums for the development of the city infrastructure and services becomes a great challenge for the city government (Patel, d'Cruz, & Burra, 2002). Patel et al. (2002) argued that it is very tough to find the proper land for the resettlement of the people with access to public facilities.

Mumbai is the financial and commercial capital of India. However, it is not a planned city, and it has become a hazard-prone megacity in the world mainly prone to floods and landslide. Rapid urbanisation and unavailability of land for development due to congestion are the factors that had led to the formation of uneven spatial distribution resulting in the creation of vulnerable hot spots – informal settlements without essential amenities (Sherly, Karmakar, Parthasarathy, Chan, & Rau, 2015). Over half of the Mumbai population live in informal settlements and squatter settlements. The slum population relative to the urban population in Mumbai increased from 15 per cent in 2001 to 17.4 per cent as per 2011 census. Rapid urbanisation (which is one of the main reasons for unplanned growth of cities) and high intensity of annual rainfall during monsoons make Mumbai highly susceptible to urban flooding (Gupta, 2007, & Chatterjee, 2010). City government and the central government have been making various policies and implementing them to improve the quality of lives of the people. In this line various infrastructure projects like Mumbai Urban Infrastructure Project (MUIP) and Mumbai Urban Transport Project (MUTP) have been under implementation to improve transport infrastructures. But these infrastructure projects caused the displacement of vulnerable people who were living in slums and squatter settlements along the railway lines and major roads. Resettlement of the project-affected people has become a significant challenge for the government. The resettlement of over 60,000 low-income project-affected people related to the Mumbai Urban Transport Project has been done in different rehabilitation sites with community participation (Patel et al., 2002). The government has been implementing housing rehabilitation policies to reduce the vulnerabilities of the people.

The slum rehabilitation schemes which started in 1995 in Mumbai have been considered as one of the best ways for urban renewal (Mahadevia, Bhatia, & Bhatt, 2018). Now with the help of non-government organisation and social workers, a significant amount of project-affected people are resettled in slum rehabilitation housing provided free of cost by the city governments through private participation. However, the life satisfaction of the residents in rehabilitation housing located near public transport remains unexplored. So the study fills a gap that currently exists in the housing literature of India.

Background

UN declaration of human rights in 1948 highlighted the importance of having adequate, affordable housing for the well-being of the people. Rapid urbanisation in the developing world is a great challenge for humanity. As per the UN-Habitat report, at least one-third of the world urban population lives in slums and squatter settlements without essential amenities (Sclar, Garau, & Carolini, 2005). The sustainable development goals of the UN aim at eradicating poverty, improving the health and well-being of the population, making inclusive, resilient and sustainable cities. We have learned that pre-disaster mitigation is crucial to limit disasters rather than post-disaster emergency actions. As a result of increasing human settlements in vulnerable areas resulting from two main reasons, rapid urbanisation and precarious economic conditions, natural disasters are becoming more severe and frequent in developing countries (El-Masri & Tipple, 2002).

Disaster in Mumbai

The dream of Mumbai becoming a world-class city with Singapore or Shanghai as a reference has been shattered by unprecedented floods like that of 26 July 2005 resulting from lack of urban planning (Bhagat, Guha, & Chattopadhyay, 2006). Millions of people were severely affected, and many of them had been dislocated by continuous rainfall during the rainy season over the years. July and August are the time for heavy rainfall (70 per cent of the average annual rainfall) in Mumbai. And 50 per cent of the rainfall during these periods occurs uniformly over Mumbai in just two or three events (Gupta, 2007). The first urban disaster management plan for Mumbai has identified the vulnerability of areas including slums to flooding (Revi, 2005). According to Mumbai disaster management plan (DMP), 10 sections along the central railway line in addition to 12 sections along the western railway line and 235 flooding points in Mumbai are identified as prone to serious flooding. Mumbai DMP also recognises people in the slum as the most vulnerable to flood, health hazards and cyclones due to the location, poor infrastructure and services, and accessibility. Studies suggested relocation of 1200 slums along the Mithi River following the 26 July 2005 rainfall. Without addressing the problems of slum residents, Mumbai cannot reduce its overall risk profile. The slum settlements are not adequately prepared for the expected sea level rise shortly (Aggarwal and Lal, 2001). Due to climate change, Mumbai is expected to experience a frequency of extreme weather events (Ciscar et al., 2009). City infrastructures like roads, rail transport, etc. are not ready for uninterrupted service throughout the year.

Risk can be reduced in two ways – stopping encroachment in hazardous sites and reducing the fragility of existing vulnerable human settlements (El-Masri & Tipple, 2002). Slum rehabilitation housing is one approach towards this.

Life Satisfaction

Pavot and Diener (1993) concluded that life satisfaction is a person's conscious cognitive judgement about his/her life in which the criteria for judgement are up to the self. Life satisfaction increases with economic growth in poor societies, whereas life satisfaction remains unchanged in developed societies. There may be direct impacts of government policies on people's life satisfaction (Appleton & Song, 2008). Life satisfaction is related to the social relationship, housing tenure. The literature on life satisfaction indicates that an increase in income does not necessarily lead to happy and content population (Appleton & Song, 2008). Since the households are given security of tenure in slum rehabilitation housing, we expect residents to have higher life satisfaction than their life in slums. The longer people stay in their current address, the more positive and significant effect they have on subjective well-being (Ballas & Tranmer, 2012).

Slum Rehabilitation Housing

The housing crisis in Mumbai remains a significant problem over the years despite various policies (Bardhan, Sarkar, Jana, & Velaga, 2015). Private participation in slum development started in Mumbai through the slum development scheme of 1991. There was increased built-up environment through the higher floor space index (FSI) over the years. The private parties were not satisfied with the lower incentives. Then with the new government, the scheme evolved into a slum rehabilitation scheme in 1995, where private parties were given more incentives in the form of transfer of development rights. Following the Afzalpurkar Committee (1995) recommendation, Slum Rehabilitation Authority (SRA) was formed as the nodal agency for the resettlement that looks into three types of rehabilitation – In Situ, Project Affected People (PAP) and Permanent Transit Tenement (PTT). The slum redevelopment involves the demolition of slums and building apartment buildings at a higher intensity and density for cross-subsidisation (Mukhija, 2001). As per the guideline for the implementation of the scheme in Greater Mumbai, the scheme aims at better health, a cleaner environment, self-respect for the people and social justice. The SRA housing is an example of the creation of mixed-income housing in the low-socioeconomic-status neighbourhood. It will limit the spatial concentration of poverty. This type of housing is supposed to be physically permanent and increase urban aesthetics. A free flat of carpet area 225 square feet in exchange of the cleared land was given to the slum dwellers. Now the carpet area will be increased to 269 square feet in the new development. Interestingly the first objective of central government scheme "Housing for all by 2022" is similar to the slum rehabilitation scheme model.

Methodology

Data on socio-economic profile of household, health and life satisfaction, and satisfaction with access to various public amenities/facilities were collected from 242 adult individuals from different households living in a rehabilitation housing near the Kanjurmarg railway station in Mumbai, India, during October 2018. The 242 samples (n = 242) were selected out of 2304 households (N = 2304) to represent residents from each floor of the 12 ground-plus-seven-storied residential buildings. The sample represents 10.50 per cent of the total slum rehabilitation housing households in the colony. To ensure maximum responses, permission was first taken from each council office in each building giving a brief of the survey purpose.

Residents' socio-demographic profile, their perception of the level of satisfaction with access, quality of neighbourhood facilities and life satisfaction were collected with the help of trained interviewers using computer-assisted personal interviewing. A five-point Likert scale was used (scores ranging from "1" = very dissatisfied to "5" = very satisfied) to measure respondents' level of satisfaction with neighbourhood facilities regarding distance and qualities. Positive satisfaction level is achieved with a minimum mean score of 3.00, while a mean score below 3.00, indicates dissatisfaction. Life satisfaction was measured using Diener's Satisfaction with Life Scale (SWLS) on a seven-point Likert scale (scores ranging from "1" = strongly disagree to "7" = strongly agree). The sum aggregate score – 30–35 = very high score (highly satisfied); 25–29 = high score; 20–24 = average score; 15–19 = slightly below average in life satisfaction; 10–14 = dissatisfied; and 5–9 = extremely dissatisfied – was used for the identification of life satisfaction level.

Through literature review, 21 variables for measuring satisfaction with neighbourhood facilities were identified with Cronbach alpha 0.915 and used for the present study. Statistical Package for Social Science (SPSS-21) was used to get frequency distribution of the variables under study, including mean, standard deviation and percentage scores of satisfaction level. Then the Pearson correlation was found out between overall satisfaction and satisfaction with each variable of neighbourhood facilities. Pearson correlation between neighbourhood and life satisfaction variables were also found out. Finally, two regression analyses were performed to find out the factors determining the overall satisfaction with neighbourhood facilities and life satisfaction among residents in slum rehabilitation housing.

Study Area

A slum rehabilitation housing in Kanjurmarg near the railway station was chosen for the study. This housing was chosen to represent the typical slum rehabilitation housing provided to the project-affected households due to the Mumbai Urban Transport Project (MUTP). It may be noted that MUTP will benefit over 6 million people who commute daily by the suburban railway system. In this case, MUTP aimed to ensure resettlement and rehabilitation of 900 households of slum dwellers who were living along the railway track to facilitate laying of railway tracks between Thane and Kurla stations on the central line. The rehabilitation site comprises 12 ground-plus-seven-storied buildings served by three staircases, two lifts and double-loaded corridor. Each building has 24 identical housing units on each floor. Each household is given one housing unit of 21 square metres that house one room, kitchen, bathroom and toilet irrespective of the household size. The residential colony has grocery shops, community offices, a study centre for small children and other commercial shops on the ground floor of each building.

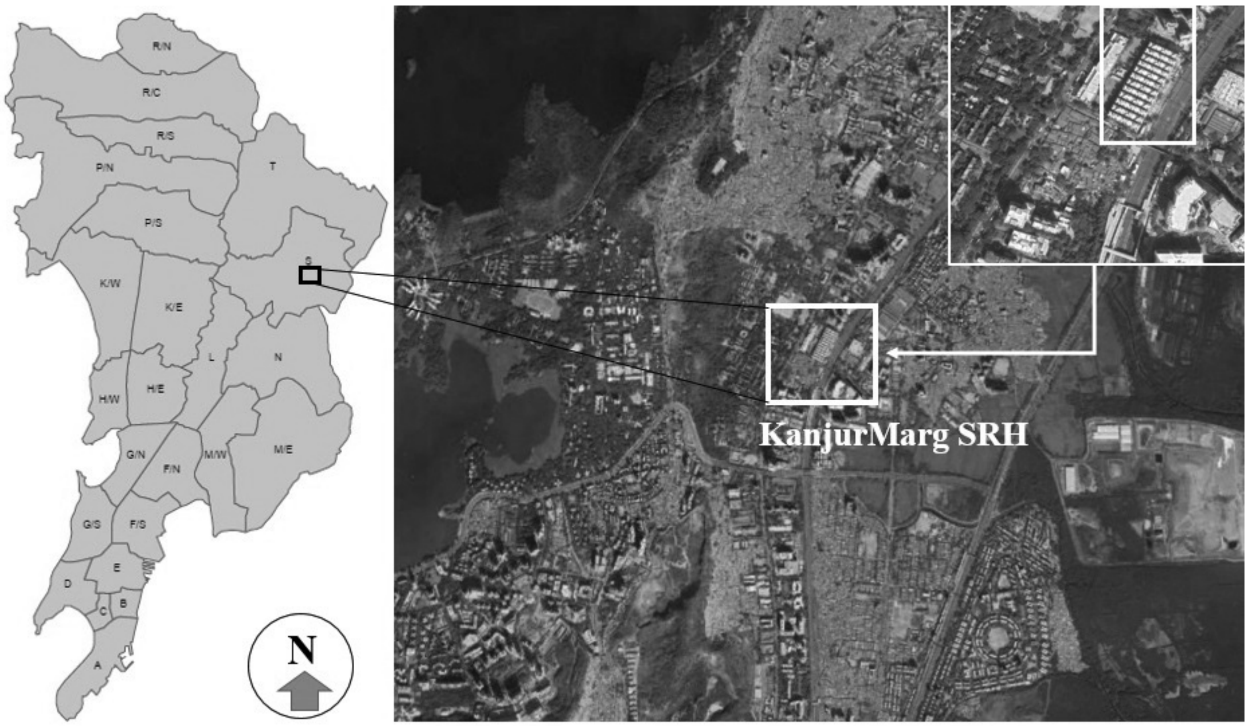

Figure 1: Map showing the location of Kanjurmarg slum rehabilitation housing

Source: Census and Google Maps

Figure 2: Slum rehabilitation housing in Kanjurmarg

Source: Authors' field visit

Results and Discussion

This section consists of two sub-sections. First sub-section presents the analysis of the socio-economic and demographic profile of the respondents, while the second sub-section presents the study of life satisfaction and satisfaction with neighbourhood facilities.

A Socio-economic and Demographic Profile of the Respondents

The respondents were roughly equally distributed (52.9 per cent female respondents). Nearly 40 per cent of the households have more than five members in their family sharing the one-room house with attached bathroom and kitchen. The mean household size is 5.22, which is more than the national average of urban household size 4.6 (Census of India, 2011) and varies from 1 to 12. Majority of the respondents (69 per cent) were below 50 years of age. Respondents were mostly married (86 per cent) followed by singles or unmarried (8.3 per cent) and widowed (5.7 per cent). Marathi (75.6 per cent), followed by Hindi (21.1 per cent), forms majority of the respondents. House owners constitute 90.1 per cent, and the rest (9.9 per cent) were renters. About 81.4 per cent of the respondents reported having lived in the present housing for over the last ten years. Majority of the respondents (96.3 per cent) have lived in Mumbai for more than ten years.

Table 1 also shows that respondents belong to the economically weaker section (annual household income up to INR 3 lakh as per the government of India) people (83.9 per cent) and the lower-income group (household with an income between INR 3 lakh and INR 6 Lakh) people (16.1 per cent). It also shows that 69 per cent of the respondents have completed their secondary level education including 13.3 per cent graduates. The illiteracy rate was 18.2 per cent. About 48.3 per cent of the respondents reported as unemployed, 32.6 per cent respondents said to have private jobs, 8.2 per cent of the respondents do their own business, and 5 per cent of the respondents are retired while 4.5 per cent of the respondents have government jobs. Vehicular ownership is 10.7 per cent of households for two-wheelers followed by bicycle (3.3 per cent), three wheelers (2.5 per cent) and four wheelers (1.2 per cent). Table 1 further shows high ownership of TV (94.2 per cent), mobile (86.4 per cent), fridge (76.4 per cent), washing machine (19.4 per cent).

Table 1: A Socio-Economic and Demographic Profile of the Respondents

Socio-economic Variables	Percentage
Household size	
>5	39.97
Mean (range)	5.22 (1 to 12)
Age (years)	
18–29	14.9
30–39	28.9
40–49	25.2
50–59	19.4
>59	11.6
Gender	
Female	52.9
Male	47.1
Marital status	
Single	8.3
Married	86.0
Widowed	5.7
Mother tongue	
Marathi	75.6
Hindi	21.1
Urdu	1.2
Others	2.1
Tenure status	
Owner	90.1

(*Continued*)

Table 1: (Continued)

Socio-economic Variables	Percentage
Rented	9.9
Length of stay in the house	
1–3 years	6.6
3–5 years	5.0
5–7 years	1.2
7–10 years	5.8
10–15 years	80.6
>15 years	0.8
Length of stay in Mumbai	
1–3 years	0.0
3–5 years	0.4
5–7 years	0.8
7–10 years	2.5
10–15 years	3.7
>15 years	92.6
Income	
less than INR 15,000	20.7
INR 15,000–INR 25,000	63.2
INR 25,000–INR 35,000	15.7
INR 35,000-INR 50,000	0.4
Occupation	
Government	4.5
Retired	5.0
Private	32.6
Own business	8.3
Unemployed	48.3

(*Continued*)

Table 1: (Continued)

Socio-economic Variables	Percentage
Others	1.2
Level of education completed	
Illiterate	18.2
Primary school	12.8
Secondary school	31.0
Senior secondary school	21.9
Diploma	2.9
Graduate	11.6
Post-graduation	1.7
Ownership	
Bicycle	3.3
Two wheeler	10.7
Three wheelers	2.5
Four wheelers	1.2
Mobile	86.4
Laptop	2.5
TV	94.2
Fridge	76.4
Washing machine	19.4
Water filter	5.4
Air conditioner	3.7

Source: Field Survey, October 2018

Satisfaction with Life Scale (SWLS)

SWLS is used to measure life satisfaction of the residents. Table 2 shows level of life satisfaction. People have the highest mean (4.99) with the third statement, that is "I am satisfied with my life". Respondents are moderately satisfied with each statement of life satisfaction.

Table 2: Satisfaction with Life Scale (SWLS) among Residents of Slum Rehabilitation Housing

Statement	Strongly Disagree (per cent)	Disagree (per cent)	Slightly Disagree (per cent)	Neither Agree nor Disagree (per cent)	Slightly Agree (per cent)	Agree (per cent)	Strongly Agree (per cent)	Mean	SD
1) In most ways, my life is close to my ideal.	-	9.1	12.8	15.7	38.4	17.8	6.2	4.61	1.33
2) The conditions of my life are excellent.	0.8	8.3	9.5	11.6	38.4	26.9	4.5	4.77	1.33
3) I am satisfied with my life.	-	5.0	8.7	12.8	38.0	26.4	9.1	4.99	1.24
4) So far I have gotten the important things I want in life.	0.4	6.6	12.0	16.1	42.6	16.5	5.8	4.66	1.26
5) If I could live my life over, I would change almost nothing.	1.2	10.7	13.2	21.1	37.2	14.9	1.7	4.33	1.29
An aggregate score of life satisfaction								23.38	5.24

Source: Field Survey, October 2018

A summed aggregate score of 23.36 indicates that majority of the residents are satisfied with their life although they like to see further improvement and move to a higher level of satisfaction by making some life changes.

Residents' Satisfaction with Neighbourhood Facilities and Correlation Analysis

The present study used mean value of 3.5 as moderate level of residential satisfaction (Mohit & Mahfoud, 2015). Residents are satisfied with distance to school (mean value 4.16), shopping centre (mean value 4.09), vegetable market (mean value 4.24), train station (mean value 4.31), bus station (mean value 4.27), auto stand (mean value 4.25) and police station (mean value 4.15). They are also satisfied with the quality of the school (mean value 4.10), train services (mean value 4.30) and quality of bus service (mean value 4.19). There is moderate level of satisfaction with access/distance to facilities including the recreation centre, workplace, government health centre, private health centre, metro station, bank, post office and fire station. The overall satisfaction with neighbourhood facilities indicates moderate level of satisfaction. The Pearson correlation (r) shows a moderate correlation with distance to the metro station, police station and fire station.

The Pearson correlation (r) between satisfaction with neighbourhood facilities and life satisfaction variables shows weak correlations (Table 4). Distance to shopping centre shows the highest relationship (ranging from r = .162 to .371) among the variables under neighbourhood characteristics.

Table 3: Satisfaction with Neighbourhood Facilities

Satisfaction with	Very Dissatisfied (per cent)	Dissatisfied (per cent)	Slightly Satisfied (per cent)	Satisfied (per cent)	Very Satisfied (per cent)	Mean	SD	Pearson (r)
Distance to recreation/ sports centre	2.5	4.1	7.9	81.0	4.5	3.81	.69	.232**
Distance to workplace	2.1	5.4	7.4	76.4	8.7	3.84	.73	.296**
Distance to school	0.8	2.9	3.3	65.3	27.7	4.16	.69	.293**
Quality of school nearby	2.1	1.7	2.9	71.5	21.9	4.10	.70	.312**
Distance to shopping centre	0.8	1.2	4.1	75.6	18.2	4.09	.58	.307**
Distance to subzi/vegetable market	0.8	0.8	2.9	64.0	31.4	4.24	.62	.302**
Distance to govt. health centre	2.1	9.1	16.1	64.9	7.9	3.67	.82	.210**
Quality of health service (govt.)	2.5	9.5	13.2	66.9	7.9	3.68	.84	.254**
Distance to pvt. health centre	0.4	10.7	9.5	61.6	17.8	3.86	.85	.071
Quality of health service (pvt.)	0.4	9.5	11.6	59.9	18.6	3.87	.83	.151*
Distance to nearest train station	0.0	1.2	2.5	60.3	36.0	4.31	.58	.371**
Quality of train service	0.4	0.8	1.7	62.4	34.7	4.30	.58	.348**
Distance to metro station	8.7	4.5	5.4	65.3	16.1	3.76	1.06	.418**
Distance to bus station	0.0	0.8	2.1	66.1	31.0	4.27	.53	.338**
Quality of bus service	1.2	0.8	2.9	68.2	26.9	4.19	.64	.387**
Distance to auto-stand	0.0	0.8	3.3	65.7	30.2	4.25	.55	.382**
Distance to bank	2.5	5.4	7.9	72.3	12.0	3.86	.78	.214**
Distance to post office	4.1	9.9	11.2	66.9	7.9	3.64	.91	.384**
Distance to religious building	6.6	8.3	21.5	56.6	7.0	3.49	.97	.358**
Distance to police station	2.5	2.9	2.9	60.7	31.0	4.15	.81	.533**
Distance to fire station	9.9	5.4	2.5	50.4	31.8	3.89	1.20	.510**
Overall satisfaction	2.1	8.3	12.4	64.0	13.2	3.78	.85	1

** significant at the 0.01 level
* significant at the 0.05 level
Source: Field Survey, October 2018

Table 4: Correlation between Satisfaction with Neighbourhood Facilities and Life Satisfaction Variables

Satisfaction with/Statement	1) In most ways my life is close to my ideal.	2) The conditions of my life are excellent.	3) I am satisfied with my life.	4) So far I have gotten the important things I want in life.	5) If I could live my life over, I would change almost nothing.
Distance to recreation/sports centre	.285**	.268**	.240**	.226**	.168**
Distance to workplace	.320**	.290**	.334**	.288**	.155*
Distance to school	.339**	.270**	.242**	.281**	.134*
Quality of school nearby	.306**	.240**	.162*	.214**	.111
Distance to shopping centre	.371**	.331**	.320**	.368**	.162*
Distance to subzi/vegetable market	.252**	.230**	.134*	.224**	.114
Distance to govt. health centre	.145*	.113	.159*	.078	-.037
Quality of health service (govt.)	.241**	.241**	.262**	.176**	.071
Distance to pvt. health centre	.259**	.271**	.242**	.222**	.255**
Quality of health service (pvt.)	.318**	.336**	.273**	.267**	.182**
Distance to nearest train station	.325**	.241**	.173**	.198**	.065
Quality of train service	.287**	.178**	.149*	.187**	.118
Distance to metro station	.289**	.196**	.184**	.094	.081
Distance to bus station	.280**	.202**	.162*	.196**	.148*
Quality of bus service	.367**	.312**	.277**	.257**	.165*
Distance to auto-stand	.369**	.298**	.248**	.270**	.165**
Distance to bank	.142*	.029	.075	.036	.030
Distance to post office	.201**	.165*	.152*	.080	.024
Distance to religious building	.270**	.197**	.172**	.070	.037
Distance to police station	.268**	.196**	.202**	.154*	.051
Distance to fire station	.292**	.186**	.185**	.115	.021

** significant at the 0.01 level
* significant at the 0.05 level
Source: Field Survey, October 2018

Table 5: Multiple Regression Model 1

	Unstandardised Coefficients		Standardised Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	.966	.276		3.504	.001		
Distance to police station	.362	.066	.344	5.517	.000	.595	1.680
In most ways my life is close to my ideal.	.130	.044	.203	2.932	.004	.483	2.072
Distance to fire station	.101	.053	.143	1.893	.060	.409	2.445
Distance to private health centre	-.152	.052	-.152	-2.952	.003	.880	1.136
The conditions of my life are excellent.	.101	.043	.158	2.337	.020	.509	1.965
Distance to metro station.	.113	.052	.140	2.166	.031	.557	1.795

Dependent variable: overall satisfaction with neighbourhood facilities

Note: R^2 = .455; Adjusted R^2 = .441

Determining Factors of Overall Satisfaction with Neighbourhood Facilities

A stepwise regression analysis was done to identify the predictors of overall satisfaction with neighbourhood facilities. The study shows that first two statements of life satisfaction under SWLS along with three variables of neighbourhood facilities – police station, private health centre, and metro station – are the determining factors of overall satisfaction with neighbourhood facilities. The study indicates that people are dissatisfied with distance to the private health centre.

Determining Factors of Life Satisfaction in Slum Rehabilitation Housing

A stepwise regression analysis using composite score of life satisfaction as dependent variable and socio-demographic characteristics and neighbourhood variables as independent variables was done. The study indicates four variables under neighbourhood characteristics namely distance to shopping centre, distance to the workplace, quality of bus service and quality of health service (private) as the determining factors of life satisfaction among residents of slum rehabilitation housing.

Table 6: Multiple Regression Model 2

	Unstandardised Coefficients		Standardised Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	.529	.502		1.054	.293		
Distance to shopping centre	.318	.124	.177	2.566	.011	.676	1.479
Quality of bus service	.257	.105	.157	2.442	.015	.782	1.279
Distance to workplace	.249	.091	.174	2.720	.007	.785	1.274
Quality of health service (private)	.210	.081	.168	2.596	.010	.768	1.302

Dependent variable: composite score of life satisfaction
Note: R^2 = .238; Adjusted R^2 = .225

Conclusion

In this study, life satisfaction and satisfaction with neighbourhood facilities among residents of slum rehabilitation housing were assessed. This study has covered one slum rehabilitation housing for the project-affected households in Kanjurmarg in Mumbai suburb. People are moderately satisfied with their life. Their overall satisfaction with neighbourhood facilities was also moderate. Findings suggest that slum rehabilitation is the right approach to improve the quality of life of the people although scope for improvement exists. The study is relevant as a large number of migrants and slum dwellers are shifting to Mumbai suburbs.

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References

Aggarwal, D., & Lal, M. (2001). Vulnerability of Indian coastline to sea level rise. *Centre for Atmospheric Sciences, Indian Institute of Technology, New Delhi*.

Appleton, S., & Song, L. (2008). Life satisfaction in urban China: Components and determinants. *World Development*, *36*(11), 2325–2340.

Ballas, D., & Tranmer, M. (2012). Happy People or Happy Places? A Multilevel Modeling Approach to the Analysis of Happiness and Well-Being. https://doi.org/10.1177/0160017611403737

Bardhan, R., Sarkar, S., Jana, A., & Velaga, N. R. (2015). Mumbai slums since independence: Evaluating the policy outcomes. *Habitat International*, *50*, 1–11. https://doi.org/10.1016/j.habitatint.2015.07.009

Bhagat, R. B., Guha, M., & Chattopadhyay, A. (2006). Mumbai after 26/7 deluge: issues and concerns in urban planning. *Population and Environment*, *27*(4), 337–349.

Ciscar, J.-C., Iglesias, A., Feyen, L., Goodess, C. M., Szabó, L., Christensen, O. B., … Bosello, F. (2009). Climate change impacts in Europe. *Final Report of the PESETA Research Project*.

El-Masri, S., & Tipple, G. (2002). Natural Disaster, Mitigation and Sustainability: The Case of Developing Countries. *International Planning Studies*, *7*(2), 157–175. https://doi.org/10.1080/13563470220132236

Gupta, K. (2007). Urban flood resilience planning and management and lessons for the future: a case study of Mumbai, India. *Urban Water Journal*, *4*(3), 183–194.

Mahadevia, D., Bhatia, N., & Bhatt, B. (2018). Private Sector in Affordable Housing? Case of Slum Rehabilitation Scheme in Ahmedabad, India. *Environment and Urbanisation ASIA*, *9*(1), 1–17.

Mohit, M. A., & Mahfoud, A.-K. A. (2015). Appraisal of residential satisfaction in double-storey terrace housing in Kuala Lumpur, Malaysia. *Habitat International*, *49*, 286–293.

Mukhija, V. (2001). Enabling slum redevelopment in Mumbai: Policy paradox in practice. *Housing Studies*, *16*(6), 791–806. https://doi.org/10.1080/02673030120090548

Parthasarathy, D. (2009). Social and environmental insecurities in Mumbai: towards a sociological perspective on vulnerability. *South African Review of Sociology*, *40*(1), 109–126.

Patel, S., d’Cruz, C., & Burra, S. (2002). Beyond evictions in a global city: people-managed resettlement in Mumbai. *Environment and Urbanisation*, *14*(1), 159–172.

Revi, A. (2005). Lessons from the deluge: priorities for multi-hazard risk mitigation. *Economic and Political Weekly*, 3911–3916.

Sclar, E. D., Garau, P., & Carolini, G. (2005). The 21st century health challenge of slums and cities. *The Lancet*, *365*(9462), 901–903.

Sherly, M. A., Karmakar, S., Parthasarathy, D., Chan, T., & Rau, C. (2015). Disaster vulnerability mapping for a densely populated coastal urban area: An application to Mumbai, India. *Annals of the Association of American Geographers*, *105*(6), 1198–1220.

Vaid, U., & Evans, G. W. (2017). Housing Quality and Health: An Evaluation of Slum Rehabilitation in India. *Environment and Behavior*, *49*(7), 771–790.

Increasing Vulnerability to Disasters in Lal Dora Areas in Delhi: A Study in Administrative Accountability and Disaster Governance

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ABSTRACT: Climate change is emerging as one of the major challenges on global scale, resulting in increasing intensity and frequency of disasters. Vulnerability is exacerbated for a developing country such as India, due to its location in the tropical belt and the challenges of increasing population density amidst resource scarcity. The strategic location of Delhi has modified the landscape of the city due to huge in-migration and the resultant unplanned urbanisation. Lack of affordable capacity of immigrants and the laxity of administration have led to vast swathes of unauthorised constructions and mixed land use, in violation of the Delhi Master plan and the zoning regulations. The paper attempts a qualitative and doctrino-legal study of the Lal Dora and extended Lal Dora areas in Delhi with an aim to investigate the causes of increasing vulnerability in the region towards geographical hazards and man-made vulnerability such as fire hazards. Methodological tools such as in-depth interviews, interactions with key informants, case studies and observations would be employed as tools for exploratory research into reasons for such large-scale unauthorised and unregulated constructions in Lal Dora and extended Lal Dora areas, in flagrant violation of building bye-laws rules and regulations. A study of comparable legal pronouncements and case study judgements related to issue of misuse of residential premises for industrial purpose would be undertaken, to investigate the role of judiciary in proclaiming the culpability and negligence of administrative authorities in enforcing the required regulations due to endemic corruption. The intersection of national, state and local jurisdictions in the capital city has resulted in several complexities and challenges in urban governance. The planning bodies such as the Delhi Development Authority and Municipal Corporation of Delhi continue to remain outside the administrative ambit of the Delhi government even after the enactment of the Constitution (69th Amendment) Act, 1991. The limited accountability of these bodies towards the electorate has resulted in ad-hoc policy solutions for the existing unauthorised settlements for parochial political gains. The paper would underscore the urgent need of proper institutionalisation of Disaster Management Authorities, with an emphasis on giving them more punitive powers for ensuring implementation of safety norms and building regulations into the development process. Even when the incorporation of disaster mitigation measures into development process has been emphasised in Hyogo Framework for Action (2005–2015) and the recent Sendai Framework for Disaster Risk Reduction (2015–2030), the ineptitude of current administration in India is conspicuous from the increasing vulnerabilities being witnessed in Delhi. The situation calls for an urgent review of the disaster governance in India for a resilient tomorrow.

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KEYWORDS: community resilience, vulnerability, New Delhi, Lal Dora, extended Lal Dora, hazard, accountability, disaster governance

Introduction

The capital city of Delhi stands as a 'poly-nuclear metropolis' marked by haphazard growth and disproportionately high population pressure beyond the carrying capacity of its land and infrastructural amenities. The strategic location of Delhi has made it an important centre of administrative, educational, political, commercial, industrial and historical functions. This has resulted in disproportionate increase in population pressure due to huge in-migration of the population from the neighbouring states in search of better opportunities for education, employment, health and other business activities. This has resulted in housing problem for the majority of in-migrants, who lack the affordability and access to political echelons for appropriate housing with adequate infrastructural services. The exclusion of private sector from land development under the regulated centralised land development policy has led to mushrooming of the unauthorised colonies and illegal settlements all over Delhi. These unauthorised settlements lack even basic amenities of potable water, sewerage and drainage systems, and health and educational facilities. The unholy nexus between the political leaders, bureaucracy and the builders has made the compliance with the laws and policies conspicuous by its absence in the city, in spite of the frequent intervention of the judiciary in the issues of land management and urban governance.

Objective of Research

The present research aims to ascertain the preparedness of Hauz Khas Village in Delhi (a Lal Dora area) to potential hazards and disasters. The research will explore if vulnerability has increased in the region despite the institutionalisation of Delhi Disaster Management Authority. An assessment of the institutional functioning and legal compliance to laws crucial to disaster management is attempted, by identifying the failures of administration in regulating the large-scale encroachments and the unauthorised constructions in Delhi. The differential legal and governance mechanisms for the Lal Dora (*abadi-deh*) and the extended Lal Dora areas under the exemptions granted by the notification of the Municipal Corporation of Delhi (MCD) have resulted in large-scale mixed land use in these areas beyond what was permitted under the legal umbrella. The exemptions have been misconstrued and misused by the private developers and the local people for developing a thriving real estate market in these areas. The research undertaken will endeavour to study the legal, administrative and political factors responsible for the proliferation of such extensive constructions and encroachments amidst constricted congested lanes and buildings in these Lal Dora and extended Lal Dora areas.

Hypothesis

Disaster management has repeatedly failed in Delhi due to the inability of enforcement agencies to enforce compliance with legal regulations for building bye-laws and land use. Despite a well-designed framework, the disaster management in Delhi continues to be a hostage to enforcement agencies which continue to be ill-prepared towards building community resilience. The success of the disaster risk reduction lies in improving the institutional capacity to enforce and monitor the implementation of the laws and regulations.

Research Methodology

The research methodology adopted for the study has been quantitative and qualitative. Primary data has been collected by means of purposive, stratified sampling and semi-structured interviews of respondents residing in the Hauz Khas Village and Pahari area in New Delhi. A study of report of Tejinder Khanna Committee, Mathur Committee and Shrivastava Committee has been undertaken to incorporate qualitative research of affected communities due to large-scale unplanned settlements and illegal encroachments. Doctrino-legal research into the Municipal and other legal laws for regulation of building bye-laws applicable in the

Delhi region for safety regulation has been undertaken with an aim of descriptive research into the rules and regulations for regulating land management and monitoring implementation of building bye-laws. The laws granting exemptions for the Lal Dora and extended Lal Dora areas have been undertaken from the period extending pre-independence time to the present date. The study focused on the social indicators such as access to basic infrastructure and essential services (health care, education, sanitation, etc.) and economic indicators such as legal status of property titles, source of income for a comprehensive study of marginality and resultant vulnerability in the region.

Disasters and Vulnerability

Disasters have for long been seen as a phenomenon which is antithetical to the process of development. In simple words, they are simply seen from the lens of an event which pushes back the process of development by several years due to widespread destruction and loss it causes. However, the recent literature in disaster management has come to highlight the phenomenon of a disaster as an event which is itself a result of the development process. Rather than viewing hazards and vulnerability as mutually exclusive concepts and identifying them with unseen and unpredictable forces of nature or terming them as an 'act of God', the disaster literature today considers hazards and vulnerability as mutually inter-dependent. In this politico-ecological framework, a disaster is rather seen as 'materialisation of risk constructed socially'. This has not only broken the walls of cultural hegemony of blind faith in technocratic solutions to remedy the vulnerabilities and reduce risks, but also underscored the importance of social, cultural, economic and historical factors which have contributed to making a certain section of population in a given space more vulnerable to potential risks than others.

The concept of 'vulnerability' helps us to examine hazard or a disaster from the position of capacity of the population to absorb, recover and respond to the impact of an event. It emphasises the need to look at the question of 'why a disaster' rather than 'what a disaster is' or 'what a disaster does'. The 'vulnerability approach' does not see disasters as a disruptive event in the linear progression of development process. They are seen as a 'result' of the development process, rather than an event which impinges upon development (Hilhorst, 2006:55). The marginality is determined by the combination of variables of social order such as age, ethnicity, class, gender and disability, which continues to deprive people of the access to resources and means to cope up with hazard. The 'dis-empowerment' of the people thus leaves them physically weak, emotionally impoverished and socially dependent.

The Disaster Management Framework in India

The legal and institutional framework for disaster management in India is provided by the Disaster Management Act, 2005, which was enacted on 23 January 2005. It envisaged the creation of Disaster Management Authorities at the national, state and local level. The National Disaster Management Authority (NDMA) is headed by the Prime Minister and the State Disaster Management Authority (SDMA) at the state level is headed by the respective Chief Ministers to formulate and implement an integrated and holistic approach towards disaster management. Delhi Disaster Management Authority (DDMA) was institutionalised in March 2008 at the NCT level under the authority of the Lieutenant Governor. Delhi Disaster Management Plan has been formulated for the state for an integrated plan and operational framework for all the disasters to ensure 'systematic assessment, communication and management of risk and identification of response' to effectively deal with a disaster (Delhi Disaster Management Plan, 2014–15). The plan also provides for coordination between the DDMA and the other institutions at district level including local authority, communities and other stakeholders for preparation and implementation of the mitigation measures.

The Disaster Management Act, 2005, also mandates the integration of mitigation measures in the development policy for the prevention of disaster and mitigation of its effects. The act legally empowers the Disaster Management Authorities to coordinate the enforcement and implementation of such policies and plans [Section 6(2e-f)] of the Disaster Management Act, 2005. However, the empirical analysis and descriptive research conducted in this paper on the working of the DDMA suggest that risk mitigation and resilience building measures undertaken by the authorities have been limited to capacity building for dealing with an emergency situation through evacuation drills in case of fire hazards, earthquakes, terrorist attack, etc. It has failed to take any action to monitor the implementation of mitigation measures through compliance with seismic safety laws, building plans and land use regulations. Lack of effective coordination with the agencies responsible for the provision of civic amenities such as drainage, water, health and urban planning has resulted disaster management in an authority, solely focused on post-disaster relief and rehabilitation measures rather than integrating disaster risk reduction into development policies. The 'top-down approach' engendered in the development planning in India has resulted in the drafting of complex building bye-laws, master plans and zoning regulations which have little relation to the ground realities and community aspirations. This is a major cause of the wide gap between the policies and practice with respect to disaster management.

Political and Administrative Structure in Delhi: An Analysis

Administrative structure of Delhi is characterised by the presence of a quagmire of local municipal bodies (NDMC, MCD and Cantonment Board), local authority (such as DDA) and Delhi Administration. The overlapping jurisdiction of these institutions has made the administrative set-up in Delhi quite complex. The designation of Delhi as National Capital Territory of Delhi (NCT Delhi) by the enactment of the Constitution (69th Amendment) Act, 1991, has resulted in significant changes in administrative structure of Delhi. The act provides for a 70-member elected Legislative Assembly and a Council of Ministers to aid and advise the Lieutenant-Governor. The jurisdiction over the bodies which are responsible for the provision of basic amenities such as electricity, water and transport has been transferred to the Delhi government elected every 5 years by the residents of Delhi. However, government agencies such as the New Delhi Municipal Council (NDMC), the MCD and the DDA continue to remain outside the administrative ambit of the Delhi government. These planning bodies are centralised and technocratic in nature with no accountability to the democratic demands and aspirations of the electorate. The intersection of local, state and national jurisdictions has resulted in several complexities and challenges in urban governance in Delhi.

The location of unauthorised industries in residential areas and ignorance of National Building Codes and building bye-laws by people by raising the floor area ratio (FAR) and unauthorised encroachments beyond the sanctioned building plans is observed in Delhi, especially in the Lal Dora and the extended Lal Dora areas. This has not only increased the vulnerabilities of these settlements towards the potential geographical and manmade hazards (such as urban flooding or industrial fire due to non-compliance with the fire safety norms), but has constantly been degrading the environment through negative externalities due to increasing pressure on the limited infrastructure and civic amenities.

Administrative Structure in Lal Dora and Extended Lal Dora Areas

The process of urban expansion in Delhi has been done through the annexation of more than 100 villages and agricultural land in the periphery to be absorbed into the urban agglomeration. The land acquisition of village agricultural land was undertaken by Delhi Development Authority (DDA) under the Delhi Development Act, 1957. Land acquisition process which covered only the acquisition of farmlands (*Khet-Khalihan*) for planned construction of colonies under the Master Plan excluded the village settlements (*Abadi-deh*) from regulated growth guided by the development control regulations. These *abadi* areas, protected by a boundary called Lal Dora (Red Chord), which existed in close proximity to the urban infrastructure networks and employment opportunities, saw the uncontrolled growth of unauthorised and haphazard settlements (Dupont, 2004:161).

The term Lal Dora was first used by the British Government in 1908 to define the 'habitation (*abadi*) land of a village' (Pati, 2015:18). These areas were demarcated by a red thread (Lal Dora) around the village extension area by the Land Revenue Department for the purpose of differentiating it from the agricultural land, which were subjected to land revenue. These areas were primarily inhabited by the people who had agriculture as their primary occupation. During the land acquisition process undertaken by DDA under the regulated land development policy of the Master Plan Delhi (1962), only the agricultural lands in the periphery of *abadi* areas were acquired, while the rural built forms in *abadi* areas were protected by a boundary called the 'Lal Dora' (Chattopadhay et al., 2014:2). These villages or the *Lal Dora* land has emerged as a thriving real estate market to cater to the housing needs of middle-class migrants. Exemption of the Lal Dora areas under the 1963 notification by the MCD from the building bye-laws has led to mushrooming of indiscriminate constructions amidst constricted congested lanes and buildings for the purpose of maximising rent extraction (Pati, 2015:19). Slow process of land utilisation of the acquired land by the DDA and exclusion of private sector participation in regulated land development under the centralised authority have led to extensive encroachments and unauthorised colonies with sub-standard building safety and inadequate basic services. Collusion between the private builders and the enforcement agencies to capture profits from the skyrocketing land values has led to mushrooming of large-scale sub-standard unauthorised colonies in these areas.

The Lal Dora areas have been occupied by the people who have traditionally engaged in agriculture. The entire old *abadi* area bears a single *khasra* number in the revenue records of the administration. The residents do not have individual ownership for the land falling within Lal Dora as a result of which the ownership of land is not recorded in the revenue records of the administration. The lack of legal entitlements has proven to be a big hurdle for a villager for seeking sanctions for the building plan by MCD due to his/her inability to establish ownership of the plot according to the guidelines of MCD (Pati, 2015:18). The Expert Committee on Lal Dora (also known as Srivastava Committee, 2007) noted that the lack of transparency and procedural clarity on the issue of ownership of land and building plans sanction and non-action by the revenue authorities to establish individual ownership are the major cause of mixed land use and encroachments which have neglected the safety norms and land use policies. The inadequate compensation provided by the government and loss of agricultural lands have deprived the inhabitants from means of sustenance, which pushed them to seek alternative livelihood options such as small-scale industry in residential premises, renting out premises for office and godown. This has resulted in mixed land use in these areas, more as a means of survival than the intention to overlook the building bye-laws and regulations. Such situations have been exploited by speculative buyers and developers. Lenient attitude of the local bodies and the government has led to the development of industries beyond the threshold of household industries. Lack of civic services in the villages, inaction of the civic authorities and cramped twisted narrow layouts have resulted in villages which lack even the basic civic services such as treated drinking water, sewerage, proper street lighting and safe electric supply. Due to land available at low prices than peripheral urbanised areas, these areas became the favourite hunting ground of middle class to satisfy their need of cheap housing.

As the Lal Dora areas were primarily agricultural in character, the drafters of the Master Plan Delhi exempted these areas from certain provisions of the Municipal Corporation Act 1957, which relate to the building bye-laws. Chapter VII of the Building Byelaws lays out policies for the sanction of building plans in Delhi. The 1963 notification No. RN-2/173 issued by the Municipal Corporation of Delhi dated 24–08–1963 in exercise of the powers conferred under Section 507 of the DMC Act laid down exemptions for buildings in the Lal Dora areas for the sanction of building plans. The notification stated that in Lal Dora areas or rural areas, certain sections contained in DMC Act do not apply, such as Sections 332, 333, 334, 335, 336, 342 and 347[1]. The report of the Expert Committee on Lal Dora noted the applicability of the following conditions for exemption from the norms of building bye-laws:

- The land use in residential and the construction shall confine maximum to 2½ storeys with maximum permissible coverage FAR and height as per bye-laws.
- It has been certified by the Revenue Department that plot forms part of old built-up *abadi* area.

- That the plot was in existence as an independent plot prior to the formation of the Corporation.

These exemptions were, however, not applicable for the non-residential activities such as factories, warehouses, slaughter houses and cold storage. The exemptions accorded have been misused by unscrupulous elements with an eye on profit, ignoring the structural safety and civic amenities concerns.

While exemption of Lal Dora areas from the provisions of the MCD Act has been clearly stated in the notification, the question of applicability of these provisions for the extended Lal Dora areas and the urbanised villages has been ambiguous among the policy implementers and the people. The extended Lal Dora areas are the ones enclosed within the peripheral boundary between the original Lal Dora and post consolidation phirni areas (peripheral boundary) under the East Punjab Holding (Consolidation and Prevention of Fragmentation) Act, 1948. The question of applicability of regulations has been dealt by the judiciary in several cases such as M*unicipal Corporation of Delhi* v. *Dalmia Industries Private Limited*, 2002 (96), DLT 441, and *Regal Traders (P) Ltd. Vs. Lt. Governor 1990 RLR 334*, in which the Hon'ble High Court held that the exemptions given to Lal Dora areas were equally available to the extended village abadi areas also. However, the Delhi High Court in *B.L. Wadhera (Dr.) v. Govt. of NCT of Delhi*, (2004), 113 DLT 263 case stated that the exemptions vide 1963 Notification, from the provisions contained in Chapter XVI of DMC Act, were applicable *only in the Lal Dora areas* and not the extended Lal Dora areas[2]. The court has clearly stated that Sections 332, 333, 334, 335, 336, 342 and 347 of DMC Act are *not applicable* in those areas which are declared as urban areas by the notification of the MCD.

Hence, the exemptions for the Lal Dora areas did not include the extended Lal Dora areas and the urbanised villages. While these exemptions were stated from certain provisions of the MCD Act, these did not imply complete negligence for building bye-laws in the construction of the building. While noting the lackadaisical attitude of the enforcement agencies with respect to unauthorised constructions in these areas, the division bench of the Delhi High Court in *B.L. Wadhera (Dr.) v. Govt. of NCT of Delhi*, [(2004), 113 DLT 263] at page 267 noted that: 'Municipal Corporation of Delhi/New Delhi Municipal Council and Delhi Development Authority are permitting occupation of high-rise buildings without sanction of building plans or fire clearance or completion certificate... the aforesaid authorities are permitting erection of high-rise buildings in these areas and are collecting various municipal and other taxes…without bothering for byelaws or the provisions made under the Acts.… if the erection of a building is contrary to the byelaws as also according to National Building Code of India, then irrespective of sanction, action can be taken for demolition under Section 343 which refers to order of demolition and stoppage of building and works'.

Study of Hauz Khas Village and Pahari Area

The Hauz Khas Village is a Lal Dora area, which was exempted from the building bye-laws and regulations under 1963 MCD notification. Formerly an agricultural area, today the village is characterised by mixed land use due to the presence of many restaurants and shops. The village is an attractive tourist destination due to Firoz Shah Tughlaq's tomb in the immediate vicinity. The construction of buildings in immediate vicinity is in absolute violation of regulations of the Archaeological Survey of India. The area is inhabited by approximately 5000 people, with less than 25 families as domicile of the village. The area is characterised by renting of private property to the migrants, especially of foreign origin, while the original landowners have mostly shifted out of the village towards more spacious and planned settlements. This has given rise to the phenomenon of 'absentee landlordism' in the village. Violation of environmental norms by restaurants through illegal construction has started to pose a threat to the monument and forest area of the region. Construction of building vertically beyond the permissible limit of floor area ratio is the most flagrant violation, which has exacerbated the risk of devastation, if an earthquake were to happen. The singular access to Hauz Khas complex through narrow and congested lanes, lined with bookstores, music stores, art galleries, etc., makes it a disaster-prone area.

The parking of cars in the streets makes the unplanned pathways vulnerable to any disaster as the evacuation in case of fire is an impossible task due to inadequate space for even an ambulance to pass. Blockage of entrance area by vegetable vendors and auto-rickshaws further makes the process of evacuation even more challenging, if a fire hazard or an earthquake were to strike. Although the shops in the village comply with the MCD regulation of installation of fire safety systems in their shops, a closer analysis suggests that either these fire extinguishers are not in working condition or the workers do not have the expertise to operate them in case of any disaster.

In the immediate vicinity of the village is a Pahari area, which is an illegally encroached Muslim *Kabristan* land. Most of the settlements on this Pahari area are slum habitations, inhabited by migrants from Bihar and Uttar Pradesh. With majority of population belonging to Muslim and Valmiki community, which are considered marginalised, the vulnerability of residents is evident due to lack of basic infrastructures such as toilets and drinking water. The residents, who are mainly employed in unorganised sector jobs, earn the income below Rs 10,000 per month. As the Pahari area is unauthorised, the residents of these slums are devoid of voter IDs and BPL cards due to their inability to provide any document as resident proof. Lack of toilet infrastructure forces the inhabitants to opt for open defecation in the forest area behind the Pahari, posing serious threat to not just health, but also security of women and children. Low quality of drinking water supplied forces the residents to call for water tanker, which charges exorbitant amounts for potable water. The problem of water logging has made vector-borne diseases such as dengue and chikungunya a frequently occurring epidemic.

Although the Hauz Khas area is now considered as an extended Lal Dora area, negligence and disregard for the building bye-laws and fire safety measures continue unabated due to vested interests and administrative negligence. The Residence Welfare Association, which has three members who are residents of the village (with one of them as President and one a woman), has not been involved in vulnerability mapping or risk mitigation measures by the disaster management authorities.

Conclusion

Although the disaster policies and the action plan devised by the Delhi Disaster Management Authority focuses on building human capacities to respond in a crisis situation through training in evacuation drills and first aid, the focus on incorporation of mitigation measures such as earthquake resistance measures in development planning and infrastructural construction continues to remain outside the jurisdiction of these authorities to monitor. In such a scenario where disaster management through compliance with mitigation and development norms continues to remain hostage to the agencies which have proved inefficient in regulating these unauthorised constructions and misuse of premises, there is an urgent need to overhaul and revisit the disaster management policies of the Delhi Disaster Management Authorities towards invulnerable development.

Notes

1. These relate to the building regulations. The exemption related to only such portions of the rural areas which lie within the village *abadis* as defined in revenue records. However, such exemption do not apply to factories, warehouses, cold storages and slaughter houses.
2. Chapter XVI of the DMC Act details the procedure for compliance with the Building Regulations and the jurisdiction and authorities of the Municipal Commissioner with respect to unauthorised constructions. Section 332 relates to prohibition of building without sanction, Sec. 333 relates to Erection of building, Sec. 343 relates to order of demolition of buildings and works in certain cases and Sec. 347 relates to restrictions on the user of buildings.

References

Delhi Development Act, 1957

Disaster Management Act 2005

Delhi Disaster Management Plan

Expert Committee – Report of the Expert Committee on Lal Dora and Extended Lal Dora in Delhi, 2007.

Ministry of Urban Development – Expert Committee Report on Unauthorized Construction and Misuse of Premises in Delhi, 2006.

Byahut, S. (2016). “Effective development regulation system for a resilient built environment: A reform project for Delhi, India” in, Awotona, A. (Ed.) *Planning for community-based disaster resilience worldwide: Learning from case studies in six continents*, Taylor and Francis Group: London and New York.

Chattopadhay, S., Dey, P. & Michael, J. (2014). Dynamics and Growth Dichotomy of Urban Villages: Case Study Delhi. *Int. Journal for Housing Science*, Vol.38, No.2 pp.81–94

Dupont, V. (2004). Socio-spatial differentiation and residential segregation in Delhi: a question of scale? *Geoforum* 35(2): 157–175.

Hilhorst, D. (2006): “Complexity and Diversity: Unlocking Social Domains of Disaster Response”, in G. Bankoff *et al* (eds) *Mapping Vulnerability: Disasters, Development and People,* 151 South Asian edition, Earthscan: London and Sterling

Pati, S. (2015). The Regime of Registers: Land Ownership and State Planning in the Urban Villages of Delhi. *SOAS South Asia Institute Working Papers*, Vol. 1, pp.17 - 31

Srirangan, K. (2000). Draft Final Report – March 2000, Delhi field studies and workshop DFID: Research Project R6860, Public Land and Property Development and Cross-Subsidisation for Low-income Housing in Delhi.

Addressing Disaster Risk Reduction through Urban Planning: A Pro-active Approach

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ABSTRACT: With the increasing population density and businesses, urban areas have become more susceptible to the impacts of natural hazards. The tremendous loss of life and economy is incurred with the occurrence of natural disasters in urban areas. Although in India, relief and response mechanisms are well established, there is little consideration for reducing disaster risks altogether. With a recent paradigm shift in the policy of disaster management in India, from disaster relief to disaster risk reduction, efforts are being made to work towards disaster prevention and mitigation. This policy originates from the belief that investments in mitigation are much more cost effective than spending on relief and rehabilitation. This study focuses on reviewing disaster risk reduction from the urban planning perspective, by means of extensive literature review. The category of literature reviewed, inter alia, are urban development policies and statutory documents, missions of smart city and disaster management authorities with their independent processes. The study attempts to identify salient urban planning principles from theoretical research which can impact disaster risk reduction significantly and then relate them to current planning practices in India to identify gaps prevailing in integrating and mainstreaming disaster risk reduction in the planning process.

KEYWORDS: disaster risk reduction, urban planning, urban disasters, disaster management, risk factors

Introduction

In recent years, urban areas have seen tremendous growth in population due to ample business and employment opportunities. It was reported that more than half of the world's population (about 54 per cent) lived in urban areas in 2014, which was an increase from 43 per cent in 1990 (United Nations, 2014). by 2050, two-thirds of the world's population is projected to reside in urban settlements where 90 per cent of which will be concentrated in Asia and Africa (United Nations, 2014). With a high density of population, assets and socio-economic activities, urban areas have become more susceptible to the risks posed by disasters (Gencer, 2013). It has been estimated that due to natural disasters around two trillion US dollars' worth of assets were lost and about one million people have lost lives worldwide in a duration of ten years from 2000 to 2009 (UNISDR, 2013). Such disaster events caused by natural hazards reveal that risks are continuously woven in any region through the gaps in development and increase in economic and population exposure (UN, 2011).

With increasing urbanisation, the impacts of natural hazards have also increased causing immense loss of life and wiping off decades of development. It is with disaster management that the efforts for reducing such losses have been made. The response procedures and processes in the aftermath of disasters have been well established, but comparatively little is done for disaster prevention and mitigation. From the development perspective, it is important that countries invest in disaster mitigation and prevention strategies

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(Clark, 2012). In disaster literature majority of work done is reactive, mostly for post-disaster reconstruction, and relatively lesser amount of pro-active work for disaster risk reduction (DRR) is available. In case the pre-disaster stage is strengthened and measures are in-place for the time of distress, post-disaster efforts can be reduced significantly with effective damage control while ensuring minimal loss of life and property. The government of India brought about a paradigm shift in the last decade in the approach to disaster management. The new approach acknowledges that, firstly, without the inclusion of disaster mitigation into the development process, sustainable development cannot be achieved and, secondly, the mitigation framework has to be multi-disciplinary including all sectors of development (GOI, 2005). This new policy originates from the belief that investments in mitigation are much more cost effective than spending on relief and rehabilitation.

This study focuses on reviewing disaster risk reduction from the urban planning perspective, by means of extensive literature review. Through a review of global literature, the role of urban planning to tackle disaster mitigation is identified. On the basis of these identified factors, gaps in urban planning policies and disaster management for risk reduction in the urban Indian context are investigated. There are various frameworks for planned urban development and disaster management in urban areas, but these frameworks seem to work independently in silos with nominal convergence. An analysis of existing literature in urban planning processes adopted across states of India reveals the disconnect. In India, even though various urban planning policies are in place for planned development, there appears to be little or no consideration for integrating and mainstreaming disaster risks in the process of urban planning adopted at present. Recent national urban missions, including the Smart City Mission and the newly launched Local Area Plan Project by the Ministry of Housing and Urban Affairs, have little or no input from the disaster risk perspective. Whereas, it is in this planning stage of strategic developmental activities that disaster risk must be a guiding factor. It is the exploration of such issues in urban planning policies, guidelines and processes which bring to light the gap in integrating urban planning and disaster management.

Disaster Risk Reduction from Urban Planning Perspective

Before the 20th century, disaster management was concentrated on emergency response. The change in this approach was brought about by the understanding that disasters are man-made even if the hazard that caused it is natural (UNISDR, 2015). In the past decades, due to large damage to life and property with the occurrence of natural hazards, a global consensus was triggered to establish the need for disaster risk reduction. For this purpose, Hyogo Framework for Disaster Risk Reduction 2005–15 was implemented in 2005 which was the first plan to explain, describe and target disaster risk reduction strategies at a global scale. Following this, the Sendai Framework for Disaster Risk Reduction 2015–30 was adopted in the Third United Nations World Conference in March 2015 in Japan. It points out various stakeholders and emphasises on the fact that disaster risk reduction practices need to be multi-hazard and multisectoral, all-encompassing and accessible in order to be competent and effective. The framework identifies four priority areas to address disaster risk reduction. Among the four priority areas, understanding disaster risk and strengthening governance to manage disaster risk, in the context of urban areas, forms the basis of this study. The shift towards disaster risk reduction is aimed at reducing and managing risks to reduce losses. Disaster risks increase as a result of increased vulnerability and exposure to hazards, since the severity of the hazards cannot be decreased, the opportunity lies in decreasing the vulnerability and exposure, while increasing the coping capacity of the community. It is through the identification and reduction of the underlying disaster risk factors that vulnerability and exposure can be reduced (UNISDR, 2015). These risk factors in the built environment are associated with poor urban development choices and practices, inefficient land management systems and inadequate planning policies and legislations.

The urban population is estimated to increase especially in the low-middle-income countries in seismically active urban areas and coastal zones (Peduzzi & Deichmann, 2009). In India, according to the 2011 Census, 53 agglomerations (27 cities) had a population of more than a million against 35 agglomerations in 2001. Since the urban areas are expanding, it is important to institutionalise good building practices and planning to take disaster risks into consideration (Johnson, 2011). It has been recognised that poor building techniques, insufficient or absent land-use and urban planning, lack of enforcement of building codes and low risk awareness of planners increase the populations' vulnerability and exposure to disasters (UN, 2011). Disaster risks may significantly increase with unsound decisions on land-use and buildings, along with the lack of willingness and capacity of the government to manage city development (UN, 2011). It is often seen that conceptually planning decisions are often different from the ground scenarios. There are two approaches to reduce disaster risks in the built environment, firstly, through location approach, where the land-use planning and zoning help to designate less intensity development on identified hazardous areas which can be used for emergency shelters and evacuation. Second is design approach, where areas exposed to hazards are used for development but with strong implementation of development controls and safe building designs (Burby, 1998). Table 1 summarises the risk factors from urban planning that influence the risk of disasters, and when incorporated in the development plans, programmes and processes may help in disaster risk reduction.

Table 1: Urban Planning Risk Factors for Disaster Risk Reduction

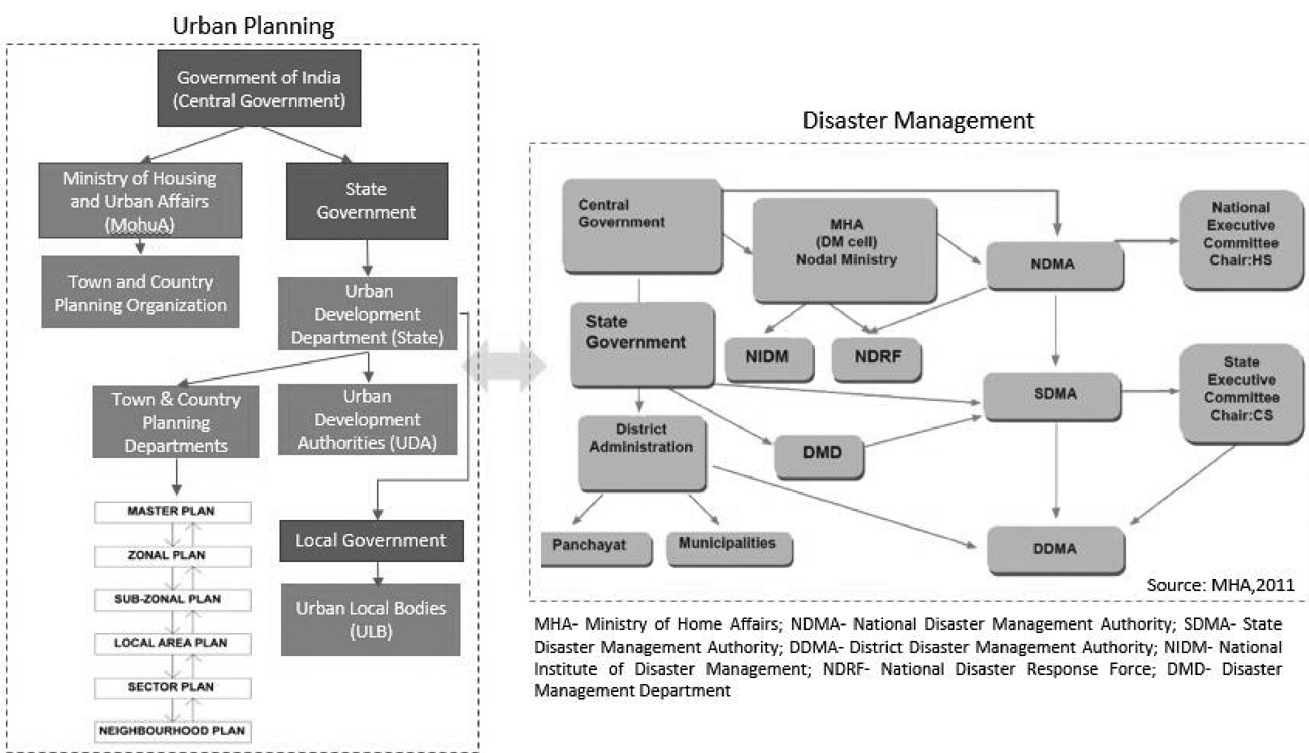
S. No.	Urban Planning Domain	Urban Planning Risk Factors
1	**Design issues**	Patter of settlement
		Lack of infrastructure, poor quality of infrastructure, unplanned infrastructure
		Compact urban forms and urban density
2	**Land-use planning**	Inadequate and inappropriate land-use
		Inappropriate land management systems
3	**Regulatory issues**	Lack of relevant building codes and their reinforcement, missing building codes
		Unsustainable development practices
		Informal settlements, poverty and sub-standard housing
		Degradation of natural systems
		Lack of collaboration and coordination between authorities and actors, lack of information
		Lack of legal framework and weak law reinforcement
		Unplanned settlements in hazardous areas
		Unmonitored real estate

Implementation of Urban Planning for DRR in Indian Context

Urban planning is widely recognised as a tool for non-structural mitigation for disaster risks to reduce exposure and vulnerability in developing as well as developed countries. Globally, the integration of disaster risk reduction in development plans and policies has been an agenda in many of the international and national agencies. Most of them have their own specialised disaster department/units; however, they do not target urban planning sector specifically (Wamsler, 2006). In accordance with the Sendai Framework 2015–30, India is among the first countries to formulate a national plan and a local strategy for disaster risk reduction in 2017, to bring down the losses from occurrence of disasters. Although the strategies aim at reducing disaster risks in the country at the local level through national programmes like 'Aapda Mitra', community volunteers, trainings, capacity building and school safety programmes, they do not however have direct involvement of the urban planning sector. To assess the level of inclusiveness and the national implementation framework of urban planning for disaster risk reduction, national disaster management plans, development schemes and plans in India are further explored.

Implementation Framework

Inter-agency coordination for strengthening disaster risk governance is a key component of Priority-2 of the Sendai Framework 2015–30, which includes improving overall disaster governance, response, warnings, data and information about hazards, and non-structural measures. Under the Disaster Management Act of 2005, various authorities are established from national to local levels for effective disaster management throughout the country. The inter-agency coordination for early warnings, capacity building and trainings, and emergency response are also well established. When it comes to risk reduction in the built environment, there seems to be a disconnect between urban planning and disaster management authorities. At the national level, responsibility of planned urban development is vested with the Ministry of Housing and Urban Affairs and the responsibility of overall coordination of disaster management is vested with the Ministry of Home Affairs. In Figure 1, the organisation structure of urban planning and disaster management (MHA, 2011) in India are elaborated to show the disconnect between them and missing 'common ground'. It is observed that the authorities at various levels in disaster management and urban planning do not seem to work in conjunction for disaster risk reduction but work in silos.



MHA- Ministry of Home Affairs; NDMA- National Disaster Management Authority; SDMA- State Disaster Management Authority; DDMA- District Disaster Management Authority; NIDM- National Institute of Disaster Management; NDRF- National Disaster Response Force; DMD- Disaster Management Department

Figure 1: Disconnect between organisation structures

An elaborate hazard-wise responsibility chart for various stakeholders/agencies from local to national level are identified in the National Disaster Management Plan (NDMP) prepared by NDMA in 2016. The Ministry of Urban Development (MoHUA) is the nodal agency for Urban Flood Risk and is responsible for providing overall disaster governance, hazard and vulnerability assessments, urban design, non-structural measures like preparation of manuals and inventories and capacity development through mock drills and trainings. For other hazards like cyclones/winds, earthquakes, landslides and drought risk, the ministry is vested with the responsibility of ensuring prevention and mitigation in planning social housing schemes and capacity development through awareness generation and community-based disaster management. However, there seems to be no clear allocation of responsibility for the Ministry of Urban Development to include a multi-hazard disaster perspective while preparing national development schemes and plans apart from social housing schemes. Neglecting this will not only incur huge economic losses and push back the development of any country by decades but may also lead to loss of life in case of urban disasters.

Statutory Documents

After the Bhuj earthquake in 2001, a techno legal regime was published with proposed amendments in Town and Country Planning Legislations, Development Control Regulations and Building Regulations/ Byelaws by an expert committee to mainstream disaster risk reduction and resilience in development activities (MHA, BMTPC, 2002). It is observed that the recommendations made by the expert committee have not been fully adopted by the state and union territories (UTs) in the amendment of legislations. The observation is made through the review of statutory documents like Town and Country Planning Acts of various states/UTs like Delhi, Uttarakhand, Madhya Pradesh and Maharashtra.

The Uttarakhand Town and Country Planning Act, 1973, Delhi Development Act, 1957, and Madhya Pradesh Town and Country Planning Act, 1973, and amended versions of all acts briefly chalk out the contents of development plans without any consideration to disaster perspective. Although the Maharashtra Regional and Town Planning Act, 1966, as amended in 2015 mentions that “the temporary use of plot land, reserved, designated or allocated for the purpose of play-ground, for management of any disaster or emergency such as Helipad or other essential use, shall also not be deemed to be a change of user”. This takes into consideration disaster response capacity development through the allocation of open spaces which serve as areas for relief distribution and emergency shelters in an event of any disaster. It is the responsibility of the state government to decide upon the way land in any region should be used such as use of land for preservation, conservation and development of areas reserved for natural resources, scenery, wildlife and forests. However, the plan does not specify that such areas must be conserved or not, instead the decision depends upon the state government. If such areas are used for development, it will lead to degradation of natural systems and hence increase disaster risks. In the act, there is no mention of considering natural hazards for making decisions on development planning in any region. But there are rules for the development of land and grant of permission based on the population density and number of industries allowed in an area.

Instead of the Delhi Development Act, 1957, it is the Delhi Master Plan, 2021, that states a few disaster management guidelines under Chapter 13 Social Infrastructure for incorporation of disaster perspective in the development. It includes referring to micro-zonation surveys and hazard, vulnerability studies prior to preparing zonal and layout plans for risk reduction. There is also consideration of following building regulations and retrofitting of structures. Although this plan incorporates certain broad aspects of disaster risk reduction, it is the detailed guidelines and implementation that shall further help to reduce disaster risk. Even in the Zonal Plan of Delhi 2021, only fire locations of fire stations and administrative centres for disaster management are mentioned. There is a need to develop detailed guidelines that include various aspects of urban planning from DRR through land-use planning, transportation planning, urban form and design for disaster risk reduction to guide the development in cities and promote resilient and sustainable development.

National Urban Development Schemes/Programmes

In the National Disaster Management Plan 2016, it is stated that all central ministries and state governments will integrate disaster risk reduction into their planning, programming and development policy at all levels (NDMA, 2016). However, in the national urban development schemes and mission floated by the Ministry of Urban Development, marginal input from a disaster perspective is observed. It is evident through schemes like JnNURM, AMRUT and Smart City Mission.

JnNURM city modernisation scheme was launched in 2005 by the government of India under the Ministry of Home and Urban Affairs. The scheme pans over various categories of cities based on the population size to transform inner-city areas and provide basic infrastructure to the citizens. The only disaster concern highlighted in the scheme is for the preservation of water bodies, slum improvement, and prevention and restoration of soil erosion and landslides in states which are under special category states with such problems. However, strategies for risk reduction in terms of planning and design to make the inner-city areas safe such as provision of easy access and evacuation routes, planned open spaces etc. should also have been considered in measures taken to improve the congested parts of inner old city areas.

The AMRUT scheme was launched in 2015 for urban transformation by local area planning. The national level implementation and monitoring of the scheme through an Apex Committee (AC), chaired by the Secretary, Ministry of Home and Urban Affairs, comprising of representatives of other related organisations and ministries; similarly, at state level, a State High-Powered Steering Committee (SHPSC) chaired by the State Chief Secretary is constituted, while ULBs are held responsible for local areas. The focus of the scheme is on providing adequate sewage networks and water supply for 25 selected cities. The thrust areas also include planned green space, parks and urban transport, when planned for disaster risk reduction may decrease physical vulnerability and exposure and increase response capacity of the urban area. The scheme plan briefly mentions the incorporation of resilience and protection of the infrastructure against disasters, which shall be included at the Service Level Improvement Plan (SLIP) which is not yet developed. At the project development stage, states/ULBs shall ensure disaster-resistant engineering and include structural design norms, while preparing the State Annual Action Plans (SAAPs). The scheme plan however does not give in detail the strategies for incorporating resilience in design even after three years of launch, instead provides a brief conceptual statement with an intent to reduce risk.

The Smart City Mission was launched in 2016 by the government of India under the Ministry of Home and Urban Affairs for improving the quality of life of citizens by local area development. The implementation and monitoring of the mission at the national level is by an Apex Committee, at state level by SHPSC and at local levels by ULBs. One hundred cities are selected under this smart city mission in four rounds of selection for redevelopment, retrofitting, green development and pan-city development. It is an urban renewal programme with thrust areas like improving infrastructure, sustainable development, e-governance and ensuring the safety of citizens. Consideration for reducing vulnerability to disasters is briefly mentioned in the mission statement and guidelines document. However, the strategies to be adopted for reducing vulnerability of the areas are not detailed out in the mission plan with guidelines on the way forward, thereby just conceptually stating the intent for the same, even at the local levels (ULBs). There seems to be little or no concern to the pattern of settlement, compact urban forms and density in terms of evacuation routes, open spaces for emergency shelters and unplanned settlements in hazardous areas. It is in such urban renewal projects based on local area development that lies the opportunity of disaster risk reduction.

Under the smart city mission, Vishakhapatnam has a resilience draft plan, Integrated Smart City Framework Plan developed in 2017, which assesses hazards and challenges in the city and explores strategic considerations for critical infrastructure and businesses while promoting green living. It is in the interest of governments and citizens that such resilience plans be chalked out before urban development begins to ensure safety and to avoid economic losses in case of occurrence of disasters. Every smart city should have detailed guidelines on how the risk reduction measures be taken forward and resilience plans based on safe land-use.

Conclusion

The study adds to the body of research on urban disaster risk mitigation and identifies salient factors to help integrate disaster risk reduction in the urban planning process in India. In order to identify the gaps in the incorporation of these factors in urban planning in India, statutory documents and development schemes/programmes are reviewed. It has been observed that in the current scenario of the planning process in India, little consideration that too still in conceptual stage is present for disaster risk reduction. Although the intent to involve disaster perspective in development planning programmes is visible, it may be inadequate for on-ground implementation, as details of how it is to be taken forward for implementation through ULBs and the supervising authority for the same is not clear. It is concluded that the appropriate implementation may follow through with the detailed incorporation of guidelines and convergence of authorities of both the disciplines of urban planning and disaster management towards risk reduction in development planning. Further investigation to determine the level of incorporation of DRR in urban planning may be carried out through local level development plans for various cities and detailed-out implementation strategies of ULBs in future for national development schemes such as Smart City Mission and AMRUT, which after three to four years of launch are still in their nascent stage of planning.

References

Bandyopadhyay, C. (2014). *Training Module on Urban Risk Mitigation.* New Delhi: National Institute of Disaster Management.

Burby, R. (1998). Cooperating with Nature: Confronting natural hazards with landuse planning for sustainable communities. *Joseph Henry Press, Washington DC*.

Clark, H. (2012, August 12). *Building resilience: The importance of disaster risk reduction.* Retrieved from Undp.org:http://www.undp.org/content/undp/en/home/ourperspective/ourperspectivearticles/2012/08/15/building-resilience-the-importance-of-disaster-risk-reduction.html

Gencer, E. A. (2013). Natural Disasters, Urban Vulnerability, and Risk Management: A Theoretical Overview. In *The Interplay between Urban Development, Vulnerability, and Risk Management. SpringerBriefs in Environment, Security, Development and Peace* (pp. 7–43). Berlin, Heidelberg: Springer.

GOI. (2005). *Disaster Management in India.* New Delhi: Government of India. Retrieved from https://www.unisdr.org/2005/mdgs-drr/national-reports/India-report.pdf

Johnson, C. (2011). Creating an enabling environment for reducing disaster risk: Recent experience of regulatory frameworks for land, planning and building in low and middle-income countries. In UNISDR, *Global Assessment Report on Disaster Risk Reduction.* Geneva: GAR, UNISDR.

MHA. (2011). *Disaster Management in India.* New Delhi: Ministry of Home Affairs, Government of India.

MHA, BMTPC. (2002). *Building a New Techno Regal Regime for Safer India.* New Delhi: BMTPC, Government of India.

NDMA. (2016). *National Disaster Management Plan.* New Delhi: National Disaster Management Authority, Government of India.

NIDM. (2014). *Urban Risks.* New Delhi: National Institute of Disaster Management.

Peduzzi, P., & Deichmann, U. (2009). Global Disaster Risk: Pattern, Trends and Drivers. In G. A. Reduction, *Risk and Poverty in a Changing Climate* (pp. 29–49). Geneva: UNISDR.

UN. (2011). *Revealing risks, Redefining development.* Geneva: Global Assessment Report on Disaster Risk Reduction, UNISDR.

UNISDR. (2013). *From Shared Risk to Shared Value – The Business Case for Disaster Risk Reduction.* Geneva: Global assessment report on disaster risk reduction: United Nations.

UNISDR. (2015). *Annual Report 2015.* Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNISDR).

United Nations. (2014). *World urbanisation prospects: The 2014 Revision: Highlights (ST/ESA/SER.A/352).* Department of Economic and Social Affairs, Population Division.

Wamsler, C. (2006). Mainstreaming risk reduction in urban planning and housing: a challenge for international aid organisations. *Disasters 30 (2)*, 151–177.

Role of Rural-Urban Linkages in Resilience: Indicator-Based Approach

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ABSTRACT: Urban-rural continuums are the dynamic systems which maintain the critical flows between urban and rural areas. Urban-rural linkages remain a major challenge for integration of climate risk in planning. The increasing urban population and their demands, in addition to posing pressure on rural resources, is also showing a rapid transformation in the dynamics of peri-urban areas.

Though urban and rural areas are differently resilient to various climate hazards, rural areas take relatively more time to come back to equilibrium from the perspective of their dependency on natural systems. A structured literature analysis was performed, which highlights that there is a lack in considering the role of urban-rural linkages while planning for disaster risk. The study is based on understanding approaches and tools for assessing disaster risk resilience of urban-rural continuum. An indicator-based approach is one of them which are widely used in disaster risk resilience research. This study prepared an indicator set using literature and focused on how the urban-rural linkage resilience can be enhanced through identified indicators. The indicators were applied to the case study of Nagpur Urban-Rural Continuum. The research thereby highlights the role of urban-rural linkages in enhancing overall climate resilience at a regional level. This study is in line with the fourth priorities for action provided by the Sendai Framework which emphasises on disaster risk reduction to enhance the economic, social, health and cultural resilience of communities.

KEYWORDS: urban-rural continuum, peri-urban areas, disaster risk resilience, Sendai Framework, urban-rural, indicator-based approach

Introduction

Resilience refers to the ability of a system to cope with the external shocks and stresses and if any disaster like situation occurs then having in-built capacities which help it to come back to the earlier equilibrium position (OECD, 2014). In other words resilience is about addressing the drivers, pressure, impact, state and response (DPSIR) of system in face of shocks and stresses. Based on that building and strengthening the natural, social, financial and human capital so that system can withstand any natural or manmade uncertainties (Institute, 2015). Currently India has one of the highest growths of urban development. In 2001, 28.53 per cent was living in urban areas, but in 2011 it was increased to 31.58 per cent. In reference to the world over situation, the population living in urban areas in China has 54 per cent, Mexico has 78 per cent and Brazil has 87 per cent. Due to the rapid growth of the economy, the rate of urbanisation is increasing in India (India, 2011). Urbanisation refers to the increasing share of urban areas in the country. One of the major

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causes for urbanisation is in-migration from rural areas to urban areas for different purposes. Due to rapid urbanisation, the limits of cities are expanding rapidly, putting pressure on the surrounding area which is in transition of development. The above phenomenon has resulted in emergence of new areas, requiring the need for adequate policy attention. The transformation of new areas develops a hybrid landscape of fragmented hybrid urban and rural characteristics (Saxena, 2015). This area of transition is in between urban and rural areas. Due to the influence of urbanisation on surrounding areas, communities living over there are forced to adjust to the changing urban way of life in a very short period of time (Fürstenberg, 2016). The intensity of use of land is different in different zones in an urban-rural continuum. The zones in between urban and rural areas are the worst sufferers from any kind of development or form disaster like situations.

Location of industries is planned in the areas of transition and development pattern in an unregulated way. So, environmental stresses are more in such areas as compared to rural areas. There is an issue of inadequate resources and if available they are not well managed to cope with the development pace. Industrial activities, dense concentration of population and inadequacy of infrastructure and facilities result in pollution of water resources and quality of groundwater and its impact on the environment and health of public (S.Selvakumar, 2017).

Zones of transition are unattended to so far as urban planning and development is concerned. Traditional planning processes look exclusively at rural and urban areas as two separate entities. The policies and programmes are also designed in the same way; therefore these programmes fail the rural and urban development in an integrated way (Karuppannan, 2012). So resilience approach should be used so as to promote the development of activities which have less environmental impact. In urban-rural transects there are functional interdependencies between urban and rural areas: such as social, economical and environmental. There is flow of people, goods and information (ideas and innovations) between these areas which is seen as potential area for research to integrate the development of these areas (Thomas Forster, 2015). So there is a need to better understand the relationship between urban and rural to bring integrated resilience development.

Concept of Rural Urban Continuum and Linkages

In India rural and urban areas are defined by the Census of India. Urban areas are classified into two categories. First is statutory towns to which state government grants municipal status and another type is census town, based on criteria such as the population, population density and workforce participation in non-agriculture sector. These criteria create different types of urban local bodies and their administrative, functional responsibilities; financial aid they will get varies from types of local bodies.

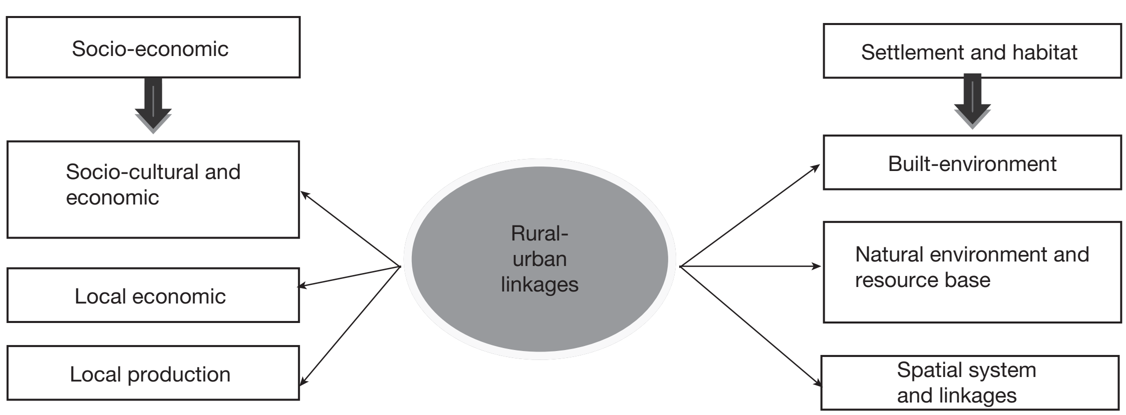

Figure 1: Rural-urban linkages

The rural-urban continuum is a conceptual tool to study different types of interactions happening between them and transition between rural and urban areas (NPTEL, 2013). Spatial and sectoral linkages have been identified in rural-urban linkage studies. Spatial flows include flows of people, goods, produce, information, waste, social interactions and remittance (Douglass, 1998), while sectoral linkage includes functional interactions between primary, secondary and tertiary sectors (iied, 2012). The nature and level linkage varies spatially and temporally. This study has identified the major sectors that link both rural and urban areas in a rural-urban continuum.

Global Platforms for Resilience Studies

Among the four priorities for action made under the agreement of the Sendai Framework which provides a platform for study to strengthen disaster preparedness, building capacities in order to bounce back in the face of disaster (UNISDR, 2015). (HABITAT, 2017) suggest rural-urban linkages as one of the entry points in resilience study as given in New Urban Agenda. There are other platforms also which provide platforms for resilience studies such as SDG11, Paris Agreement and Addis Ababa Action Agenda (HABITAT, 2017).

Problem Statement and Research Question

The relationship between rural and urban areas is changing over the period of time as urbanisation takes place, but these are poorly understood and assessed. Understanding the spatio-temporal changes in linkages of both the areas that can have multiple impacts is essential to inform policy and decision makers. Developing indicators and how they can be used for gaining resilience as a whole is the main research question of the study.

Aims and Objectives of the Research

Aim

The purpose of this study is to understand the spatial and sectoral linkage that exists between rural and urban areas in a continuum and how it can be used for gaining resilience as a whole.

The objectives of this study are as follows:

- To study through literature the existing gap in the resilience of rural-urban linkages in a continuum.
- To identify the spatial flows and sectors that link rural and urban areas in a continuum.
- To develop indicators from various studies that can be applied for measuring linkage resilience in a rural-urban continuum.

Methodology

Firstly the basic terminology, concepts, key words are studied with the help of platforms available for research such as Google Scholar, Mendeley, Web of Knowledge, Sci-hub etc. Further a structured literature review has been conducted for the study of rural-urban continuum in the context of disaster risk resilience. Key terms such as rural-urban continuum, rural-urban linkages, resilient rural-urban development, and type of rural-urban linkages were searched on the Web of Knowledge research platform. The result of the literature study shows that the rural-urban linkages in a continuum are poorly understood from a disaster perspective. Further spatial flows (migration, agriculture produce and goods, information, waste, remittance) and sectors (relation between primary, secondary and tertiary sectors) which links rural and urban are identified and indicators have been identified for assessing these nature and level of linkages through literature study.

Exiting Gap in Research of Role of Rural-Urban Linkages in Resilience Study

For content analysis of the existing study, we took the references of peer-reviewed publications, articles, books and other documents. Figure 2 shows the year-wise reviewed publication and number of reviewed publications. We analyse from the below graph that the trend in the study of rural-urban linkage is increasing over the past 10 years.

Figure 3 shows the areas of categories of study which has been conducted so far from rural-urban linkage perspective. The number of reviewed publications for the study of rural-urban linkages is less and the number of publications is more in environmental studies and planning development.

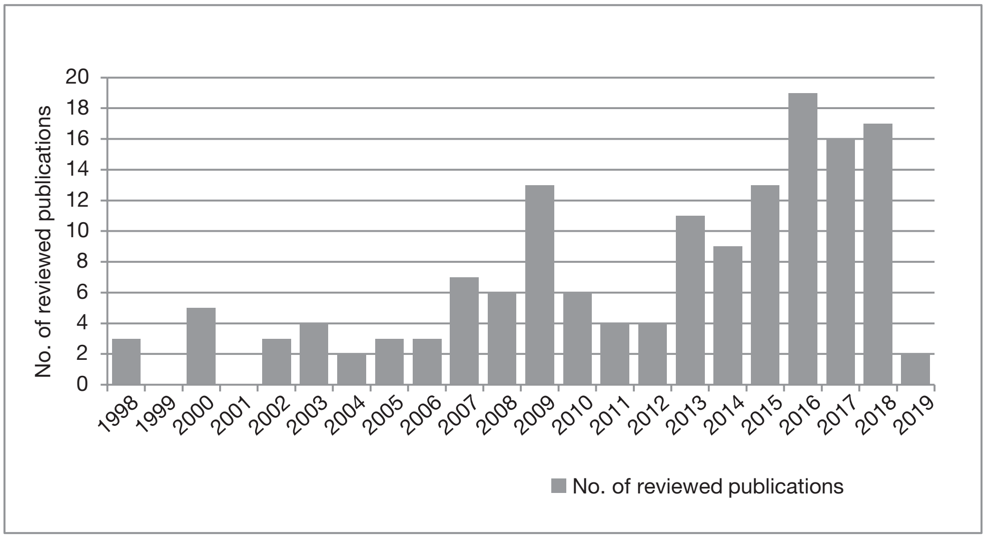

Figure 2: Year-wise number of reviewed publications

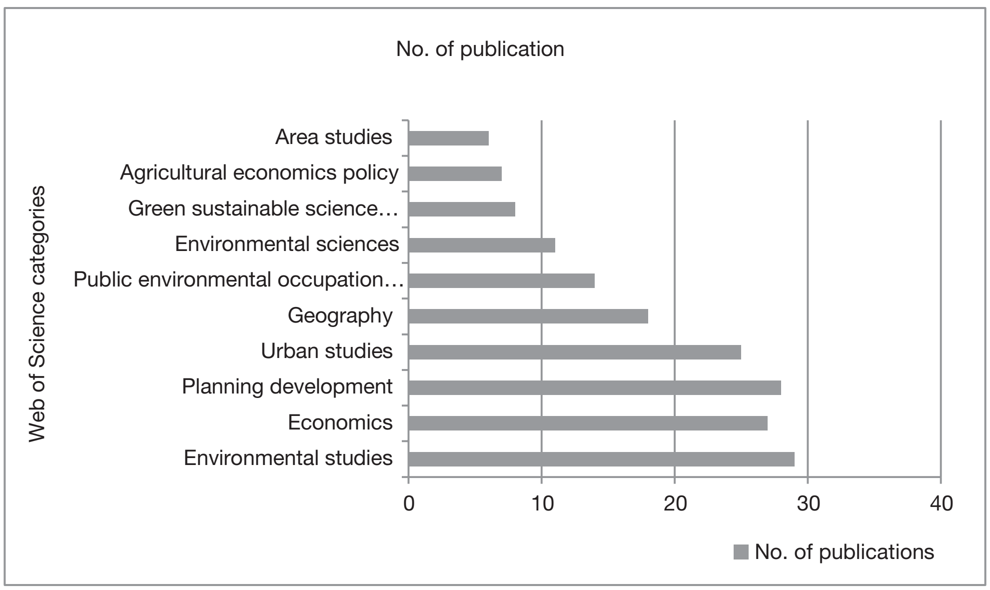

Figure 3: Category-wise number of reviewed publications

State of Art Literature Analysis

Process Carried Out

Web of Knowledge data was processed using VOSviewer tool. From Figure 4, we have analysed that in the early 20th century the terms used such as rural-urban linkage and rural-urban continuum and recently the research field focused on disaster risk, disaster risk reduction but in isolation without considering that rural and urban areas are functionally interdependent. From the above network analysis we can say that there is a need to consider both areas while planning for disaster risk resilience.

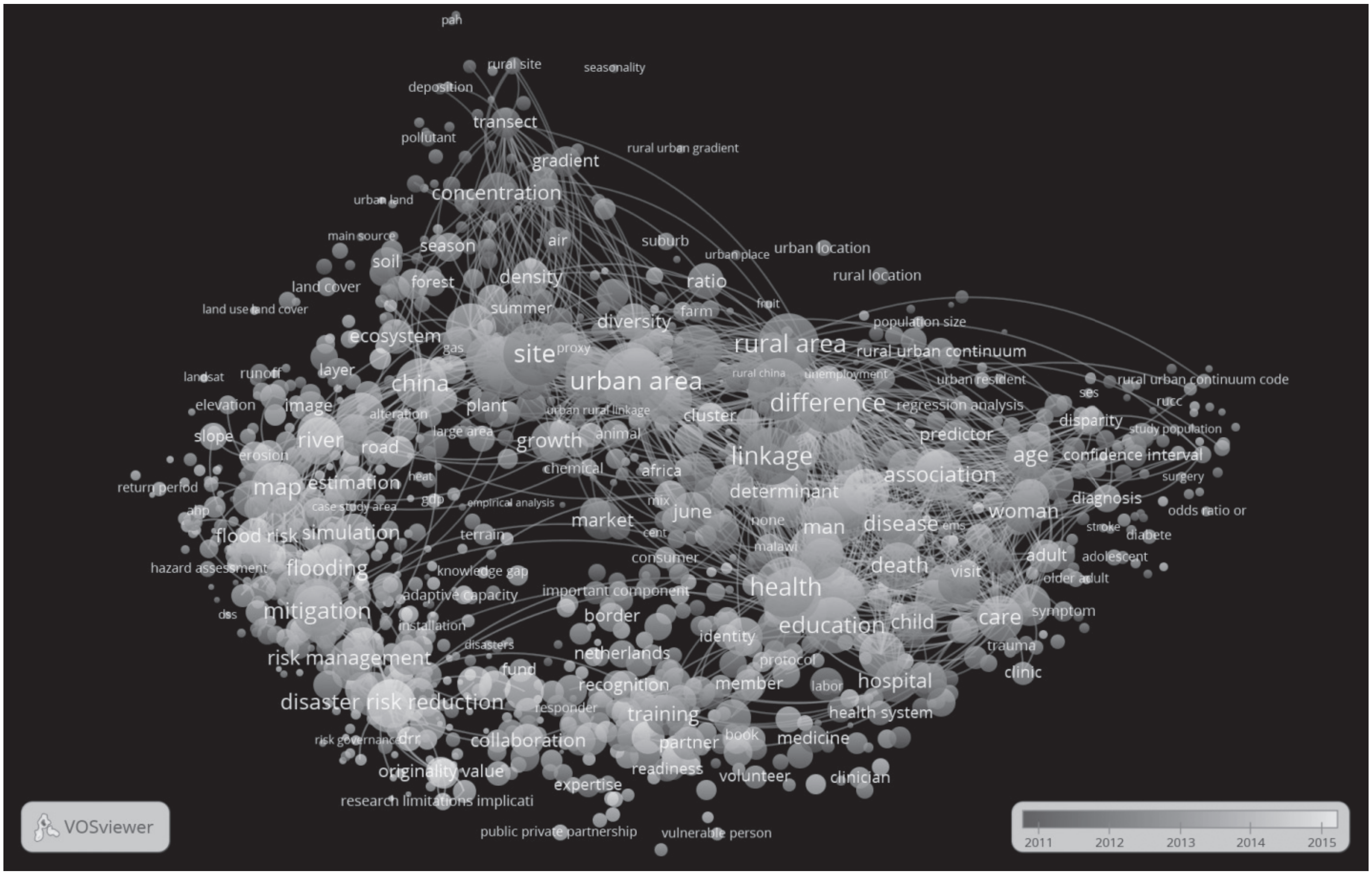

Figure 4: Overlay analysis

Identification of Spatial Flows and Sectors That Links Rural-Urban Areas in a Continuum

Figure 5 shows the conceptualisation of rural and urban system and its characteristics. If any shocks/stress occurs in any of the area in a continuum then it leads to disturbances in the components that are functionally interdependent on each other. Because of that both the areas should be considered while planning for disaster risk resilience.

Dennis August Rondinelli (1976) has identified seven major types of linkage between rural and urban areas, while Tacoli (1998) has identified spatial and sectoral linkages shown in Table 1.

Table 1: Linkage Elements

Author	Identified Linkages
Dennis August Rondinelli (1976)	Physical linkages, economic linkages, population movement linkages, technological linkages, social interaction linkages, service delivery linkages, political and administrative linkages
Tacoli (1998)	Spatial (migration, flow of finance, flow of information, agriculture produce and goods) and sectoral linkages (interactions between primary, secondary and tertiary sectors)

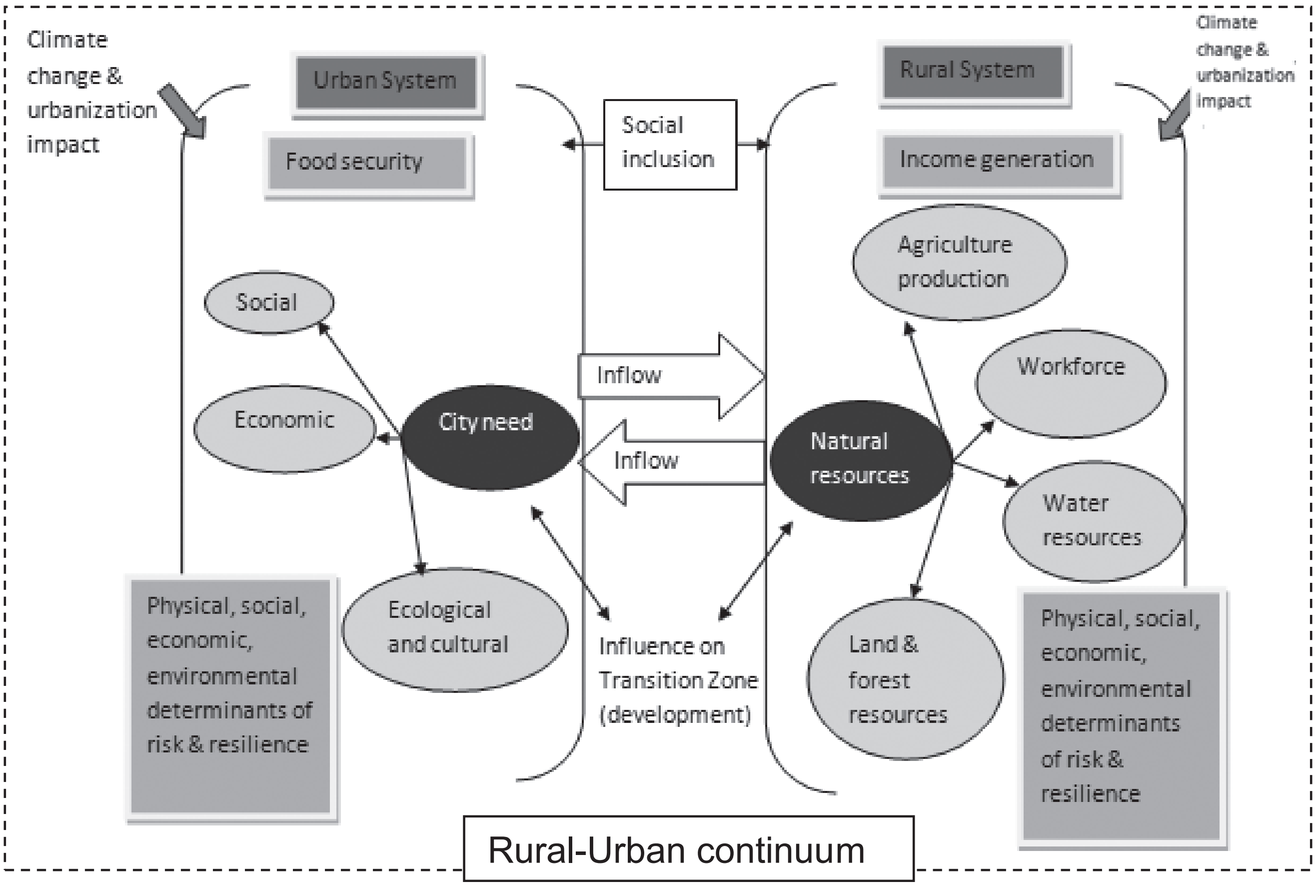

Figure 5: Conceptualisation of rural-urban continuum in face of shocks

Review of Resilience-Related Studies

Existing Resilience Frameworks

In resilience studies, there are many tools and frameworks that have been developed by various organisations in different research areas. The indicators that have been selected in those frameworks vary based on the purpose of study. Existing frameworks like IFRC Framework for Community Resilience, 2014, DFID, 2011, City Resilience Framework (Arup, 2015) in resilience study focus on either urban areas or village settlements but not for both as one unit. This study has been conducted to develop some indicators which can be used for analysing the components of rural-urban continuum and thereby will help in measuring the resilience of a rural-urban continuum against shocks and stresses.

Indicators-Based Approach

Indicators-based approach is one of them which are widely used in disaster risk resilience research. There is no specific definition for indicator, but some researchers say it is a variable which describes the study (Chevalier, 1992), while some describe it as a proxy measurement used for something which we can't directly quantify for the purpose of study, whether it may be a single component or multiple components (Wong, 2002). The use of indicators for assessing resilience is from the early 20th century (Birkmann, 2006). Developing indicators is a more useful approach to assessing resilience than trying to measure resilience itself, because of the dynamic nature and the complexity of interrelations between the components of rural and urban systems. To capture the different components of rural-urban areas, which contribute directly or indirectly to resilience, is essential. Such indicators then can be converted into an index which helps us in summarising the whole scenario in a simple way. In the research world it faces many conceptual and methodological problems, but if constructed in a structured way as per the purpose, it will be very helpful in the resilience of rural-urban continuum study.

Indicators Selected

The capacities of the system help in bouncing back to an earlier equilibrium position. This study has developed some proxy indicators for each type of linkage from various research studies. Following proxy indicators determines the level of resilience of the system.

Proxy indicators have been listed in Table 2.

Rural-Urban Linkages and Resilience

Spatial linkage: According to Tacoli (1998), spatial linkages consist of flows of people from rural to urban areas. In the process of urbanisation or during natural hazards such as drought and flood people move from rural area to urban for the sake of employment opportunities to survive shocks (Nitin Srivastava, 2016). In such cases the agriculture production goes down in rural areas while pressure increases on the infrastructure and basic services. An arrangement which manages uncertainties helps to achieve resilience. The flow of information includes transfer of information from urban to rural related to mitigation and adaptation measures that should be taken during any shock or stress, crops to be taken in the drought like situation from migrant or from institutions located in urban to rural population. Financial flows include money transfer from urban to rural or bidirectional which can be used as a strategy for achieving livelihood resilience in the face of shock. Understanding the nature and level of these linkages in a specific rural-urban continuum will help in developing strategies for resilient development.

Sectoral linkages: It includes the agriculture sector, the flow of agricultural produce from rural areas to urban areas for satisfying the need for food in city. Understanding the agriculture production and food linkage between rural and urban areas helps in achieving food resilience of urban areas, while on the other hand it helps rural households to improve their livelihoods. Water is an important part of satisfying the need of domestic, non-domestic, industrial and irrigation purposes. Achieving water resilient system in the rural-urban continuum requires understanding each component of the water sector. Further the waste that generates in the whole process right from production to consumption linkages needs to be understood to give feedback to other sectors such as agriculture and food and water environment in order to synergise between them for achieving resilience as a whole (Siraj Tahir, 2018).

Table 2: Category-wise Proxy Indicators

Type of Linkages	Sub-category	Proxy Indicators	Source
Spatial linkages	Migration	Number of rural population migrating to urban area, demographics of migrants, socio-economic status of migrants, reason for migration, characteristics of migration, period of migration and frequency, locations of labour market, daily commuters (number), location within urban area attracting people from rural, place of preferences for migration and residence	(Gete Zeleke, 2008), (Berhane, 2016)

(*Continued*)

Table 2: (Continued)

Type of Linkages	Sub-category	Proxy Indicators	Source
	Remittances	Finance: purpose of remittance, remittance mechanism (mode of transfer of cash), income of migrant, expenditure on rent, food, proportion of households receiving remittance, average annual amount of remittance received per year, volume of household remittance inflow (Rs.), per cent of consumption covered by remittance Food: frequency, types and volume of food remitting, effects of food remitting on poorer rural households, mode of food transfer, flow of goods including foodstuff	(Henry Rempel, 2007)
	Transportation	Typology of road, road material, alignment, drainage facilities, distance between city and rural area, availability of transport means, public transport frequency, capacity of public transport, impact of transport linkage on local economy, agriculture production, consumers' access to city where they can engage in income-generating activities, impact on human communication	(Lauren Joy Avery, 2017)
Sectoral linkages	Agriculture and food	Agriculture and food, availability of land, type of crops such as food crops, cash crops, plantation crops, horticulture crops and non-crops, quantity of crops inflow-outflow (kt/year), food flow- inflow, consumption and outflow (kg/person/year), flow of major nutrients from agriculture produce, major markets, PDS, storage facilities, processing units, retailers, wholesalers, buyers, supermarkets, shops, agriculture labourers (per cent), ratio of labour force to farm land, intensification, Gini coefficient, diversification of crops, pattern of land ownerships	(Berhane, 2016), (Srijantr, 2003), (Nicolas Urruty, 2016)
	Water	Availability of water resource (surface and GW), flow for different purposes in rural and urban areas such as domestic, non-domestic and irrigation (per cent), locations where water is getting transferred, shifting of rural resource to non-agricultural sector, impact on agriculture production, change in income, change in livelihood strategy, irrigation method in village, groundwater levels, salinisation of farms	(WHO, 2009), (Feras Ziadat, 2017)
	Waste	Number of water-polluting industries, location of discharge points, domestic effluent, industrial effluent (Mm^3/d), PH, BOD, COD (Kg/day), recycling of waste water (per cent), reuse of waste water (per cent)	(DST, 2008)

Discussion

Global frameworks have been providing a platform for rural urban linkage study and it is increasing in recent years but research in rural-urban linkages from the resilience perspective is very little. Linkages have been identified between rural and urban, but detailed structural categorisation of indicators for assessing resilience is required.

Applying rural-urban linkage in the Indian context is too difficult because the data on these spatial and sectoral linkages is hardly managed by administrative authorities at local, district, state and national levels. Applying this concept in an Indian context first requires well-established database regarding spatial and temporal characteristics of linkages (location-wise migration, flow of produce and goods at every level of the functioning system).

Conclusion

From the structured literature analysis we conclude that there is a lack of consideration of rural-urban linkage in resilience. The process of rapid urbanisation and increasing disaster occurrences requires the utilisation of rural and urban for achieving resilience. Developing the set of indicators for understanding and assessment of these linkages is required for resilience of a rural-urban continuum. Rural-urban linkage provides an opportunity for achieving resilience of the rural-urban continuum without affecting one another while developing.

References

Arup. (2015). *City Resilience Framework.* Rockefeller Foundation.

Berhane, M. (2016). *Rural-Urban Linkage of Adwa Town and its Surrounding Rural Areas: Its Nature and Effects on Rural Livelihood Diversification.* Mewael Berhane: Addis Ababa University.

Birkmann. (2006). *Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies.* New York: United Nations University Press.

Chevalier, S. C. (1992). *User Guide to 40 Community Health Indicators. Community Health Division.* Ottawa: Health and Welfare Canada.

Dennis August Rondinelli, K. R. (1976). *Urban Functions in Rural Development: An Analysis of Integrated Spatial Development Policy.* Agency for International Development, Technical Assistance Bureau, Office of Urban Development, 1976.

DFID. (2011). *Defining Disaster Resilience: A DFID Approach Paper.* London: DFID.

Douglass, M. (1998). A regional network strategy for reciprocal rural-urban linkages: An agenda for policy research with reference to Indonesia. *Third WorldPlanning Review* 33.

DST. (2008). *Re-imagining the Rural-Urban Continuum: Understanding the role ecosystem services play in the livelihoods of the.* Kathmandu: Institute for Social and Environmental Transition - Nepal.

Feras Ziadat, S. B. (2017). *Land resource planning for sustainable land management.* FAO.

Fürstenberg, J. (2016). Towards Urban Resilience: Assessment of Community-based Risk Reduction Strategies in Yogyakarta, Indonesia. In U. G. Badan Penerbit Fakultas Geografi, *Rapid Urbanisation and Sustainable Development in Asia* (p. 12).

Gete Zeleke, W. A. (2008). Seasonal Migration and Rural Livelihoods in Ethiopia: An Empirical Study. *GMP*, 76.

HABITAT, U. (2017). *IMPLEMENTING THE NEW URBAN AGENDA BY STRENGTHENING URBAN-RURAL LINKAGES.* Nairobi GPO KENYA: Habitat III.

Henry Rempel, R. A. (2007). The role of urban-to-rural remittances in rural development. *Journal of development studies*, 324–341.

IFRC, I. F. (2014). *IFRC Framework for Community Resilience.* Retrieved 11 14, 2018, from IFRC: https://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/what-is-a-disaster/what-is-vulnerability/

IFRC. (2014). *IFRC Framework for Community Resilience.* Retrieved 11 14, 2018, from IFRC: https://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/what-is-a-disaster/what-is-vulnerability/

IFRC. (n.d.). *International Federation of Red Cross and Red Crescent Societies- about disaster management*. Retrieved 11 14, 2018, from https://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/what-is-a-disaster/what-is-vulnerability/

iied. (2012). *Urbanisation and rural-urban linkages*. Retrieved 1 08, 2019, from iied: https://www.iied.org/rural-urban-linkages

India, C. o. (2011). *Census of India.* Ministry of Home Affairs, Government of India.

Institute, U. L. (2015). *Resilience Strategies along the Rural–Urban Transect.* Washington, DC: Urban Land Institute.

Karuppannan, S. (2012). URBAN PLANNING AND SUSTAINABILITY IN DEVELOPED AND. *6th International Conference and Workshop on the Built Environment in Developing Countries, 4–5 December 2012, Adelaide, Australia*, 10.

Lauren Joy Avery, M. B. (2017, 3 14). Rural-Urban Connectivity in Achieving Sustainable Regional Development. *INTERGOVERNMENTAL TENTH REGIONAL ENVIRONMENTALLY SUSTAINABLE TRANSPORT (EST) FORUM IN ASIA*, p. 23.

Nicolas Urruty, D. T.-L. (2016). Stability, robustness, vulnerability and resilience of agricultural systems. A review. *Agronomy for Sustainable Development*, 15.

Nitin Srivastava, R. S. (2016). Enhancing City Resilience Through Urban-Rural Linkages. In *Disasters and Resilience in Asia* (p. 10).

NPTEL. (2013). *Rural-Urban Continuum: Meaning and Context.* NPTEL.

OECD. (2014). *Guidelines for Resilience Systems Analysis.* OECD publication.

S.Selvakumar. (2017). Water Resources and Industry. *ELSEVIER*, 8.

Saxena, A. M. (2015). Peri-urban areas. *IJERT*, 5.

Siraj Tahir, A. (2018). WATER AND CIRCULAR ECONOMY: A WHITE PAPER. *White paper* (p. 18). Arup, Ellen MacArthur Foundation and Antea Group.

Srijantr, F. M. (2003). *Between concentration and fragmentation: the resilience of the land system in the Chao Phraya delta.*

Tacoli, C. (1998). *Rural-urban interactions: a guide to the literature.* London: IIED.

Thomas Forster, G. S. (2015). Strengthening Urban Rural Linkages Through City Region Food Systems. *UNCRD/UN Habitat issue of Regional Development Dialogue*, 19.

UNISDR. (2015, 3 18). *Sendai Framework for Disaster Risk Reduction*. Retrieved 1 15, 2019, from UNISDR: https://www.unisdr.org/we/coordinate/sendai-framework

WHO, D. (2009). *THE RESILIENCE OF WATER SUPPLY AND SANITATION IN THE FACE OF CLIMATE CHANGE.* France: WHO press.

Wong, C. (2002). Developing Indicators to Inform Local Economic Development in England. *SAGE JOURNAL*, 32.

Modern Social Change and Rapid Urbanisation: Its Causes and Challenges on Disaster Risk Management

Kanagaraj S.[a] and V. Priya[a]

ABSTRACT: This paper attempts to understand and give an overview of various issues related to rapid urbanisation and its challenges to disaster risk management (DRM). As per the World Economic Forum, city dwellers are going to be two-thirds of the world's population by 2050. It is clearly evident that the developing countries have the highest and rapid urbanisation; particularly Asian region is going to be increased by 64 per cent by 2050, creating huge risk to manage various kinds of natural as well as manmade disasters. Improper urban planning may lead to serious problems such as migration issues, livelihood problems, sanitation, solid waste management, urban flooding etc. There are several examples of such incidences which can be learned from the earlier disasters that occurred in Indian cities. Hence it is the need of the hour to understand and foresee the various factors associated with modern social change and its causes, rapid urbanisation and disaster risk management. This review paper reveals, based on case examples in the Indian context, the following strategies which shall be considered as effective strategies such as creation of effective awareness programmes, role of private sectors in DRM, community action planning (CAP) in DRM, need for participatory urban risk management, cost–benefit analysis (CBA) for DRM, role of social capital in DRM, disaster risk management training, social mobilisation in DRM and smart cities for DRM. It can be concluded that effective disaster risk management greatly contributes to sustainable development which is the need of the hour due to rapid urbanisation and modern social change.

KEYWORDS: disaster risk management, disaster risk reduction, rapid urbanisation, modern social change, social mobilisation, community action planning

Introduction

India is the world's second highest populous country, comprising 18 per cent of the world's population. It is estimated that India will surpass China by 2024 (UN Population Division 2017). At present 55 per cent of world's population lives in urban areas which is projected to increase by 68 per cent by 2050. According to the 2011 Census, India's urban population is 377.1 million which accounts for 31.4 per cent of the country's population living in urban areas. The country is witnessing rapid urbanisation. It is evident from the estimates that the urban population is projected to grow about 600 million (40 per cent) by 2031 and 850 million (50 per cent) by 2051. Due to rapid urbanisation there are lots of challenges, including basic infrastructure, housing and employment opportunities to the urban poor (Handbook of Urban Statistics GOI 2016). All these issues are the real challenges of disaster risk management (DRM). Moreover, a population shift to towns in two decades will add additional challenges to the urban poor; it will further manifest into significant issues if it is not managed proactively (Gupta et al. 2017a). In addition, the urban sprawl has been increasing which is creating important issues at the global level on the road to

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urbanisation. It is not the issue of developed countries alone but developing countries as well; it increases the social and environmental issues. Hence it is vital for the governments and civil society organisations to research on urbanisation and its problems (KesavaRao et al. 2016). "Understanding Disaster Risk" has been given first priority in Sendai Framework for Disaster Risk Reduction (SFDRR) (2015–30); it signifies still a long way to understand what makes disaster (Nations Office for Disaster Risk Reduction n.d.).

As per the UN report, the loss of human lives is less but the occurrence of disaster is increasing (UNISDR 2004). Disasters are various environmental phenomena which are unavoidable in this living world. Disaster is defined as "a serious disruption to a community's survival, resources and livelihood systems that result from vulnerability to hazard impacts and results in the loss of life, property and environment on a scale which overwhelms their capacity to cope unaided" (Gupta et al. n.d.). In order to manage the disaster in an effective way India hosted its second Asian Ministerial Conference on DRR (AMCDRR) and laid the roadmap on DRM which enables aligning with SFDRR (Prime Minister's Agenda-10 on Disaster Risk Management). Also integrating disaster risk management into developmental planning can bring back the present increase of disaster impact. Additionally, when countries build strong policies, they can minimise the impact even up to 31 per cent, potentially cutting the global average losses. If the countries respond actively, they can save lives and assets (World Bank 2018).

Urbanisation in India

Urbanisation is a continuous changing process which is generally considered as social, demographic, political and economic progress of a society. It reasons huge modifications in the environment from regional to global scales (Huang et al. 2009). It is not a side effect of economic growth but an integral part of the process. Urban areas in India contribute a major part of the country's economy about two-thirds of economic output. More number of people migrate to cities in search of economic opportunities due to rapid urbanisation (Urbanisation in India: Integral part of economic growth, World Bank n.d.). There is a growth of 2774 towns encompassing 242 statutory and 2532 census towns over the decade. Population increase in urban areas was 31.8 per cent (Ministry of Housing and Urban Affairs, Government of India n.d.). As per the estimation of the UN, the population of urban areas is projected to be more than the rural areas (see Figure 1).

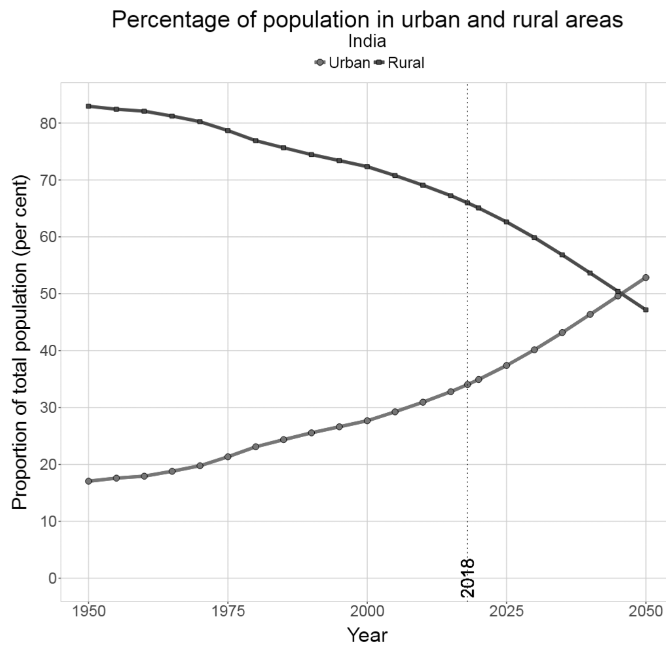

Figure 1: Growth of urbanisation (Source: https://population.un.org/wup/Country-Profiles/)(Retrieved on January 10, 2019)

Causes of Modern Social Change

India is a diverse country and its society is enormously heterogeneous. In this world, India has the longest persistent civilisations, which continuously adapt to changing political and social conditions. The family system has shown extraordinarily steady units of society which adopted the conditions of rapid urbanisation. However, due to advancement in technologies and economic liberations in the light of globalisation has had a significant impact on the life of Indian society which affected the family patterns. (Kashyap 2004). M. E. Jones states that social change "is a term used to describe variations in, or modifications of, any aspect of social processes, social patterns, social interactions, or social organisations". It is proven that the mechanism for social change is social innovations like fair trade, microfinance and emission trading (Choi and Majumdar 2015).

Major Issues and Challenges of Rapid Urbanisation

The consent of socio-economic conditions and climate change issues recommends that this will only rise in coming years. Therefore, actions taken today on developing infrastructure can mitigate huge loss due to floods and droughts (Güneralp et al. 2015). Economic damages due to water-related hazards augmented above 500 per cent from the early 1980s, mainly because of rapid urbanisation in unprotected places (Adikari and Yoshitani 2009). Also the prime issues in India pertaining to floods are improper drainage system, inundation due to urbanisation and river bank erosion, due to encroachment of the flood plain areas artificial flood is created, hence appropriate drainage network system for the cities needs developed (Mohapatra and Singh 2003). Urbanisation growth is at an exceptional pace which causes widespread transformation in ecological process of the environment which includes urban heat, greenhouse emissions, poor water quality, biodiversity losses etc., enriching the vulnerability of urban regions (Sharma and Joshi 2016). The challenge of rapid urbanisation is drift in India is frightening and in serious requirement for attention. The cities are centres of economic opportunities where huge number of people migrate to satisfy their needs. Due to these socio-economic factors, population increase and poverty urban areas have seen rapid growth (Gupta et al. 2017b).

Challenges on Disaster Risk Management

The population in the city increases manifold through network of families through a "chain migration" which accelerates rapid urbanisation (Weinstein 1991). Rapid urbanisation encounters many challenges such as need for basic services, employment opportunities, infrastructure, adequate housing especially for the poor, energy demand increase and safety threat. All these are fundamental issues of the DRM (Ministry of Housing and Urban Affairs, Government of India n.d.) (Hayat 2016). The significant urban sectors are solid waste management, buildings, transport, industry and climate adaptation require systems thinking approach to disaster risk management (Dubash et al. 2018). Cities provide 80 per cent of global gross domestic product (GDP) which takes 75 per cent of global primary energy and is accountable for about 70 per cent of greenhouse gas emissions which is the main source of many environment and climate-related issues (The Global Commission on the Economy and Climate 2014). It is projected that the population of urban would twofold to about 60 crores in succeeding 20–25 years. They contribute more than 60 per cent of India's GDP and it will further go up to 70 per cent of national GDP in the next 15 years (Indian Urban Infrastructure and Services, March 2011). The latest urban mobility and living style increases the high carbon emission (Roy et al. 2018). It is also considered to be significant challenges for DRM.

Methodology

This narrative review article is based on literature review of peer-reviewed and grey literature (official UN reports, Government of India reports and Websites). The information was obtained from many sources such as globally accepted scientific database Scopus http://www.scopus.com, Springerlink http://www.springer.co.in, http://www.onlinelibrary.wiley.com, Science Direct http://www.sciencedirect.com, and acknowledged books, abstracts and conference proceedings. The search option was adopted for the review of literature from web sources using keywords such as "Rapid urbanisation" "Modern social change in India", "Disaster risk management in India", "Urbanisation in India", "Disaster risk reduction in India", "Challenges of disaster risk" and "Challenges of rapid urbanisation". The searches were limited from ___ to 2019. The inclusion and exclusion criteria are shown in Table I.

Table I: Inclusion/Exclusion Criteria

	Inclusion Criteria	Exclusion Criteria
Study types	Peer-reviewed original research published and indexed in Scopus, official documents of the UN and Government of India	Other than Scopus, opinion materials

(*Continued*)

Table I: (Continued)

	Inclusion Criteria	Exclusion Criteria
Study outcome	Participatory urban risk management, effective awareness, role of private sectors, community action planning, cost–benefit analysis, social capital, risk management training, social mobilisation, smart cities	Study outcomes based on countries other than India
Dissemination type	Publications between____ and 2019	Publications before _____
Country	Focusing India	Countries other than India
Language	English	Other than English

(*Continued*)

Table I: (Continued)

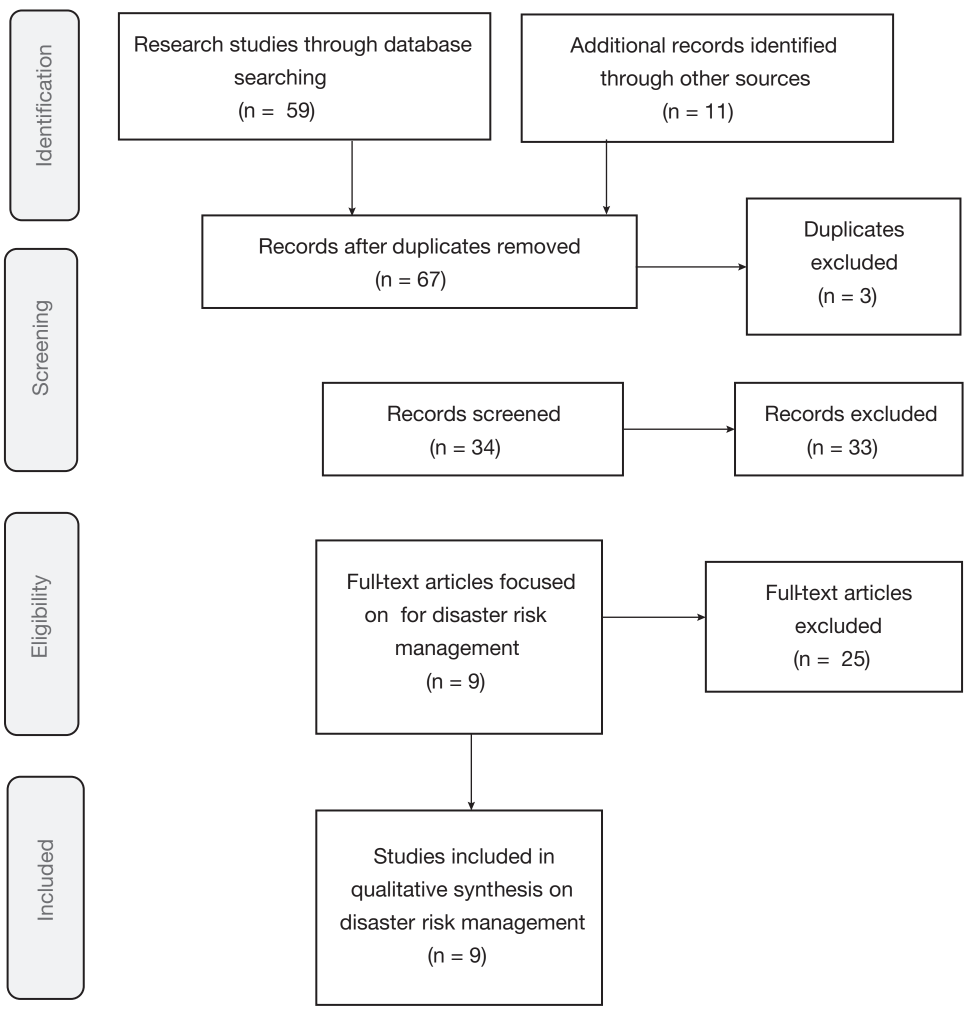

Figure 2: PRISMA flow diagram screening process

Search Outcome

The primary search output, constructed on inclusion criteria, comprised of 59 research studies and 11 records were found relevant from grey literature. After eliminating 3 duplicates, around 67 studies were found related to the study; continuous screening was done on abstracts and titles to select the most relevant sources and was followed full-text review. Around 34 research studies were found to be relevant for full-text review and 36 research studies were excluded as they were not providing solutions for DRM. Research articles were excluded due to the following reasons: the study did not follow the inclusion criteria (e.g. study not based on Indian context discussing DRM). Among 34 research studies, 9 were found more relevant fullfilling all the inclusion criteria and discuss more on DRM with appropriate results on DRM. Figure 2 provides the review search screening process explained in a PRISMA flow diagram.

Findings

The nine most relevant studies (summarised in Table II) selected were the following.

Table II: Summary of Relevant Studies

S. No.	Study Details	Study Title	Study Design	Outcome Measures	Key Findings
1.	Asharose et al. 2015	Awareness workshop as an effective tool and approach for education in disaster risk reduction: A case study from Tamil Nadu, India	Case study	Key measures/ strategies for disaster risk management based on context India	The trailing workshops found useful to bring significant change in disaster risk reduction. Sustainability can be ensured by imparting awareness into people's culture and life.
2.	Jain 2015	The role of private sector for reducing disaster risk in large scale infrastructure and real estate development: Case of Delhi	Case study		It is found that there are gaps in regulation of private sectors' large-scale infrastructure projects to invest in disaster risk reduction which need sufficient measures to ensure inclusion of DRR.
3.	Prashar et al. 2013	Community action planning in East Delhi: a participatory approach to build urban disaster resilience	Survey research design		The study reveals significant effect of community action plan (CAP) methods for urban communities reduces disaster risks.

(*Continued*)

Table II: (Continued)

S. No.	Study Details	Study Title	Study Design	Outcome Measures	Key Findings
4.	SAARC Disaster Management Centre, New Delhi 2010	Urban Risk Management in South Asia, Launch of Global campaign on Making cities Resilient	Compilation of case studies on South Asian cities, drawn from various academic, research and field organisations		It is essential to concentrate on public participation to transform the society.
5.	Kull et al. 2013	Probabilistic cost-benefit analysis of disaster risk management in a development context	Review article		This study analyses the case studies and founds cost–benefit analysis and disaster risk management.
6.	Sanyal and Routray 2016	Social capital for disaster risk reduction and management with empirical evidences from Sundarbans of India	Review article		This focus emphasises on understanding the role of social capital with respect to disaster risk management.
7.	Saxena et al. 2013	Development of habitation vulnerability assessment framework for coastal hazards: Cuddalore coast in Tamil Nadu, India – A case study	Case study		The study focused to find out comprehensive vulnerability framework and constructed Composite Vulnerability Index (CVI) which helps in effective way for the disaster risk management.
8.	Gibson et al. 2018	Drawing the case studies together: synthesis of case studies and group discussions	Case study		This study focuses on how social mobilisation helps in disaster risk management and effective action to reduce the risk.

(*Continued*)

Table II: (Continued)

S. No.	Study Details	Study Title	Study Design	Outcome Measures	Key Findings
9.	Hayat 2016	Smart Cities: A Global Perspective			It primarily focuses on how smart cities help in disaster risk reduction. The holistic approach to reducing the vulnerabilities in cities helps disaster risk management.

Discussion

This section discusses the effective measures for disaster risk management. It is found from various research studies based on the Indian context.

Creation of Effective Awareness Programmes

Sensitising disaster risk management is effective to manage the issues. It is done through workshops and a positive change has been found in the level of understanding on disaster and importance of DRR and DRM. Moreover, the sustainability of the awareness level shall be ensured by making into part of people's life and culture (Asharose et al. 2015).

Role of Private Sectors

This study primarily focuses on the part of the private sector for reducing disaster risk in large-scale infrastructure and real estate development. The regulation needs to be streamlined in such a way to invest in disaster risk reduction measures. It is found the process is not adequate to ensure the inclusion of disaster risk reduction which increases the risk as the development happens in disaster-prone areas by building in vulnerable areas (Jain 2015).

Community Action Planning (CAP)

As we understand from various studies that there has been an increase in the risk due to rapid urbanisation. In order to avoid the risk, the community-led risk management has been reduced significantly by adopting community action planning (CAP). The primary aim of CAP is community-led action plans. This approach endeavours disaster risk management through community participation. It helps to build solid connections with local community which is crucial for disaster risk management (Prashar, Shaw and Takeuchi 2013).

Need for Participatory Urban Risk Management

It is factual that making an enabling environment for heterogeneous communities in urban areas is a continuous process. Their participation and involving them in decision-making process may take extensive than normal. Community-based institutions provide good results in disaster risk management (Urban Risk Management in South Asia, Launch of Global campaign on Making cities Resilient 2010).

CBA (Cost–Benefit Analysis) for DRM (Disaster Risk Management)

CBA is a valuable tool for assessing and organising decision support tool. This study reveals cautious evaluation of CBA benefits the strategies of DRM. Mainly in terms of economic efficiency, metrics were interpreted qualitatively and quantitatively. CBA in DRM is intensely connected to process relatively than to outcome (Kull et al. 2013).

Role of Social Capital in DRM

This study emphasises understanding the role of social capital in connection to the various phases of DRM cycle and lures attention to the influence in reducing the risk. Different kinds of social capital namely bridging, bonding and linking played a vital role (Sanyal and Routray 2016).

Disaster Risk Management Training

This study reveals that the significant impact created due to disaster risk management training. It was evident that the training reduced the damages of tsunami 2004 in Samiyarpettai village as compared to Pudukuppam village in Tamil Nadu (Saxena et al. 2013).

Social Mobilisation in DRM

This study attempted to identify numerous strategies for addressing underlying risk factors that were found from the case studies. It is found that social mobilisation is one of the actors to connect the gap between government and local levels for effective disaster risk management. Also empowerment of women due to social change turns out better for disaster reduction (Gibson et al. 2018).

Smart Cities

The recent efforts have been made with due consideration of various risks and challenges of DRM. Massive innovations affordable technologies have been brought into the domain of communication. City planners are making serious efforts to provide sustainable, resilient cities for the effective DRM as part of Smart Cities implemented by the Government of India (Hayat 2016).

Conclusion

It is clearly evident from the studies that DRM contributes to sustainable development. Sendai Framework guides effective DRM for the period from 2015 to 2030. There is a major shift from disaster management approach to addressing disaster risk management (National Disaster Management Plan (NDMP) n.d.). Also this review study reveals, based on case examples in Indian context, the following strategies shall be considered as effective strategies such as creation of effective awareness programmes, role of private sectors in DRM, CAP in DRM, need for participatory urban risk management, CBA for DRM, role of social capital in DRM, disaster risk management training, social mobilisation in DRM and smart cities for DRM. It can be concluded that effective disaster risk management greatly contributes to sustainable development which is the need of the hour due to rapid urbanisation and modern social change. It is an important need to be addressed by the government and civil society organisations in a holistic manner for a better world.

References

Adikari Y, Yoshitani J (2009) Global trends in water-related disasters: an insight for policy makers. United Nations Educational, Scientific and Cultural Organisation.

Alberti M, Marzluff J, Shulenberger E, Bradley G, Ryan C, Zumbrunnen C (2003) Integrating Humans into Ecology: Opportunities and Challenges for Studying Urban Ecosystems. BioScience 53(12), 1169–1179. DOI 10.1641/0006–3568(2003)053[1169:IHIEOA]2.0.CO;2.

Asharose, Saizen I, Sasi, P (2015). Awareness Workshop as an Effective Tool and Approach for Education in Disaster Risk Reduction: A Case Study from Tamil Nadu, India. Sustainability, 7(7), 8965–8984. DOI 10.3390/su7078965.

Bandyopadhyay C (2014) Training Module on Urban Risk Mitigation. New Delhi: National Institute of Disaster Management, Ministry of Home Affairs.

Choi N, Majumdar S (2015) Social Innovation: Towards a Conceptualisation. In: Choi N, Majumdar S (ed.) Technology and Innovation for Social Change, Springer India, New Delhi, pp 7–34. DOI 10.1007/978–81–322–2071–8_2.

Dubash N, Khosla R, Kelkar U, Lele S (2018) India and Climate Change: Evolving Ideas and Increasing Policy Engagement. Annual Review of Environment and Resources 43(1): 395–424. DOI 10.1146/annurev-environ-102017–025809.

Gibson T, Tongwa A, Bari S, Chantry G, Gupta M, Molina J,... Aretaake R (2018) Drawing the case studies together: synthesis of case studies and group discussions. Disaster Prevention and Management: An International Journal. DPM-07–2018–0223. DOI 10.1108/DPM-07–2018–0223.

Güneralp B, Güneralp İ, Liu Y (2015) Changing global patterns of urban exposure to flood and drought hazards. Global Environmental Change 31: 217–225. DOI 10.1016/j.gloenvcha.2015.01.002.

Gupta A, Chopde S, Singh S, Wajih S, Katyal S (n.d.) Prime minister's AgendA 10: India's disaster risk management roadmap to Climate resilient and sustainable development.

Gupta AK, Singh S, Wajih SA, Mani N, Singh A (2017)[b] Urban Resilience and Sustainability through Peri-Urban Ecosystems: Integrating Climate Change Adaptation and Disaster Risk Reduction. Gorakhpur (U.P.) India: Gorakhpur Environmental Action Group.

Gupta AK, Wajih SA, Mani N, Katyal S (2017)[a] Vulnerabilities of urban poor children and urban/peri-urban ecosystem based resilience | PreventionWeb.net. Gorakhpur, Uttar Pradesh.

Handbook of Urban Statistics, Ministry of Urban Development, Government of India, Retrieved from http://www.indiaenvironmentportal.org.in/files/file/handbook of urban statistics 2016.pdf on 22.01.2019

Hayat P (2016) Smart Cities: A Global Perspective. India Quarterly: A Journal of International Affairs 72(2): 177–191. DOI 10.1177/0974928416637930.

Huang S, Yamano M, Wang, Ch (2009). Detecting urbanisation effects on surface and subsurface thermal environment — A case study of Osaka. Science of The Total Environment 407(9): 3142–3152. DOI 10.1016/j.scitotenv.2008.04.019.

Indian Urban Infrastructure and Services. (2011, March) [Submitted by the High Powered Expert Committee (HPEC) for estimating the investment requirement for urban infrastructure services, set up by the Ministry of Urban Development, Government of India in May, 2008]. Government of India. Retrieved from http://icrier.org/pdf/FinalReport-hpec.pdf on January 11, 2019.

Jain G, (2015) The role of private sector for reducing disaster risk in large scale infrastructure and real estate development: Case of Delhi. International Journal of Disaster Risk Reduction 14: 238–255. DOI 10.1016/j.ijdrr.2014.09.006.

Kashyap L, (2004) The Impact of Modernization on Indian Families: The Counselling Challenge. International Journal for the Advancement of Counselling 26(4): 341–350. DOI: 10.1007/s10447–004–0169–7.

Kesava Rao P, Mishima Y, Srinivasulu S, Rao N (2016) Identification of Urban Sprawl-A Case Study of Vijayawada City, Andhra Pradesh, India. International Association of Lowland Technology 18(1): 59–64. DOI 10.14247/lti.18.1_59.

Kull D, Mechler R, Hochrainer-Stigler S (2013) Probabilistic cost-benefit analysis of disaster risk management in a development context. Disasters 37(3): 374–400. DOI 10.1111/disa.12002.

Ministry of Housing and Urban Affairs, Government of India. (n.d.) Retrieved from http://mohua.gov.in/cms/urban-growth.php

Mohapatra P, Singh R (2003) Flood management in India. Natural Hazards 28(1): 131–143.

National Disaster Management Plan (NDMP) (n.d). Retrieved from https://ndma.gov.in/images/policyplan/dmplan/National Disaster Management Plan May 2016.pdf on 16.01.2019

Nations Office for Disaster Risk Reduction U (n.d.) Sendai Framework for Disaster Risk Reduction 2015 - 2030. Retrieved from https://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf on 16.01.2019

Prashar S, Shaw R, Takeuchi Y (2013) Community action planning in East Delhi: a participatory approach to build urban disaster resilience. Mitigation and Adaptation Strategies for Global Change 18(4): 429–448. DOI 10.1007/s11027–012–9368–4.

Roy J, Chakravarty D, Dasgupta S, Chakraborty D, Pal S, Ghosh D (2018) Where is the hope? Blending modern urban lifestyle with cultural practices in India. Current Opinion in Environmental Sustainability 31: 96–103. DOI 10.1016/j.cosust.2018.01.010.

Sanyal S, Routray J (2016) Social capital for disaster risk reduction and management with empirical evidences from Sundarbans of India. International Journal of Disaster Risk Reduction 19: 101–111. DOI 10.1016/j.ijdrr.2016.08.010.

Saxena S, Geethalakshmi V, Lakshmanan A (2013) Development of habitation vulnerability assessment framework for coastal hazards: Cuddalore coast in Tamil Nadu, India—A case study. Weather and Climate Extremes 2:48–57. DOI 10.1016/j.wace.2013.10.001.

Sharma R, Joshi P (2016) Mapping environmental impacts of rapid urbanisation in the National Capital Region of India using remote sensing inputs. Urban Climate 15: 70–82. DOI 10.1016/j.uclim.2016.01.004.

Urban Risk Management in South Asia, Launch of Global campaign on Making cities Resilient (2010). SAARC Disaster Management Centre, New Delhi.

Urbanisation in India: Integral part of economic growth, World Bank. (n.d) Retrieved from http://web.worldbank.org/archive/website01291/WEB/0__CO-22.HTM

Weinstein J (1991) Urban growth in India: Demographic and sociocultural prospects. Studies in Comparative International Development 26(4): 29–44. DOI 10.1007/BF02743761.

World Bank (2018) Disaster Risk Management Overview. Retrieved from https://www.worldbank.org/en/topic/disasterriskmanagement/overview

World Population Prospects: The 2017 Revision, United Nations, Department of Economic and Social Affairs. Retrieved from https://www.un.org/development/desa/publications/world-population-prospects-the-2017-revision.html on 11.01.2019

An Analysis of Night Shelters (Rain Basera) in the Context of Sustainable Development Goal 13 (Target 13.1)

Priya Akash Sondhi[a], Akash Sondhi[b] and Astha Mehta[c]

ABSTRACT: The waxing and waning numbers of homeless show a considerable increase with a proportionate necessity for more night shelters. It necessitates design thinking of the issue to be able to approach it in a scientific manner so that the rights enshrined in the Indian Constitution for the homeless, monitored keenly by the Hon'ble Supreme Court, reach the grassroot level as envisaged by the portals of justice of our country. It requires design thinking and empirical study about general awareness and administration of night shelters to be able to achieve the Sustainable Development Goal 13 (Target 13.1) which emphasises on strengthening resilience and adaptive capacity to climate-related disasters. The night shelters or Rain Baseras need to be considered as an important aspect of this agenda. This paper is based on the formulative study of the topic wherein Convenience Non-Probability Sampling was done by the authors for design thinking.

KEYWORDS: night shelter, Rain Basera, design thinking, homeless, shelterless

Introduction

Climate change is today's reality. Shifting weather patterns and extreme weather events have become a common phenomenon. The rain patterns and cold wave patterns have been disturbed resulting into increased vulnerability for the economically marginalised sections of society. The homeless who already have unfavourable and higher rates of many adverse health conditions are exposed even more to these shifting and extreme patterns and take far longer time to regain their strength after every extreme weather event. Thus, the existing inequalities will further deepen due to climate change.

The impact of this uncertainty and disturbance in weather patterns is far higher in India due to the high population density, low resilience and adaptive capabilities of marginalised sections. This is further intensified due to low access to resources. It affects the aged, sick, disabled, women and children depending upon the levels of vulnerability faced by them.

Night shelters or Rain Basera provide a pivotal dimension of resilience and adaptive capacity for the vulnerable sections of the society against cold wave and other vagaries of the weather. To make Rain Basera accessible, a mobile app has also been launched.

It is important to note that the international community has shared certain visions to address climate action under Sustainable Development Goal 13. These goals were set by the United Nations General Assembly in 2015 at the Paris Agreement; Indian Government has shown an earnest commitment to realise them.

In view of the above-mentioned propositions, the authors have done a study on the awareness, sufficiency and efficacy of the initiative, which is the call of the day. It brings out the challenges faced by actors

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and stakeholders, including the enabling government authorities, non-governmental organisations (NGOs), assisting the initiative and the homeless face varied challenges. In order to appreciate the research in a logical manner, the authors have divided this paper into the following parts: Part I – Theoretical Background, Part II – Research Methodology and Part III – Design Thinking, followed by Conclusions and Suggestions.

Part I: Theoretical Background

Night shelters were started first by Mr Booth as "The Salvation Army" in October 1889 in London (Waldo and Walsh, 1896). They were a charitable institution wherein poor persons would pass a night under the roof, either free of cost or upon payment of a fee (Walsh 1900).

In India, the Indian Government started an initiative called Rain Basera, with government departments responsible for them in early 1980s. Now in Delhi alone, the Delhi Urban Shelter Improvement Board is the authority responsible for the homeless with around 198 night shelters under them. The map of Rain Baseras is also available online.

Moreover, the twelfth Law Commission of India in 1990 had in its report on legislative protection of Slum and Pavement Dwellers[1] recommended that "Statutory protection should be extended to the pavement dwellers by providing that notwithstanding any provision contained in any local law for the time being in force, no person using a pavement for shelter or for sleeping or taking refuge shall be evicted there from unless the Commissioner of Police or his deputy authorised in this behalf has recorded his satisfaction in writing that it is essential to do so for either maintaining law and order or on the ground that public interest so demands having regard to some special circumstances or to deal with a situation calling for urgent action in this behalf" (lawcommissionofindia.nic.in).

This executive function has been keenly monitored by the judiciary. To begin with right to shelter was recognised as an important right though the magnitude of content of components of this right would depend upon the extent of economic development of the country (Francis C Mullin v U.T of Delhi, 1981). It was observed that the right to life guaranteed by any civilised society implies the right to food, water, decent environment, education, medical care and shelter. Shelter for a human being is not mere protection of life and limb (Chameli Singh vs State of U.P, 1996). Supreme Court also made it expressly clear that it is the duty of the state to provide right to shelter to the poor and indigent weaker sections of the society in fulfilment of the constitutional objectives and that right to residence and settlement is a fundamental right under Article 19(1)(e) (Ahmadabad Municipal Corporation v Nawab Khan Gulam Khan, 1997).

Later on, the judicial creativity and monitoring of the night shelters began with the famous "night shelter case", in the year 2001, wherein the co-relationship between hunger and deaths due to cold was examined by the Hon'ble Apex Court.[2] (Peoples Union for Civil Liberties v Union of India, 2010). A series of important Supreme Court orders followed which resulted into review of state-wise situation and issuing of directions.

The People's Union for Civil Liberties (PUCL) (night shelter) case was followed by a plethora of cases which are evident of the fact that rights of marginalised and poor get protected in a system where the judiciary plays an important role in upholding the spirit of the constitution. For example, the National Urban Livelihoods Mission was launched in 2013 under the "Scheme of Shelters for Urban Homeless" by the Government of India, Ministry of Housing and Urban Poverty Alleviation. Its progress is being monitored. Being dissatisfied with the progress of providing shelters and utilisation of the funds under it, the Hon'ble Apex Court formed a committee under the Ministry of Housing and Urban Poverty Alleviation to do physical verification of the night shelters and submit the report (E.R Kumar v Union of India, 2017). Interim stay was granted by the Delhi High Court to the closure of 38 temporary night shelters in Delhi till next hearing (S.K. Aledia vs DUSIB, 2018).

Thus, the executive and judiciary are playing their own important role to strengthen resilience and adaptive capacity of the marginalised homeless to climate-related disasters and attain the goal of Sustainable Development.

Moreover, in the evolutionary journey towards Sustainable Development, United Nation General Assembly in 2015 had put forth Sustainable Development Goals (SDGs): a collection of 17 global goals. The SDGs cover social and economic development issues including poverty, hunger, health, education, global warming, gender equality, water, sanitation, energy, urbanisation, environment and social justice. The SDGs are part of Resolution 70/1 of the United Nations General Assembly: "Transforming our World: the 2030 Agenda for Sustainable Development". SDGs are made action-oriented by 169 targets.

This study focuses on Rain Basera of SDG 13, Target 13.1. It emphasises on strengthening resilience and adaptive capacity to climate-related disasters. The night shelters or Rain Basera need to be considered as an important aspect of this agenda.

We also need to address the same in order to achieve these goals at the domestic level.

In view of the above-mentioned theoretic background, the authors proceeded with the following research methodology.

Part II: Research Methodology

Scope: Rain Basera are an important aspect of the welfare philosophy of the Indian state. We have Rain Basera functioning since around four decades. It is very essential to develop a deep insight into the level of satisfaction of the homeless about this initiative. It is equally important to understand the challenges faced by the authorities and the NGOs assisting them in the management of Rain Basera.

Rationale: Since Rain Basera are a part of the larger welfare goals of the state, a formulative study would generate inferences necessary for further research. This would aid other researches on the subject.

Objectives:

- To study the general awareness level of the homeless about Rain Basera.
- To study whether the homeless are satisfied with the administration of Rain Basera.
- To analyse the challenges faced by the authorities who run Rain Basera.

Hypotheses

The users of Rain Basera initiative are in general satisfied. They look forward to certain proactive steps from the governance for better functioning of the initiative.

Universe of the Study

The universe of the study is Delhi NCR. According to the National Capital Region Planning Board Act, 1985, total 23 districts of the adjoining states of Uttar Pradesh, Haryana and Rajasthan as well as the National Capital Territory of Delhi comprise the National Capital Region (NCR) of India.

Research Design

The research design is formulative in nature. The design has aided the authors in gaining deeper insight into the challenges in the initiative of Rain Basera and generates a hypothesis which will be helpful in a conclusive research. This research will provide direction in order to initiate more structured researches.

Collection of Data

The data of Rain Basera users was collected by the Interview method since most of the users of Rain Basera are uneducated. After interview a schedule was filed by the authors. Totally, 100 male and 100 female Rain Basera users were interviewed. Around 25 people belonging to authorities responsible for running Rain Basera and NGOs assisting them were also interviewed about the challenges faced by them.

Sample Design

Due to paucity of time the researchers have chosen Convenience Non-Probability Sampling. The choice of the authors resulted into every single unit in the sample not having an equal chance of getting selected. Convenience design was selected due to paucity of time. The choice was made for the convenience of the authors.

Sample Size

According to the 2011 Census, the population of Delhi NCR is 16,787,941. It consists of 8,987,326 males and 7,800,615 females. South Delhi had a population of 2,731,929, of which male and female were 1,467,428 and 1,264,501 respectively. It is 16.27 per cent of the Universe. South Delhi comprises the following nine divisions: Connaught Place, Naraina, Hauz Khas, Malviya Nagar, Vasat Kunj, Chattarpur, Okhla, Dwarka and Palam.

With this research methodology in mind, the authors proceeded with the following design thinking.

Part III: Design Thinking

Design thinking is an established problem-solving approach, which is well suited for problem with high level of uncertainty (Liedtka, et al., 2017). Though well intended, social projects such as Rain Basera are often complex in undertaking as they address socio-economic, cultural and regional diversity. The unique nature of design thinking approach depends on the deep understanding of the problem via user needs and then follows it up by matching the actual need with innovative solutions which are accepted by its intended user. It results in solutions which are frugal, ingenious and often avant-garde. To study the proposed objective the researchers decided to follow Stanford's model of design thinking (Plattner, 2018) The five-stage framework is presented in Figure 1:

- Empathise: understanding what challenges users/actors/stakeholder face by observing them and interacting with them.
- Define: developing a point of view to frame a problem to focus on.
- Ideate: generating multiple ideas for solutions.
- Prototype: building a prototype, minimum viable product.
- Test: solicit feedback about prototype from users, actors and stakeholders.

Phase I: Empathise

The actors and stakeholders for Rain Basera are shown in Figure 2. We interacted with the Rain Basera users, care takers, supervisors and NGO coordinators to understand the functioning of the Rain Basera and the problems they face. We approached people with a set of questions; interaction was in the form of semi-structured interviews, focused-group interviews and free-flow experience sharing.

The primary data collected was focused on (1) general information of the Rain Basera users, and (2) awareness-related question and administration-related question.

While asking these questions we also observed non-verbal cues such as their expressions on particular aspects. We noted the points where we observed expressions such as frowning, anger, displeasure and interest while interacting.

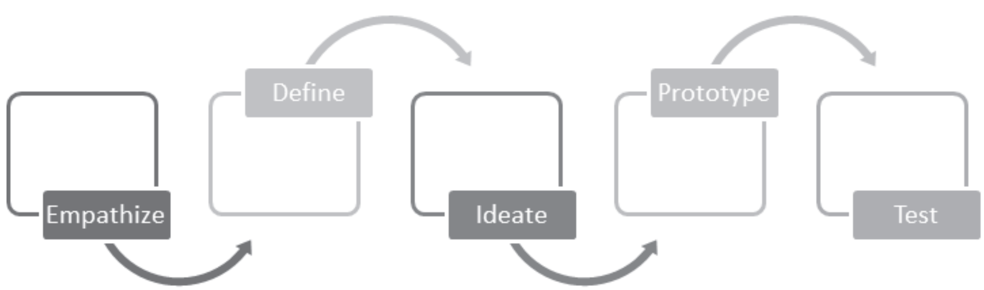

Figure 1: Design thinking framework

Figure 2: Rain Basera actors and stakeholders

Major Findings of the Research

The authors have divided major findings of the research into the following subparts: A. major findings among men, B. challenges among men, C. other observations among men, D. major findings among women, E. challenges among women, F. other observations among women and G. challenges faced by authorities.

The major findings among men and women regarding General and Awareness Information are shown in Table 1.

A. Major Findings Among Men Regarding Administration-Related Information

- Most of them are satisfied with general cleanliness in Rain Basera (94 per cent), bathroom sanitation (74 per cent), get blankets (100 per cent), proper ventilation (87 per cent), electricity (91 per cent), drinking water (64 per cent), behaviour of staff (92 per cent), medical assistance (95 per cent) safety of self (94 per cent) and safety of belongings (87 per cent).
- All of them feel that pavement dwellers do not use Rain Basera due to donations, alcoholism and drugs and disciplines enforced by the Rain Basera on them.
- All of them said that their entries are recorded in Rain Basera (94 per cent).
- Most of them felt that the administration does not stop people who are not poor and are needy from entering Rain Basera (9 per cent).
- Most of them find Rain Basera open when they visit them (98 per cent).
- Most of them feel that there is no unused place for more homeless people to sleep (67 per cent).

Table 1: Major Findings in Men and Women Regarding General and Awareness Information

RB Prominent Age Group	21–50 Years (42 per cent)	21–50 (50 per cent)
RB employment status (employed)	(42 per cent)	(39 per cent)
Native of	UP (30 per cent) followed by Bihar (24 per cent)	Bihar (44 per cent) followed by UP (24 per cent)
Family size in RB	4 family members using Rain Basera (42 per cent)	3 family members using Rain Basera (38 per cent)
Homeless since using RB since	10–14 years (41 per cent) 0–5 years (56 per cent)	0–5 (56 per cent) 0–5 years (68 per cent)
Obtained information about RB from	NGOs (60 per cent) followed by friends (25 per cent)	NGOs (48 per cent) followed by friends (32 per cent)
Suggest use of RB to other homeless	(93 per cent)	(96 per cent)
Socialise in RB	(91 per cent)	(95 per cent)

(*Continued*)

Table 1: (Continued)

RB Prominent Age Group	21–50 Years (42 per cent)	21–50 (50 per cent)
Not aware of nearby RB	(74 per cent)	(64 per cent)
Not aware of the RB Mobile App	(98 per cent)	(96 per cent)
Not able to guess how many RBs are there in Delhi	(85 per cent)	(92 per cent)
RB operate in summers and rain	(79 per cent)	(61 per cent)
Aware of the RB rescue teams	(89 per cent)	(84 per cent)
Feel that all RB are not permanent structures	(84 per cent)	(81 per cent)
Aware that they need not pay in RB	(97 per cent)	(100 per cent)
Not aware that DUSIB website displays RB in that area	(98 per cent)	(96 per cent)
Feel that RB might be used for people not poor	(87 per cent)	(92 per cent)
Feel that the homeless are aware of Rain Baseras	(96 per cent)	(93 per cent)

B. Challenges Among Men

- Rain Baseras have men with meagre or no source of income as a large majority of them are unemployed (40 per cent)
- Male only Rain Basera: men are living away from their families who reside in their native village.
- A large majority of men (60 per cent) use one or other form of addiction: alcohol, drugs, pan masala.
- A handful of Rain Basera men are originally from Delhi (20 per cent).
- A small number of Rain Basera men users own a rental home, but prefer to live in Rain Basera.
- The nature and culture of permanent and temporary Rain Basera are different. Majority of temporary Rain Basera men users are patients or runaways due to family discord.
- The perceptions of permanent and temporary Rain Basera users are different about the operation of Rain Baseras during summer and rain.
- A few users of temporary Rain Baseras are from other countries, like an Afghan citizen who was injured in a war came for his treatment to New Delhi during winter and stayed for over two months in two different temporary Rain Basera.
- Rain Baseras are used by people who are not poor, also demonstrating the need to study social disorganisation.

C. Other Observations Among Men

- The people residing near Rain Baseras or working near them are not able to tell their location.
- A region-wise segregation is observed in temporary and permanent. The inmates tell people belonging to other states to use different Rain Baseras.
- Absconding men both from Delhi and from other states find refuge in Rain Baseras.
- Teenagers and minor adults from middle income with family quarrels stay in Rain Basera.
- Students from villages who come to Delhi to write examination (written physical for police or defence) use Rain Basera for overnight stay for short duration.
- Most of the people do not use smartphones.
- Many permanent Rain Baseras do not have beds. Some government or private assistance is required.
- Temporary Rain Baseras have serious issues of bathroom, access to sanitation and ventilation: Nearby government-run bathrooms, toilets and urinals were locked in the night by the authorised contractor.

- Donations given by people to pavement dwellers and Rain Basera inmates need some norms.
- We need Rain Baseras during rains and heat wave also.
- Local shops near Rain Basera don't know about the purpose, function and intended use of Rain Basera. Local shops often give incorrect information about the location of Rain Basera.

D. Major Findings Among Women Regarding Administration-Related Information

- Most of them are satisfied with general cleanliness in Rain Basera (92 per cent), bathroom sanitation (82 per cent), get blankets (85 per cent), proper ventilation (76 per cent), electricity (93 per cent), drinking water (84 per cent), behaviour of staff (81 per cent), medical assistance (96 per cent), safety of self (92 per cent) and safety of belongings (89 per cent).
- All of them feel that pavement dwellers do not use Rain Baseras due to donations received by them.
- All of them said that their entries are recorded in Rain Baseras.
- Most of them felt that the administration does not stop people who are not poor and are needy from entering Rain Basera (82 per cent).
- Most of them find Rain Basera's open when they visit them (92 per cent).
- Most of them feel that there is no unused place for more homeless people to sleep (82 per cent).

E. Challenges Among Women

- Rain Baseras have single old women with meagre or no source of income (24 per cent).
- Some Rain Basera users are singe mothers with their children (38 per cent).
- Some Rain Basera user women are originally from Delhi (14 per cent).
- We must spread awareness about the Rain Basera Mobile App.
- The perceptions of permanent and temporary Rain Basera users are different about the operation of Rain Baseras during summer and rain.
- Rain Baseras are used by people who are not poor, also demonstrating the need to study social disorganisation.
- Heaters are required in most of the Rain Baseras.
- The people residing near Rain Baseras or working near them are not able to tell their location.
- The inmates tell people belonging to other states to use different Rain Baseras.
- Women suffering from domestic violence find refuge in Rain Baseras.
- Most of the people do not use smartphones. We must provide the services provided via app in a different manner like toll free number.
- Some Rain Baseras do not have beds. Some government or private assistance is required.
- Temporary Rain Baseras have issues of bathroom sanitation and ventilation.
- Donations given by people to pavement dwellers and Rain Basera inmates need some norms.
- We need Rain Baseras during rains and heat wave also.

F. Other Observations Among Women

- Some Rain Basera inmates also assist the rescue teams of the NGOs.
- Some Rain Baseras are assisting people in learning skills for better livelihood prospects.

G. Challenges Faced by Authorities

In order to understand the challenges of the authorities, the authors interviewed the authorities handling Rain Baseras. We located the following challenges:

- People prefer to sleep outside for donations.
- Need for some more facilities, for example, heaters.
- Lack of proper assistance from law and order machinery.
- Unruly behaviour of the inmates.
- Alcoholism and drug addiction.

Phase 2: Define

The next step for the authors was to develop a point of view based on our understanding after the interaction. Following were key observations after interaction with people. The authors did data collection to arrive at the following findings for the same.

The authors used the following steps for developing point of view statement:

- User: Residents are either labourers or unemployed and/or beggars, appreciate the sense of community provided in Rain Basera and want to earn sustainable livelihood.
- Need:
  - Residents of Rain Basera want to earn sustainable livelihoods, keep engaged, visit their native and want to have a place to keep their belongings secure.
  - Single mothers with multiple children are common place in the Rain Basera; they often practice begging on the road.
  - The Rain Basera NGO wants residents to be skilled and be employed. DUSIB and Rain Basera NGO wants people on the streets and in the open to come and live in Rain Basera. For temporary Rain Basera, access to drinking water, electricity, mobile phone charging points and well-functioning toilets were a critical needs. Also required were more in number and round-the-year operation of Rain Basera.
- Insight: If a mechanism is in place where Rain Basera residents especially women can work within Rain Basera and earn would result in outcomes to meet the needs of the user and can attract more roadside people to Rain Basera; an awareness and communication programme in place which can disseminate information about Rain Basera and discourage citizens from roadside donations can be an important step towards the anticipation purpose and function of Rain Basera.

Phase 3: Ideate

In this stage we appraised the point of view statement for challenges and brainstormed and prioritised the challenges. This was followed by exploring multiple solutions to challenges. A focus on unique solutions both on an urgent basis and in the near-future perspective was enumerated.

The authors considered six challenges: Table 2 presents multiple ideas we came up with unique solution to the prioritised challenges.

Table 2: Ideation Phase: Multiple Solutioning of Prioritised Challenges

Challenge	Solution
Drinking water in temporary shelters	• Extra water containers • More frequent water supply • User friendly app to report/alert water requirement and sanitation issues
Toilets in temporary shelters	• Engagement with agencies to provide access to sanitation and toilets • Coordinate with local police to ensure compliance of the functioning of the public toilets at all times • More government aid for mobile toilets
Opportunities for better livelihood in permanent shelters	• Skill development programmes • Working as micro enterprise • Mahila Grah Udyog Model
Unruly behaviour of Rain Basera users in both	• Appointment of more staff • Installing CCTV camera • Appointment of councillors
Ineffectiveness of DUSIB website for both	• Radio programmes • SMS push notifications to inform about Rain Basera and share link of DUSIB website and DUSIB App. • Set up of an interactive voice response (IVR) number
Pavement dwellers not using Rain Basera	• Influence pavement dwellers by puppet show model • Donation camps in Rain Basera • User-friendly app to alert control room about pavement dwellers

Phase 4: Prototype

The authors aimed to create the prototype based on innovation, sustainability, cost-effectiveness and time-bound implementation.

Innovation was brought in via a system-integration mindset, that is leveraging on existing system and process in place. Leveraging on existing government programmes of MSME and meeting the need of users to earn livelihood. The proposed creation of the Rain Basera brand and create products for domestic and home use aims to create sustainable livelihood. The financing of the initiative can be leveraged by government-supported initiatives for MSME and donation camps and endowments by CSR from companies. It was observed by the authors of the study that the NGO SPYM focused on managing the Rain Basera with full accountability and ownership; the staff took ownership and maintained a positive attitude towards the task at hand. With this reality test the authors believe that the Rain Basera Sustainable Livelihood Programme is pragmatic and feasible.

Solutions identified in the ideation phase were selected by discretion to create a prototype solution. The solutions were further prioritised based on urgency and importance and low- priority, low-importance solutions were ignored. Further high-priority solutions were proposed to be implemented in phase-wise manner; the authors propose two steps: Step 1 and Step 2.

Step 1 (0–3 months) Rain Basera (temporary) rapid intervention

- Water containers' numbers to be assessed and provided in line with the number of users in temporary Rain Basera.
- Engagement with Sulabh International or a similar agency to manage portable toilets at temporary Rain Basera.
- Helpline mechanism to alert drinking water issues, electricity and sanitation issues such as leaking toilets in temporary Rain Basera.

Rain Basera awareness and better management programme

- DUSIB and coordinating NGO to drive radio campaign directed towards citizens to create awareness and purpose of Rain Basera. Citizens on the roads to be discouraged for giving alms on the street. Donation camps be held at Rain Basera. Citizens wanting to donate to be invited and support skill development programmes for Rain Basera residents.
- Double staff to be appointed at Rain Basera to check and control unruly behaviour.
- CCTV camera to be installed immediately at sensitive Rain Basera where altercations have been reported earlier. Camera to be extended at other Rain Baseras.
- DUSIB to explore other mechanisms such as SMS push notification.

Step 2 (3–6 months and beyond) Rain Basera Skill Development and Sustainable Livelihood Programme

- Women-centric skill development on the lines of Barefoot College Tiloniya (Night School Model) to be put in place.
- Unique initiatives such sanitary napkin production unit to be extended and augmented to niche products such as diapers.
- Skill development to focus on well-made quality products and not cheap products. Coordinating NGOs such as SPYM and others to create a brand and take pride for Rain Basera-manufactured products.
- Barefoot College Tiloniya uses puppet show type model for as and education practice and also to create awareness and communication. A similar model would be feasible in sharing the overall simplified message of Rain Basera to the people on streets, passing citizens and local business about the importance of Rain Basera and various programmes within it.
- The puppet show programme should be leveraged to create awareness on family planning, health and hygiene, drugs and alcoholism rehabilitation programmes.

Phase 5: Test

As per the design thinking framework, we tested the proposed solutions via feedback on the proposed programmes from the involved actors in Rain Basera from the point of view of user acceptance.

Rain Basera (temporary) rapid interventions

The supervisors of the temporary Rain Basera confirmed that it is possible for him to arrange extra water containers and more frequency of water supply. They also demonstrated proactiveness by informing the coordinating NGO on leaking toilets.

Rain Basera awareness and better management programme

The coordinating NGO realised that the current method of putting up pamphlet is limited in creating the awareness of the programme. They acknowledged that a radio campaign can be effective in sharing the message about purpose of the Rain Basera.

Skill Development and Sustainable Livelihood Programme

When we approached our users, the NGO and the authorities they were eager to implement solutions to their challenges as an opportunity to upgrade themselves. However, some of them had queries about the timeframe in which the solutions can be implemented and whether the government would be willing to fund the same.

Based on our user feedback we revised the solution process flow as follows:

- **Drinking water issue in temporary shelters:** Extra water containers.
- **Toilets in temporary shelters:** Co-ordinate with local police to help in using government-sponsored toilets.
- **Opportunities for better livelihood:** SPYM and other NGOs operating Rain Basera to explore the option of registering Rain Basera as "Micro Enterprise" and build capability of the Rain Basera under skill development, finance and market-access programmes of Medium, Small and Micro Enterprise Government of India.
- **Unruly behaviour of inmates:** Appoint more staff.
- **Ineffectiveness of DUSIB website:** Proposed a unique Radio programme "Kambhal ki Kahani Rain Basera ki Jubani", The Story of a Donated Blanket.
- **Pavement dwellers not using Rain Baseras:** The Rain Basera programme uses a mobile app which any citizen can use to alert Rain Basera control room about any person on the road who needs help.

Conclusion and Suggestions

In general, the Rain Basera users are happy with the initiative and the administration of Rain Baseras. There are certain challenges which can be attributed to the nature of the stakeholders involved. The authors considered six challenges out of our formulative study for the purpose of design thinking. Based on the design thinking framework and methodology, understanding the need of the users and considering the perspective of the stakeholders, the authors came up with a set of unique solutions. The proposed solutions were validated with the stakeholders and users. While no solution was rejected the authors considered the inputs received from the stakeholders and iterated the proposed solution. The inputs received on the time frame of implementation and finance part were revised to address the inputs.

Acknowledgements

The authors would like to acknowledge the Rain Basera users for sharing their lives and experiences. They are also appreciative of one and all members of SPYM NGO who enabled the interview process and also earnestly supported the altruistic cause by keeping the vulnerable safe in the ambit of Rain Basera.

Notes

1. Report no 138. Please see: <http://lawcommissionofindia.nic.in/101–169/Report138.pdf>
2. This also brought into light the importance of proper implementation of directions of the Hon'ble Supreme Court of India (in CWP 196/2001) with regards to the food schemes on the food including the ICDS, MDMS, PDS, NREGA, Antodaya Yojana, NOAPS, NFBS and NMBS in the state of Delhi. <http://delhishelterboard.in/case_study_2014_15/Volunteer-ID-12714.pdf> accessed 29 November 2018

References

Ahmadabad Municipal Corporation v Nawab Khan Gulam Khan AIR (1997) SC 152

Chameli Singh vs State of U.P (1996)2SCC 549

E.R Kumar v Union of India (2017) 12 SCC 792

Francis C Mullin v U.T of Delhi (1981)1 SCC 608

http://lawcommissionofindia.nic.in/101–169/Report138.pdf

Hasso Plattner, An Introduction to Design Thinking Process Guide, https://dschool-old.stanford.edu/sandbox/groups/designresources/wiki/38873/attachments/74b3d/ModelGuideBOOTCAMP2010L.pdf, accessed on 3 January 2019.

Jeanne Liedtka, Randy Salzman and Daisy Azer(2017) Design Thinking for the Greater Good Innovation in the Social Sector, Columbia University Press

Peoples Union for Civil Liberties v Union of India (2010)5 Supreme Court Cases 423

S.K.Aledia vs DUSIB (2017) SCC OnLine Del

Waldo F J, and Walsh D (1896) A Discussion on Night Shelters. The British Medical Journal 2: 323–324

Walsh D (1900) The Legal Position of Salvation Shelters. Charity Organisation Review 7: 72–80

Waste Management for "Resilient Cities": Comparison of Pre- and Post-disaster Concerns

Bindu Aggarwal[a] and Anil K. Gupta[b]

ABSTRACT: To date, the trend towards urbanisation has been accompanied by greater pressure on the environment and increased demand for basic services. Due to their high concentration of people, infrastructures, housing and economic activities, cities are particularly vulnerable to the impacts of climate change and natural disasters. One of the targets of SDG-11 calls to reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management. Most of the wastes originate from human activities.

Disasters, whether natural or anthropogenic or technical ones, are known to result in magnificent quantities of disaster waste generation. Floods and cyclones mix up materials from anything in their path, causing various kinds of debris—from hazardous to non-hazardous, biodegradable and recyclable to non-recyclable waste to be combined into piles. This can cause mounds of debris to deteriorate rapidly making recovery and recycling more challenging, in addition to posing health and environmental risks. Disaster waste is far more complicated than ordinary waste due to presence of toxins, inert and infectious substances often difficult to segregate. Mishandling of disaster waste or delayed disaster waste management post any disaster leads to environmental emergency.

The paper reviews accelerated need to address the issue of disaster waste management post-disaster by strengthening the existing solid waste management systems as well as developing disaster waste management plan and building local capacities aiming at city resilience building, along with a comparison of pre- and post-disaster scenarios with respect to waste management system and infrastructure resilience in cities.

KEYWORDS: urban resilience, resilient city, solid waste management, disasters & disaster waste

Introduction

The safe disposal of solid waste is critical for public health, and is especially true during an emergency. Not only will existing collection and disposal systems be disrupted, but there will be extra waste caused by the emergency itself. Initially, for camps of displaced people or refugees and similar new sites, there will be no arrangements in place at all. If solid waste is not dealt with quickly, serious health risks will develop which will further demoralise the community already traumatised by the emergency. This paper highlights the key issues to consider in managing solid waste during and shortly after a disaster.

What is Solid Waste?

The term "solid waste" is used to include all non-liquid wastes generated by human activity and a range of solid waste materials resulting from the disaster, such as,

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- general domestic garbage such as food waste, ash and packaging materials;
- human faeces disposed of in garbage;
- emergency waste such as plastic water bottles and packaging from other emergency supplies;
- rubble resulting from the disaster;
- mud and slurry deposited by the natural disaster;
- fallen trees and rocks obstructing transport and communications.

Urban environmental services in developing countries are being severely affected due to rapid growth of cities, increase in poverty, increasing urban population density and the limited capacity of municipal authorities. Such deficiencies in primary services which include management of excreta, drainage, collection and segregation of solid waste pose acute health hazard for residents and constitute a major environmental threat. Persistent health hazards owing to insufficient hygienic conditions not only directly affect the poorest fraction of the population but also critically influence public goods such as air, water and soil, thus affecting the rich as well as the poor. Such circumstances pose hindrance to reduction of poverty and the advancement of human dignity (WHO et al. 2000; Beier et al. 1976).

Disaster Waste Management and Its Link to the Sustainable Development Goals

Under present circumstances the influence of disaster to the community blocks the procedure of government to achieve the SDG goals and targets by 2030. Past experiences of disasters inform us that large volumes of waste generated post-disaster are itself a revenue-generating resource if managed correctly and a burden if not addressed sustainably in time. The three important pillars of sustainable development namely social, economic and environment are negatively influenced by disaster waste. At the same time disaster waste if managed and handled properly will beneficially impact the six essential elements of SDG: dignity, people, prosperity, planet, justice and partnership.

Table 1: Linkages between Sustainable Development Goal and Disaster Waste Management

SDG Goal	Linkage Status	Linkage Detail
#1. End poverty in all its forms everywhere	Direct	Prevent exposure of poor and vulnerable communities to hazardous disaster waste. Put disaster waste to planned disposal creating income-generation opportunities.
#2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	Direct	Production of organic manure from disaster organic waste and prevent hazardous waste to find its way into precious agricultural land. Production of construction bricks from disaster waste and avoid use of fertile soil for preparing construction bricks.
#3. Ensure healthy lives and promote well-being for all at all ages	Direct	DWM will prevent the exposure of people, community and natural resources to hazardous waste.
#4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Indirect	Inclusion of sustainable waste management education during and post-disaster in the national curriculum can bring lifelong learning opportunity.
#5. Achieve gender equality and empower all women and girls	Indirect	Exposure of women and girls to hazardous waste will be prevented and they can be involved in recycling of disaster waste hygienically, thereby generating income.
#6. Ensure availability and sustainable management of water and sanitation for all	Direct	Surface and ground water will remain safe from any contamination as the hazardous waste is disposed safely.

(*Continued*)

Table 1: (Continued)

SDG Goal	Linkage Status	Linkage Detail
#7. Ensure access to affordable, reliable, sustainable and modern energy for all	Direct	Use of waste in generating energy, thereby reducing waste volume and touching waste to energy.
#8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Direct	Utilisation of 3Rs in solid waste management will generate employment.
#9. Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation	Direct	Derive and develop construction material from disaster waste.
#10. Reduce inequality within and among countries	Indirect	Adopting inclusive approach in job placement for waste recycling leading to community empowerment.
#11. Make cities and human settlements inclusive, safe, resilient and sustainable	Direct	Adopting disaster waste management techniques like recycling and reduction to make cities sustainable.
#12. Ensure sustainable consumption and production patterns	Direct	Producing beneficial sustainable products from waste like organic manure, energy, construction material etc.
#13. Take urgent action to combat climate change and its impacts	Direct	Poor waste management has been identified as producer of greenhouse gases (GHG); however, if managed judiciously GHG production can be arrested and related climate change can be avoided.
#14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	Not applicable	N/A
#15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land degradation and half biodiversity loss	Direct	Hazardous waste will be managed properly avoiding degradation of terrestrial ecosystem.
#16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	Indirect	In the presence of safe waste management plan community will live safely in healthy environment. Involvement of community and government in waste management will lead to ownership of waste management exercise and make them accountable.
#17. Strengthen the means of implementation and revitalise the global partnership for sustainable development	Direct	Global partnership and sharing of techniques for waste management will boost the economy and contribute to sustainable development.

The Objective of Managing Solid Waste

The sphere standards provide that people should be able to live in an environment that remains uncontaminated by solid waste, including medical waste, and have the procedures in place to dispose of their domestic waste conveniently and effectively.

Pre-disaster Urban Challenge

Two factors – rapid urbanisation and growth of population in cities of developing countries – overwhelm the capacity of most municipal authorities to manage municipal solid waste. According to a survey conducted by United Nations Development Programme under which 151 mayors of cities from around the world were surveyed, it was found that the second-most serious problem that city dwellers face (after unemployment) is improper solid waste disposal (UNDP 1997). Typically one- to two-thirds of the solid waste that is generated remain uncollected. Local factors that vary from one place to an other place must be given due importance in the design of a SWM system. They are described in the following sections.

Waste Amount and Composition

The suitability of vehicle and treatment option to be utilised for waste transport and treatment is determined by quantity and composition of waste.

Access to Waste for Collection

It becomes difficult for various means of transport to access waste sources owing to width, slope, congestion or surface of approach roads. Those hindrances are visible in unplanned settlements, such as slums, and thus impact the selection of equipment.

Awareness and Attitudes

The entire SWM system is predominantly affected by public awareness of and attitudes towards waste. Public awareness and participation influence all steps in SWM—from storage of waste at household level to waste segregation, recycling, frequency of collection, littering amount, willingness to pay for services and opposition to the siting of treatment and disposal facilities.

Institutions and Legislation

Institutional issues involve existing and forthcoming legislation and the extent to which laws are implemented.

Urbanisation and Solid Waste Generation in India

Generation and Collection

MSW has become an acute problem in India due to rapid urbanisation and uncontrolled growth rate of population. Table 2 depicts per capita waste generation as per population size and its growth during a decade (Annepu, 2012).

Various studies have shown positive findings in respect of responsible behaviour of small towns towards generation rate of MSW (Bhide & Shekdar, 1998; Kansal, 2002; Kansal, Prasad, & Gupta, 1998; Rao & Shantaram, 1993). A comparative study on MSW generation in some states of India in years 2000 and 2011 is depicted in Table 3.

Findings of FICCI survey show that MSW disposal at dumpsite varies from 16 to 100 per cent, like in Kozhikode it is as low as 16 per cent and in Greater Mumbai it is 100 per cent (CPCB, 2013; FICCI, 2009).

Table 2: Per Capita Waste Generation Rate

Population Size	Waste Generation*(Kg/capita/day)	Waste Generation**(Kg/capita/day)
>2,000,000	0.43	0.55
1,000,000–2,000,000	0.39	0.46
500,000–1,000,000	0.38	0.48
100,000–5,00,000	0.39	0.46
<100,000	0.36	–

Source: CPCB Report (2000b) and calculated from R.K.Annepu (2012)***

Table 3: Statistics of MSW Generated in Different States of India

S. No.	States	Municipal Solid Waste (TPD) 2000	Municipal Solid Waste (TPD) 2009–2011	Collected (TPD) 2009–2011	Treated (TPD) 2009–2011	Growth (per cent)
1.	Andhra Pradesh	4376	11,500	10,655	3656	163
2.	Assam	285	1146	807	73	302
3.	Delhi	4000	7384	6796	1927	85
4.	Gujarat	NA	7329	6744	873	–
5.	Karnataka	3278	6500	2100	2100	98
6.	Kerala	1298	8338	1739	4	542
7.	Madhya Pradesh	2684	4500	2700	975	68
8.	Maharashtra	9099	19,204	19,204	2080	111
9.	Manipur	40	113	93	3	182
10.	Meghalaya	35	285	238	100	713
11.	Orissa	655	2239	1837	33	242
12.	Punjab	1266	2794	NA	Nil	121
13.	Puducherry	69	380	NA	Nil	451
14.	Rajasthan	1966	5037	NA	Nil	156
15.	Tamil Nadu	5403	12,504	11,626	603	131
16.	Tripura	33	360	246	40	991
17.	Uttar Pradesh	5960	11,585	10,563	Nil	94
18.	West Bengal	4621	12,557	5054	607	172

Source CPCB (2000b, 2013)

Table 4 Change in Composition of Municipal Waste with Time (in per cent)

Year	Biodegradables	Paper	Plastic/rubber	Metal	Glass	Rags	Others	Inert
1996	42.21	3.63	0.60	0.49	0.60	–	–	45.13
2005	47.43	8.13	9.22	0.50	1.01	4.49	4.02	25.16
2011	42.51	9.63	10.11	0.63	0.96	–	–	17.00

Source: Planning Commission Report

Solid Waste Management Practices and Challenges in India

Municipal Solid Waste Rules (MSWR) govern MSWM in India. However, mostly ULBs lack action plans for execution and enactment of the MSWR (CPCB Report, 2013). It is unfortunate that no city in India can exhibit 100 per cent segregation of waste at household level and only 70 per cent waste is collected on average. Only 12.45 per cent of collected waste is disposed of scientifically (CPCB Report, 2013). A survey of important parameters of MSWM practice followed in India is detailed below.

Lack of Segregation

There is lack of organised and scientifically planned segregation of MSW either at household level or at community bin (Kaushal, Varghese, & Chabukdhara, 2012). Further due to improper handling the segregated constituents got mixed up again during process of transportation and disposal (CPCB Report, 2013).

Collection

Waste generated by houses, street sweeping and commercial sectors is usually collected into communal bins (Kumar et al., 2009).

Reuse/Recycle

Optimal recycling is impossible as proper segregation of waste is lacking (Pattnaik & Reddy, 2010).

Transportation

Bullock carts, hand rickshaws, compactors, trucks, tractor, trailers and dumpers are used in India for transportation of waste. Trucks having 5–9 tonnes capacity are used without adequate cover system in small towns. Among other modes of transportation, stationary compactors, mobile compactors/closed tempos and tarpaulin-covered vehicles are used and about 65, 15 and 20 per cent of waste are transported through these vehicles, respectively (Joseph, 2002).

Disposal

Unscientific disposal of MSW is observed in villages and towns of India. The current scenarios for MSWM for 59 cities have been indicated in Figure 4 (Kumar et al., 2009). The following disposal practices are in use in hierarchy.

Open dumping: In India, MSW generated is usually directly disposed in low-lying areas in routine way violating the practices of sanitary landfilling (Lo, 1996; Mor, Ravindra, Dahiya, & Chandra, 2006).

Landfilling: Landfilling would continue to be an extensively accepted practice in India. According to CPCB, 2013 report, till date, India has 59 constructed landfill sites and 376 are under planning and implementation stage. Apart from this, 1305 sites have been identified for future use.

Landfill gas-to-energy plants: From landfills mainly methane (CH_4) and carbon dioxide (CO_2) gases are produced (Barlaz, Ham, & Schaefer, 1990; Reinhart, McCreanor, & Townsend, 2002).

Biological treatment of organic waste: The waste generated in India has more organic content—about 50 per cent—as compared to 30 per cent generated by developed countries. Following composting methods are commonly adopted in India:
Aerobic composting.
Vermi-composting.
Anaerobic digestion.

Table 5: Number of Composting/Vermin Composting Plants in Some States

State	Number of Plants (Composting/ Vermicomposting)	State	Number of Plants (Composting/ Vermicomposting)
Andhra Pradesh	32	Madhya Pradesh	4
Chhattisgarh	15	Maharashtra	125
Delhi	3	Meghalaya	2
Goa	5	Orissa	3
Haryana	2	Punjab	2
Gujarat	86	Rajasthan	2
Himachal Pradesh	13	Tripura	13
Karnataka	5	Uttarakhand	3
Kerala	29	West Bengal	9

Source: CPCB(2013)

Table 6: Number of Energy Recovery Plants in Some States

State	No. of RDF plants/ Waste to Energy Plant (PP)/Biogas (BG)	State	No. of RDF plants/ Waste to Energy Plant (PP)/Biogas (BG)
Andhra Pradesh	3-RDF, 4 PP	Delhi (UT)	1-RDF, 1 PP
Chandigarh (UT)	1-RDF	Gujarat	2-RDF
Chhattisgarh	1-RDF	Kerala	2-BG
Maharashtra	19-BG		

Source CPCB (2013)

Thermal Treatment

Currently, there is no large-scale working MSW incinerator in India (Sharholy et al., 2007).

Gasification is also one of the thermal treatment techniques (Ahsan, 1999; Sharholy et al., 2007). Refuse-Derived Fuel (RDF) is another upcoming technology; status of RDF plants in India is presented in Table 6.

Public–Private Partnership in MSWM in India

In India, the PPP mode is still in its nascent stage and there is no success story under MSWM cities (Hanrahan, Srivastava, & Sita, 2006).

Contribution of Rag-Pickers in SWM in India

Even though rag-pickers save almost 14 per cent of the municipal budget annually, their role is largely unrecognised and they are generally deprived of the right to work (Chintan NGO report). According to an estimate, the rag-pickers reduce up to 20 per cent load on transportation and on landfill (Pappu et al., 2007).

Post-disaster Waste Management

Currently there is absence of training among communities to manage disaster waste and when disaster strikes a community is unable to utilise their available resources and capacities to deal with waste. They are not aware of various steps of disaster waste management, namely segregation, recycling, composting, combustion and final disposal, and are unable to opt anyone of these (EPA 2008).

Disaster Waste Management Practices Followed during Previous Disasters

Hurricane Katrina is known to have generated 90.3 million m^3 of disaster waste in America and is known to be the most expensive natural disaster in history of America. Thankfully, Federal Emergency Management Agency (FEMA) realised the requirement of technical and scientific delivery of waste management and handed over the job of waste management to US Army Corps of Engineers (USACE). USACE exhibited swift results and removed more than 15.1 million m^3 of disaster waste from 16 southern counties. This operation was continued for 12 months from September 2005 to September 2006 (Brandon et al. 2011).

Post-Katrina Dell Computer and Best Buy partnered with Environmental Protection Agency (EPA), the states and local governments to increase collection and safe recycling of computers and related electronic equipment, including monitors, printers, computer peripherals, multifunction machines, fax machines, scanners, DVD players, notepads, laptops, keyboards, mouse, radios, mobiles, disks and speakers, that were wrecked by impacts of Hurricane Katrina. This effort resulted in recycling of more than 220,000 pounds of electronic debris (EPA 2008).

San Diego County experienced two wildfires in October 2003 which caused destruction of 6000 structures, destroyed 4000 vehicles and burned 400,000 acres of land. It generated as high as 128,000 tonnes of debris. Out of this 128,000 tonnes 60 per cent of waste in the form of concrete, metal and vegetative debris amounting to 74,000 tonnes was recycled. Recycling lowered the demand for landfill site and consequently 185,000 cubic yards of landfill space were preserved (County of San Diego Debris Removal and Recycling Programs for the 2003 Cedar & Paradise Fires Final Report 2005).

Another situation is from Escambia County, Florida, which was hit by Hurricane Ivan on September 15, 2004. It was accompanied by wind velocity exceeding 130 miles per hour. Within a period of 12 hours ten million cubic yards of disaster waste were generated and required immediate handling. Escambia County successfully diverted more than half of the debris from disposal in landfills and recovered more than 90 per cent of the displaced beach sand. Escambia County opted to dispose vegetative waste in a manner which generated revenue through export to Italy, helped in land reclamation, used as a raw material in paper mill and generated energy through incineration and preserved 6.5 million cubic yards of landfill space. Almost 60 per cent of vegetative waste was exported to Italy to be used as biomass for energy generation, 15 per cent of it was sold to paper mills, 15 per cent was used as landfill cover; and 10 per cent was incinerated on-site in air curtain incinerators (EPA 2008).

Post-earthquake in January 1994, city of Los Angeles depended on recycling for managing disaster debris. City staff recognised the fact that recycling would reduce the requirement of landfill area and stabilise the economy through recycling. A request was made to FEMA to adopt recycling as the most favoured methodology of disaster waste management. Subsequently help was sought from private sector and business contracts were established successfully to recycle the waste. Within six months 56 per cent of the waste generated by earthquakes which amounted to 1.5 million tonnes (EPA 2008).

Promoting Green Response for Resilient Cities

The following six steps are suggested for minimal impact on environment and restoration of normalcy:

- Hazardous substances: Early identification of all sources of acute risk (such as chemical spills from damaged infrastructure) is strongly suggested. Rapid assessment and advice is rendered by the Joint UNEP-OCHA Environment Unit during emergency. It is also suggested to restrict access until clean-up measures can be taken.
- Emergency waste management: Shortlist emergency waste disposal sites involving local authorities to prevent contamination of water sources and agricultural land, disease vectors and odours. Proper risk assessment is advised before

burning waste, especially in the case of plastics. Healthcare and any other forms of hazardous waste must be disposed of using suitable methods, for example, steam sterilisation (autoclaves).

- Sanitation: Consider locating latrines downstream of wells, at least 30m from groundwater sources and at least 1.5m above the water table. Take care of up- and down-stream impacts of water use and sanitation, as well as its progressive influence on a watershed.
- Refugee IDP camps: Try to keep camp populations' size below 20,000 and locate camp sites at least 15km from ecologically sensitive areas and neighbouring camps. Avoid deforestation to set up camp and try to use recycled construction material. Proper IEC be done on 3 Rs: "Reduce, Re-use and Recycle" of waste management in camps.
- Transport: Air pollution and fuel consumption can be reduced considerably by using maintained vehicles and ecofriendly driving techniques. Explore possibilities to choose cleaner fuels and fuel-efficient, low-emissions vehicles to minimise carbon emissions. Storage of waste oil is suggested in plastic drums or waste oil is properly disposed of or taken back to its source.
- Green procurement: Environmental impact of humanitarian operations can be reduced by smart procurement decisions: Opt for goods with the minimum possible packaging, especially containers that can be reused or recycled. Purchase materials from local or national markets to minimise travel miles and carbon emissions and prefer recycled materials. Choose vendors with certified safe and sustainable production practices, in particular for forest products, water supply, metals and plastics.

Disaster Waste Planning and Management Components

A number of components need to be considered in planning for disaster waste management. These include the following:

Organisational Coordination

To facilitate organisational coordination, the following steps should be taken:

- Define intradepartmental relationships, designate a debris manager and establish a debris "team".
- Outline and evaluate potential for specific disaster events and develop functional checklists by disaster for debris manager and team.
- Become familiar with emergency plans, procedures and the Standardised Emergency Management System.
- Identify local, state and federal agencies involved in disaster debris management.

Waste Assessment

Pre-disaster Assessment

To facilitate pre-disaster waste assessments, the following steps should be taken:

- Develop local checklists of available resources.
- Conduct a disaster event analysis and waste characterisation analysis.
- Identify temporary storage sites.
- Identify end-uses and markets.
- Identify facilities and processing operations.
- Identify processing techniques and barriers.
- Identify processing equipment needs.
- Determine contract needs.
- Review mutual aid agreements with neighbouring districts and cities.
- Identify labour needs.
- Review local ordinances.

Post-disaster Assessment

In addition to the issues mentioned above under pre-disaster assessment, post-disaster assessments include the following:

- Waste identification: geographic presence of waste through governmental sources, GIS, news, local sources and implementing agencies, as well as

selection of geographic area to be included in the waste plan.
- Waste characterisation: quantification, composition and quality of the identified waste streams and dumps/landfills through site visits and wastes sampling/analysis, and collated on "waste maps".
- Capacity assessment: evaluation of institutional and operational capacity including personnel, machinery, recycling and lifetime of disposal facilities as well as in-country waste management expertise. Local community interest in waste management issues to be included in this assessment as well as issues surrounding livelihoods.
- Risk assessment: in accordance an assessment of the risks associated with each waste stream and/or dump/landfill site in order to allow for proper handling, processing and disposal.
- Prioritisation: each of the identified waste streams and/or waste dumps/landfills is given a ranking (e.g., emergency, medium term and long term) based on the hazard risk assessment, and taking into account the reconstruction plans as well as general sustainability of the proposed interventions.

Development of Plan

To facilitate the development of a plan, the following steps need be taken:

- Make disaster waste management programmes a priority.
- Become familiar with national and local federal debris removal criteria and guidelines.
- Develop a debris removal strategy.
- Identify project scope, set programme goals and identify labour needs.
- Identify processing equipment needs and determine method of operation.
- Adapt programme length and review funding options.
- Establish a public information programme.
- Develop monitoring and enforcement programme.
- Pursue regional coordination and set up a simulation and training programme.

Temporary Storage Sites

To facilitate the identification and designation of temporary storage sites for disaster wastes, the following steps need to be taken:

- Determine need for facilities.
- Develop criteria to evaluate potential sites.
- Identify temporary storage sites.
- Consult with local solid waste facility operators and local cleansing departments regarding establishment of temporary storage or processing areas.
- Identify permits or variances if needed.
- Perform environmental review of site.
- Prepare a site development and operation plan.
- Prepare inspection and site management guidelines.
- Prepare a site restoration plan to return it to its original state.

Kerbside Pick-Up Programme

To facilitate an effective kerbside pick-up programme, the following steps need to be taken:

- Identify/estimate the quality and quantity of material to be picked up.
- Determine processing and facility needs.
- Identify labour and equipment needs.
- Secure programme funding in advance.
- Select method to locate kerbside waste.
- Determine method of implementation, particularly in the use of everyday waste collection systems for the purpose.
- Identify temporary storage areas.
- Identify/establish markets for collected materials.
- Develop public information programme/strategy, including the time period for collection, waste categories to be collected etc.
- Develop monitoring and enforcement programme.

Building Demolition

Besides buildings that have actually collapsed, a number of standings, but damaged buildings deemed unfit for habitation and use will have to be demolished and cleared before reconstruction can commence.

Debris Processing and Separation/Segregation

The first key action relates to the segregation of wastes to remove potential hazardous wastes, particularly those that are chemical, asbestos, clinical or carcasses wastes. These will have to be temporarily stored before it can be disposed or properly treated. Similarly, scrap metals such as steel, copper, aluminium etc. need to be segregated so that it can be effectively recycled. Other types of wastes need to be stockpiled temporarily, before they can be effectively and properly processed. For example, vegetative matter can be either shredded and composted (for soil conditioning) or carbonised (for use as charcoal).

Recycling and Disposal

To facilitate proper recycling and disposal the following lists of actions need to be taken:

- promote recycled-content products with public works personnel;
- encourage RCP selection;
- assist manufacturers with financing or assistance with permits if they are expanding or in start-up phase; and
- encourage separation and recycling of construction waste at new construction sites.

References

Basnayake, B.F.A., Chiemchaisri, C., Visvanathan, C., 2006. Wastelands: clearing up after the tsunami in Sri Lanka and Thailand. Waste Manag. World. March–April 2006, pp. 31–38.

Brandon et al. (2011) A Case History Study of the Recycling Efforts from the United States Army Corps of Engineers Hurricane Katrina Debris Removal Mission in Mississippi Engineer Research and Development Center, US Army Corps of Engineers.

Da Zhu etal The world bank (2008). Improving Municipal Solid waste Management in India. A sourcebook for policy makers and practitioners.

Environmental Protection Agency (2008) Planning for Natural Disaster Debris (Available online http://wwwepagov/CDmaterials/pubs/pnddpdf

Environment and Humanitarian Action Network. Environment and Humanitarian Action in the age of global reform agendas. Background Document to the nexus dialogue. http://www.eecentre.org/wp-content/uploads/2017/10/Backgroundconcept.pdf

Federal Emergency Management Agency, "Public Assistance Debris Management Guide," FEMA 325, July 2007, http://www.fema.gov/government/grant/pa/demagde.shtm#5.

http://www.eecentre.org/about-eec/

http://www.eecentre.org/wp-content/uploads/2017/11/2-Joint-Statement-Feb2017.pdf

IDRIM (2015). Climate and Disaster Resilient Smart Cities.

Joint UNEP OCHA Environment Unit 2009. Environmental Emergencies learning from multilateral response. https://www.unocha.org/sites/unocha/files/EnvEm_LearningFromMultilateralResponse.pdf

Joshi and Ahmed (2016) Status and Challenges of Municipal solid waste management in India: A review. Cogent Environmental Science.

Karunasena et al. (2012). Approaches for capacity building for disaster waste management : https://www.researchgate.net/publication/304902748.

Kaseva and Mbuligve (2005). Appraisal of solid waste collection following private sector involvement in Dar es Salaam City, Tanzania. Habitat International.

Kobayashi Y (1995) "Disasters and the problems of wastes" International Symposium on Earthquake Waste, 12–13 June, Osaka Shiga: Japan,6–13

Lindell M L and Prater C S (2003) "Assessing community impacts of natural disasters" Natural Hazards review 4(4):176–185

Perera K L S (2003) "An overview of the issue of solid waste management of Sri Lanka" 3rd International conference on environment and health, 15–17 December 2003, India Chennai: University of Madras :46–352

ProAct Network and Groupe URD 2014. Environment and Humanitarian Action Increasing Effectiveness, Sustainability and Accountability A Study Undertaken For The Joint UNEP/OCHA Environment Unit Version 1

Shaw R (2006) "Indian Ocean tsunami and aftermath: need for environment-disaster synergy in the reconstruction process" Disaster Prevention and Management 7(1):5–20

Shekhar A V (2009) Sustainable solid waste management: An integrated approach for Asian countries. Waste Management.

The final report, "County of San Diego Debris Removal and Recycling Programs for the 2003 Cedar & Paradise Fires Final Report," published in 2005, can be found at: http://www.ciwmb.ca.gov/disaster/Fires2003.

UN Environmental/OCHA Joint Unit 2017. Commonwealth of Dominica. Management of Post – hurricane disaster waste.

UN Environmental/OCHA Joint Unit 2017. The Environmental Emergencies Guidelines 2nd Edition. http://www.eecentre.org/wp-content/uploads/2017/02/EE_guidelines_english.pdf

UNEP (2010) Waste and Climate change. Global trends and strategy Framework.

UNEP 2008, Disaster Waste Management Mechanism. A Practical Guide for construction and Demolition Wastes in Indonesia.

UNEP 2012, Managing post-disaster debris: the Japan experience Report of the International Expert Mission to Japan

UNEP 2015, Disaster Waste Management Policy, Strategy and Action plan.

UN HABITAT, 2009, Darfur Early recovery, Stabilized soil blocks for sustainable urban growth.

United Nations Office for the Coordination of Humanitarian Affairs Emergency preparedness Section. Disaster Waste Management Guidelines. http://eecentre.org/Modules/EECResources/UploadFile/Attachment/Disaster_Waste_Management_Guidelines.pdf

Yasmin and Rahman (2017). A review of solid waste management practice in Dhaka city, Bangladesh. International Journal of Environmental Protection and Policy.

Flood Management in Indian Cities: Challenges and New Paradigms

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ABSTRACT: India has been vulnerable to a large number of disasters in varying degrees on account of its unique geo-climatic conditions. Disaster risks in India are further compounded by increasing vulnerabilities related to changing demographics and socio-economic conditions, unplanned urbanisation, development within high-risk zones, environmental degradation, etc. Additionally, regional ecological challenges coupled with climate-change processes are likely to increase flooding vulnerability affecting livelihood, infrastructure, and ecosystem services. Rapid urbanisation is taking place and almost 50 per cent of the country will be urbanised by 2050. The growing trend of urbanisation as reflected in the high spatial concentration of people as well as properties and their increased vulnerability with climate change raise more fundamental questions concerning how cities and community should prepare in order to cope up with increased exposure to flooding events. Hence, this study examines the causes and consequences of flood in Indian cities and seeks for more sustainable alternatives for planning flood resilient urban environment. The challenges of managing urban floods in the context of land use, city and population growth, wetland degeneration, and waste disposal also have been discussed. Best practices from case studies of flood management around the globe have been used to strengthen existing capacities of the urban systems in Indian cities. Consequently, the study proposes a 'Flood Resilience Framework' linking principles of urban planning, vulnerability as well as best practices of flood risk management around the globe. Such a framework shall include appropriate land use planning, sustainable urban drainage, and green infrastructure as an intervention for planning flood-resilient urban areas.

KEYWORDS: urban areas, vulnerability, flood management, flood resilience

Introduction

Floods can be defined as 'the submergence of dry area by a large amount of water that comes from excessive rainfall, an overflowing river or lake, melting of snow or an exceptionally high tide'. The flooding in urban regions is attributed to both natural and man-made factors such as excess rainfall, global warming, climate changes, and improper planning of land use and infrastructure facilities. Increasing trends of flooding are observed in India over the past several years that affect major cities in India. The most notable floods that happened in major cities in India are Hyderabad in 2000; Ahmedabad in 2001; Delhi in 2002, 2003; Mumbai in 2005; Surat in 2006; Kolkata in 2007; Jamshedpur in 2008, 2010 and 2009; Chennai in 2004 and 2015; and Guwahati in 2015 (Urban Flooding-Standard Operating Procedure).

About 34 per cent of India's population now lives in urban areas (U.N. World Urbanisation Prospects 2018). Considering the demographic changes and population growth of the country there should be a proper plan to make the urban areas prepare to meet consequences of various disasters and thereby making the cities to develop in a sustainable way. Hence this study aims to examine the causes and consequences of flood in Indian cities and seek for more sustainable alternatives for planning flood-resilient urban environment. The objectives of the study are (1) to examine the problems and challenges of flood management in urban centres

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in India and (2) to propose a flood management framework for minimising the risks due to urban flooding.

The paper is structured into the following sections. The next section explains the methods and materials the study has followed. The third section deals with the causes, the consequences, and the challenges of urban flooding in the selected cities of India. This is followed by discussion about the new avenues and possibilities for flood risk reduction and mitigation strategies at various levels of urban planning. The discussion on the proposed flood-resilient framework which can be adopted in the Indian contexts is attempted in the fifth section. Finally the inferences of the research are presented.

Methods and Materials

In order to achieve the research aim, the study followed case-based analysis as well as content analysis of various relevant literatures. Following the first objective, the potential challenges and consequences of flooding in urban centres have been comprehended from the cases of Mumbai and Chennai cities. Further on the best practices for flood risk reduction and mitigation strategies across the globe such as those in China and the Netherlands have been analysed from content analysis of suitable literature. Finally the study attempts to propose an appropriate framework for flood management for Indian cities from critical review of literature.

Causes, Consequences and the Challenges of Urban Flooding

The following section describes the various challenges encountered during recent floods in the cities of Mumbai and Chennai and the various spatial as well as socio-economic consequences there on.

Mumbai

Mumbai, the financial capital of India located on the western coast of Arabian Sea, has been frequently exposed to series of flood hazard. The map of Mumbai city is shown in Figure 1. The city of Mumbai consists of two administrative districts: the Island City District and the Suburban District. Geographically, Greater Mumbai is an island separated from the mainland by the narrow Thane Creek and the relatively wider Harbour Bay. The density of the population in both the administrative districts is 19,652 per sq.km and 20,980 per sq.km (census 2011) respectively.

Mumbai is prone to flooding and witnesses severe disruptions almost annually, for example, flooding during between 2004, 2005 and 2007. The main causes of flood in Mumbai are said to be heavy rain accompanied with high tides. Average annual rainfall in Mumbai is around 240mm (flood preparedness guidelines, 2017).

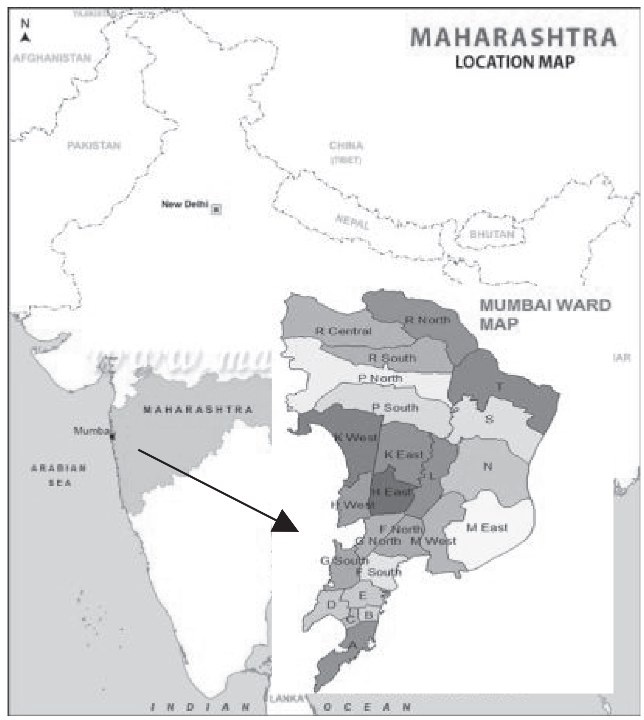

Figure 1: Mumbai map

Additionally factors such as intensive land reclamation, faulty drainage systems, incapable storm water drains and reduction in the carrying capacity, changes in the path of the rivers and reduction in the catchment areas, etc. also contributed to flooding in Mumbai. The Storm Water Drainage (SWD) system in Mumbai city is more than 100 years old (Prof. P. T. Kadave, 2016).

The flooding leads to severe damages to public and private properties like infrastructure, industries and residential buildings, communication, etc., accounting to a loss of nearly 1300 crores in agricultural, animal husbandry, and fisheries sector. About 22 per cent of the areas were waterlogged for more than two days. More than 1 lakh houses were submerged. The frequent flooding and its consequences have posed major challenges for the sustainable development of Mumbai urban area. Few notable challenges are ill-maintained land reclamation, older drainage network, encroachment of the major river corridors, and changes in the path of the rivers especially Mithi River. Additionally the sea level rise is also considered to be the major threat faced by the Mumbai city. Solid waste disposal and management is also identified to be a potential challenge in the case of Mumbai city.

Chennai

Chennai, the capital city of Tamil Nadu, is the fourth largest Metropolitan City in India. The Chennai Metropolitan Area (CMA) falls in three districts of the Tamil Nadu State viz. Chennai District, part of Kancheepuram District, and part of Thiruvallur District. It extends over 1189 sq.km. And it includes Chennai City Corporation area, 16 municipalities, 20 Town Panchayats, and 214 villages comprising 10 Panchayat Unions. The total population of Chennai UA/Metropolitan area is 8,653,521. Population density is seen to be 26,553/sq.km. Figure 2 presents the map of CMA which mainly includes three districts.

Chennai was affected by flooding during 1943, 1969, 1978, 2005, and 2015. Of these, the flooding in the year 2015 was one of the most deleterious disasters in Chennai causing loss of lives and properties. Due to the formation of depression over the southwest of Bay of Bengal and owing to a strong El Nino, Chennai received almost 1200 mm of rain in November, which was nearly 300 per cent above than the normal 407.4 mm rainfall.

According to a study conducted by (Interdisciplinary Centre for Water Research Indian Institute of Science, Bangalore May 2016), the flooding happened due to the effects that prevailed like short-term, medium- or middle-term, and long-term effects. Firstly, short-term effects like tidal waves' levels, warming of the Bay of Bengal, no proper drainage facilities, flood forecasting, reservoir operations, and administrative responses were the main reasons that contributed to flooding. Secondly, the medium reasons are changes in the climate, urban heat islands, land use changes, El Nino that are happening now that led for flooding, and, finally, long-term effects like the development of low-lying areas, encroachment, and hydrological designs were the reasons for flooding. It is noted that major effects are due to urbanisation (urbanisation has been increased 20 times) and caused land use changes, disappearance of many waterbodies, reduction in the infiltration of the hydrological cycle, encroachment along the waterways, areas of the major lakes in the city has been reduced, green cover has been replaced, and nearly 99 per cent of the green areas is lost; wetland management was very poor which lead to shrinking of major wetlands. Inadequate capacity of drainage infrastructure, unscientific drainage network, lack of connectivity of storm sewers with the macro drainage system, improper solid waste management, and forecasting problems are the various reasons identified for flooding in Chennai.

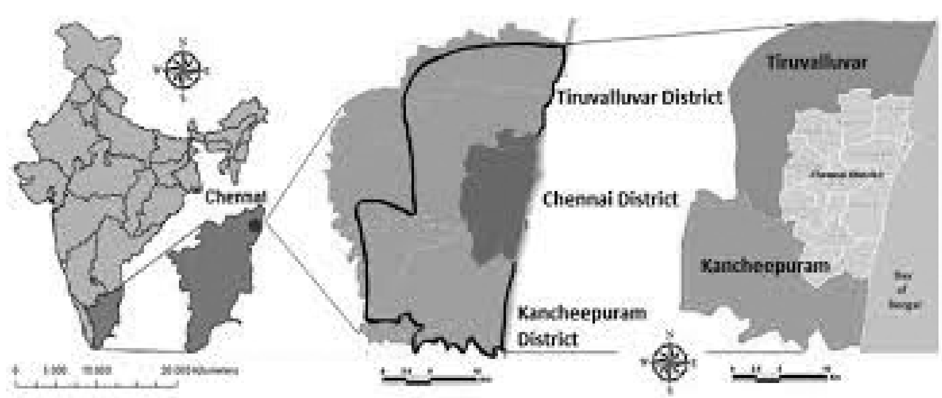

Figure 2: Chennai metropolitan area map

The flooding has caused various impacts to the lives, proprieties, businesses, and cattles. Nearly 18 lakh people were displaced due to the prolonged water logging in most of the parts of CMA and caused an economic loss of nearly US $ 14 Billion.

Chennai majorly faces the challenges of flood plains which are encroached by the economically weaker settlements. Waste disposal and dumping of wastes in the wetlands are other challenges. Chennai has three rivers like Adyar, Cooum, and Kosathalaiyar and one canal which is Buckingham Canal in which the entire morphology of the rivers had changed along with the reduction of carrying capacity, path of flow, and canal is fully encroached. Drainage and storm water management is given least importance which is one of the major factors for flooding even when a minimum amount of rainfall recedes.

From the two cases it is noted that majorly Indian cities are lacking in the storm water drains and management of ecologically important components like wetlands, rivers, and lakes. And both the cases revealed that changes in the land use affected the rivers carrying capacity and path of flow which is mainly due to urbanisation and encroachment. Hence cities needed to be given importance for managing and planning the development.

New Paradigms for Flood Risk Management in Urban Areas

To frame a flood-resilient framework that can be adopted by the urban areas in India, case studies on various urban centres across the global have been carried out and the best strategies implemented have been analysed. The following section explores the flood risk reduction and mitigation strategies in the context of China and the Netherlands.

Case Study: Wuhan, China

Wuhan, located in the central part of China, is a megalopolis in the middle reaches of Yangtze River as well as the capital city of Hubei Province.

Figure 3 shows the location of Wuhan city in China which is the commercial centre in China. Geographically, the mainstream of the Yangtze River is affected by the flood discharge from various other waterbodies around. Its average annual precipitation is 1280.9mm. Almost 1.06 million people were affected and 263,000 people were relocated during the flood in 2016 in Wuhan, with a direct economic loss of 5.3 billion yuan.

Figure 3: Wuhan, China, location map

Flood Risk Management Measures in Wuhan

Having realised the exposure to and the consequences of frequent flooding, various strategies for managing the same have been framed in the context of Wuhan city. Following suitable environmental and social safeguards various structural as well as non-structural measures were incorporated for flood risk reduction and mitigation at various levels. The various environmental safeguards focused on sustainable development of physical environment, ecosystems, and biodiversity. While the social safeguards focused on displaced community, gender-specific interventions as well as various indigenous communities (Porter, 2012).

City-Level Interventions

The flood risk management planning at city level involved developing master plans for management of the river basin, urban and rural drainage. The city-level intervention also focused on planning for appropriate emergency response as well as for post-flood recovery incorporating structural measures for reducing the expected risk. The main flood risk management involves the management of flood hazards, exposure, and vulnerability. In flood hazard, structural measures are dikes, detention basins, reservoirs, etc. along with watershed conservation programmes. This also included assets maintenance, monitoring, rehabilitation, funding, and upgrading the functions of such facilities. Exposure management includes land use management, flood hazard zoning, land development control, building regulations, and resettlement programmes. And vulnerability management includes flood forecasting, flood early warning systems, and post-flood recovery programmes.

Consolidating these measures at non-structural measures at city level a planning concept namely Sponge City concept has been implemented in China. The main aim of the Sponge City concept is to integrate eco-hydrology, climate-change impact assessment and planning, and consideration of long-term social and environmental well-being within the urban land use planning process. It also advocates the use of ‘blue’ and ‘green’ spaces in the urban environment for storm water management and control (Faith Ka Shun Chana b, 2012). Figure 4 shows the Sponge City concept at city scale.

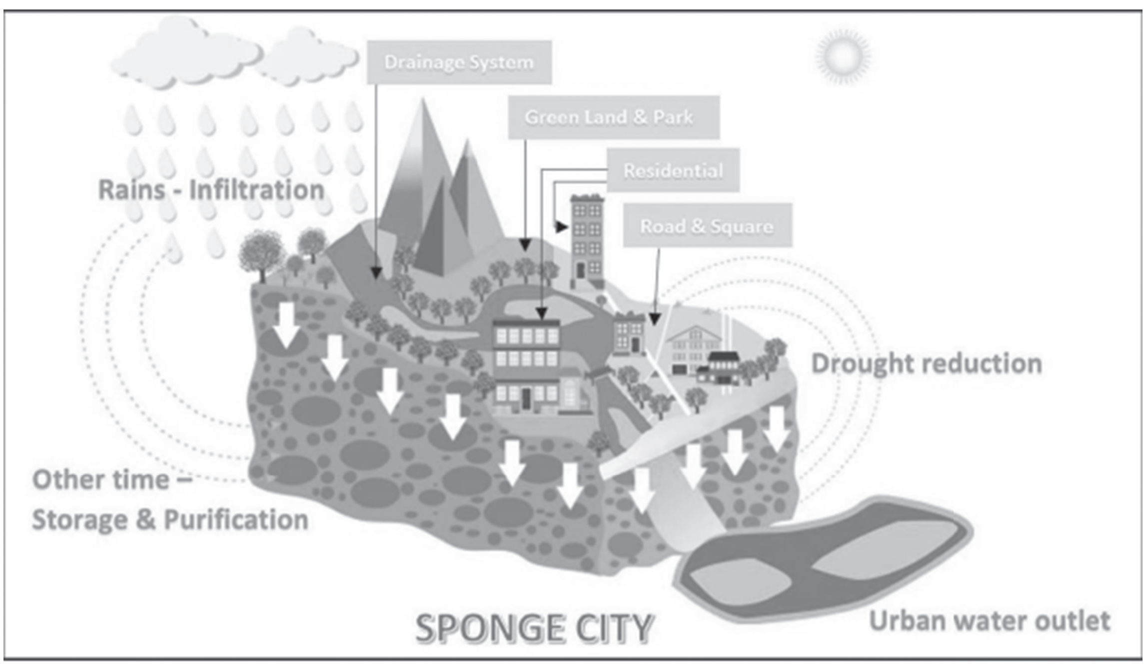

Figure 4: Sponge City concept

The Sponge City concept aims to

- adopt and develop LID concepts which improve effective control of urban peak runoff and to temporarily store, recycle, and purify storm water;
- upgrade the traditional drainage systems using more flood-resilient infrastructure (e.g. construction of underground water-storage tanks and tunnels) and increase current drainage protection standards using LID systems to offset peak discharges and reduce excess storm water; and
- integrate natural waterbodies (such as wetlands and lakes) and encourage multi-functional objectives within drainage design (such as enhancing ecosystem services) whilst providing additional artificial waterbodies and green spaces to provide higher amenity value.

Codes for Development

The Sponge City concept also facilitated various codes for holistic development such as designs of urban residential and properties zone planning, roads, waste water, and urban green spaces. This includes how a city should be planned for preserving green spaces, how the roads to be designed including green infrastructure installation, designing of the drainage network, storm water storage, and managing the drainage capacity.

These interventions were planned and managed through participation of public as well as private stakeholders.

Building-Level Measures

Using construction materials that are less susceptible to damage by water and building with floor levels raised above flood levels or with second story or flat roofs that provide refuge are the building-level measures followed.

Institutional Measures

The city-level measures also include appropriate legal provisions for flood management such as flood-control (management) plans for rivers, lakes, and cities, elimination of waterlogging (poor rural land drainage), formulation of estuary regulation plans for various rivers, etc. Delineation of planned reserves zoned for flood-control use (e.g. flood-detention areas), zoning flood-control areas as ‘flood-prone’, ‘flood detention’, and ‘protected’ zones, with provision for the administration of the use of land within zones, are the few other legal measures prepared.

Miscellaneous

Regulating residential development to manage population increase in hazard areas, managing the types of enterprise permitted in hazard areas, and integrating planning of public infrastructure are some of the other measures formulated for flood management at city level.

Case Study: The Netherlands

Introduction

About 60 per cent of the areas are flood prone in the Netherlands. Flood hazard is caused by floods on the two major rivers: Rhine and Meuse. The 1953 storm surge was a flood with more than 1853 people died in the Netherlands. Almost 26 per cent of the Netherlands lies below sea level which is one of the major reasons for flooding. Rise in the sea level and climatic changes, urbanisation, land reclamation, and deforestation were the other reasons for flooding. Figure 5 shows the Netherlands location map.

Figure 5: The Netherlands location map

City-Level Measures

Flood Risk Management: Institutional Framework

Institutional framework mainly deals with prevention, protection, recovery, and response mechanisms which integrate various stakeholders like states, provinces, administrations, regions, and municipalities and formulate various plans, programmes, and actions for each mechanism. They framed spatial planning acts, water act, provinces act, municipalities act, safety regional act, disaster compensation act, national water plans, national water management plan, national flood-crisis plan and large-scale evacuation plans, land use plan, flood disaster management plans, crisis coordination plans, national strategy programme, and national flood protection programme.

Multi-layer Safety for Flood Risk Management

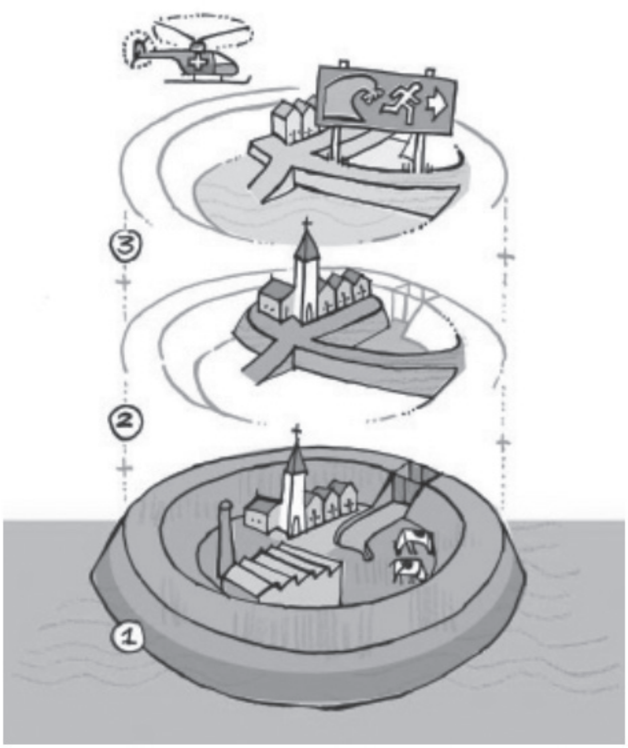

Figure 6: Multi-layer safety concept

Multi-layer safety includes three levels of planning and mitigation process. Firstly it includes flood protection and flood defences strategies and plans at the city level. Secondly it deals with the spatial planning level of the city which includes zoning, land use management, not building in flood-prone unprotected areas, or through building codes (adapting houses to regular flooding: raised houses or floating houses). Green roofs, water squares, water gardens, and innovative detention areas (e.g. temporary storage of rainwater in underground parking garages, etc.) are the strategies adopted to overcome the situation. Thirdly it includes the evacuation, alerts, and response plans. Figure 6 shows multi-layer safety measures.

Flood Alert Warning System

Flood alert warning system works in order to alert the people about the occurring floods. This includes storm surge warning services, where the meteorological centre informs about the present climate condition, rainfall data, and flooding. Then an alert is sent to the official centre and from there flood forecasts information of water levels, wind speed, wind direction, etc. details are informed to the media, alert messages are sent, and necessary precaution measures are taken.

Dikes

Dikes are constructed along the coasts to prevent flooding inside the city areas. There are totally 95 dike rings constructed as flood defences. Figure 7 shows the dikes provided along the banks of the river.

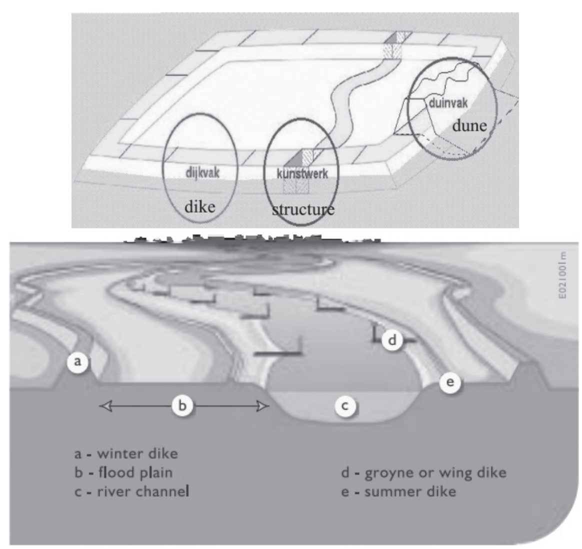

Figure 7: Dike rings

At Neighbourhood Level

Spatial Planning

All buildings along lakeshores and the coast have to be raised on stilts or artificial mounds and/or flood proofed. Some experiments were carried out with floating houses at Rotterdam and Amsterdam. If houses are not built above the flood levels, frequent flood damage in these areas is expected in the near future. The image shows the floating houses constructed. Figure 8 shows the floating houses planned along the corridors of water bodies.

Figure 8: Floating houses

Disaster Warning to the Population by the Emergency Services

Air raid siren used to warn the population in case of a disaster occurring is installed at neighbourhood level to convey the information of the disaster and for the evacuation purposes.

So by analysing both the cases, these cities mainly focused on the sustainable way of managing floods that included sustainable urban drainage systems (SuDS), river-based master plans, land use planning, wetland management and institutional level plans, programmes, acts, and integration of stakeholders.

Discussion

Learning from the challenges of flood hazard in urban areas and appropriate flood management strategies across the globe, the study proposes a framework for flood risk management (FRM) in the context of Indian cities integrating urban development, flood hazard, and vulnerability. The components of FRM framework are explained below.

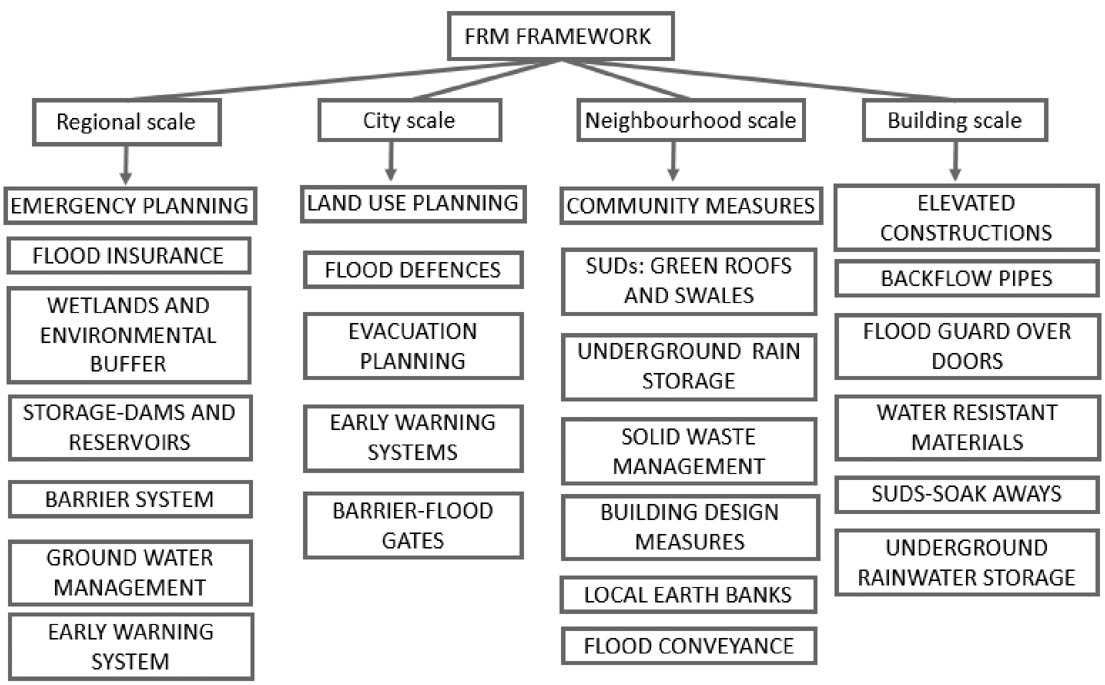

Figure 9: FRM framework

The general framework of FRM deals with different scales of interventions such as at regional level, city level, and neighbourhood level, and finally at building level to mitigate potential challenges of future flood. This framework has been derived by reviewing a study done by Bloch (2013). The proposed framework has been presented in Figure 9.

This framework can be used as a guiding map for flood mitigation strategies. The above-mentioned components are essential to overcome the effects of flooding and thereby to manage this it includes flood preparedness, prevention, response, emergency, and evacuation plans. Generally flood risk management consists of structural and non-structural measures which include all the above-mentioned components. The following section deals with the components of the framework proposed.

Regional Scale

At regional scale cities should be planned to have storage dams and reservoirs which should be maintained periodically for the catchment and discharge of the excess water. Then the barrier to defend flooding must be provided; importance should be given to wetland since it acts as the flood sink and environmental buffer zone must be developed along the water bodies. Then at institutional level evacuation plans for shifting the people to safe places must be arranged in advance and should be announced to them by proper early warning system. And flood insurance at policy level must be incorporated for residential and industrial areas.

City Scale

At city level proper land use plans must be developed. Land use planning helps in balancing the urban ecosystems and should use various tools for regulation like zoning of the flood plains and flood catchment areas. Building regulations and codes can be focused on such areas giving standards for development and regulating what kind of development and infrastructure must be planned in such areas. The same evacuation plans must be developed for city scale, and flood gates and flood defences should be incorporated.

Neighbourhood Scale

At neighbourhood level community measures should be given importance considering both structural and non-structural measures of development that include sustainable urban drainage systems, water storage systems, local earth banks, flood conveyances, and solid waste management strategies. Since many cities in India are facing faulty drainage network and poor storm water drains, alternative methods of SuDS can be planned that integrate blue and green infrastructure which is a natural type of approach for managing drainages and storm water. SuDS include bioswales, artificial wetlands, ponds, retention and detention tanks, and green roofs which integrate various other components of infrastructure. SuDS can be provided from building level to large region-scale planning of cities. It is used in the Netherlands as green infrastructure and China as a Sponge City concept for managing storm water. It prevents water pollution and majorly helps in managing urban floods.

Building Scale

Building-scale implementation is with regards to the design standards to be adopted, type of materials to be used for the construction, and incorporating various sustainable measures of development at building level.

Conclusion

The case studies of causes and consequences of various floods in the context of Mumbai and Chennai revealed that urbanisation, improper management and maintenance of drainage systems, improper wetland management, and land use changes are the major reasons that lead to socio-economic damages due to flood hazard. The study also comprehended the various potential challenges of frequent flooding in urban areas that need to be given importance. Hence the study realised that there is a need for appropriate intervention for flood risk reduction and mitigation. The proposed framework for flood risk management focuses on environmental and social safeguards at various levels of planning such as regional scale, city scale, neighbourhood scale, and building scale.

Considering the socio-economic development of Indian cities as well as their potential challenges of disaster management, the proposed FRM framework suggests appropriate macro- as well as micro-level interventions for flood risk management in major cities in India. However these measures have to be prioritised based on its context. Basically planning-level interventions need to be given priority and followed by the above-mentioned zoning of the areas and regulating the development.

References

Dr Robin Bloch(2013) Integrating Flood Risk Management and Land Use Planning-ICLEI FORUM

Faith Ka Shun Chana, B, C (2012) Sponge City In China—A Breakthrough of Planning and Flood Risk Management in the Urban Context Richard.

Interdisciplinary Centre for Water Research Indian Institute of Science, Bangalore May 2016.

Municipal Corporation Of Mumbai (2017)- Flood Preparedness Guidelines.

Porter, Y. K. (2012). Flood Risk Management in the People's Republic of China Learning to Live with Flood Risk.

Prof. P. T. Kadave, A. D. (2016). Mumbai Floods, Reasons and Solutions. International Journal of Scientific and Research Publications, Volume 6, Issue 3, March 2016.

U.N. (2018). U.N. World Urbanisation Prospects.

Urban Flooding-Standard Operating Procedures.

Transport Emission Reduction: Building Resilient Neighbourhoods

Arnab Jana[a] and Krishnan Narayanan[b]

ABSTRACT: Building resilient settlement requires focus on mitigation strategy to climate change. This study examines the potential of mitigatory policy interventions to reduce greenhouse gas (GHG) emissions from urban transportation in Bhendi Bazaar, Mumbai, India. Bhendi Bazaar is a mixed-use settlement under urban redevelopment, intending to create positive change in the settlement through improvements in socio-economic, physical, and environmental quality. Urban redevelopment process consists of demolition and reconstruction of the existing buildings and rehabilitation of the residents. Therefore, it provides opportunity to reconfigure settlements and bring affordable housing near workplace and facilities or vice versa which may reduce the need to travel, thereby reducing the GHG emissions by the traffic. Urban redevelopment of inner-core neighbourhood of city results in more compact development and controls urban sprawl. However, compaction may not result in reduction of travel time, and long-distance and energy-intensive travel will continue in absence of appropriate mix of local jobs and local facilities suitable to the residents of the neighbourhood. This study quantifies GHG emissions from the neighbourhood under different socio-economic and demographic scenarios. Different scenarios were created using data from structured questionnaire survey and expert opinion survey. Different policy interventions – existing and proposed – were considered in scenarios generation.

KEYWORDS: resilient settlement, mixed-use neighbourhood, GHG emission, urban redevelopment

Introduction

According to Zhang and Li (2018) *"Urban Resilience* is the passive process of monitoring, facilitating, maintaining and recovering a virtual cycle between ecosystem services and human wellbeing through concerted effort under external influencing factors".

Cities have become significant players in regard to policies, which are attempting to respond to peak oil and climate change. Recently, these policies have been focused on building resilient cities, which aim to enhance a city's ability to respond to a natural resource shortage and the recognition of the human impact on climate change. Resilient cities are believed to adapt better to change through adjusting inner systems, for example, by changing their transport-land use system to reduce energy consumption and exposure of the system to potential natural disasters (e.g. sea-level rise). A resilient city reduces its ecological footprint (e.g. energy consumption), while simultaneously improving its quality of life. Resilient city policies are concerned with strengthening a city's capacity to adapt to shocks, such as natural disasters. Such policies increase the degree of collaboration between urban subsystems (social, environmental-infrastructural, economic, and institutional systems), while enhancing the robustness of each subsystem.

In a resilient city every step of development and redevelopment of the city will make it more sustainable: it will reduce its ecological footprint (consumption of land, water, materials, and energy, especially the oil so critical to their economies, and the output of waste and emissions) while simultaneously improving its quality of life (environment, health, housing, employment,

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community) so that it can better fit within the capacities of local, regional, and global ecosystems. Resilience needs to be applied to all the natural resources on which cities rely.

In resilience thinking the more sustainable a city is the more it will be able to cope with reductions in the resources that are used to make the city work. Sustainability recognises that there are limits in the local, regional, and global systems within which cities fit, and that when those limits are breached the city can rapidly decline. The more the city can minimise its dependence on resources such as fossil fuels in a period when there are global constraints on supply and global demand is increasing, the more resilient it will be.

India has the second highest population in the world and is fourth highest emitter contributing to 6.65 per cent of total global greenhouse gas (GHG) emissions. The resilience of cities in response to natural disasters and long-term climate change has emerged as a focus of academic and policy attention. Transport sector contributes to 6.64 per cent of India's GHG emission. Factors for rise in vehicular emissions are increase in vehicle kilometre travelled (VKT) and number of vehicles on the road. People do not travel for the sake of travel. They travel for purpose and derive benefit from it. Most regular and frequent travel is the work commute. Vehicular efficiency and fuel improvement alone cannot reduce the emissions to achieve the reduction target. We have to hit at the root cause of travel to reduce the travel demand by bringing places of work and living closer.

According to the Human Development Report 2018, in terms of Quality of Life (QoL), India ranks 130th out of 189 countries with Human Development Index of 0.640. Aspirations of Indians for better QoL are yet to be fulfilled. Vehicle ownership is one of the aspirations. Previous researches have reported high degree of association between per capita income and vehicle ownership. With increase in per capita income, vehicle ownership is expected to increase.

Salon et al. analysed the 14 factors that affect VKT as shown in Table 1. Many policy ideas can be developed by combining these factors to reduce VKT. Planners and local government officials aiming to affect VKT must choose among them. To choose wisely, it is necessary to know – in addition to its cost, likelihood of political acceptance, and any co-benefits – how much each policy option will actually affect VKT. Sizable gaps exist in the knowledge base at a time when decision-makers at the local level are being increasingly called upon to take action to reduce VKT. Also, there is a knowledge gap in analytically understanding the effect of policy option in reducing emission. This study is an attempt to analyse resultant emission from applying different policy interventions.

According to Handy there are three basic strategies among the policies that aim to reduce VKT: reducing the need for travel, making alternatives to the private car more available and/or more attractive, and making cars less attractive to use for everyday trips. Selected policies are applied to neighbourhood under studies to assess their capacity to reduce emission in transport.

Table 1.1: Factors that Affect VKT Adapted from

Land Use Planning	Pricing	Public Transport	Non-motorised Transport	Incentives and Information
1. Residential density 2. Land use mix 3. Regional accessibility 4. Network connectivity 5. Jobs-housing balance	1. Road pricing 2. Parking pricing	1. Public transport access 2. Public transport service	1. Pedestrian strategies 2. Bicycle strategies	1. Telecommuting 2. Employer-based trip reduction 3. Voluntary travel behaviour change programmes

In recent decades, one of the main arguments in relation to the reduction of energy consumption and greenhouse gas emissions has focused on passenger transport, as this accounts for over 20 per cent of the world's primary energy use and 13 per cent of energy-related CO_2 emissions. Of the many factors influencing travel patterns at a city level, urban spatial change is particularly important. In particular, employment decentralisation and clustered development in the suburbs are often believed to be associated with shorter commutes than in areas of sprawling development and even monocentric spatial structures. One major reason for this, according to economic research, is that polycentric spatial structures provide more opportunities to enhance spatial matches between the residential and job location choices of households living in the suburbs.

Energy use in transport is a function of mode used, distance travelled, and frequency of trip. For transport on a road network, traffic flow also affects the amount of energy consumed. Traffic congestion occurs when the volume of traffic is greater than the capacity of the road network. Congestion imposes significant social costs, with interruptions to traffic flow lengthening average journey times, making trip travel times more variable, and reducing the efficiency of vehicle engine operations; it also has a negative effect on air quality.

Since India is a vast nation with large vehicle fleet and higher running time, it is nearly impossible to make a significant decrease in emission through 2020 manufactured vehicles without a reduction in vehicle use.

To reduce transport energy through higher-density land use, conditions must be suitable for non-auto travel. According to Meurs and Haaijer, reduced car mobility will be achieved when shops, schools, and other daily-use facilities are located close to the home, the road network in the neighbourhood is laid out for slow traffic (e.g. bicycles and pedestrians) and is therefore unsuitable for cars, and the accessibility of locations beyond the neighbourhood discourages car use. The reduction in car use and transport energy consumption will be greatest when such conditions occur in densely built-up areas.

Mixed land uses and concepts of self-containment are important in reducing energy consumption in transport. Nevertheless, local jobs and local facilities must be suitable for local residents; otherwise, long-distance, energy-intensive movements will continue. The "compact city" might be an appropriate urban form to cope with these concerns. Mixed land uses generate local jobs and local facilities for local residents and can reduce the need for long-distance, energy-intensive travel for work and shopping. Urban regeneration indirectly results in reduction of transport energy. Urban regeneration provides affordable housing near workplace or vice versa which reduces the need to travel, thereby reducing the GHG emission by the traffic.

Data and Methods

According to Choguill, a "no single city can contribute to overall sustainability if its own component parts are found not to be sustainable". He advocated a neighbourhood as the smallest unit of urban planning. Following the same concept, resilience thinking is applied to a mixed-used neighbourhood under urban development.

Bhendi Bazaar Cluster Redevelopment Project Area

18th Century marked the rapid growth of Mumbai as it was connected to hinterland by rail. Mumbai flourished and became the commercial hub attracting business communities from across the country to set up their businesses. Labourers from across the country came and lived in settlements that grew parallel to docks. Bhendi Bazaar is one such settlement. Bhendi Bazaar is a mixed-use development undergoing redevelopment under "Urban Redevelopment Scheme". The landowners and factory owners constructed rental dormitory-style tenements with common lavatories called "Chawls" for the labourers and other migrants. It was meant for single-resident worker. Eventually they brought their families. Most of the inhabitants used to live and walk to their workplace.

table 2.1: Details of Bhendi Bazaar Cluster Redevelopment

	Existing	Proposed Rehab	Sale Component
Land in Acres	16.5	13.2	3.3
Buildings	250	14	2
Households	3200	3514	1424
Commercial Establishments	1250	1379	NA
Location	–	In Situ	In Situ

Source: Saifee Burhani–Home Landing Page

The commuting data used in this study are derived from a household interview survey conducted in C and E wards of Mumbai in 2018. Among other questions, employed respondents were asked to state the location of their homes and workplaces as well as their education level.

Arandomstratifiedsampleprobabilityproportional-to-size sampling strategy (PPS) with method was used to collect the data. Face-to-face interviews were conducted, with the survey successfully collecting 334 residential (home-based survey) and 127 commercial (destination-based survey). The secondary data were compiled from a number of sources. Participation in the study was voluntary

- **1655:** number of adults and children covered in the study
- **1654:** normal travel habits (adults + school-going children)
- **1370:** working day data (individuals)

Table 2.2: Data Sources

Data	Data Sources
Origin and destination data	Primary survey (travel diary)
Socio-demographic data	Primary survey (PS)
GIS data	UDRI GIS repository

Note: UDRI-Urban Design Research Institute, Mumbai, India

Individual trip distances are derived from travel diary survey data as the source of daily VKT estimates. In these cases, the distances travelled are calculated for the reported trip origins and destinations along the road network using algorithms to identify the most likely route.

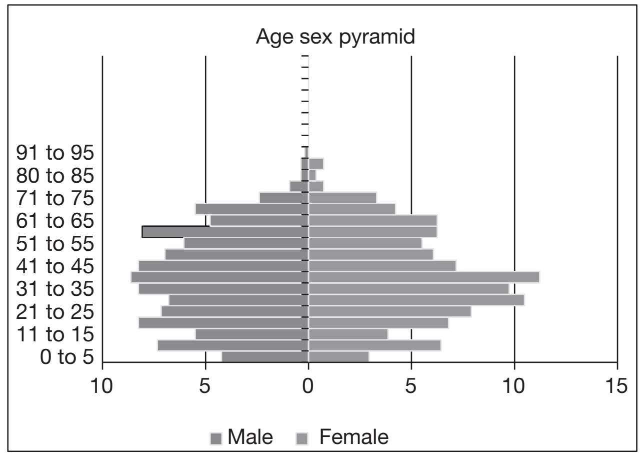


Figure 2.1: Age-sex pyramid

Vehicle Emission

Motor vehicles are powered predominantly by internal combustion engines that use petroleum-based fuels like gasoline and diesel. Incomplete fuel combustion or high in-cylinder temperatures cause these engines to produce carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), non-methane hydrocarbons (HC), sulphur oxides, and airborne toxins. Exposure to these pollutants is associated with a range of acute health effects and chronic diseases, some of which can result in early death.

Bharat Stages

On February 19, 2016, Bharat Stage-VI (BS-VI) notification had been released by the Indian Ministry of Road Transport and Highways which will go into effect for vehicles that are manufactured after April 1, 2020. by this proposal, India leapfrogged BS-V and approved BS-VI after BS-IV, as BS-IV was implemented in 2017 nationwide. The proposed BS-VI standards are tightening the PM emission limit as well as introducing particulate number (PN) limits for heavy- and light-duty vehicles, which are equivalent to the standards in Europe – likely to lead to more use of Diesel Particulate Filter (DPF) and tightening the in-service conformity test requirement.

Emissions (**G**) in the transport was calculated by equation (1):

$$G = A \times S \times I \times F \quad (1)$$

where
A denotes the level of travel activity (A) in passenger km, across all modes;
S denotes the mode structure (S);
I denotes the fuel intensity of each mode (I), in litres per passenger-km;
F denotes the carbon content of the fuel or emission factor (F), in grammes of carbon or pollutant per litre of fuel consumed.

Passenger kilometre is calculated as follows in equation (2):

$$\text{passenger-km} = \sum_{i}^{n} Bi * Ci \quad (2)$$

where
Bi denotes mode-km in mode category *i*
Ci denotes average passenger occupancy per mode in category *i*

Table 2.3: Details of Passenger Km Generated and Emission Factor

Mode	Fuel	Passenger Km	Emission Factor (g/Km)	Average Passenger Occupancy	g/pKm
Two-wheeler	Gasoline	331,119.4	45.60	1.00	45.60
Car	Gasoline	103,014.9	143.54	1.25	114.83
Ola/Uber/Taxi	Gasoline	228,104.4	143.54	1.30	110.41
Auto Rickshaw	CNG	22,074.62	57.71	1.20	48.09
Bus	CNG	217,067.1	806.50	51.00	15.80
Train	Electricity	732,141.7	–	–	0.00795
Metro	Electricity	–	–	–	0.00795
Monorail	Electricity	–	–	–	0.00795

Table 2.4: Commuting Relationship

1	Resident of Bhendi Bazaar and work outside Bhendi Bazaar	736
2	Non-resident of Bhendi Bazaar and work in Bhendi Bazaar	322
3	Resident of Bhendi Bazaar and work inside Bhendi Bazaar	312

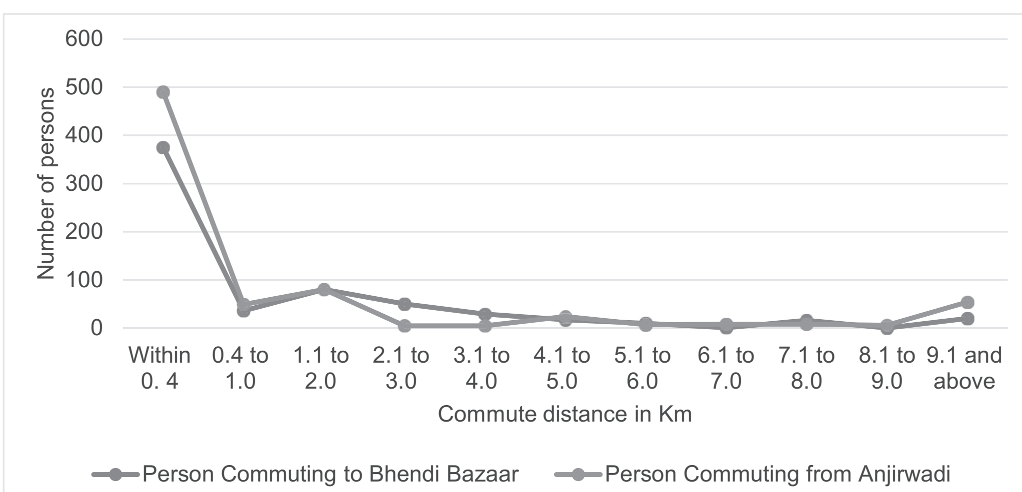


Figure 2.2: Commuting relationship

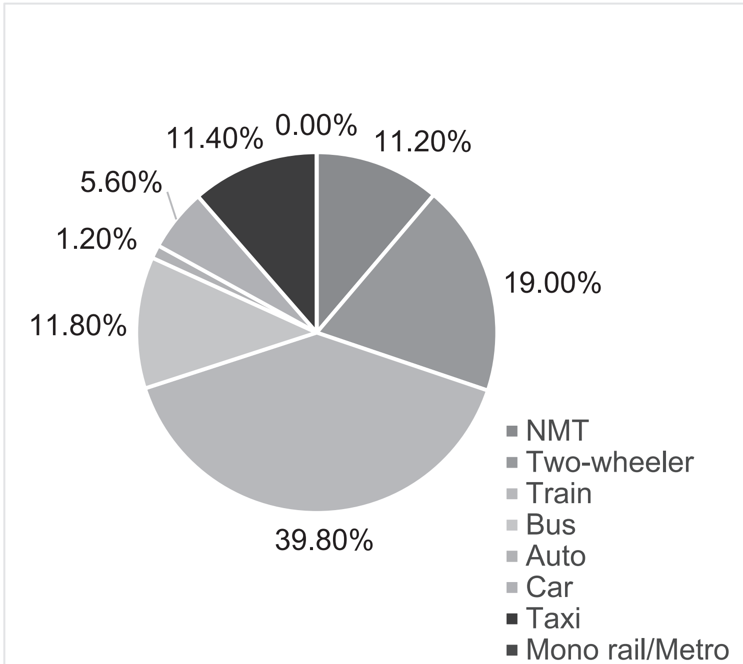


Figure 2.3: Modal split from the primary survey

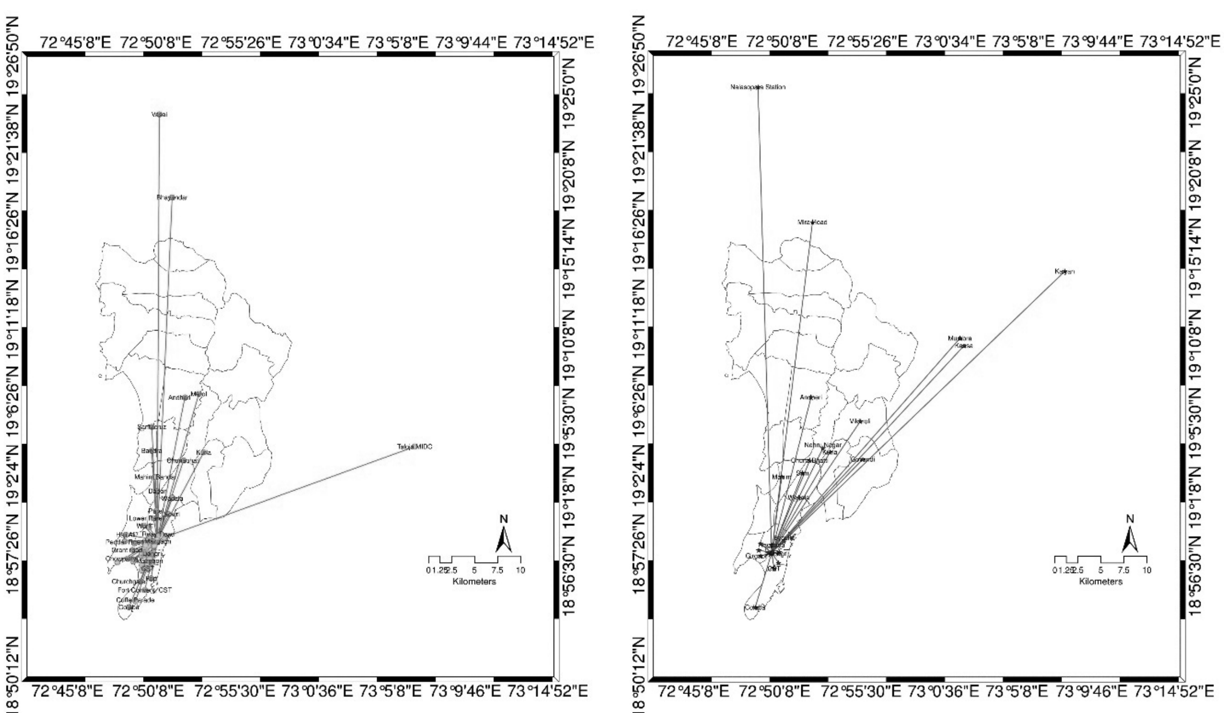


Figure 2.4: (a) Outbound commute flow map from Anjirwadi, and (b) inbound commute flow map to Bhendi Bazaar

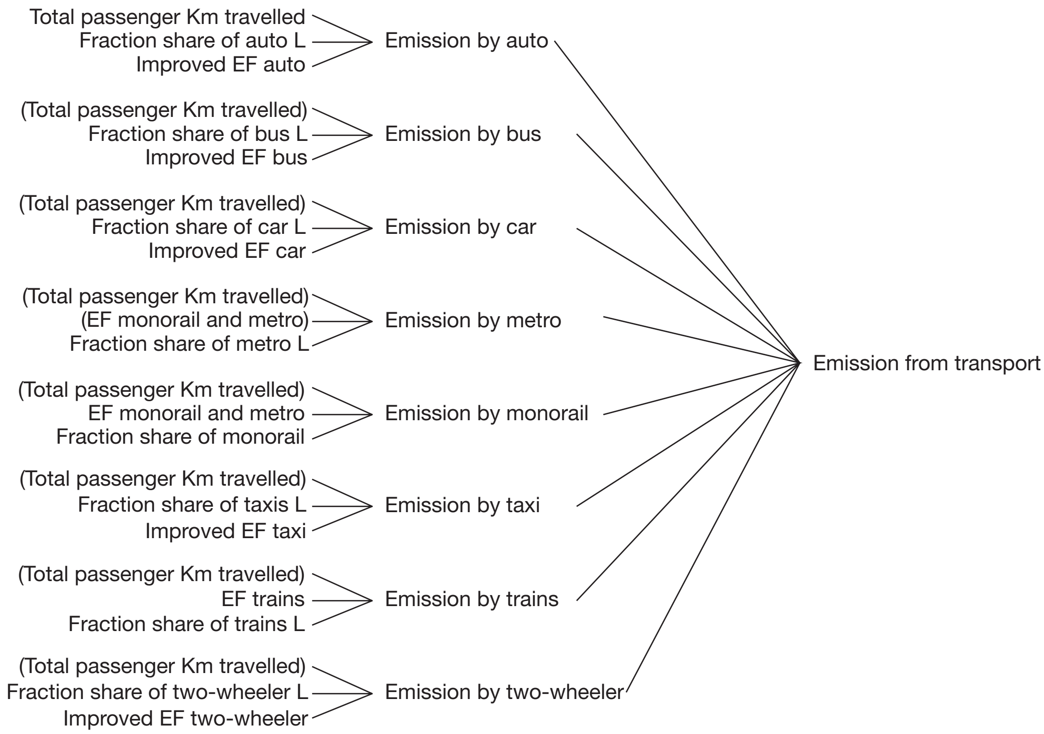


Figure 2.5: Cause tree

3. Results and Discussion

Policy measures were classified into three categories:

- Change in level of activity
- Shift in mode of travel
- Energy efficiency improvement of mode and improvement of carbon content of the fuel or emission factor

Policy measure (a) is captured in change in passenger-km, (b) is captured in change in percentage share of mode, and (c) is captured in effect of improved emission factor.

Five scenarios were generated in the model.

- *Bharat Stage Scenario:* Effect of deployment of Bharat Stage-IV and Stage-VI.
- *Activity Change Scenario:* Assumed 5 per cent decrease in passenger Km by containment of commute (job housing balance).
- *Structural Change Scenario:* Change modal structure.
- *Sustainability Scenario:* Deployment of above three policy measures.
- *Business as Usual (BAU) Scenario:* No policy measures applied.

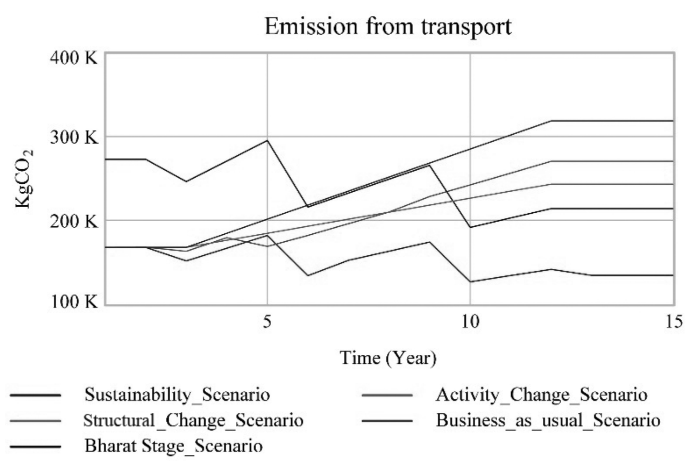
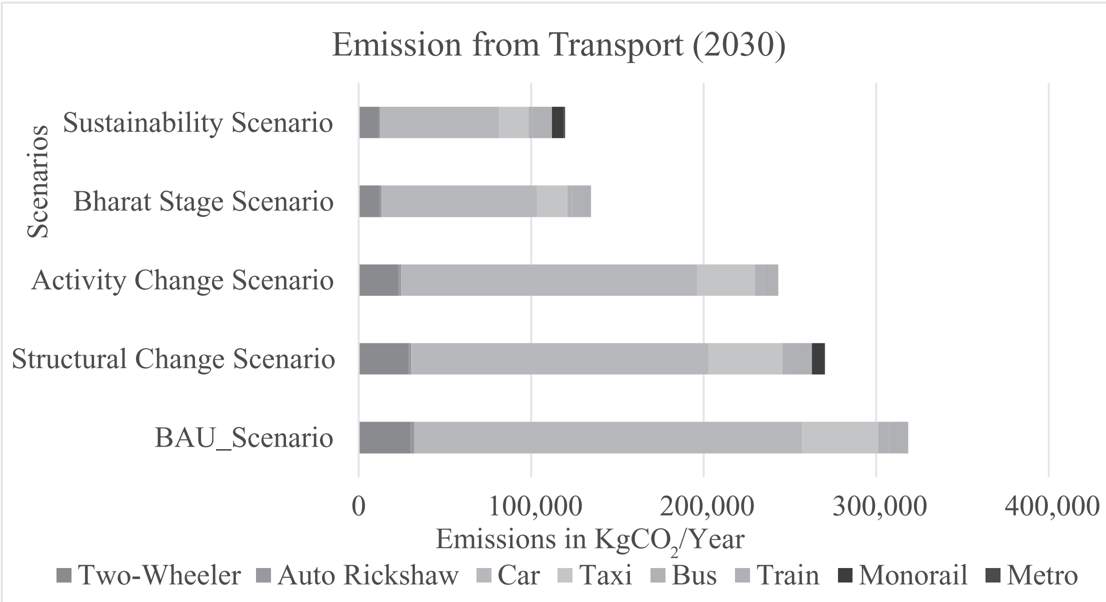


Figure 2.6: Emission from transport under different scenarios



Conclusion

Implementing Bharat Stages (BS-IV and BS-VI) policy measure results in 57.7 per cent reduction in emission in comparison to BAU. Activity Change Scenario and Structural Change Scenario result in 23.6 per cent and 15.1 per cent reduction in emission respectively. Implementing all the policy measures under Sustainability Scenario results in 62.4 per cent reduction in emission in comparison to BAU.

Acknowledgements

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Bibliography

C. C. Environment, "2016 Insights Together Secure Sustainable & Energy, Climate Change Environment," 2016.

C. L. Choguill, "Developing sustainable neighbourhoods," *Habitat Int.*, vol. 32, pp. 41–48, 2008.

D. Banister, S. Watson, and C. Wood, "Sustainable cities: Transport, energy, and urban form," *Environ. Plan. B Plan. Des.*, vol. 24, no. 1, pp. 125–143, 1997.

D. Salon, M. G. Boarnet, S. Handy, S. Spears, and G. Tal, "How do local actions affect VMT? A critical review of the empirical evidence," *Transp. Res. Part D Transp. Environ.*, vol. 17, no. 7, pp. 495–508, Oct. 2012.

H. Meurs and R. Haaijer, "Spatial structure and mobility," *Transp. Res. Part D Transp. Environ.*, vol. 6, no. 6, pp. 429–446, Nov. 2001.

J. Dargay and D. Gately, "Income's effect on car and vehicle ownership, worldwide: 1960–2015," *Transp. Res. Part A Policy Pract.*, vol. 33, no. 2, pp. 101–138, Feb. 1999.

L. J. Schipper, C. Marie-Lilliu, K. (Sweden), and I. E. Agency, *Carbon-dioxide emissions from transport in IEA countries: recent lessons and long-term challenges*. Swedish Transport and Communications Research Board, 1999.

L. Schipper, "Automobile use, fuel economy and CO_2 emissions in industrialized countries: Encouraging trends through 2008?," *Transp. Policy*, vol. 18, no. 2, pp. 358–372, 2011.

M. J. White, "Confirmations and Contradictions Urban Commuting Journeys Are Not 'Wasteful,'" *J. Polit. Econ.*, vol. 96, no. 5, pp. 1097–1110, 1988.

R. Lathia and S. Dadhaniya, "Policy norms and proposed ways to achieve goals of Indian vehicle emission programme," *J. Clean. Prod.*, vol. 208, pp. 1339–1346, Jan. 2019.

S. L. Handy, "Longer view: The road less driven," *J. Am. Plan. Assoc.*, vol. 72, no. 3, pp. 274–278, 2006.

X. Zhang and H. Li, "Urban resilience and urban sustainability: What we know and what do not know?," *Cities*, vol. 72, no. August 2017, pp. 141–148, 2018.

"Saifee Burhani - Home Landing Page." [Online]. Available: http://www.sbut.com/bhendibazaar-past.html. [Accessed: 12-Aug-2016].

Planning of Alternative Street Routes in Urban Areas during Floods

Abhishek Kashyap[a] and Debasish Ghose[a]

ABSTRACT: In an urban scenario, floods often cause congestion and blockage in roads near lake beds and waterbodies which can cause problems to the commuters and may even endanger their lives. This paper addresses this problem by describing a methodology of planning alternative routes in a dynamic flood scenario using information from a predictive flood model. In the solution formulation, graph theory is used to model the transportation network, each road having different travel times and road capacities. Different traffic flows in the city are characterised by a starting point called source and an end point called the destination. The initial routes taken by the vehicles are monitored by using the data from a flood model which predicts the spread of the flood. If the routes are compromised, re-routing of the vehicles takes place using the earliest arrival flows algorithm for solving a multiple-source problem to find alternative optimal routes. Simulations are performed on a real street environment which show the effectiveness of the methodology.

KEYWORDS: traffic control, flood model, dynamic flow

Introduction

Every year floods cause widespread damage to people and infrastructure all over the world. In an urban scenario, floods occur mostly due to heavy rains and insufficient drainage. This is accelerated in areas with an existing water body. Many a time, certain roads which are usable in the summer season may become submerged as and when the flood starts. Such roads usually have a moderate to high traffic plying on them and their damage can lead to a congestion in the road network if there is a lack of prior information about them. This can severely impact the travel time of the commuters, leading to delays. Delivery of emergency services and resources such as medical services are also highly impaired in such situations. Sometimes the commuters may find themselves caught in high flood waters, leading to catastrophic results. However, in any city, there are always multiple routes connecting one place to another. Thus, by determining alternate routes on the fly by using available information on rainfall and expected spread of flood can highly reduce the problem of congestion. This paper addresses the problem of dynamic route planning in a flood scenario using information from a predictive flood model in the context of an Indian city.

Finding optimal routes in a disaster scenario has been traditionally viewed as an optimisation problem with the road network modelled as a graph network. In [1], a least cost distance model is used to find the optimal routes to evacuate the people while considering the slope of the area and land cover. However the capacity of the roads is not considered in this approach. [2] mention several minimum cost algorithms that can be used in the transportation problem by taking the transport time as the cost to be minimised. However, the flow of vehicles through the network is considered to be steady. In [3], the problem has been approached by considering a heuristic algorithm that maximises the flow rate along the selected routes, keeping the capacity constraint in mind. [4] use a optimisation approach in which the travel time of the vehicles is taken to be the volume of the traffic.

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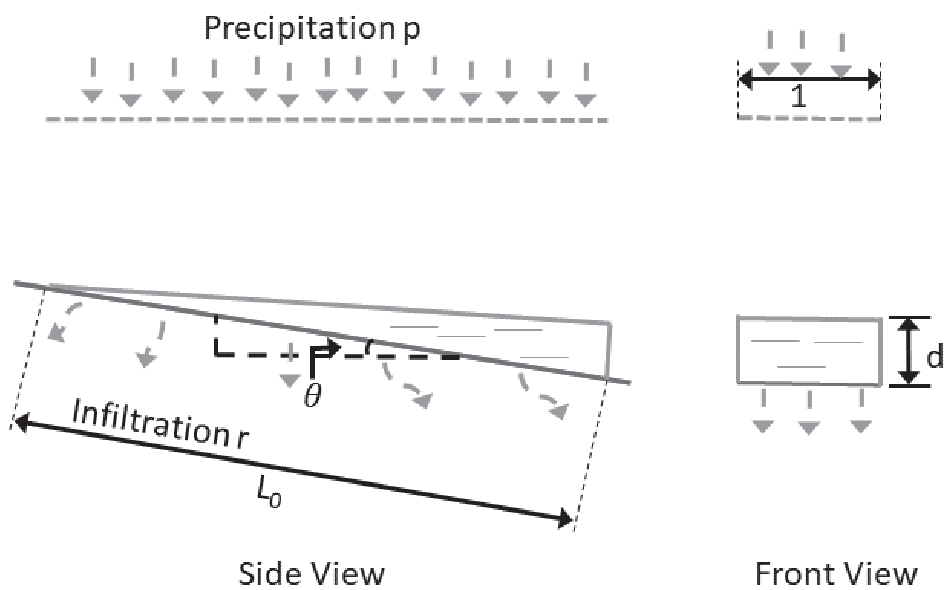

Figure 1: Flow visualisation in the flood model

The concept of dynamic flows or flow over time was first introduced in [5] to find the maximum number of units that can be sent through a network in a given time by using the concept of temporally repeated flows. A key feature of these flows is they mimic the flow of units across a network making them apt for use in transportation problems. [6, 7] approach this problem in the reverse direction and give algorithms for the quickest flow problem which aims to find the optimal flow needed to send a finite number of goods in minimum time. In [8], the concept of earliest arrival flows is defined which finds the optimal flow of vehicles for all instances of time till the defined time limit. In this paper, the above algorithms have been suitably adapted to generate alternate routes for transportation during floods. The novelty of the modified algorithm is that it allows for the re-routing of the flow as and when the flood changes the road network. A paper using a similar approach has been used in resource distribution problem in a flood scenario using UAVs in [9].

There also has been considerable research in other domains related to flood-affected areas. For instance, the use of image features to classify land and water and give information about the flood has been discussed in [10]. [11] use a LiDAR to achieve the same goal. In [12], authors focus on resource allocation using game theoretic methods. [13] discuss two strategies for locating survivors during floods.

Preliminaries

A brief description of the flood model used to simulate flood conditions is given along with the model of the road network.

The Flood Model

Accurate modelling of the flood environment is quite difficult as it involves a number of parameters and their interplay. Considering a very simple model, the Hortonian overland flood model can be applied to predict the flood movement where the parameters of the surface run-off are determined by the continuity equation and the momentum equation [14]. It assumes that the surface run-off is the difference between the precipitated and infiltrated water which flows down in the form of a sheet. For a given infiltration rate r and a precipitation rate p, the following relation can be derived from the continuity equation for flow down plane of length L_0 as seen in Figure 1:

$$Q=(p-r)L_0\cos\theta \quad (1)$$

where, Q is the discharge per unit width of the plane and θ is the inclination angle of the plane. Let d be the depth of the flow determined using the Darcy-Weisbach (DW) equation for laminar flow and Manning's equation for turbulent flow [14]. These equations can be written in the general form as follows:

$$d=\alpha Q^m \quad (2)$$

where, α and m are constants determined as follows:

$$\begin{aligned} \alpha &= \left(\frac{f}{8gs_0}\right)^{(1/3)} & m&=\left(\frac{2}{3}\right)(\text{DW}) \\ \alpha &= \left(\frac{l^{0.6}}{s_0^{0.3}}\right) & m&=\left(\frac{3}{5}\right)(\text{Manning}) \end{aligned} \quad (3)$$

In Eq. 3, $s_0=\tan\theta$ is the slope of the plane, g is the acceleration due to gravity, and f and l are the friction factor and Manning's coefficient, respectively [14], which are positive constants and depend on the surface of the terrain.

The Road Network

The roads can generally be assumed to be two-way and hence the road network is modelled as an undirectional or a bidirectional graph, $G=(N\times E)$. The nodes $N=\{1,2,3,\ldots,n\}$ represent the set of road junctions and other key features on the transport map. Any two nodes i and j that are connected by a road segment belong to the set of edges E. Each road segment is characterised by its length L_{ij} and its capacity C_{ij} or how many vehicles can be accommodated on it side by side. The speed of the vehicles depends on the size of the road; wider roads such as highways offer greater speed to the vehicles, while narrow alleyway roads reduce the speed of vehicles plying through them. Hence roads with the same length can have different travel times t_{ij}, based on the average speed of the vehicles plying through it.

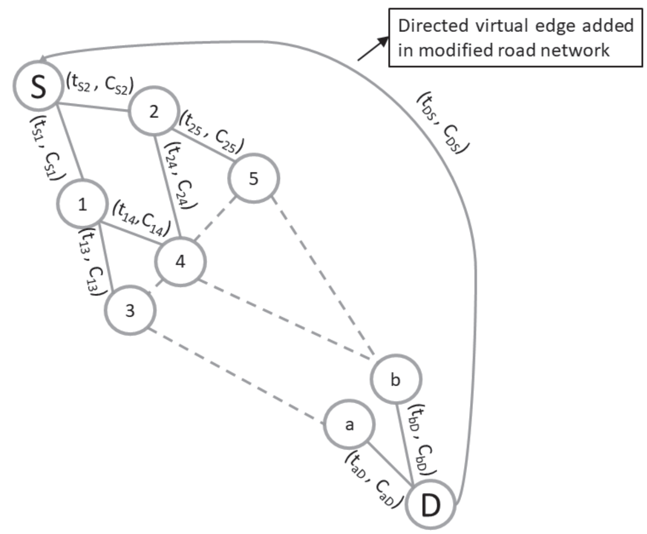

Figure 2: Graph representation of road network

Problem Formulation and Solution Methodology

In this section, the methodology for finding the optimal routes given a starting point or node and a destination point. This is followed by the re-routing problem and the approach used to solve it.

The Basic Routing Problem

Given a starting point or source S and a destination point D in the road map, assume that on an average V vehicles in a time interval ply in the region as shown in Figure 2. The nodes are represented by circles connected by the straight lines representing road segments. The dotted lines indicate the intermediate nodes and edges present in between the nodes. The quickest flow approach is used to model the problem as it describes not only the paths chosen but also how the vehicles move over time with the objective of minimising the travel time and the path which the vehicles need to take among the available paths belonging to the edge set of G while moving from the source S to destination D. Since different paths have different travel times, the minimum time T is a summation of the travel time of the paths chosen. The quickest flow algorithm outlined in [6] is implemented on the road network to find the desired paths. A modified binary search algorithm is used to find this minimum time T. The modified algorithm first computes a lower bound time and an upper bound time for the flow and then binary search is applied on these bounds to find the exact minimum time. The problem is then converted into a maximum dynamic flow problem with T as the time bound and the concept of temporally repeated flows [5] is applied. The original graph representation of the road network is modified by adding a virtual directed edge from the destination point to the starting point with cost $t_{DS} = -(T+1)$ and capacity $C_{DS} = \infty$ (Figure 2) and thus the problem is converted into a static minimum circulation problem as given below:

$$\underset{x_{ij}}{\text{minimise}} \sum_{ij} t_{ij} x_{ij}, \quad (i,j) \in E, \quad i \neq j \tag{3}$$

$$\text{subject to,} \sum_{k} x_{ki} - \sum_{m} x_{im} = 0, \quad i,k,m \in N \tag{4}$$

$$0 \leq x_{ij} \leq C_{ij} \tag{6}$$

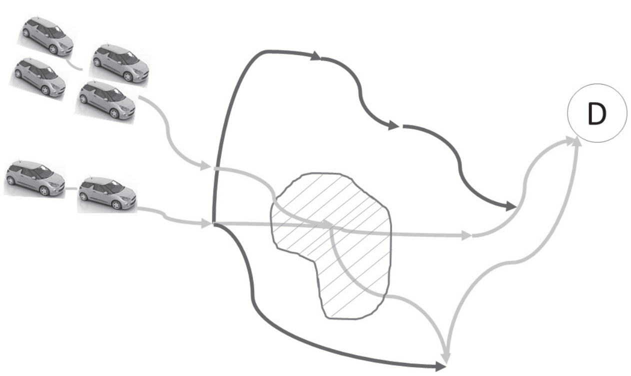

Figure 3: Re-routing the flow

Here, Eqn. 4 is the objective function to be minimised where x_{ij} represents the static flow value of vehicles in the edge (i,j); Eqn. 5 is a constraint applied on all nodes in the graph for flow balance in and out of the node and Eqn. 6 limits the flow in any edge to the maximum capacity of that edge. To obtain the dynamic flow F from the solution of the static circulation problem, path decomposition [2] is applied to the feasible static flow $x = x_{ij}$ to express it as a sum of path flows $(x_p)_{p \in P}$ where P is the set of all paths from S, with each path having a travel time, τ_p, all bounded by the minimum time T. From time $\tau = 0$, flow is sent at a constant rate x_p into all paths $p \in P$ till time $T - \tau_p$, thus ensuring that the last flow arrives before time T.

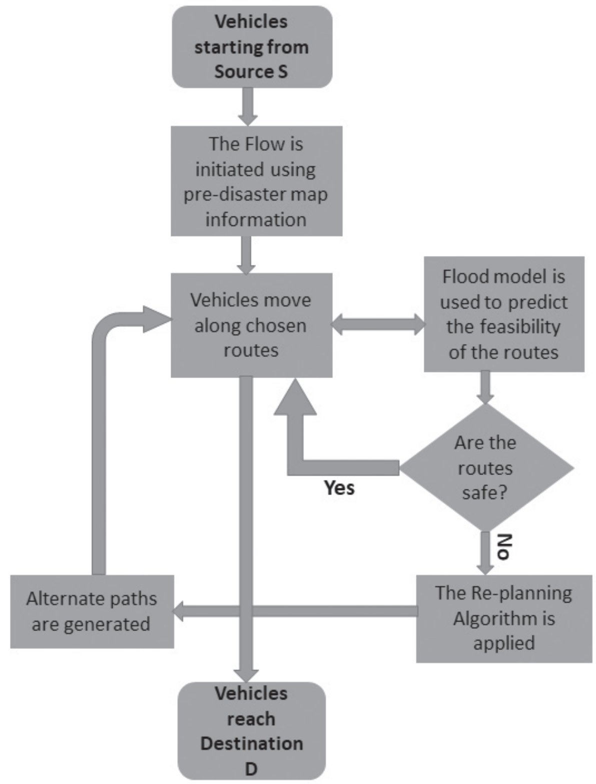

Figure 4: Flowchart of the algorithm

The Re-planning Algorithm

As floods can change the existing road environment and render some routes unusable, therefore, many a time the flow of vehicles needs to be deviated from its original chosen paths and re-routed through alternate routes in an optimal manner. Figure 3 gives a representation of the above scenario. Vehicles moving through initially defined paths (green paths) towards the destination point are impeded by the flood which has submerged the area shown by the blue patch. In such a situation the vehicles at the frontier of each path are considered as an additional source node in the road network and the re-routing problem is converted into a multiple-source single-destination problem earliest arrival flow problem which is solved using the algorithm given in [15]. A virtual source is considered to modify the problem into a single-source problem and it is connected to all the sources via edges of zero travel time and capacity equal to the capacity of the route in which the source lies. Flow is started through this virtual source and the earliest arrival pattern is constructed recursively by determining the sequence in which vehicles are sent from each of the sources and identifying the times or breakpoints when the supply of vehicles from a source is stopped. Once the sequence and the breakpoints have been identified, the quickest flow problem is solved repeatedly across each breakpoint to determine the paths. The complete steps in the algorithm are given in Algorithm 1 and Figure 4 gives the flowchart of the algorithm.

Algorithm 1: Planning of routes

//Given a starting point *S* and Destination *D* and number of vehicles *V*

1: $t = 0$ Initialise starting time

2: Initiate the flow of vehicles using *Quickest Flow*

3: **while** *VehicleCount* ≠ *V* **do** *VehicleCount* is the number of vehicles reaching the destination

4: Update vehicle position along chosen paths with time

5: Get information update from flood model

6: **if** Chosen Path is unusable **then**

7: Reroute the flow along alternative routes using

Replan Algorithm

8: Update chosen paths

9: **end if**

10: $t += 1$

11: **end while**

Table 1: Road Parameters

Street Type	Capacity	Speed of Vehicles
Red coloured (primary streets)	4	17 *m/s* or 60 *km/hr*
Blue coloured (secondary roads)	2	10 *m/s* or 36 *km/hr*
Green coloured (narrow roads)	1	5 *m/s* or 18 *km/hr*

Simulation Results

Bangalore is known to be the city of lakes. During the rainy season, the lakes tend to overflow sometimes and flood the nearby roads. This problem has been aggravated nowadays due to human intervention. In order to test our routing algorithm, a test case of the real street map of an area is taken from Open Street Map which contains the Arekere and Hulimavu Lake area near Bannerghatta, Bangalore (Figure 5a). The street map of the area is extracted as can be seen in Figure 5b. Table 1 gives the parameters of the various roadways in the map. For the simulation the red star in the map is taken to be the start point and the magenta star is taken to be the destination point. We assume that 60 vehicles are travelling during the given travel window. During no flood condition, the routes chosen by the vehicles are shown in black in Figure 6a. A hypothetical flood situation is assumed and roads near the Arekere lake are assumed to be flooded as seen as a blue patch in Figure 6b. The re-planning algorithm is applied in the light of the new information and the re-routed paths are computed as seen in Figure 6b in magenta. The time for the vehicles to reach through the initially defined routes is 118.79s or around 2 minutes and for the re-routed paths is 301.45*s* or around 5 minutes. Though the time scales are small, it can be seen that the delay caused is more than twice the usual time because of the flood.

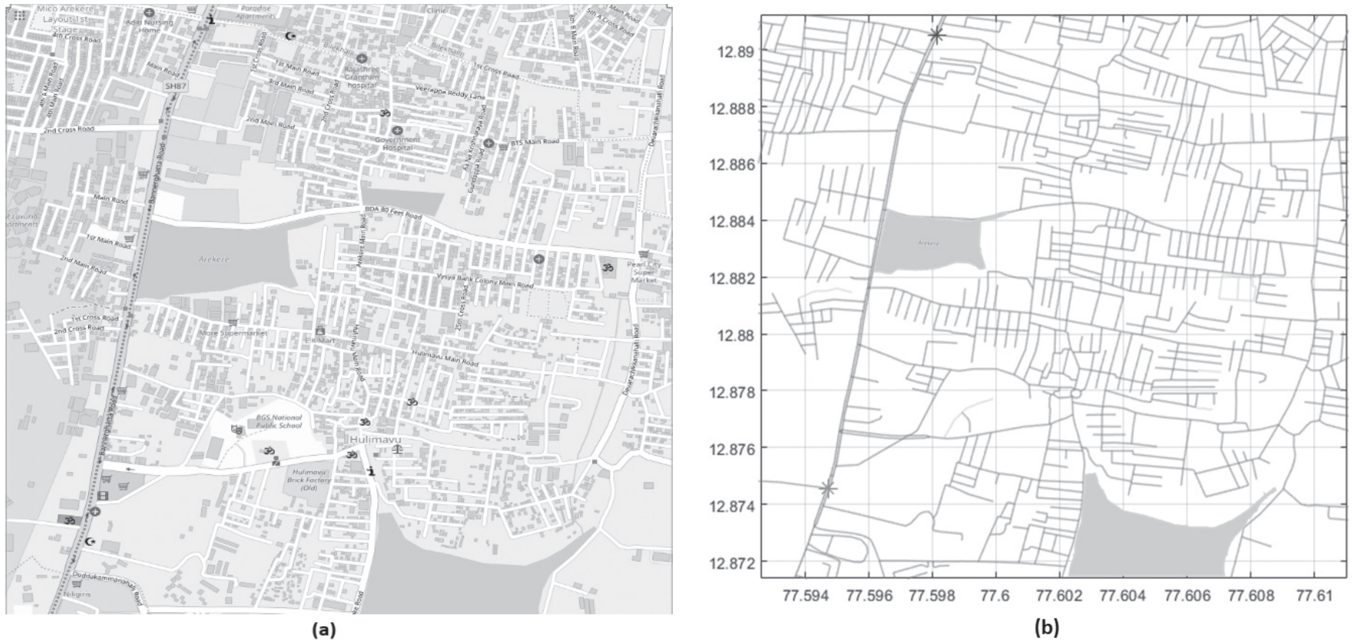

Figure 5: (a) Map of Arekere-Hulimavu area in Bengaluru; (b) extracted street map

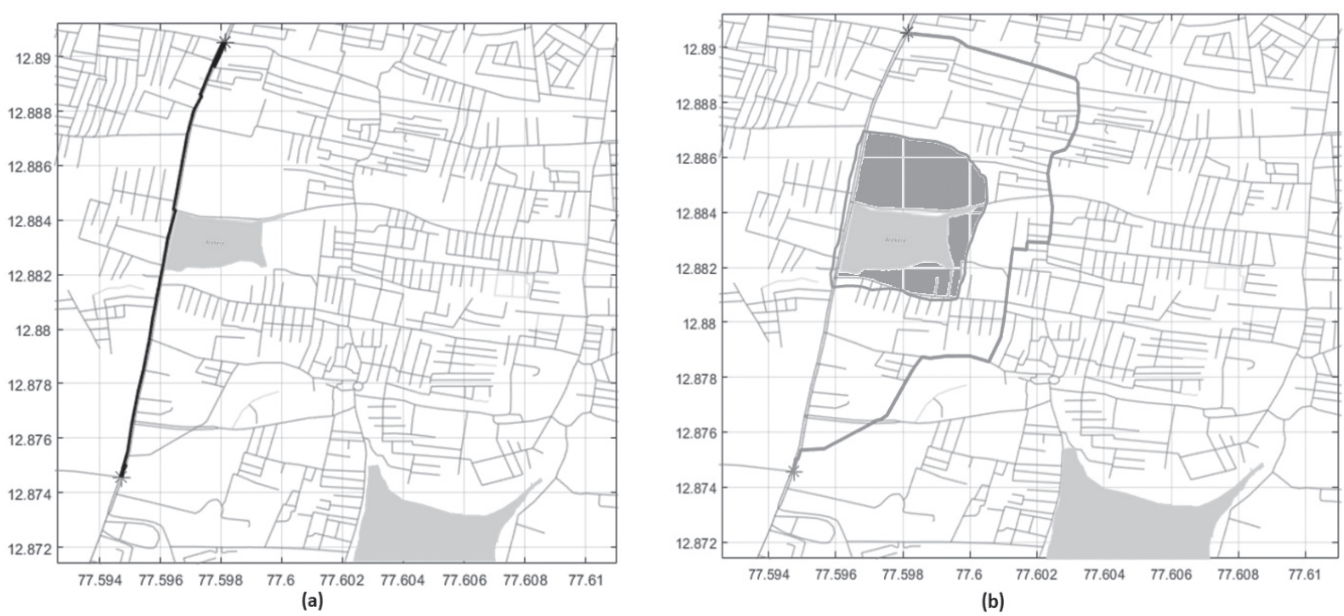

Figure 6: (a) Initially chosen routes; (b) re-planned paths

Conclusion

In this paper, we address the problem of planning alternative routes for vehicles scenario in an event of flood. The algorithm chooses the routes which take the minimum time to reach the destination, taking into account the capacity of the roads by considering the flow of vehicles as a dynamic flow by accurately modelling the movement of vehicles in real life. Flood models can be used in tandem to predict the flood movement and the vehicles can be effectively re-routed on the fly to alternate paths in the event of any change in the road network caused by the flood. In the future, the research can be extended to include source and destination points.

Acknowledgements

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Notes

1 Wood N, Jones J, Schmidtlein M, Schelling J, and Frazier T (2016) Pedestrian flow-path modeling to support tsunami evacuation and disaster relief planning in the us pacific northwest. International Journal of Disaster Risk Reduction 18: 41–55.

2 Ahuja RK, Magnanti TL, and Orlin JB (1993) Network Flows: Theory, Algorithms, and Applications. Prentice- Hall Inc.,Upper Saddle River, NJ, USA.

3 Guo D, Gao C, Ni W, and Hu X (2016) Max-flow rate priority algorithm for evacuation route planning. In: 2016 IEEE First International Conference on Data Science in Cyberspace (DSC), pp. 275–283.

4 Bayram V, Tansel BC, and Yaman H (2015) Compromising system and user interests in shelter location and evacuation planning. Transportation Research Part B: Methodological 72: 146–163.

5 Ford LR and Fulkerson DR (1958) Constructing maximal dynamic flows from static flows. Operations Research 6: 419–433

6 Burkard RE, Dlaska K, and Klinz B (1993) The quickest flow problem. Zeitschriftfur Operations Research 37: 31–58

7 Hoppe B and Tardos E (2000) The quickest transshipment problem. Mathematics of Operations Research 25: 6–62.

8 Gale D *et al.* (1958) Transient flows in networks. The Michigan

9 Kashyap A, Ghose D, Menon PP, Sujit PB, and Das K (2019) UAV aided Dynamic Routing of Resources in a Flood Scenario. (Submitted to European Control Conference 2019).

10 Shriwastav S, Ghose D (2019) Detection and tracking of land-water boundary in flooded region using UAV based images. To appear in the Proceedings of 4th World Congress on Disaster Management, Mumbai, India.

11 Balasubramaniam S, Kashyap A, Shriwastav S, Majumder R, Abhinay NS, Ghose D (2019) LiDAR based land-water boundary identification during floods. To appear in the Proceedings of 4th World Congress on Disaster Management, Mumbai, India.

12 Majumder R, Warier RR, Ghose D (2019) Game theoretic model based resource allocation during floods. To appear in the Proceedings of 4th World Congress on Disaster Management, Mumbai, India.

13 Ravichandran R, Abhinay NS, Ghose D, Das K (2019) Searching for survivors in a flood scenario using UAVs and ground based observers. To appear in the Proceedings of 4th World Congress on Disaster Management, Mumbai, India.

14 Chow VT, Maidment DR, and Mays LW (1988) Applied hydrology. McGraw-Hill, Inc, New York.

15 Baumann N and Skutella M (2009) Earliest arrival flows with multiple sources. Mathematics of Operations Research 34: 499– 512

Resilient Cities and Human Settlements

Simran Pal Kaur [a] and Goutham Raj K. J.[a]

ABSTRACT: As more than half of the world's population is said to be living in cities, it's imperative to make them safe, resilient and sustainable now and for the generations to come. Cities are a physical manifestation of interaction, clustering and groupings of individuals. Urbanisation is a global phenomenon which has made cities to flourish and prosper but has also brought some vices along with it. Unplanned development and expansion is causing many people to settle onto precarious regions. The people from disadvantaged socioeconomic background suffer abject poverty and are more susceptible to hazards as they lack the means to 'bounce back'. 'Sustainable Cities and Communities' is one of the Sustainable Development Goals (SDGs) promoted by the United Nations. The 2030 Agenda is universally calling for collective action towards sustainable development. However, ensuring sustainability and resilience becomes a real challenge when our cities are facing not only the natural disasters but also man-made disasters due to unplanned development which disproportionately affects certain groups of people more. The paper concludes by outlining probable solutions to planning and policy recommendations for ensuring planned development which can help to make our cities disaster resilient and ensure the safety of its citizens.

KEYWORDS: disaster, resilience, poverty, unplanned development, settlements

The Paradox of Urbanisation

Urbanisation is, predominantly, perceived as the engine for economic growth in the current wave of development. Urban centres are believed to be the spaces for enormous opportunities. The opportunities that cities provide are concomitant to distress in hinterlands that propels the city-ward migration in huge proportions. To define urbanisation, it is the process of increase in area of urban centres and proportion of the population living in that area. In contemporary times more than 50 per cent of the world's population is living in cities while it is approximately 31 per cent in India. The current 50 per cent of the world's urban population share will be increased to 60 per cent by 2030. The significance of urbanisation has been paramount in today's development trajectory considering the overall share of urban centres in world's GDP and job creation. UN-Habitat accounts urban centres share as 70 per cent in global GDP. In India, although the urbanised population is 31 per cent in proportion to total population the urban areas that contribute to the GDP will rise to a whopping 70–75 per cent in 2020 from the current 63 per cent as per a report by Barclays. A World Economic Forum study revealed that there are 5 Indian cities in top 10 most dynamic cities in the world based on a city momentum index which focuses on socioeconomic and real-estate indicators (Kelly, 2019).

The multi-dimensional need to push for city-ward migration is stressing cities that are already burdened with existing populations. Ideally, a city requires inward migration when its population is outnumbered to fill all the opportunities created within and then the emerging gaps are to be bridged by migration. In the current development paradigm, more than the pull factors in cities, it is the push factors in hinterlands that are causing massive migration patterns. India is experiencing a huge city-ward migration, without much investment in new cities creation, historically; the existing cities are over-burdened with the relentless influx and further crippled with poor urban management. Hitherto failure in formulating a comprehensive agrarian

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policy to create self-reliant farming communities has increasingly pushed the limits of distressed migration into cities in search of livelihood. Most of these city-ward migrants are semi-skilled and unskilled labourers set out for livelihood quench in cities in order to serve their distressed families back at home. There are 100 million circular migrants in India contributing to the relentless fluctuations in regional migration patterns (Bhide, 2013). These circular migrants are susceptible to several vulnerabilities emerging from territoriality of the policy, dependency and financial inability to access basic amenities and decent housing (Ibid.).

As discussed above, historically, the urbanisation is viewed as a phenomenon rendering economic prosperity but the discrepancies like rapidity and size of current urbanisation process are analysed as 'urbanisation of poverty'. The distressed migration into already saturated large cities in circumspection due to fallacious planning, inefficient management and exhausting resources is creating depriving externalities in the lives of poor migrants. The poor migrants in the cities of India and other middle- and low-income group countries are unable to avail basic amenities and decent housing. Most of the informal housing, in the rush for shelter, is sometimes situated on unused land left due to its unsuitability.

Unplanned Development

The urban development in mid-income countries is described as socially segregated, characterised by unequal access to urban areas, infrastructure, services and security (Mitlin and Satterthwhaite, 2013). The unplanned building construction and settlement extension, mismanagement of sewage and garbage and lack of drinking water and electricity can be considered as unplanned development. Basically, it is to develop towns or areas without planning infrastructure which is unhygienic and unhealthy for settlement. The 2015 (a) report by United Nations International Strategies for Disaster Reduction (UNISDR) revealed that 90 per cent of people in urban areas in low-income countries live in unsafe, exposed housing. The encroachment involved in unplanned development is a major environmental degrading factor in cities. It can be in multiple forms like land-filling or reclamation of lakes, swamps, riverbeds and sea and deforestation of already declining green spaces and farmlands. The Institution of Mechanical Engineers revealed in their report that the degradation of natural calamities is one of the major contributors to increasingly recurring calamities (IMechE report, 2013). The unplanned and unauthorised development or urbanisation has become the poor's only pursuit to gain footholds in the city due to transient nature of state policy (referring to cut-off dates and security tenures) and market repulsion to their unaffordability. Lack of an agency to let people build their own houses and an increasingly closed system created by the state and market agencies in land and housing are rendering homelessness and unsafe housing in Indian cities. These haphazard settlements are often built on unsafe areas such as steep slopes, riverbeds, flood plains, saltpans, swamps, low-lying areas and railway tracks. In both formal and informal economies the urban informality is often associated with low pay and high exposure to environmental hazards (Brown et al., 2014). The unplanned development will result in increasing disaster risk to the marginalised urban poor considering their settlements on unsafe lands.

Vulnerability as a Socioeconomic Differential

There is a close correlation between disasters, poverty and environment (Chambers, 1989). Without the resources to protect themselves the pressure induced by socioeconomic status of poor households, forces them to live on haphazard locations. As the poor exploit the sensitive environmental resources for survival disaster risk increases. The continuous state led displacement into suburbs and absence of alternative sources of income are making the urban poor exploit the natural environment to attain subsistence. Poverty as a factor influences both the choices for safer environment and the ability to recover from a disaster. As per UN-Habitat, the world's slum population decreased by 20 per cent from 2000 to 2014 but it grew in absolute numbers from 807 million to 883 million in the same period. The high-population growth rate in low-income countries is an alarm for dire consequences if not mended with planning strategies to reduce the risk and integrated livelihood creation to alleviate the poverty and formalise their lives. Ex-mayor of Barcelona Dr Clos stated that the 98 per cent of the world's urbanisation growth by 2050 is to be accounted from global south of which 50–60 per cent will be informal.

The rapidly growing small and medium towns are the most susceptible to increasing disaster risk than the rural areas and large cities (UNISDR, 2011). The current urbanisation trend in India, that is small and medium towns largely absorbing the city-ward migrants, and the increasing share of census towns suggest that the Indian urbanisation is prone to disaster risk. Concentrations of people, poverty and disaster are increasing the susceptibility of cities to risk.

What Is Resilience?

Resilience has been interestingly defined in many ways by different writers. Generally in contemporary sense resilience is defined as ability or capacity to spring back to how the situation was before any change.

Resilience is also seen as an integrated web of social interactions that has certain characteristics which help the people to survive in case of hazards.

The scientific community and local governments can together find out the physical and social factors affecting resilience (Donovan and Elliot, 2012).

In context of cities, 'resilience' is their ability to recover from disaster. Resilient cities are cities that are built and rebuilt after a disaster, taking into consideration the natural and man-made hazards impending. Cities also nurture their social networks along with governance as a way to recover from disaster (Hamnett, 2006). The US Government in the 2011 Presidential Policy Directive defined resilience as 'the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies' (Spencer, 2013).

Disaster resilience has multiple aspects to it. The first step begins by ensuring that the city infrastructure and its people are prepared for any impending disaster. The second step is the response to the hazard in order to save as many lives as possible. The third step is to recover and rebuild what is lost. It becomes essential to take people out of trauma and build back again to restore to earlier lives. More accurately resilience is defined not as the ability to 'bounce back', but rather as the ability to 'bounce forward' by integrating the four elements of anticipation of threats, reduction of vulnerability, and responding and recovering from disastrous events (Spencer, 2013).

To make population and cities more resilient, both physical and psychological preparation are required, individually and collectively. The influence of national, state and local action should also be incorporated. Disaster resilience and management in cities is a challenge that tries to reduce the possibilities of loss. Resilience should instil a self-organisational capacity in the city and its citizens.

Disasters in Cities

Disasters are sudden catastrophes or mishappenings that occur due to natural or man-made reasons. In this era disasters are taking a worse form and are getting aggravated due to unplanned development in our cities. People settling near coastal regions, flood plains and seismic zones are more vulnerable. Unplanned development is also causing environment degradation which in turn triggers climate change in the long run.

Urban Floods

A large number of regions in India are susceptible to disasters, one of which is flooding which causes huge amount of loss and destruction. The urban floods are observed more often now during monsoons when the city's drainage systems fail to channelise the quantity of water through its sewages because the passages are not well-connected, narrow or clogged. The occurrence of urban floods reflects that our cities are not ready for such fatefulness and that planning is lacking.

An influx of people is moving into the cities every day. The land is limited in supply and its cost is consistently upgrading. As many new entrants are not able to afford the rising land prices, several have encroached nearby waterbodies. The festival idol immersions in waterbodies also clog the channels. The flood water doesn't have a channel to go into the next waterbody. The expansion of urban settlements and lack of infrastructure for solid waste disposal have resulted in clogging the storm water channels and natural channels which leads to flooding.

When mining is done close to the bed and catchments, the waterbody and its channels are disturbed. Poorly planned construction of bridges and roads hinders the flow of water which causes congestion in drainage systems. Poor planning in case of erecting too many dams also results in flooding.

When a city floods, it comes to a halt. Homes and vehicles lay inundated. The hospitals get crowded and pose the risk of exposing more people to infections leading to a health crisis. Many people lose their lives and the infrastructural services of transport, telecommunication and power also paralyse. Unplanned development in urban areas causes more risks than one can account for. Lack of accountability on the part of government and city administration reflects their apathy to such grave issues.

As the number of lakes is reducing, the inter-connections of the drainages are also lost due to neglect. Poor land use planning cripples the city's capacity to manage the population pressures. In 2015, Mumbai experienced massive urban floods. The expanse of settlement has not left any open space where water can percolate to the ground easily. Paved and impermeable ground hinders the water to find its way into the soil underground and causes inundation to increase.

Singapore has proved that proper planning and drainage system can solve the problem of water security by collecting rain water for use in urban areas.

Earthquakes and Fire Breakouts

With rising urbanisation and expanding informal settlements the government is failing in its capacity to set building standards across the states. The precarious built environment of multi-storey buildings and dependence on concrete poses major risk during the earthquake. To accommodate the growing population the buildings have more floors built than there should be. As building regulations are not followed, the buildings are erected tall and very close to each other to economise on the cost of land and accommodate larger number of people. When a seismic activity occurs the buildings convulse and collapse as they are not designed to be a resilient structure. The collapse of one building may also affect the neighbouring structures and hence intensify the damage.

In case of a fire breakout, the fire rescue brigade may not be able to enter the lanes between the buildings because of insufficient space for the vehicle to move in. In cases where the buildings lack appropriate size of sufficient windows, the situation gets worse. In Mumbai, fire breakouts in highly dense buildings occur often. The fire safety measures are insufficient and the fire brigades also fail to rescue because of lack of space.

75 per cent deaths during earthquakes happen when buildings collapse. Buildings in informal settlements and low-cost buildings have higher chance of collapsing. This indicates how disasters affect poor communities more. They are unable to access resources and knowledge to build safer environments. To address the risks in urban areas, building codes and land planning are essential (UNISDR 2015).

The lack of proper planning is reflected in short-term objectives which fail to include long-term resilience of our cities. The action is required before any impending disaster risk. Post-disaster action to quickly build back buildings and infrastructure will restore people's life temporarily only until the next fatality. "As the emergency passes, this cause gets forgotten: the trauma of earthquakes makes people want to forget, but when that amnesia reaches the institutional level, then history repeats itself" (The Guardian, 2015).

Landfill Collapse

The sites demarcated for garbage and other solid waste are mounting up beyond permissible limits. The people may be maintaining an account of their monthly expenditure but none make an account of the waste they produce. Due to lack of proper planning for waste disposal, landfills in parts of the city are becoming a common dumping ground. The landfills are not only an eye-sore but also pose risk of health and life to people. In September 2017, Delhi's Ghazipur landfill collapsed after days of incessant rain. Two people died as the mountain of garbage swept many into the adjacent canal (Hindustan Times, 2017).

The other two landfills, Okhla and Bhalswa in Delhi, were commissioned in 1994 and 1996 respectively, are not designed as per the Municipal Solid Waste Rules and do not have authorisation from Delhi Pollution Control Committee (Financial Express, 2017). The Ghazipur landfill was commissioned in 1984 and had long passed its utility. It was 50 metres high, when the permissible height is only 20 metres. The mountain is a reflection of the city's unplanned waste management, posing threat to the lives of people.

The process of building a disaster-resilient city is quite a challenge. It will require collective effort from all stakeholders such as government, NGOs, corporate sector and all citizens to make smart decisions. A good network of information dissemination, technical advancement, infrastructural development and scientific temper becomes important to understand all kinds of disasters and the ways to tackle them (Applegate, 2008).

Policy Recommendations

Building resilience is also a matter of creating life and work opportunities for people. To ensure building resilience by reducing disaster risk to combat unplanned development include certain practice-oriented and regulatory changes such as

Investment in Resilient Infrastructural Development and Public Regulations

Investment, revenue diversification and financial inclusion will allow to invest in infrastructural development that is disaster resilient and mitigates the impending risks. Enforcement of safety-enhancing regulations such as building codes, zoning and land use planning rules can be helpful (UNISDR, 2011).

Adequate Service Provision

Accessibility, availability and maintenance of electricity, water supply and drainage system and a planned urban built-up environment are crucial in reducing urban disasters such as floods and fire breakouts (UNISDR 2013). Market insurance and adaptive social awareness and protection can provide better safety nets.

Effective Governance and Transfer of Risk

Incorporating disaster mitigation regulations as an integral part of local development and city development plans will ensure long-term effectiveness. Poor households should be provided with insurance cover for the catastrophe. Effective and inclusive organisational stakeholders can collaborate and come into partnerships for sound decision-making for disaster resilience and establish potent and strong points of communication and coordination. The local governments need to be strengthened because they come first to rescue people from the crisis as they are closest to the community.

Build Back Better

Dr Joan Clos (1997–2006 Barcelona's Mayor) said that what makes a city resilient is planning. Developing long-term infrastructure by re-designing and re-engineering can be learnt from countries which have scaled up its preparedness. The disaster reduction measures should be integrated into development programmes in high-risk areas even if it requires external support.

Planning Interested Poverty Alleviation to Build Resilience

'No Poverty' is the first Sustainable Development Goal (SDG). The aim is to end poverty in all forms as a part of the 2030 Agenda. Poor people are more susceptible to disaster risks. There is a correlation between disaster, environment and poverty. Housing supply policy and improving access to livelihood can help to reduce poverty. With well-functioning land allocation system, planning authorities can provide liveable alternative sites to informal settlers. An appropriate process of planning and regulation can help reduce their vulnerability (Hamnett, 2006).

Decentralisation of Development

A decentralised approach to development will help reduce rural to urban migration and urban to urban migration by addressing the issue of unplanned development. Many poor people live in ecologically vulnerable areas such as coastal regions and flood plains. Sometimes the poor tend to exploit the environment. Poverty affects the choice for a safe environment and is also a factor for inability to recover because of lack of means to 'bounce back'. To save them from being further pushed into destitution, the disaster risk reduction interventions should also focus on poverty alleviation programmes.

Disaster Assessment and Community Building

Every region should develop and test indicators of vulnerability to disasters and major challenges to fight it. Nation's capacity to accommodate more people safely should be improved. Communities should be encouraged to ensure their livelihood and poor people's survival by participating in disaster protection training programmes. Robert Chambers is a British development practitioner who suggested 'putting a floor under the poor' – enabling poor to survive their hard time without making their conditions even worse in future, if it can't be improved. Reducing vulnerability to disaster risks is not the same as poverty alleviation but it has a common ground.

Conclusion

Sustainable development cannot be achieved unless settlements can be made resilient to natural hazards and are planned to ensure that new development does not increase their vulnerability. Despite several virtues of urbanisation it brings with itself the vice of unplanned development that is hampering the city and its people. The city loses resilience when it is not able to endure the pressure of the expansion and hap-hazard development. The impacts of all natural and man-made disasters fall disproportionately on the already vulnerable and poor communities. The need is to develop our cities strategically in a planned manner to build resilience and safety for all human settlements. An integrated approach to disaster management, resilience building and poverty alleviation has to be a collective effort of the government, institutional organisations and communities.

References

Applegate, D. Challenges to Building a Disaster-Resilient Nation. Society for Science & the Public Stable. Science News, Vol. 173, No. 19. June 21, 2008.

Bhide, A. (2013). 'The Invisible Migrant'. Urban Transition. Infochange Agenda. Pg 10–13.

Biswas, K. Saklani,U. Tortajada, C. Truth about urban flooding: Cities like Mumbai get inundated regularly due to administrative apathy, not climate change. Times of India. August 31, 2017

Brown, D. Mcgranahan, D. Dodman, D. (2014). Urban informality and building a more inclusive and resilient green economy. IIED. London.

Chambers, R. (ed). Vulnerability: How the poor cope. IDS Bulletin. Vol. 20. 2 April 1989.

Cross, R. Nepal earthquake: a disaster that shows quakes don't kill people, buildings do. The Guardian. 30 April 2015.

Crowley, K. Donovan, N. Elliot, J. Earthquake disasters and resilience in the global North. The Geographical Journal, Vol. 178, No. 3. September 2012.

Hamnett, S. Vulnerable and Resilient Cities. Alexandrine Press Stable. Built Environment (1978-), Vol. 32, No. 4, Learning from Urban Disasters: Planning for Resilient Cities (2006)

Kelly, J. (2019 Jan 04). These are the world's 20 most dynamic cities. WEF. https://www.weforum.org/agenda/2019/01/how-to-cure-the-growing-pains-of-the-worlds-most-dynamic-cities/

Mitlin, D., & Satterthwaite, D. (2013). Urban Poverty in the Global South. Scale and Nature. New York: Routledge.

Singh, D. Unplanned urbanisation increasing flood impacts. UNISDR. 9 August 2012.

Spencer, M. Lessons from Japan: Resilience after Tokyo and Fukushima. University of South Florida Board of Trustees Stable. Journal of Strategic Security, Vol. 6, No. 2. Summer 2013.

UN-Habitat. Concept Note- World cities day. Building resilient and sustainable cities. https://unhabitat.org/wp-content/uploads/2018/08/Final-World-Cities-Day-Concept-Note.pdf

UN-Habitat. Economy: https://unhabitat.org/urban-themes/economy/

IX Resilient Mega Cities

Household Location, Land Use Changes and Monsoon Rainfall Impact on Disaster Risks in Informal Settlement: A Case Study in Kolkata City, India

Dinabandhu Mahata[a] and Sulochana Shekhar[a]

ABSTRACT: In the present era, urban growth centres are a multidimensional spatial process. The high percentage of urban population growth occurs in informal settlements. Economically deprived population reside in this settlement area, where the livelihood cost is minimal. The informal settlements are characterised by a high growth rate, high density, overpopulation, unplanned buildings and road network and low standard of sanitation infrastructure. Drainage infrastructure is essential for reducing risk in flood-prone places. The main aim of the study is to identify the disaster risks prone area in Kolkata city region and investigate land use factors and household location influenced the structural flooding impact in informal settlements. The study has used multiple data sources to fulfill the needs of objectives. The study has been carried out using the secondary data, like satellite data collected for the land use study from the United States Geological Survey (http://earthexplorer.usgs.gov/) and Google Earth map. Population data were collected from the Census of India data (Socio-cultural table and Economic Table). Meteorological data were collected from the metrological department, Govt. of India. Lastly extensive search of review articles necessary for this study has been carried out through the high standard database such as Scopus, Science Direct and Environment complete. Statistically, bi-variate and cross tabulation methods have been used for the data analysis. by using the data, different rates ratio have been calculated among the desired variables. The study has been carried out with the help of ARC GIS (10.2) and ERDAS (2014), Google earth Software. The geographical data that were used in this study for subsequent processing included layer stake, georeferencing and supervised classification. Disaster risk assesses the potential loss of property or houses of a person and a community. The environmental hazards like floods and storms have an impact on the slum population because they usually live in the lowland area and near the wetland areas. The disaster risk prone area is located near Salt Lake and the Rajarhat Newtown. All people who live there come under low-income households and work in the informal sector; they mainly depend on the informal labour market. The study reveals multiple vulnerability factors, including unsafe construction practices, poor drainage systems, institutional incapacity, the inadequacy of land and settlements in high-risk areas. The findings suggest policy implication of sustainable land use planning, proper drainage and sanitation system to manage disaster risk in the informal settlements.

KEYWORDS: informal settlement, population growth, land use, disaster risk, Kolkata

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Introduction

In the present era, urban growth is a multidimensional spatial process. The high percentage of urban population growth occurs in informal settlements. Economically deprived population resides in this informal settlements with minimum livelihood cost. The informal settlements are characterised by a high population density and low standard sanitation infrastructure and other basic facilities. Urban informality is a common problem in Third World countries (Nassar & Elsayed, 2018). In the world, one in eight people lives in the slum area (Almanac, U.H.S., 2015- 2016). The increased inflow of population and use of resources create pressure on the various natural systems, increasing their vulnerability (Greeshma & Kumar, 2016). The disaster risks are increasing with urban growth (Fraser, Leck, Parnell, & Pelling, 2017). The urban activities are influencing the flood hazards (Douglas, 2017). Informal settlements in the coastal area are prone to high risks (Sietchping, 2005 & Claudianos, 2014). Cities are also facing risk due to climate change, which results in rise in sea level, flooding, drought and intensified storms (Adger 2006 & Nur & Shrestha, 2017). The recent study of flood disasters directly impacts on of the local population and which was directly influenced by climatic conditions (Delalay et al., 2018). The housing is meant to provide shelter and security of human being and is considered fundamental rights in the society, in which the built environment is created, used and maintained for the physical, social and economic well-being and quality of life of individuals and households (Lawrence, 2004, & Govender, Barnes, & Pieper, 2011). The low-lying city periphery has undoubtedly increased population exposure and environmental hazards (Rumbach, 2014).

Kolkata city is more vulnerable during the monsoon season. There are two factors that influence the city flood: the geophysical factor and human factor. The geophysical factors include cyclone, land cover, annual rainfall (heavy rainfall in monsoon), poor drainage, sewer overflow, etc. The human factors also influence the flood situation in the city region. These include greenhouse gas emission, artificial drainage, haphazard building and unwanted scatter settlements, etc. The topographic elevation, household's location and heavy rainfall are the proximate determinant of the flood. The most vulnerable area in the world has climate-related risks (Boughedir, 2015). Natural disasters are increasing in many regions in the world due to the growing exposure to human activities (Abedin & Shaw, 2015). The rapid economic growth and expansion of the suburban area in the coastal settlements result in flood risk (Chacowry, Mcewen, & Lynch, 2018). People living in slum area are vulnerable to these risks due to low elevation, degraded vegetation, open drainage and heavy rainfall. Due to the south-west monsoon, Kolkata city received heavy rainfall from June to September, and the people were affected due to flood. The main aim of this study is to identify the disaster risk prone area and to examine the land use and land cover pattern changes in the study region. In addition the influence of household location, land use changes and monsoon rainfall in relation to the structural flood in the study region was examined.

Methods and Materials

Study Area

Kolkata is one of the oldest cities of India. The city is more than 300 years old.

The Kolkata city region has a potential for the commercial market. The informal settlements are found on the site of the river bank, canal side, road and railway tracks in the city region.

Kolkata city is governed by the Municipal Corporation which comes under the Kolkata Metropolitan Region (census of India, 2011). The study region has been selected based on the census data, where more than 40 percentages of people are living in the slum region. According to the census data, Kolkata city has the highest percentage of the slum settlement situated near the port, riverside and surrounding of the market area. It covers parts of Chitpur, Bhowanipore, Beliaghata and Tangra, including parts of Park Circus, Garden Reach and Metiabruz region in the Kolkata city region.

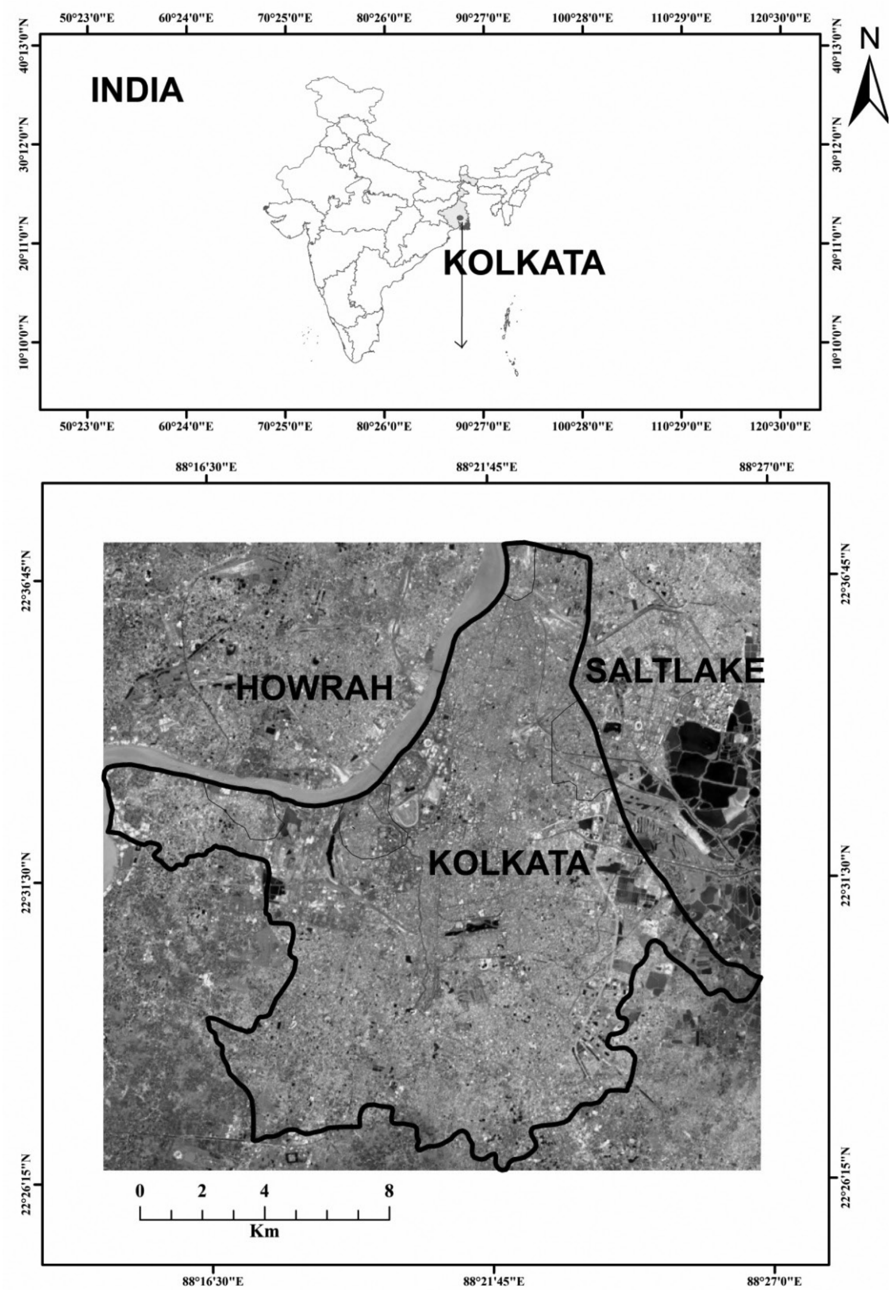

Figure 1: False colour composition of study area of the Kolkata city, India

Data and Methodology

The study has used multiple data to fulfil the needs of objectives. The following are the details of data sources that have been used to execute the study. The population data were collected from the Census of India (primary census abstract, socio-cultural table, and Economic Table) and satellite data collected from the United States Geological Survey (http://earthexplorer.usgs.gov/). The images were collected from the different sensors of Landsat satellite series for the Kolkata city, i.e. Landsat 7

ETM+ and Landsat OLI 8. The basic information of the satellite images are:

Satellites	Acquisition Date	Path and Row
Landsat 7 ETM+	17 November 2000	138 and 44
Landsat 7 OLI	5 March 2011	138 and 44

Rainfall data were collected from IMD (Metrological Department, Govt. of India). From the extensive literature review was coming out on the informal settlement of Kolkata city. The study used the statistical as well as the spatial analysis method to fulfil the objectives. Statistically, bi-variate and cross tabulation methods have been used for the data analysis. by using the data, different rates ratio have been calculated among the desired variables. The spatial analysis has been carried out with the help of ARC GIS (10.5.1) and ERDAS (2014). Two satellite images were classified with supervised classification in ERDAS imagine (2014) software. The geographic coordination of slum location was collected by the use of Google Earth software.

Results and Discussion

According to the 2011 census, India has around 377 million urban population, and 31.16 per cent of the population live in the urban areas. Kolkata city is the seventh largest city in India and has 4.6 million population. The socio-demographic profile shows the basic social and economic indicator of the slum community. The census data (2011) shows that Kolkata city has 300755 slum households. The sex ratio of this communities is 903.

Male and female literacy is more than 60 per cent, but the employment rate is very low. Only 38 per cent of people are employed in the job market, and more than 60 per cent of people do not have any formal jobs.

Table 1: Socio-demographic Profile of Slum Population in Kolkata City

No. of Household	300755
Total Slum Population	1409721
Sex Ratio	903
Child Sex Ratio	955
Literacy Rate	65.84
Male	69.18
Female	62.14
Percentage of Working Population	38.87
Male	58.93
Female	16.66
Percentage of Non-working Population	61.13
Male	41.07
Female	83.34

Source: Census of India, 2011

The data also show that more than 80 per cent of female population are not working in the formal job market.

Land Use Pattern and Household Location Influence of the Disaster Risk in the Study Region

The growth of slum population in an urban area is one of the major issues in the 21st century. In general, the urban poor people live in the most vulnerable situation in the city region. They make a settlement in the low-cost area prone to climatic hazard and flood. They build the houses using bamboo thatches and other basic raw materials. Because of the poor infrastructure and household location, the study region is directly influenced by disasters. Population growth coupled with increased risk of exposure to hazards increase the vulnerability to disasters (Jain, 2015). The population density, built up area and open space at area level are significant contributors to the disaster risk (Kumar & Bhaduri, 2018).

Land-use planning is one of the most influential instruments for climate change adaptation (Downes, Storch, Downes, & Storch, 2014). Figure 2 (a) represents the land use pattern of the study region in the year 2000. The satellite image shows that most of the slum settlements are situated in the river bank, wetland and climatic hazard region. In this particular place, people are more vulnerable to climatic hazards like cyclone and flood. They are always at the risk of the recurrent and prevalent flooding events in densely populated low land and neighbourhood area (Ling & Chiang, 2018).

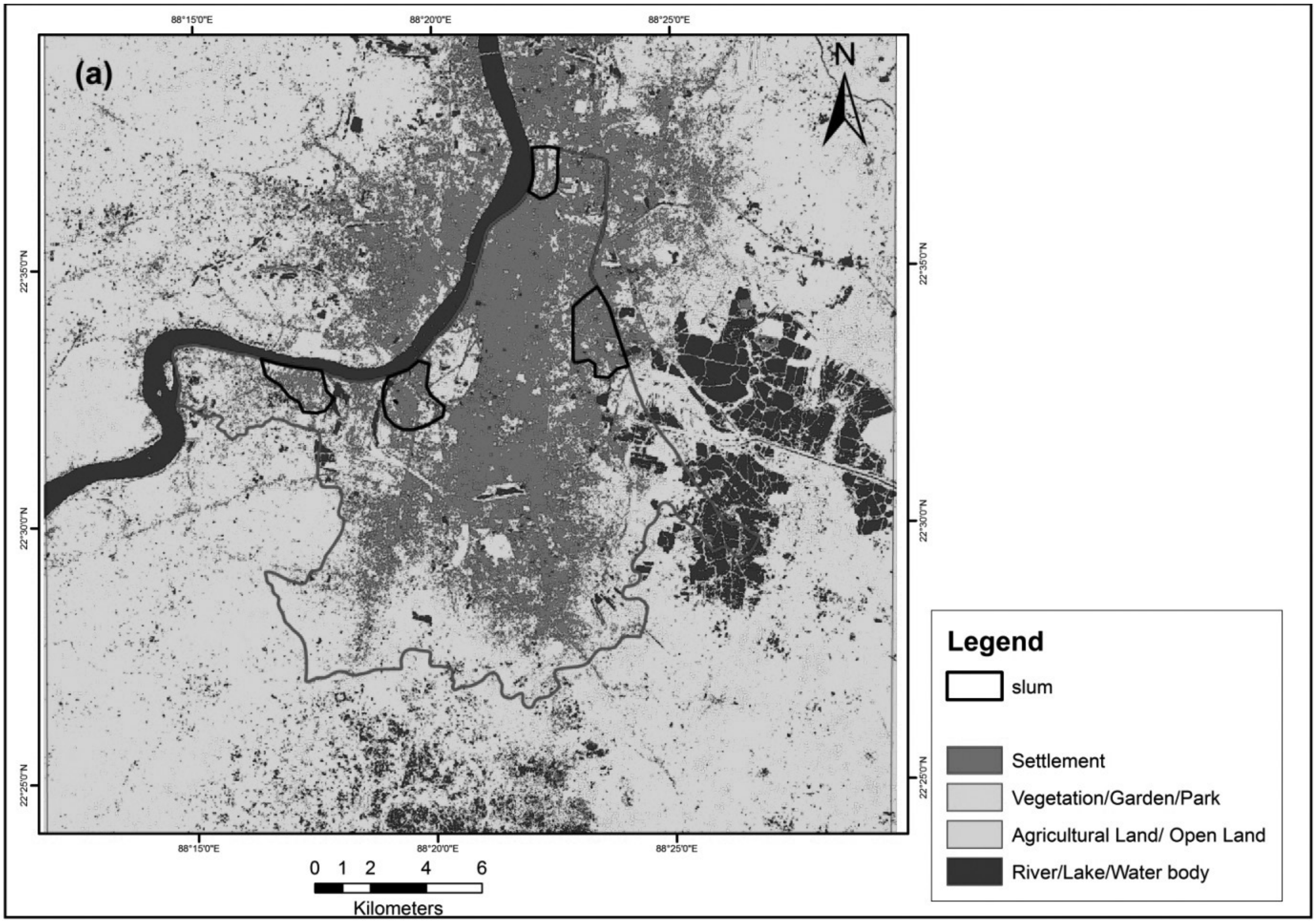

Figure 2: Land use pattern and slum location in the study region of Kolkata city

Table 2: Percentage Changes of Land Use Patterns in Slum Settlement, Kolkata City

Land Use	2000	2011
Settlement	**60.6**	**87.4**
Vegetation/Garden/Park	**13.5**	**4.2**
Agricultural Land/Open Land	**22.8**	**6.3**
River/Lake/Water body	**3.0**	**2.1**

The supervised land use classification shows that land use pattern is changed from 2000 to 2011. The land use pattern in the Kolkata city region as well as the slum settlement region changes over the period. From Figure 3(b) it can be seen that the build up area is increasing and other land use pattern like vegetation, agricultural land, open land and water body area is decreasing from 2000 to 2011.

The spatial growth of slum settlement in Kolkata city has not followed any planning model. The spatial extension was observed by using the remote sensing data. In the early years of 2000s, the slum settlement area was 60.6 per cent, and it increased up to 87.4 per cent in 2011. The captured the spatial growth of slum settlement in between 2000 and 2011. And the other land uses area is decreasing from 2000 to 2011.

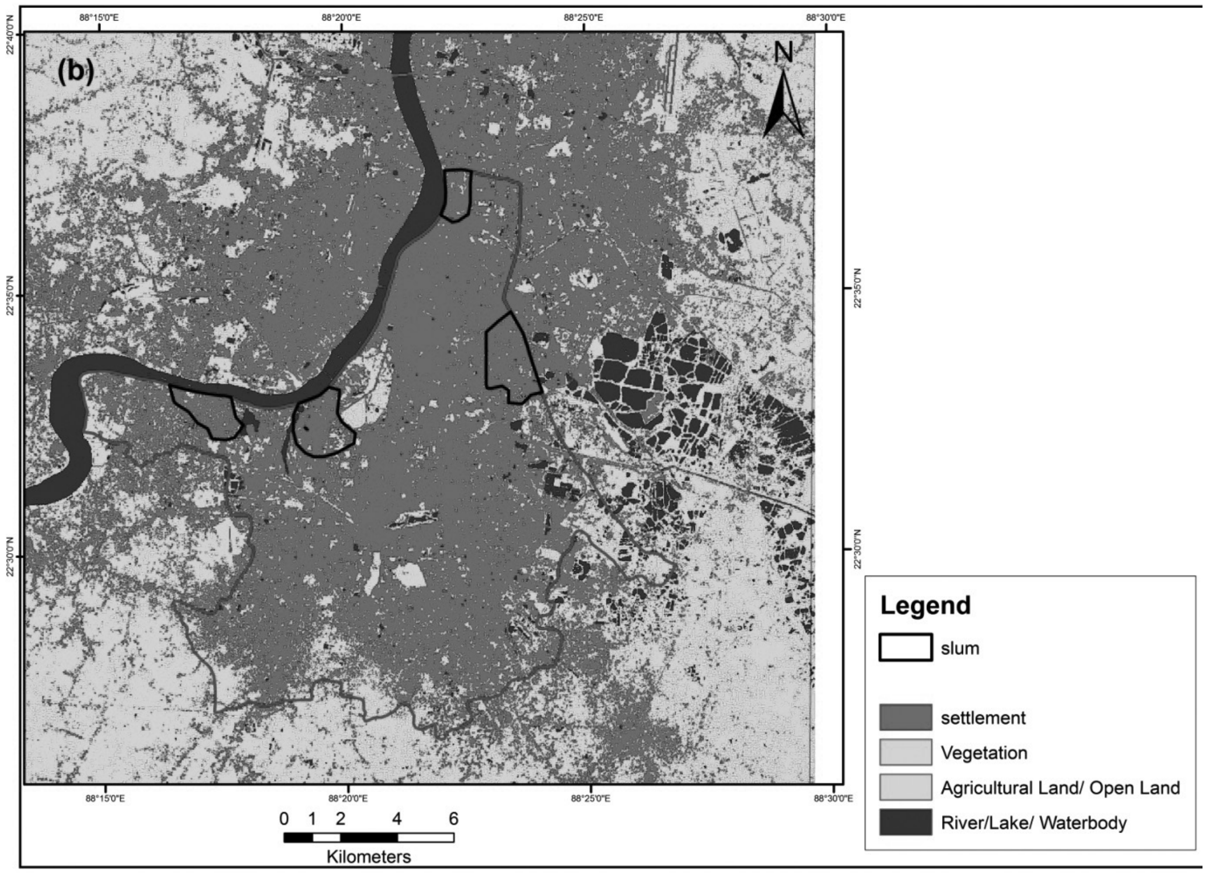

Figure 3: Land use patterns and slum locations in the study region of Kolkata city

Influence of Monsoon Rainfall on the Disaster Risk in the Informal Settlement

Kolkata city is located below 10 metres (9.14m) mean sea level; this mean sea level indicates that this area is at high risk of flood in the monsoon season.

The natural or social system is sensitive to experiencing damage from climate change or its impacts (Wilk, Jonsson, Rydhagen, Rani, & Kumar, 2018). Climate Change frequently affects cities in low-elevation coastal zones and houses in low-income areas (Middelbeek, Kolle, & Verrest, 2014). Kolkata is under the tropical wet and dry climate. The city region receives annual rainfall of 1500 mm. The highest rainfall occurs during the monsoon season (July to September). During the monsoon season, Kolkata receives heavy rains in the city region. Due to water logging conditions, the normal life of people in slum gets affected greatly.

Conclusion

We conclude that informal settlements located near the water body and low-elevation region, have a highest vulnerability exposure. In the context of climate change and household waste management, people face the geophysical events. The slum communities are exposed to high levels of vulnerability with limited coping capacity. Land use patterns were found to have significantly influenced flooding in the slum region of Kolkata city. At present, vegetation cover decreased because of growth of the settlement and other urban infrastructure. The drainage system did not perform well during the monsoon season. The lack of drain cleaning, use of plastic, the heavy rainfall directly influenced the food in an informal settlement. The findings suggest policy implication of sustainable land use planning, proper drainage and sanitation system for the efficient management of disaster risk in the informal settlements.

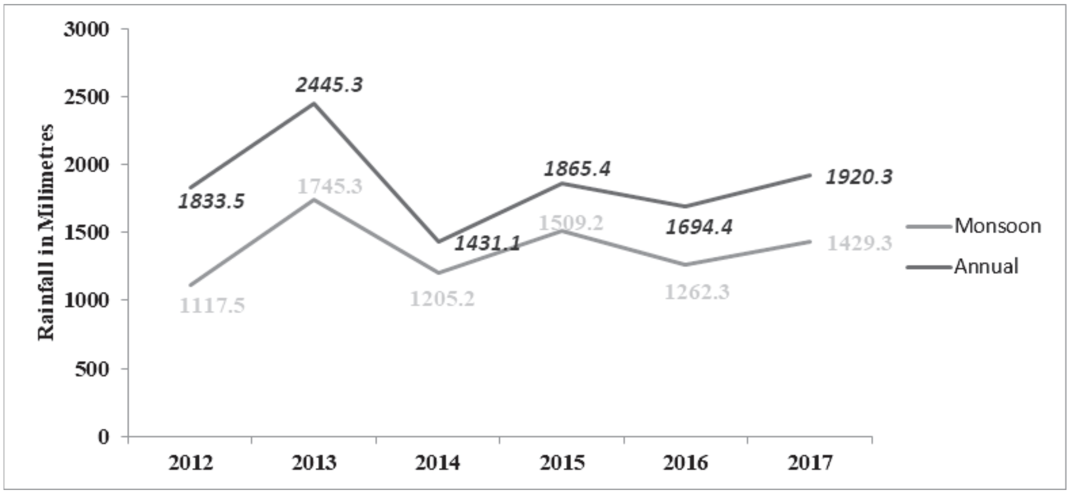

Figure 4: Monsoon season and annual rainfall (mm) in the Kolkata city

Source: India Meteorological Department, Rainfall statistics from the different year

References

Abedin, A., & Shaw, R. (2015). The role of university networks in disaster risk reduction: Perspective from coastal Bangladesh. *International Journal of Disaster Risk Reduction*, *13*, 381–389. http://doi.org/10.1016/j.ijdrr.2015.08.001

Adger, W. N. (2006). Vulnerability. *Global environmental change*, *16*(3), 268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Almanac, U. H. S. (2015). *2016. Tracking Improvement in the Lives of Slum Dwellers*. Technical Report

Boughedir, S. (2015). Case study: disaster risk management and climate change adaptation in Greater Algiers: overview on a study assessing urban vulnerabilities to disaster risk and proposing measures for adaptation. *Environmental Sustainability*, *13*, 103–108. http://doi.org/10.1016/j.cosust.2015.03.001

Census of India (2011). Kolkata city census data (Retrieved from https://www.census2011.co.in/census/city/215-kolkata.html

Chacowry, A., Mcewen, L. J., & Lynch, K. (2018). Recovery and resilience of communities in flood risk zones in a small island developing state: A case study from a suburban settlement of Port Louis, Mauritius. *International Journal of Disaster Risk Reduction*, *28*, 826–838. http://doi.org/10.1016/j.ijdrr.2018.03.019

Claudianos, P. (2014). Preventive resettlement of at-risk informal settlers in highly disaster-prone areas. In *Procedia Economics and Finance* (Vol. 18, pp. 312–319). Elsevier B.V. http://doi.org/10.1016/S2212–5671(14)00945–9

Delalay, M., Ziegler, A. D., Singh, M., James, R., Sudmeier-rieux, K., Mcadoo, B. G., & Kochhar, I. (2018). Towards improved flood disaster governance in Nepal: A case study in Sindhupalchok District. *International Journal of Disaster Risk Reduction*, *31*, 354–366. http://doi.org/10.1016/j.ijdrr.2018.05.025

Douglas, I. (2017). Flooding in African cities, scales of causes, teleconnections, risks, vulnerability, and impacts. *International Journal of Disaster Risk Reduction*, *26*, 34–42. http://doi.org/10.1016/j.ijdrr.2017.09.024

Downes, N. K., Storch, H., Downes, N. K., & Storch, H. (2014). Current Constraints and Future Directions for Risk-Adapted Land-Use Planning Practices in the High-Density Asian Setting of Ho Chi Minh City. *Planning, Practice & Research*. Taylor & Francis. http://doi.org/10.1080/02697459.2014.929835

Fraser, A., Leck, H., Parnell, S., & Pelling, M. (2017). Africa's urban risk and resilience, *26*, 1–6. http://doi.org/10.1016/j.ijdrr.2017.09.050

Govender, T., Barnes, J. M., & Pieper, C. H. (2011). Housing conditions, sanitation status and associated health risks in selected subsidized low-cost housing settlements in

Cape Town, South Africa. *Habitat International*, *35*, 335–342. http://doi.org/10.1016/j.habitatint.2010.11.001

Greeshma, P., & Kumar, K. M. (2016). Disaster Resilience in Vulnerable cities through Neighbourhood Development: A case of Chennai. In *Procedia Technology* (Vol. 24, pp. 1827–1834). Elsevier B.V. http://doi.org/10.1016/j.protcy.2016.05.229

Jain, G. (2015). The role of private sector for reducing disaster risk in large scale infrastructure and real estate development: Case of Delhi. *International Journal of Disaster Risk Reduction*, *14*, 238–255. http://doi.org/10.1016/j.ijdrr.2014.09.006

Kumar, B., & Bhaduri, S. (2018). Disaster risk in the urban villages of Delhi. *International Journal of Disaster Risk Reduction*, *31*, 1309–1325. http://doi.org/10.1016/j.ijdrr.2018.04.022

Lawrence, R. J. (2004). Housing and health: from interdisciplinary principles to transdisciplinary research and practice. *Futures*, *36*(4), 487–502. https://doi.org/10.1016/j.futures.2003.10.001

Ling, T., & Chiang, Y. (2018). Strengthening the resilience of urban retailers towards flood risks - A case study in the riverbank region of Kaohsiung City. *International Journal of Disaster Risk Reduction*, *27*, 541–555. http://doi.org/10.1016/j.ijdrr.2017.11.020

Middelbeek, L., Kolle, K., & Verrest, H. (2014). Built to last? Local climate change adaptation and governance in the Caribbean – The case of an informal urban settlement in Trinidad and Tobago. *Urban Climate*, *8*, 138–154. http://doi.org/10.1016/j.uclim.2013.12.003

Nassar, D. M., & Elsayed, H. G. (2018). From Informal Settlements to sustainable communities. *Alexandria Engineering Journal*, *57*, 2367–2376. http://doi.org/10.1016/j.aej.2017.09.004

Nur, I., & Shrestha, K. K. (2017). An Integrative perspective on community vulnerability to flooding in cities of developing countries. *Procedia Engineering*, *198*, 958–967. http://doi.org/10.1016/j.proeng.2017.07.141

Rumbach, A. (2014). Do new towns increase disaster risk? Evidence from Kolkata, India. *Habitat International*, *43*, 117–124. http://doi.org/10.1016/j.habitatint.2014.03.005

Sietchiping, R. (2005, April). Prospective slum policies: Conceptualization and implementation of a proposed informal settlement growth model. In *Third Urban Research Symposium.“Land, Urban and Poverty Reduction* (pp. 4–6).

Wilk, J., Jonsson, A. C., Rydhagen, B., Rani, A., & Kumar, A. (2018). The perspectives of the urban poor in climate vulnerability assessments – The case of Kota, India. *Urban Climate*, *24*, 633–642. http://doi.org/10.1016/j.uclim.2017.08.004

The Degradation of Urban Environment in Mulund, Mumbai: Identifying the Gaps in Residents' Expectation and Policy Implementation

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ABSTRACT: In developing countries such as ours, it often happens that in spite of various policy interventions, the urban environment continues to exhibit signs of degradation or decay. While there can be a number of reasons behind this, one prominent reason is the existence of a gap between residents' expectation and policy implementation. It happens so that in most cases, residents' expectation and policy implementation hardly go hand in hand, resulting in developmental loopholes and consequent degradation of the urban environment. It becomes extremely important to take into consideration the expectations of the residents as they are the one confronting the ground realities of the region on a regular basis. Therefore, they have a detailed view of the prime needs of the region. Thus, by means of taking the residents' views into consideration, the gap between their expectation and the actual policy implementation by the government in any area can be understood to address the issues related to the degradation of its urban environment. With this understanding, the paper endeavors to identify the existing gap between residents' expectation and policy implementation in the suburb of Mulund in Mumbai. Identifying this gap will be helpful towards enabling the policymakers in formulating and implementing relevant policies that would prove beneficial in combating the issue of degradation of Mulund's urban environment. Considering the nature of the study, a combination of both primary and secondary data is used to address the problem. The results derived reveal the existence of a significant gap between residents' expectation and the current policy intervention in the suburb. In other words, the dualism of expectation versus reality is clearly highlighted in the study and the need for addressing the issue is brought into the light. The study also forwards suggestive measure for the stakeholders to address the issue. Here it is worth mentioning that although conducting such a study for the whole of Mumbai would have been much fruitful, due to various constraints, this study has been limited to the suburb of Mulund.

KEYWORDS: urban, environment, residents' expectation, policy

Linking the Degradation of Urban Environment to Gaps in Residents' Expectation and Policy Implementation

Urban areas of today are no longer what they used to be a century ago. They have evolved in their essence and character. The growing urban population and the changing nature of urban life are among the complexities that are being confronted by the urban areas of today. At present, more than half of the world population is urban and the number is fast increasing. The urban areas of the global south are central to the environmental challenges of the 21st century (Martini, McGranahan, Montgomery & Farnandez-Castilla,

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2012). The growing concentration of population in the urban areas is exerting tremendous pressure on urban infrastructure and environment (Ghosh, 2018:1126). This has raised severe concerns across the globe, leading to various policy interventions for combating the crisis. The growing developmental pressure leads to increasing expectation on the local governments to respond with adequate policies to preserve a certain perceived quality of life (Stevenson, 2009). However, in spite of the implementation of various policies, it is often seen that the urban environment continues to exhibit signs of degradation or decay. The existence of a gap between residents' expectation and policy implementation happens to be a major cause behind it. It is necessary to account for residents' expectations because they are the one to confront these issues on a day-to-day basis with deeper insight into the existing picture. The paper argues that the formulation of policies without accounting for the expectations of the residents cannot be inclusive enough to solve the issues of the urban environment. To establish this, an attempt has been made in this paper to identify the existing gap between residents' expectation and policy implementation in the suburb of Mulund in Mumbai. Although a study covering the whole of Mumbai would have been extremely fruitful, due to certain constraints, the present study has been limited to the suburb of Mulund. Nonetheless, the study will definitely serve towards understanding why residents' expectation and policy implementation must go hand in hand to combat the crisis of urban environment of Mulund as well as the whole of Mulund.

Objectives and Research Questions

The study is based on the following objectives:

- To understand the problems causing degradation of Mulund's urban environment; and
- To identify and examine the gaps existing between residents' expectation and policy implementation for improving the quality of the urban environment in Mulund.

The main research questions of the study are as follows:

- What are the main problems confronting the urban environment of Mulund?
- How do the residents view these problems? What are their experiences?
- What are the expectations of the residents from the policymakers? How far are the policies formulated by the government, in consonance with the expectations of the residents?
- How will it be possible to bridge the gap between residents' expectation and policy implementation?

Methodology

The study makes use of both primary and secondary forms of data to draw the analysis. Primary data is collected directly from the field, using the methods of field observation, and residents' interview. The collection of secondary data was done by means of an extensive literature review from relevant books, journals, reports, news articles, etc. This is followed by a qualitative and quantitative analysis of the data. The former was done by means of narrative analysis and content/document analysis, whereas the later was done using statistical measures.

The Urban Environment of Mulund and Its Degradation

Mulund, an eastern suburb of Mumbai, is the abode of 3,41,463 persons (Census, 2011). It lies at the north-eastern edge of Mumbai, in the T-ward of Mumbai Suburban District (Fig 1). The suburban railway line passing through the suburb divides it into two parts – Mulund East and Mulund West. The suburb houses a cosmopolitan population comprising Maharashtrians, Gujaratis, Tamils, Malayalis, Kannadigas, Sindhis and Punjabis (Nair, 2005). Mulund was a lesser known suburb prior to the deindustrialisation phase that hit Mumbai, including Mulund, during the 80s and the 90s. These vacated industrial sites began getting used for residential development (Kulshrestha, 2018). The growth of real estate (residential and commercial both), along with the growth of urban infrastructure and amenities, changes the very character of the suburb. As the suburb emerged in the urban scene of Mumbai with a renewed vigor, along with positive aspects of urban growth, came the negative counterpart of urban environmental issues.

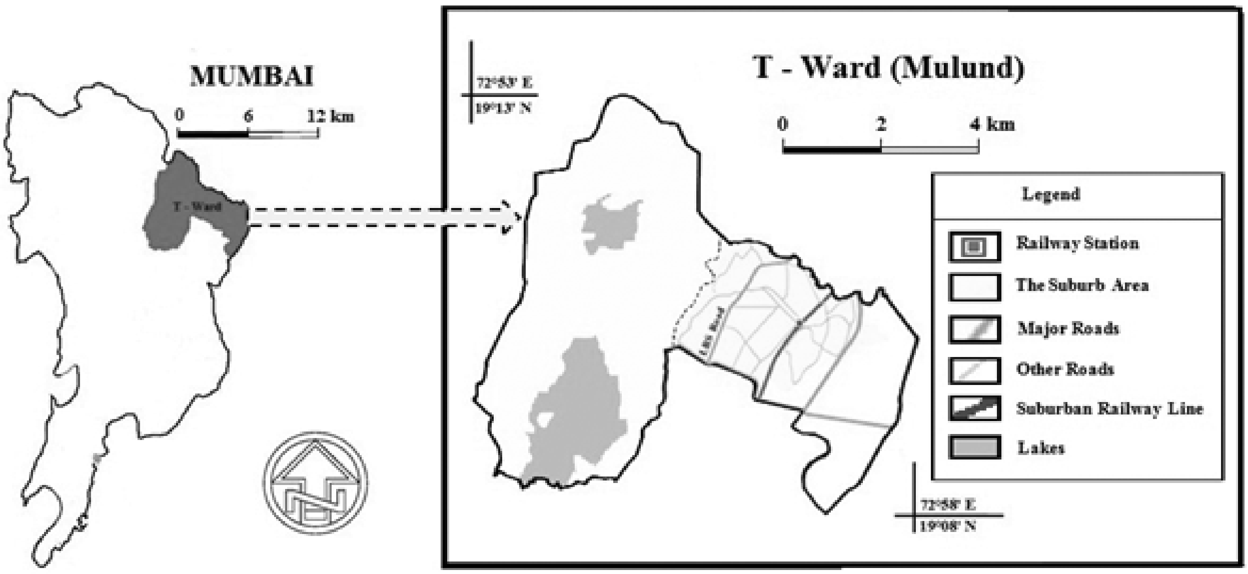

Figure 1: Map showing location of T – Ward (Mulund) in Mumbai

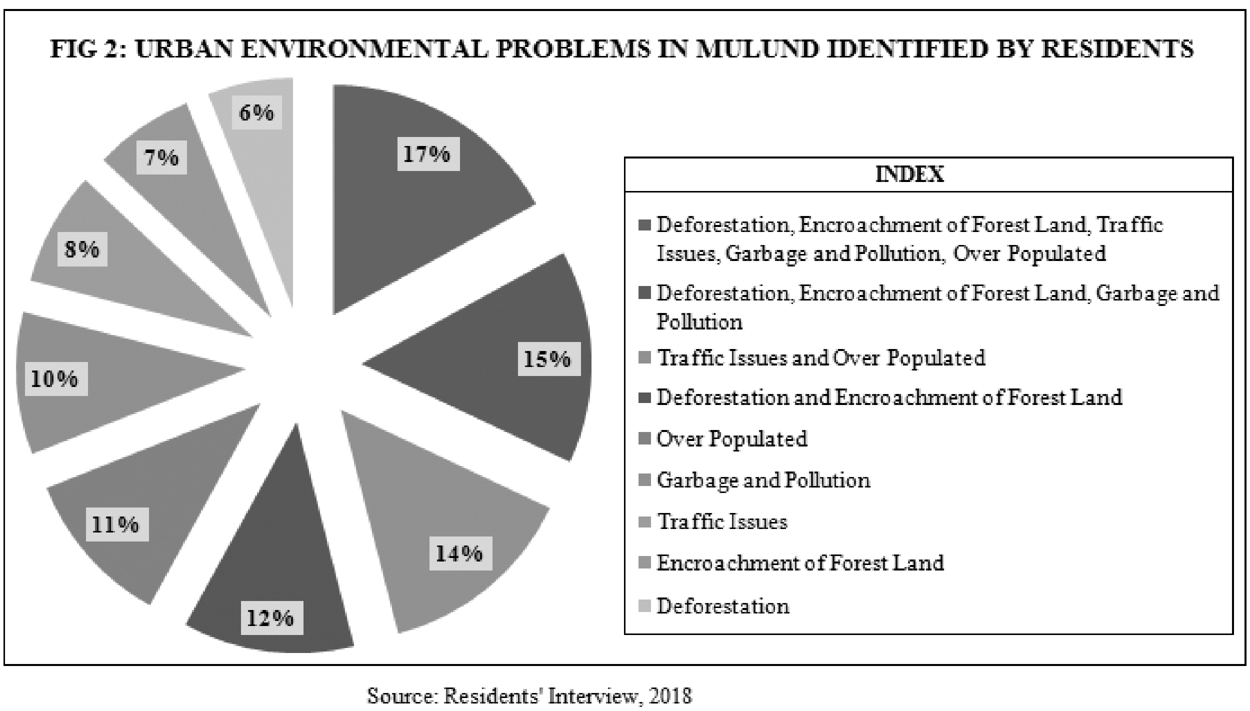

Figure 2: Urban environmental problems in Mulund identified by residents

Source: Residents' Interview, 2018

The issues related to the degradation of the urban environment in Mulund include decreasing of green cover, encroachment of forest land, traffic congestion, garbage disposal, and pollution (Fig 2). Most of these problems are recent in nature and have emerged as a corollary to the rapid infrastructural growth undergone by the suburb. Following the deindustrialisation phase, the suburb witnessed significant growth in real estate activities, consequently ‘the suburb lost its greenery to high-rises which have now encroached upon almost every vacant piece of land – not even sparing the forest cover’ (Sen, 2017). As narrated by a 71-year-old resident,

> Mulund’s greenery is gradually decreasing. It is in the process of becoming a concrete jungle, which it has already become to a great extent. It is hard to believe how the suburb has changed with time. (Source: Residents’ Interview, 2018)

The area along the edge of the SGNP in Mulund west not only has witnessed growth in the human settlement but also bears testimony to encroachment into the forest habitat. This has resulted in growing instances of man-animal conflict in the area. Reports of residents and pets being attacked by leopards are seen to make news headlines from time to time. The SGNP is, in fact among the reserves with the highest density of leopards in India (Bose, 2017). Thus, encroaching into its territory makes the residents vulnerable to leopard attacks. The vulnerability is more so in case of the people residing in the slums and squatter settlements that have grown up along the encroached areas. As narrated by one such slum resident, aged 50,

> Our slum does not have toilet facility, so we rely on the pay and use ‘public toilet’ that is located nearby, but, of late for some reason they have started to lock it up during the night, making it inaccessible to us. The other alternative for us is to go to the jungle at night which is risky. (Source: Residents’ Interview, 2018)

There are also many open drains and gutters in Mulund that not only reduces the aesthetic appeal of the suburb but also serve as spots for garbage dumping and flourishing of mosquitoes and flies. The scenario becomes further clear from the narrative given by a 35-year-old resident,

> People keep dumping their garbage in these open drains and gutters. This often clogs the drains and leads to overflowing. The problem becomes more serious during the monsoons as these drains start overflowing and the dirty water covers the streets. (Source: Residents’ Interview, 2018)

Waterlogging and floods are not uncommon in Mulund during the rainy season. The presence of hilly terrain in the west and the general ‘west to east’ slope of land brings a heavy flow of surface runoff during the rainy season and floods the low lying areas of the suburb. Even the railway tracts get submerged under water. As narrated by a 55-year-old resident of LBS Road,

> Nirmal Lifestyle area gets flooded at least once every year. Mulund Check Naka and many other spots in Mulund get flooded. (Source: Residents’ Interview, 2018)

Mulund also has a huge landfill overloaded with waste. This 44-year-old dumping ground is spread across 25 hectares and has long exceeded its capacity. Currently, there is around 70 lakh metric tonnes of garbage, with its height as high as 36 metres, at the dump (Parab, 2017). People residing in the vicinity of the dumping ground are living amidst foul smell and the threat of vector-borne diseases. An article published in *The Times of India* states,

> The Mulund dumping ground has left citizens gasping for breath, not just because of the horrid stench, but also because of frequent fires which envelop large swathes in thick smoke. The dumping ground has become a health hazard for 3,000 flats of Hariom Nagar, barely 100 metres away. (Sen, 2017)

The growing population of the suburb has also contributed to an increase in the number of vehicles. As a result, traffic issues have become more frequent than ever. As narrated by a 47-year-old resident,

> The tremendous growth of residential real estate and the rise in the number of home buyers is not only contributing to population growth but also to the growth in the number of vehicles. Consequently, traffic issues have been growing. (Source: Residents’ Interview, 2018)

Thus, from the above discussion, it becomes clear that there are a number of urban environmental issues confronting Mulund and the residents of the suburb have much clarity on the existence of these issues.

Residents' Expectation and Policy Implementations

It is natural for the residents to have expectations from the government. In terms of the degradation of the urban environment in Mulund as well, the residents expect the government to take necessary steps. The residents expect the government to ensure healthy growth of Mulund's urban environment, and for this, they expect the government to take care of the issues confronting the urban environment of Mulund. The issues requiring urgent attention of the government authorities, as identified by the residents, are traffic issues, pollution, open drains and gutters, population growth, and deforestation (Fig 3).

However, a majority of the residents (77 per cent) feel that the policymakers have turned a blind eye towards many of these issues and there is either lack of proper policy or there is a drawback towards policy implementation. A deeper investigation into the scenario brought into light the following findings on policy implementation.

- Although a number of policies have been implemented by the government in Mulund for the betterment of the suburb, there is a general dearth of policies targeting its urban environmental needs;
- Forest lands in Mulund are invariably encroached by slums and high-rises. There has also been a significant controversy related to certain land developed by various builders which were on and off classified and reclassified as forest land, non-forest land, and private forest land and so on. It is only recently the Supreme Court's verdict regularised these homes lifting off the private forest land tag (Lewis, 2014). The improper maintenance of land records by the government bodies lies as the root of the whole menace.
- The annual phenomena of waterlogging and floods in Mulund indicate the presence of an insufficient water discharge management system, requiring necessary policy action.
- With respect to the presence of open drains and gutters too there are no adequate policy measures undertaken.
- After years of conflict over the Mulund Dumping Ground, the Bombay Municipal Corporation (BMC) finally declared its official shut down on 1st October 2018. A phase wise processing of garbage within a period of six years is planned to be carried out. This definitely reveals a positive scenario in terms of policy implementation.
- The LBS Road that runs from Mulund to Sion is well known for its traffic hassles. The BMCs has come up with plans for widening the LBS Road soon (Pillai, 2017). It is another positive sign as the widening of the road will contribute to the reduction of traffic woes in Mulund.

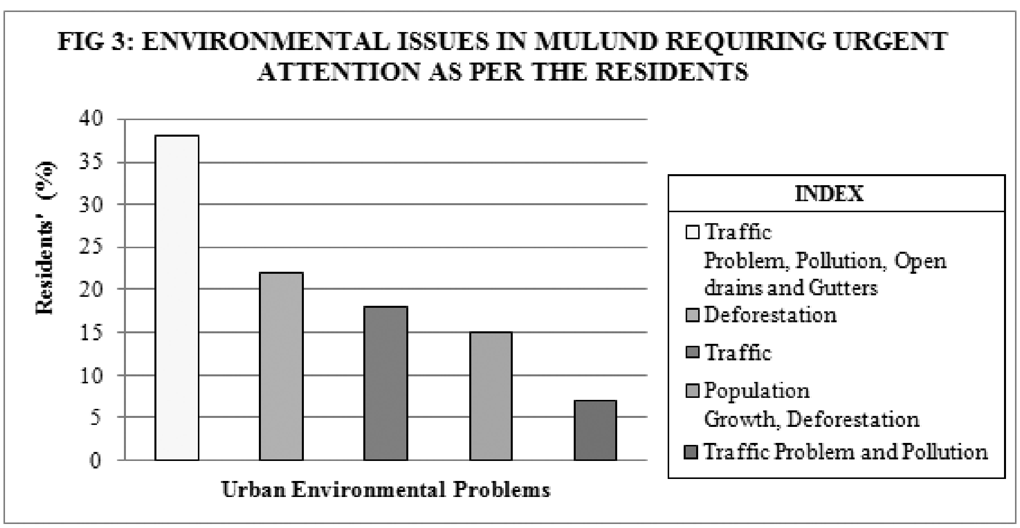

Figure 3: Environmental issues in Mulund requiring urgent attention as per the residents

Source: Residents' Interview, 2018

How to Bridge the Existing Gap?

In order to bridge the existing gap between residents' expectations and policy implementation to address the environmental issues of the suburb, the following measures are suggested:

- Residents' expectations from the policymakers must be given due attention prior to the formulation of policies.
- A healthy mechanism of interaction between residents and government agencies must be initiated. Strengthening the aspect of e-governance can be beneficial in this regard.
- A special cell concerning the environmental problems of the area must be formed with representatives from the government as well as local residents.
- Residents must be encouraged to come forward and get involved in the activities to combat the environmental degradation of the suburb.
- The existing issues such as loss of forest cover, issues of waterlogging, existence of open drains and gutters must be addressed at the earliest.
- The damage done by the encroachment of SGNP cannot be undone; however, full proof steps must be taken to ensure that incidences of encroachment henceforth do not happen.
- The closure of Mulund dumping ground has increased the pressure of waste disposal in the remaining two dumping grounds of Mumbai, i.e., Deonar Landfill and Kanjurmarg Landfill, which are again nearing saturation. Although plans are being processed for allocation of land for setting up new dumpsites, this is hardly a long-term solution. It is high time for setting up recycling plants and 'waste to energy plants' to ensure effective management of waste.
- Setting up a system of waste collection where residents can earn incentives on the amount of waste deposited by them can serve as a method of involving people more into waste management efforts.

Conclusion

The study brings to light the urban environmental problems of Mulund as well as identifies the gaps existing between residents' expectation and policy implementation. Stressing on the need to bridge this gap, certain suggestive measures to tackle the scenario are also forwarded in the study. Nonetheless, as the study brings to light the nature of this existing gap, understanding the issue will facilitate the process of formulating relevant policies for combating the issue of degradation of Mulund's urban environment. Moreover, the fact that the key to effective amelioration of urban environmental problems lies at the timely implementation of effective urban policies, it is utmost necessary to address these issues within the time before the problems go beyond control.

Reference

Bose, M. (2017). Mumbai logs world's highest leopard density. *Deccan Herald*. Retrieved from https://www.deccanherald.com/content/646034/mumbai-logs-worlds-highest-leopard.html

Census of India. (2011). *District Census Handbook: Village and Town Wise Primary Census Abstract (PCA)* (pp. 469–485). Mumbai: Census of India.

Ghosh, R. (2018). E-GOVERNANCE, AN INITIATIVE TOWARDS BETTER GOVERNANCE: A CASE STUDY OF DURGAPUR MUNICIPAL CORPORATION. In *12th World Congress of RSAI* (p. 1126). Goa: RSAI. Retrieved from http://www.regionalscience.org/images/PDF/Proceedings_RSAICongress2018.pdf

Kulshrestha, S. (2018). *Urban Renewal In India: Theory, Initiatives And Spatial Planning Strategies*. New Delhi: SAGE Publishing.

Lewis, C. (2014). Maharashtra orders regularization of homes on 'private forest land'. *Times Of India*. Retrieved from https://timesofindia.indiatimes.com/city/mumbai/Maharashtra-orders-regularization-of-homes-on-private-forest-land/articleshow/45567524.cms

Martini, G., McGranahan, G., Montgomery, M., & Farnandez-Castilla, R. (2012). The New Global Frontier: Cities, Poverty and Environment in the 21st Century. In *The New Global Frontier* (p. 1). London: Taylor and Francis.

Nair, D. (2005). The prince of suburbs. *The Economic Times*. Retrieved from https://economictimes.indiatimes.com/the-prince-of-suburbs/articleshow/1344722.cms

Parab, B. (2017). Mulund dump closure cost doubles. The Asian Age. [online] Retrieved from http://www.asianage.com/metros/mumbai/260617/mulund-dump-closure-cost-doubles.html

Pillai, S. (2017). 400cr project to widen Mumbai's arterial LBS Marg gets a push. *Hindustan Times*. Retrieved from https://www.hindustantimes.com/mumbai-news/400-crore-project-to-widen-arterial-lbs-marg-gets-a-push/story-lZ8KaVOpeKq0IEVWecdiuK.html

Sen, S. (2017). Green grid now a concrete jungle, starved of open spaces. *Times Of India*. Retrieved from https://timesofindia.indiatimes.com/city/mumbai/green-grid-now-a-concrete-jungle-starved-of-open-spaces/articleshow/56529318.cms

Sen, S. (2017). Mulund east: Dumped, diseased, forgotten. The Times of India. Retrieved from https://timesofindia.indiatimes.com/city/mumbai/mulund-east-dumped-diseased-forgotten/articleshow/56529342.cms

Stevenson, S. (2009). *Understanding local government* (2nd ed.). Metthew Bender & Company.

Geospatial Analysis of Disaster Management in Greater Mumbai: Perceptions and Expectations of the Locals

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ABSTRACT: Greater Mumbai being the economic capital of the country and having a littoral location is highly prone to both natural and man-made disasters. For effective disaster management, it is important to make use of comprehensive and accessible baseline data and incorporate the same in a user-friendly Geospatial framework. In contemporary world where technology is just a click away, GIS can prove to be an extremely powerful tool for management and mitigation of disasters. In the study of geography, the spatial dimension describes and compares patterns where environmental factors are located. These patterns are determined by using quantitative and qualitative research to compare areas in relation to a particular variable. The aim of this approach is to amend these factors and create more equity in relation to the variable being studied. In the present study, space is studied with relation to disasters and through the perspective of disaster management. In this research an attempt is made to understand the disasters prevailing in different wards of Greater Mumbai. The comparison between wards is done to bring forth the spatial patterns and disparities. This would represent the footprints of disasters and its dynamics.

The present research aims at carrying out geospatial analysis by collecting baseline data for Greater Mumbai using questionnaire surveys and secondary data from government agencies. Hazard mapping, Vulnerability Index and Disaster Risk Index for Greater Mumbai were calculated and mapped ward-wise with an aim of promoting and providing an equitable approach to disaster management for Greater Mumbai.

The methodology used for the study includes Geospatial analytical techniques and perception analysis using questionnaire surveys. With reference to Kate's model of hazard perception and response, respondents were interviewed adopting stratified random sampling technique for 24 wards of Greater Mumbai. Perception of people regarding disasters, its impact and safety measures adopted by them and how management of disasters was presumed were evaluated. Their idea of safe zones, safe routes, direction and resilience was noted and mental maps were prepared. Levels of communications in terms of disaster management were confirmed and anomalies if any were taken into account. Expectation of local people in terms of disaster management varies with space and time. Detailed geospatial mapping was carried out and an attempt is made to incorporate the same in a GIS tool as a web map, in order to build a Disaster Information System which would help to disseminate information to local people and build a resilient city in the future. Along with this quantitative and statistical analysis, SWOT analysis is also carried out. This study has led to a deeper

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understanding of the problem and has led to great discoveries regarding areas, people's perception and their expectation from future in terms of disaster management and mitigation.

KEYWORDS: spatial dimensions, hazard risk and vulnerability analysis, disaster management, GIS, perceptions, information system

Introduction

Disasters are not natural. Natural events become disasters because of the fragile relations that exist between the natural, human and built environment. Major disasters always occur in towns and cities in the developing world where resources are limited, people are vulnerable and needs are particularly great. Emergency challenges should be thoughtful, and sustainable planning and construction is essential. Rebuilding post disasters emphasises the role of the built environment in the re-establishment of lives and sustainable livelihoods. When disasters occur, human intervention may naturally follow. These interventions can take the form of relief groups setting up distribution centres to that of emergency aid workers. As Bender S (2000) has noted, these interventions are "done not so much *to* the landscape as *with* the landscape, and what is done affects what can be done." The disaster "culture" that exists is one of both attachment to the past and apprehension of the future. While people are emotionally bonded to the memories of the landscape, there is a fear of not being able to recover what was lost, or even worse, completely losing the sense of place. A landscape so filled with memory serves to draw people towards it or to keep them away, permits the assertion or denial of knowledge claims, becomes a nexus of contested meaning.

The concept of "space" in geography can be absolute, relative or cognitive. Unlike absolute space, which is fixed, is asocial and timeless; relative space describes space in a wider concept as it is socially made and remade over a period of time. Thus relative space is dynamic, fluid and ever changing. Absolute space is defined as the connections or connectivity between points in space. Relative space can take the form of socioeconomic or cultural space. The socioeconomic space consists of sites, situations, routes, regions and patterns. The cultural space consists of a space where groups live and interact. The cognitive space is defined and measured in terms of values, feelings, beliefs and perceptions. Therefore, it is described in terms of behavioural space, like landmarks, paths and environments. In the study of geography, the spatial dimension describes and compares patterns where environmental factors are located. These patterns are determined by using quantitative and qualitative research to compare areas in relation to a particular variable. The aim of this approach is to amend these factors and create more equity in relation to the variable being studied. (Source: Knox, P.L. & Marston, S. A. 2007). However, if the study of spaces is carried out with a perspective of a socio-environmental issue taking into consideration its dimensions, impact and distribution, it can lead to a detailed analysis, observation of patterns, future trends and solutions to tackle the issue in future. Hence, in the context of disasters in Mumbai, in the present study, space is explained with relation to hazards and risk and through the perspective of disaster management and mitigation. This research analysed different disaster-prone locations in different wards of Greater Mumbai. The comparison between wards is done to bring forth the spatial patterns and disparities. This would represent the footprints of disasters and its dynamics.

Human responses to natural hazards are assumed to be rooted primarily in the way individuals think, behave and interact in the environment. Disasters that are unexpected occur suddenly, causing widespread damage, and are understood to be traumatic and associated with a high degree of psychological disturbance. The survivors are most often seen as having significantly disrupted lives, which require lengthy periods of recovery.

The mental health and trauma of large proportions of the affected population can be served by relief and rescue workers and healthcare providers, as well as by strengthening and supporting the socio-cultural coping mechanisms of the local communities. Relief and rescue workers are, as a general pattern, sensitive to the emotional and psychological needs of people in distress.

When perceptions of people are analysed in terms of disaster management in the study area, it is noted that people have a vague idea about overall disaster management and are often confused about exact location, exit routes, and nearby facilities for protection. However, when a map is shown as picture with the help of Google map often used in the smartphones, they could relate to it with the help of nearby known landmarks or roads. Hence it is necessary to incorporate the same knowledge and baseline data into a standardised disaster information system, which can be made available to the citizens and help them chalk out their plan of actions in times of emergency and ensure public and private safety.

One of the most significant factors affecting the accuracy of participant's cognitive map is their familiarity with the environment and so individual differences arise due to differences in their spatial knowledge about the locality. Sketch maps of cognizance drawn by them revealed their acquaintance with the landscape. Long-time resident of the area illustrated more detailed sketch maps bringing out the affinity to the locales. The sketch is characterised by spatial nature compared to the more sequential maps produced by newcomers to the area. Spatial relationships between landmarks is important during evacuation. In general, people prefer routes that are initially long and straight, even if they cover a much greater total distance.

The methods for studying perception of natural hazard developed by the Chicago school (e.g., Kates 1962) have been applied to hazard events in Japan by K. Ando. Ando (1982) examined the relationship between people's perception and adjustment to flood hazard in Waju, the settlement and fields surrounded by ring Evees in Gifu Prefecture. He measured the image of the flood hazard using the Sematic Differential (SD) method. Four basic dimensions of the image were identified by the factor analysis: seriousness, controllability, appearance and expectancy. The analysis of the relationship between the image and adjustment behaviour proved that people perceiving the flood hazard as serious and destructive were inclined to make many adjustments.

Methodology

Questionnaire survey using random stratified sampling method: Questionnaire survey was carried out accordingly in all the 24 wards of Greater Mumbai. The technique adopted for the survey was random stratified sampling method. This was done to achieve perception of population regarding disasters in Greater Mumbai. People belonging to age groups from 10 to above 60 years who were affected by disasters in the past participated, and their perspectives were brought forward through the questionnaire survey. Stratified random sampling is a method of sampling that involves the division of a population into smaller groups known as strata. In stratified random sampling stratification, the strata are formed based on members' shared attributes or characteristics. When conducting research on a group of entities with similar characteristics, it may be observed that the population size is too large. It is a more feasible approach to select a small sample group representing the population. The small group used is referred to as a sample size, which is a subset of the population that is used to represent the population. A stratified random sampling involves dividing the entire population into homogeneous groups which are called strata. The main advantage of stratified sampling is that it captures key population characteristics in the sample.

With respect to disaster management, stratified random sampling technique was adopted for a sample population which are representative. In each of the 24 wards of Greater Mumbai, vulnerable areas were surveyed and perceptions of people residing in these areas were noted and analysed. The homogenous characteristics of these strata of population are that, all of them have been affected by disasters or are prone to disasters. In these 24 wards, areas which have been affected by disasters in the past, especially the low-lying areas, slums and congested localities, were considered. To examine perceptions of people, selected age groups were considered. The respondents were categorised in groups as per their level of education, occupation and socio-economic status. Shopkeepers as well as vendors were also interviewed as they are more exposed to disasters such as road accidents and fire accidents. A total number of 1000 sample respondents were interviewed. Based on the focus of research and characteristics of questions the entire questionnaire survey was divided into sub-groups, which reflected the various aspects of the respondents.

The questionnaire was divided into seven major sub-groups:

- Primary Information – This includes questions such as name, age, gender, address, education and occupation.
- Family Information – In order to understand the socio-economic status of the respondent, questions regarding number of family members and annual income were asked.
- Background Information – Questions regarding the name of the ward in which the respondent is residing and for how many years they are residents in the area were asked.
- Awareness – To understand the level of awareness about disasters, questions were asked about whether people think they are vulnerable to disasters and how often the disasters affect them.
- Preparedness - To understand the levels of preparedness, questions regarding types of disasters affecting, precautions taken and accessibility to key facilities were asked.
- Mitigation – To evaluate the mitigation levels in the area, questions were asked such as awareness about government schemes for disaster management, effectiveness of government schemes, whether affected by disaster in the past, any precautions taken by the government, if they are planning to change residence due to disasters and their knowledge about disaster-related information.
- Resilience – To analyse the expectations of people in terms of making the city more resilient in future, questions regarding awareness about any rescue operations and expectations from the government or other bodies in terms of disaster management in future such as better roads, sanitation, food/shelter, mobile App, information or any other expectation were noted.
- Mental Map – Lastly the respondents were asked to draw a mental map indicating the escape route in times of distress from his current location. This was done to know their idea of space, direction and area.

Geospatial Analysis: Analysis of questionnaires and mental map sketches was carried out using geospatial techniques, and maps for respondents perceived safe areas and perceived safe routes in Greater Mumbai were obtained. A comparative analysis was carried out between perceived safe areas and actual safe areas using overlay technique.

Analysis of Questionnaires

The most important types of disasters which the respondents feel vulnerable to in their respective area are as follows:

Regarding measures for coping up with disasters, respondents prefer contact and rescue path (Table 1.2). Apart from this, according to them, first aid was also important. They wanted to be informed about possible exit route for rescue in times of emergency during disasters. Further, the respondents indicated their preferred routes which are mostly the main roads in their neighbourhood. This they had illustrated through mental sketches.

Table 1.1: Types of Disasters

Disaster	Percentage
Health Epidemics	32 per cent
Floods	30 per cent
Fire Accidents	23 per cent
Road Accidents	12 per cent
Landslides	4.2 per cent

Table 1.2: Measures for Coping up with Disasters

Measures	Numbers	Percentage
First Aid	463	46.3
Contacts	408	40.8
Rescue Path	125	12.5
Any other	4	0.4
Total	1000	100 per cent

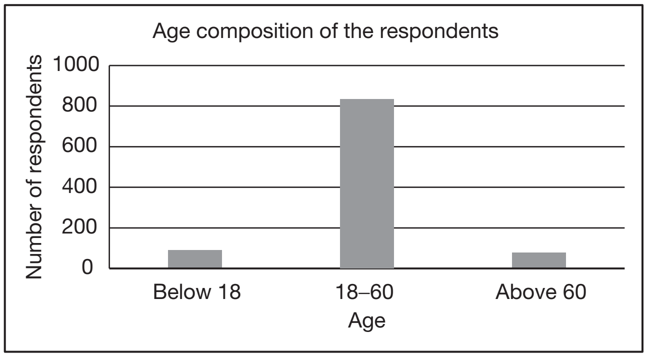


Figure 1.1

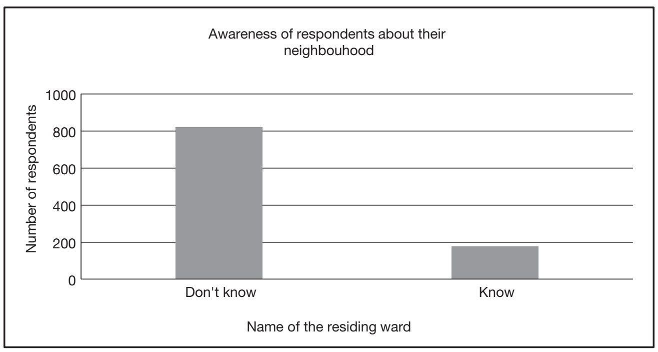


Figure 1.2

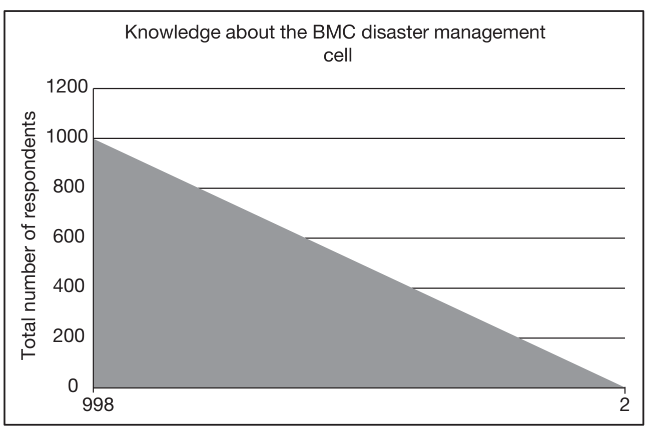


Figure 1.3:

More than 60 per cent respondents feel that they are vulnerable to disasters, whereas 50 per cent people feel they are at less risk and more than 80 per cent respondents feel that they will be rarely affected by disasters in future. In a general sense it was noted that people feel vulnerable to various hazards such as flooding, road accidents, diseases, landslides and fire accidents; however, they also feel that these might be minor or onetime events and will not account to large scale disasters, for example, like the 2005 major flood. More than 90 per cent of respondents are not aware about government schemes for disaster management. 60 per cent feel that the government schemes are effective, but they do not have idea about procurement of the same. More than 70 per cent respondents feel that government has not taken precautions to reduce disasters. 30 per cent revealed cleaning of drainage and improvement of roads are necessary. Respondents (50 per cent) rated the government schemes as adequate. Respondents (90 per cent) do not prefer to be relocated and wanted to continue to live in the same place. 80 per cent of the respondents are unaware about disaster-related information from any source. Regarding the awareness about the rescue operations undertaken by government during disasters, 25 per cent of the respondents rated the schemes as good, 70 per cent as satisfactory and 5 per cent as bad. To know the expectation of the people regarding measures or facilities that should be taken to ensure a resilient city in future, following ratings were given:

In order to analyse the expectations of people from future regarding disaster management, following questions were asked to the respondents, i.e., whether they feel these aspects are needed in future (Table 1.3.).

Mobile App is rated as the highest preferred facility or measure. They wanted the communication service to be stable and not collapse during emergency. Followed by better communication, dissemination of information, health facility, sanitisation and better roads. It is noted that since most of the people use mobile phones, they would like an application with all the warning and information regarding disasters in their area. There is also a need for local disaster management cells as stated by the respondents.

Table 1.3: Expectations of the People from Future In-terms of Disaster Management

Expectations	No. of Respondents	Per cent
Local disaster management committee should be set up	194	19.4
Local residents should be grouped and trained	71	7.1
First Aid	102	10.2
Monetary Aid	90	9
Food/Shelter	357	35.7
Better Communication	564	56.4
Sanitisation	377	37.7
Health Facility	413	41.3
Better Roads	335	33.5
Mobile App	644	64.4
Dissemination of Information/Warning	462	46.2
Any Other	3	0.3

Vulnerable Areas

The vulnerable areas in each of the 24 wards were considered for the questionnaire survey. These areas were mostly those which have been affected by disasters in the past or are situated at such places where disasters are most likely to occur. One such example to one of the questionnaire survey location is Tanaji Nagar in P South Ward, which is next to a huge open drainage, and people here have no escape route because they are stranded due to water-logging everywhere. It is one of the worst affected areas of flooding in the study area (Photos 1.1 to 1.4).

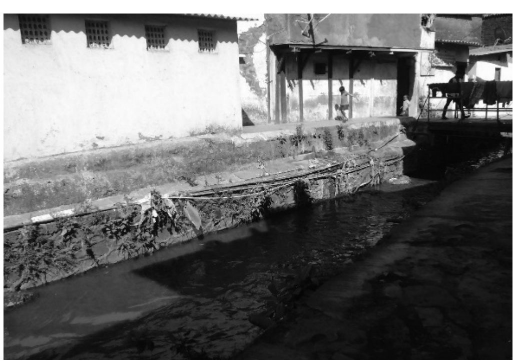


Photo No. 1.1: Tanaji Nagar, Malad, P-(South) Ward

Photo No. 1.2: Vashi Naka, Chembur, Ward M-(West).

Photo No. 1.3: Vakola, H-(East) Ward Photo No. 1.3.

Photo No. 1.4: Shastri Nagar, H-(East) Ward

Results and Discussion

Perception Analysis: According to Kate (1971) each human being has a perception about his area, his idea of vulnerability and his response to disasters. The person will make certain adjustments at individual level to protect him and his surrounding during disasters. He also states that environment acts as a stressor towards human response to disasters. Similarly, as we go further in space and time the perception as well as human response varies to a great extent. (Fig.1.4.) Human response to hazards usually fails to match the real probability of being affected by that hazard; our perception of risk normally differs from the reality of risk because we receive, filter and distort information. An individual's understanding is always less than perfect. This creates perceptual uncertainty, which, coupled with environmental variability, means that our views of hazard risk and damage potential are at best partial and selective.

Every individual receives signals and stimuli from the environment around them and uses these in building up an understanding of that environment and in deciding how best to respond and behave in relation to that environment. Kates (1971) sees hazards as the outcome of interaction between human use systems (like land-use) and natural event systems (the natural environmental processes which give rise to hazards). This interaction promotes actual hazard events which we perceive and then respond to. The way we react can in turn modify the human use system (e.g., by changing land use), the natural events system (e.g., by changing the magnitude/frequency relationship for river flooding), or both (Fig. 1.5).

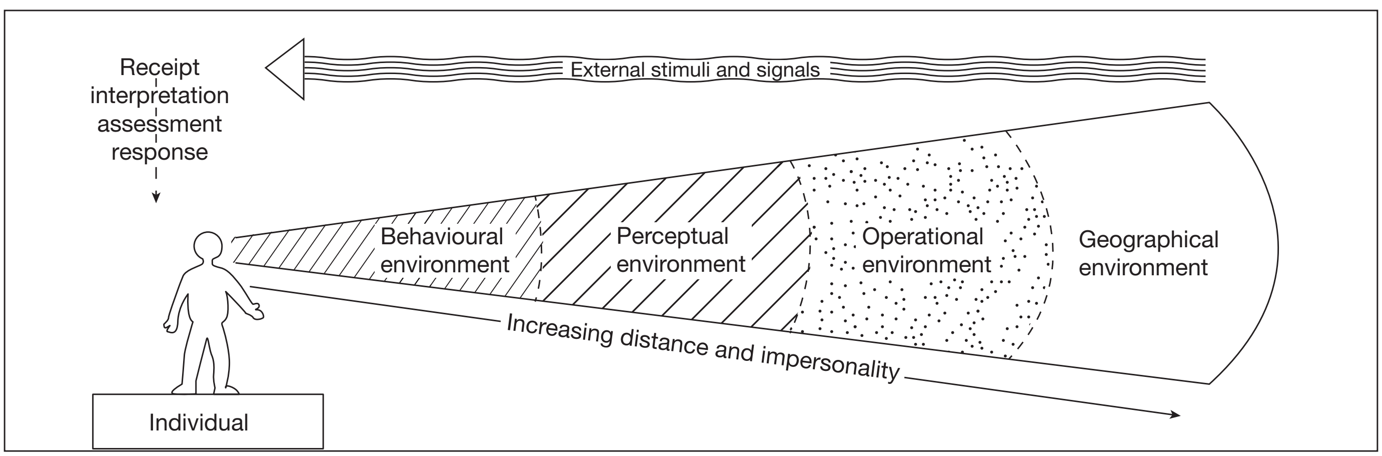


Figure 1.4 The individual and their cognitive environment

(Source: http://www.lancaster.ac.uk/*)*

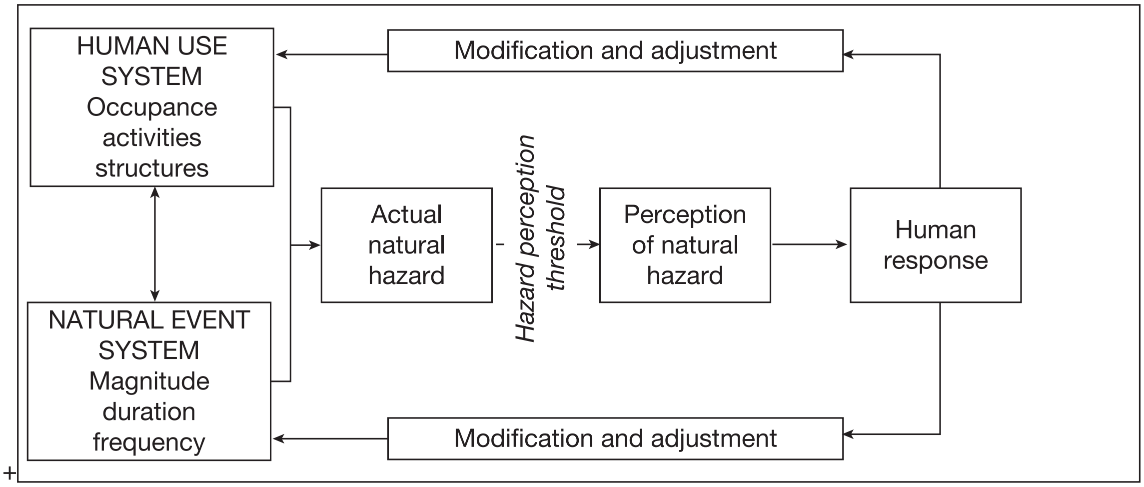


Figure 5 Model of human perception and response to natural hazards

(Source: after Kates, 1971)

Mental Maps of Vulnerability: Mental maps (also called cognitive map) are a component of the behavioural geography. People have mental maps of the spaces and places around them (Cloke et al, 1991). Sarre (in Graham, 1976, p. 259) defines mental maps as "A model of the environment which is built up over time in the individual's brain". Mental maps are stored in the brain, so they don't really exist. Nevertheless you can see those maps as mental constructs which are a result of a geographical environment and the human action in the world (Gregory et al, 2009).

Drawing sketch maps is a technique, pioneered by Lynch (1960), that enables us to gather much detailed information about people's cognitive maps and has been used extensively. It aims to reproduce the individual's internal image of the environment and is relatively easy in essence.

Analysis of Respondents' Perceptions and Mental Maps of their Neighbourhood: For the present research, to explore the spatial perception, respondents were asked to draw map sketches based on their spatial cognizance. Usually people connect to their surroundings through landmarks such as buildings, malls, railway stations, etc., or through major roads or facilities such as police stations, hospitals, open ground, etc. These mental maps created indicate their familiarity and spatial associationship of landmarks. It is observed that areas near railway stations are perceived as safe locations and major roads are considered as safe during disasters (Fig. 1.6). Based on these a map of Greater Mumbai showing perceived safe zones and perceived safe routes is prepared and represented.

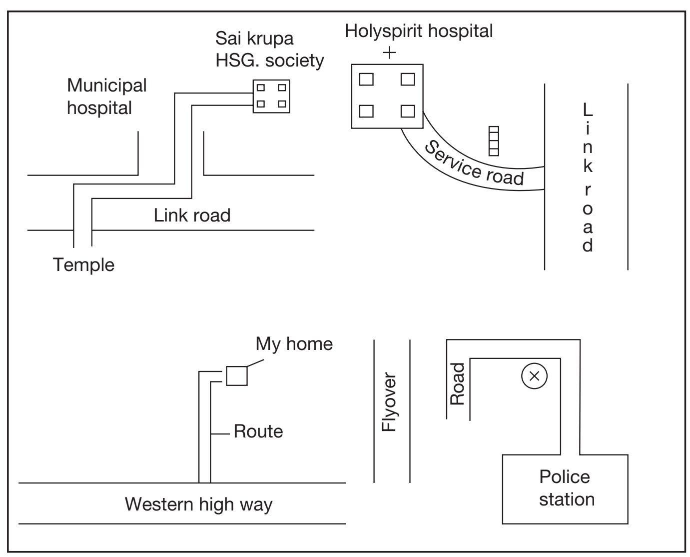
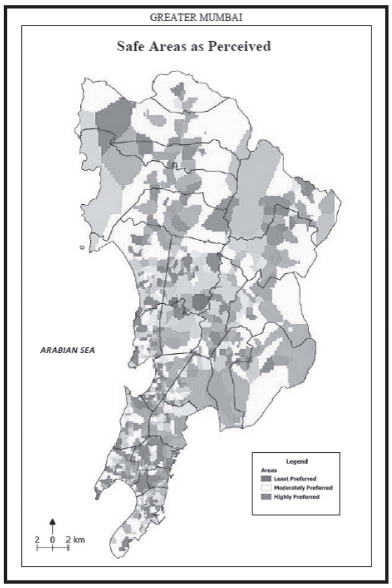


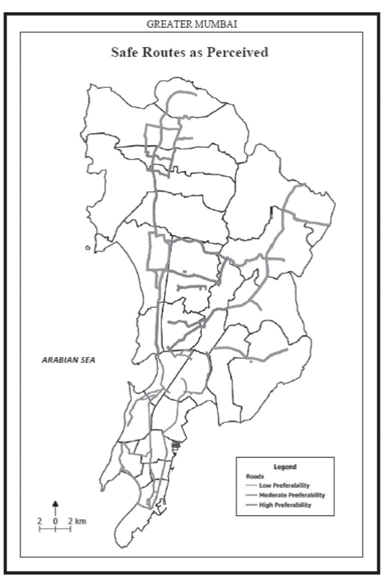
Figure 1.6 Mental map sketches obtained from respondents in Greater Mumbai

Perceived Safe Areas: Areas with very high preferability (Map No. 1.1) are areas such as Powai, Deonar, Parel, Bandra, Andheri, BKC and Colaba. South of Greater

Mumbai is perceived as safe zone, perhaps due to the better connectivity of roads and also during 2005 disaster the island city in the south was unaffected. Respondents also indicated peripheral areas of Greater Mumbai as safe. As per the perception of respondents prefer locations of safe rescue areas proximity to their homes in times of distress irrespective of the connectedness and infrastructure. Refuge and escape factor and accessibility to their home are their priorities. They are more concerned about their loss and damage of the property.



Map No. 1.1.



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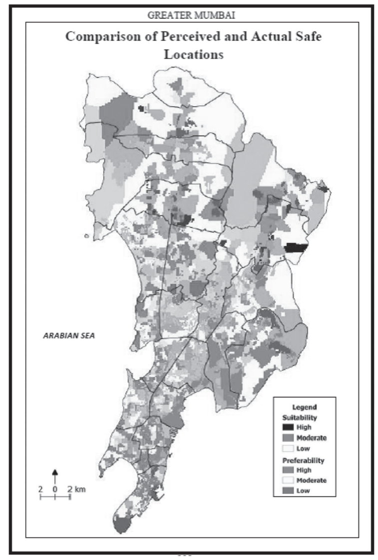

Map No: 1.3.

Perceived Safe Routes: The preferred routes identified by the respondents from their spatial knowledge in the given map of Greater Mumbai is shown in Map No. 1.2. They pointed out that major roads such as national highways, link roads, primary roads in the city and suburbs are safe routes. The general perception is that during times of distress, lanes and secondary roads are blocked or submerged. They marked especially the main roads in Dadar, Matunga, Bandra, Mahaim, Sion-Panvel Express way, LBS Marg, Kurla CST roads as preferred routes in spite of being low-lying areas.

Comparison between Suitable Safe Areas and Perceived Safe Areas

Anomalies (Map No. 1.3) between areas perceived as safe zones by the respondents and proposed safe zones through analysis. Safe locations are in Colaba, Mulund, Borivali and Chembur. However, most of the respondents have marked these areas as least or moderately preferred as safe areas during disasters. According to their perception, coastal areas and beaches are safe, but in reality, it is not to be considered as protected and safe. One of the most significant factors contributed in the mental drawn by the respondent is their spatial perception of locality where they are residing. Therefore, the mental sketches were accurate with respect to the landmarks and routes. The new residents living in the localities could not present a legible and accurate mental map because they have a vague idea of spatial landmarks. Disaster space is perceived by its inhabitants in different ways, because this relates to memories and past experiences. Thus, there is a strong relationship between behaviour, conception and construction of this type of space. People organise information so that it fits with previous knowledge. People with similar backgrounds of disaster knowledge act in similar ways. This similarity depicted through mental maps refers to people that belong to the same group, which can be age, sex, culture, occupation, temperament or familiarity. Through mental maps is how humans convert space into place it is an important part of how human beings perceive their environment during disaster is crucial. Different mental maps will project different perspectives and experience of disaster space at different time.

Conclusion

The fact that an increasing number of people and local authorities are affected by natural and man-made hazards shows there is necessity of adequate mitigation and preparedness within disaster management. Authorities with limited monetary or technological capacities are unable to tackle the catastrophic situation. One possible approach to gear up with the issues is the acquisition of information by mental sketch maps complemented by questionnaires, which allows to capture hazard perception. Mental maps and questionnaire survey conducted for the study are modes to investigate the risk perception and probable mechanism for rescue and mitigation in disaster-prone areas of Greater Mumbai. Citizens can be integrated into disaster management approaches on different levels, and their engagement within the whole process varies accordingly. Mental maps have been used digitally in Geographic Information Systems. Integrative disaster risk reduction can be considered as a promising approach for facing the increasing number of people and infrastructure which are affected by disasters.

Acknowledgements

We would like to thank all the concerned civic bodies and government offices for providing us data as well as information. Special thanks to the Disaster Management Cell of BMC for providing ward maps, i.e., the base maps from their handbook. Also, thanks to the Department of Geography, University of Mumbai, for providing access letter to obtain all the data and information from various sources.

References

Macdonald N. et al. 2006. The significance of Gilbert F. White's 1945 paper 'Human adjustment to floods' in the development of risk and hazard management.

Pei Zhang, Antonie Jetter, Understanding Risk Perception Using Fuzzy Cognitive Maps; 2016 Proceedings of PICMET '16: Technology Management for Social Innovation

Peter Gould and Rodney White, Mental Maps. Penguin, Harmondsworth, England, 1974

Sammaddar S. et al. 2011. Identifying Vulnerability Pattern in a Flood Prone Micro-Hotspot of Mumbai, India - IPCBEE vol.4 (2011) IACSIT Press, Singapore

Tomaszweski. B. et al. Geographic Information Systems for Disaster Response: A Review. Journal of Homeland Security and Emergency Management Volume 12(Issue 3):571–602, June 2015

Wakabayashi. Y, Behavioral Studies on Environmental Perception by Japanese Geographers, Geographical Review of Japan Vol. 69 (Ser. B), No. 1, 83–94, 1996

Wisner Ben, et al. 2003. At Risk: natural hazards, people's vulnerability and disasters

Towards Smart and Sustainable Cities: Demonstrating the Role of ICT in the Context of Fire Events in Indian Cities – The Case of Mumbai

Shyan Kirat Rai[a], Arnab Jana[a] and Krithi Ramamritham[b]

ABSTRACT: The increasing frequency and intensity of disasters pose a big challenge for city managers to find solutions for building resilient cities. In spite of many cities lying in high disaster-risk zones, there is a lack of local level effective disaster management implementation roadmap and strategical planning. One of the reasons is the lack of solutions that can provide an inclusive platform for stakeholders and citizens. To address these concerns, the research proposes a framework to upgrade the existing local disaster response system to meet the requirements of cities. The framework consists of an upgraded local disaster body, namely Smart City Disaster Management Body (SDMB). The role of Information and Communication Technology (ICT) in better disaster management actions is discussed and demonstrated as a developed ICT-based system. The system is tested in the fire drills in sync with the workflow of SDMB. The system components and the problems are identified by attending fire drills, existing literature, pre- and post-system implementation controlled group surveys conducted among the stakeholders. The proposed solution is found suitable to address the challenges related to Disaster Response (DR) and moreover can help in building resilient, smart cities.

KEYWORDS: smart cities, sustainable cities, disaster response, ICT, urban sustainability

Introduction

Disaster management needs to be considered while developing resilient urban spaces. Sharma and Tomar (2010) pointed out the increasing disaster risk for the Indian cities due to unplanned growth, deficits in the infrastructure and poor services. To address the rapid urbanisation and resource constraints, GoI has taken a significant step to build 100 smart cities across the country. The plan aims to create managed urban spaces through a green field and retrofitting development. It also intends to provide a better quality of life to the citizens by efficient management of the resources ("Smart City Mission, GoI" 2015). The lack of futuristic goals in planning pose challenges in front of the city managers to build resilient cities. The role of government agencies is very important during disaster management phases (Alawadhi et al. 2012). According to Chong et al. (2018), the lack of dedicated city-specific disaster strategies are major concerns in the context of their functioning. From our field study, we deduced that the current system might not support the existing and future requirements of disaster management activities which will be highly dependent on increasing use of ICT in the daily life. The involvement of organisations without a framework of information management will not be able to capitalise on the technical and social benefits of a city (Lee and Lee 2014).

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E-governance and mobile-based systems are going to be the prominent features of the fast-growing Indian cities. The capacity to capture, process and transfer data have made Information and Communication Technology (ICT) the backbone of the service delivery process. It also serves as a tool to bridge the socioeconomic divide (Chourabi et al. 2012). Mhaske and Choudhury (2010) stress the importance of the internet and social media in building resilient cities through data acquired from the citizens. Wentz (2006) points the role of organisation and their dependence on the technology to serve the technology aware citizens, thus, enhancing the role of ICT in future cities.

This research is focused on the development of a holistic solution for locally efficient disaster management in Indian cities. The paper proposes a disaster management system dedicated to fit the city requirements by combining agencies, authorities, working bodies and citizens using an ICT platform. It is developed on top of the existing version, with modifications aimed at better disaster response. We have developed and tested a mobile and web-based system in the fire drill event, closely supervised by the city managers. To precisely identify the problem and to get the feedback, pre- and post-system implementation surveys with stakeholders were performed.

Literature Review

Disaster: A Concern for the Indian Cities

As per the report published in 2016 by National Disaster Management Authority (NDMA), most of the proposed Indian smart cities lie in the disaster-prone areas (NDMA 2016). Apart from flood, landslides, earthquakes and cyclones, an increase in the frequency of heat waves has also added to the concern. The FICCI risk report lists major cities that lie in the “highly impacted” category on the basis of the occurrence frequency of unprecedented events like fire and building collapses (FICCI 2016). In many instances, the impacts from these events are exacerbated by the rapid, unplanned urbanisation; overcrowding; lack of inclusive growth; poor planning and maintenance; and lack of adequate infrastructure. With the frequency of disasters expected to increase in the future, the cities lack a detailed road map of disaster management. We argue that there is a lack of focus on climate resilience apart from the disaster preparedness being under-funded. Thus, the DM planning is especially important in the context of smart cities.

Resource Constraints in Urban Disasters

Disaster response and preparedness are crucial dimensions in making cities resilient through data intensive techniques, especially with limited ability to invest in meeting all infrastructural needs (Mishra, Sen, and Kumar 2017). The India Risk Survey report published in 2015 found that India has an existing deficiency of around 97.59 per cent fire stations (FICCI 2016). Currently, 1705 fire stations exist as compared to the 70,868 stations that should exist as per the Standing Fire Advisory Council (SFAC) norms. The report also presented the data related to the deficiency of 72.75 per cent fire stations in urban fire services. The average police public ratio in India is 152 police officers per 100,000 of the population, while the standard set by the United Nations suggested a ratio of 222 officers per 100,000 people (Pal and Ghosh 2014). Mumbai has 34 existing fire stations, and it still faces the deficiency of 66 fire stations to match the international standards (Mumbai Fire Brigade 2014).

Role of ICT in DRR

The strategic principles align the three main dimensions, technology, people, and institutions for any smart city (Nam and Pardo 2011; Alawadhi et al. 2012). They stressed the importance of technology as the key to fill the socioeconomic divide in the service delivery. The report by NASSCOM states that India added 88 million internet users from 2008 to 2012 and at the end of that period the total number stood at 137 million, 60 per cent of the users connected to the internet through mobile (NASSCOM 2016). The report predicts that India will have around 371 million mobile internet users by June 2016. While 71 per cent of this number will belong to the ever-growing urban areas. These numbers prove to be strong encouragement in using ICTs as a backbone of response system at the time of disaster. ICT applications from various domains play an important role during disaster phases in smart cities. Batty (2013) discussed the role of big data in smart cities and city planning from the perspective of sustainability. Alazawi et al. (2012) developed an Intelligent Cloud Based Disaster Management System (ICBDMS) for vehicular networks. Arfat et al. (2017) developed a mobile application, a backend cloud-based big data analysis system, and a middleware platform based on cloud and fog technologies for disasters. Aqib et al. (2018) applied deep learning based techniques for forecasting traffic plans during disasters in smart cities.

Problem Statement and Motivation Firefighting in Mumbai

The study area Mumbai is the capital city of the state of Maharashtra. It is the hub of economic activities and known as the commercial capital of India. It extends 12 km East to West, where it is the broadest, and 40 km North to South with an area of 437.71 sq. km (Mumbai Fire Brigade 2014).

To identify the gaps in the disaster response strategies, stakeholder surveys and fire drills were conducted. The survey focused on the usage of ICT and citizen involvement during fire events. Disaster Management Control Room (DMCR) is the central agency responsible for disaster management in the MCGM. Every ward has its local DMCR which coordinates with the ULBs and central DMCR during a disaster. These organisations record distinct information from various sources and many channels before taking further action. This increased the response time. The information flows from DMCR toward office and vice versa. On many occasions, the information flows from other ULBs like fire stations, police stations, and hospitals or any aware citizens to the central or ward DMCR.

Over the years, researchers have discussed the benefits of centralisation of data during disasters. Kumar et al. (2019) discussed the impact of data centralisation on data consistency that results in common information flow among the organisations. Decentralisation of real-time data is one of the key challenges in the current working procedures. The actions of participating organisations depend on the availability of credible real-time information. This lacks in the existing scenario as the real-time data is not available across various organisations. Organisations can use ICT as a tool for information exchange to improve the silo working situations for better coordination. Further, the absence of dedicated Information Technology (IT) specialists and an interdivisional cell that can support the technical requirements shows the gap in planning. We argue that the existing DM system needs to be re-engineered based on how the ICTs are used to address the existing problem.

A Survey Among the Stake Holders Identifying the Pain Points

To perceive the gap and requirements, we conducted stakeholder surveys. People from different socioeconomic strata and diverse urban spaces were part of the survey. We collected and analysed the acquired responses. In total, 100 people participated in the survey; 42 per cent of them were females. The age group that participated in the survey was between 17 and 60 years. Out of the total, around 90 per cent people knew how to read or write in at least one language. The online and offline survey included socially backward people living in the slums. It was very interesting to observe that about 98 per cent of the total surveyed people owned a mobile phone. 80 per cent of them knew how to operate installed applications on the smartphone. However, out of the remaining 20 per cent, 11 per cent used the smartphone for only making calls. This indicates creating a mechanism to communicate at times of the disaster. A lesser percentage (46 per cent) of the people had previously used ICT during a disaster, out of which only 40 per cent of the users were satisfied with the existing functionalities of the mobile application and websites. The percentage is very less, because Mumbai faces yearly floods and frequent fire events. 95 per cent of the people stressed on the better functionalities as the driving force to use the ICT systems which could be the reason for less usage. Around 80 per cent believe ICT can help them in better ways during the disasters. The survey results strengthened the idea of citizen-centric topology during the disaster management process. From the survey with the decision makers, we deduced that various organisations maintain actionable data during disaster events and they have not been able to use it for the collective benefits. This supports the proposed idea where concerned organisations can use ICT for better information management and decision-making.

The Approach

We took motivation by reviewing the existing disaster management strategy of the Mumbai city. Further, the study of related literature, semi-structured surveys with stakeholders and attending fire drills helped to identify the gaps related to the existing disaster management scenario of the Mumbai city. To address the issues, we propose a new disaster management system suitable for a smart city environment. The system demonstrates the role of ICT in effective service delivery during disasters like fire. A case study based approach that uses qualitative method for proposed solution testing was chosen for this study. We tested the system and its components using developed mobile and web application along with the existing ICT during a fire drill in Mumbai. The system and its functionalities were developed based on the response and feedbacks collected in the form of qualitative surveys among agency officials, rescuers, and the citizens. To study the effectiveness and the response of the system semi-structured qualitative surveys with stakeholders was carried out.

Smart Disaster Management Body (SDMB): The Proposed Solution

ICT implications require trained human resources and specific organisations like IT and interdivisional cell. These departments can work on the technological component to be incorporated into the existing organisational structure for efficiency. Researchers have discussed the slow advancement in the use of modern ICT in the organisations due to the lack of direct citizen participation in the response system, unavailability of skilled human resource, and fast-paced technological development. Further the idea of considering citizens as resources in the resource constraint developing countries should also be considered.

It is a challenge to design a generic DR model for different cities with different disaster profiles. ICT being a robust tool can be developed as per the city requirements. Our solution considers ICT intervention and common information channel coupled with the administrative components as the key entities. The available ICT tools like mobile devices and applications can bring every class of society on a single information platform. One of the success stories is the m-Indicator app (m-indicator n.d.), which is used by more than 10 million people across socioeconomic class for accessing information related to modes of public transportation like train, buses, and taxies, etc., in Mumbai. The government has planned to provide free Wi-Fi services and low-cost smartphones to citizens, which can further boost the delivery of ICT solutions (MoCIT and GoI 2016). These initiatives would encourage the use of ICT solutions during disasters by citizens.

Proposed ICT-Based Local Disaster Management Body and Its Components

The proposed system as a solution with a retrofitted version of DMCR “Smart Disaster Management Body (SDMB)” is shown in Figure 1(a), with dotted boxes representing the new introduced ULBs, and information sharing arrows depict the new information flow structure. SDMB is designed according to the dynamics, hierarchy of information flow, and essential services planned in cities. This body addresses the concerns and limitations of the existing disaster response system for cities. It also plays a direct role in policy formulation for DM strategies. We introduced a single channel for information transfer between the agencies and citizens. In the proposed system the information flow is coordinated by SDMB to other participating entities and thus provides hierarchical control over the centralised data. ULBs have their data repository that would be in congruence with the SDMB database.

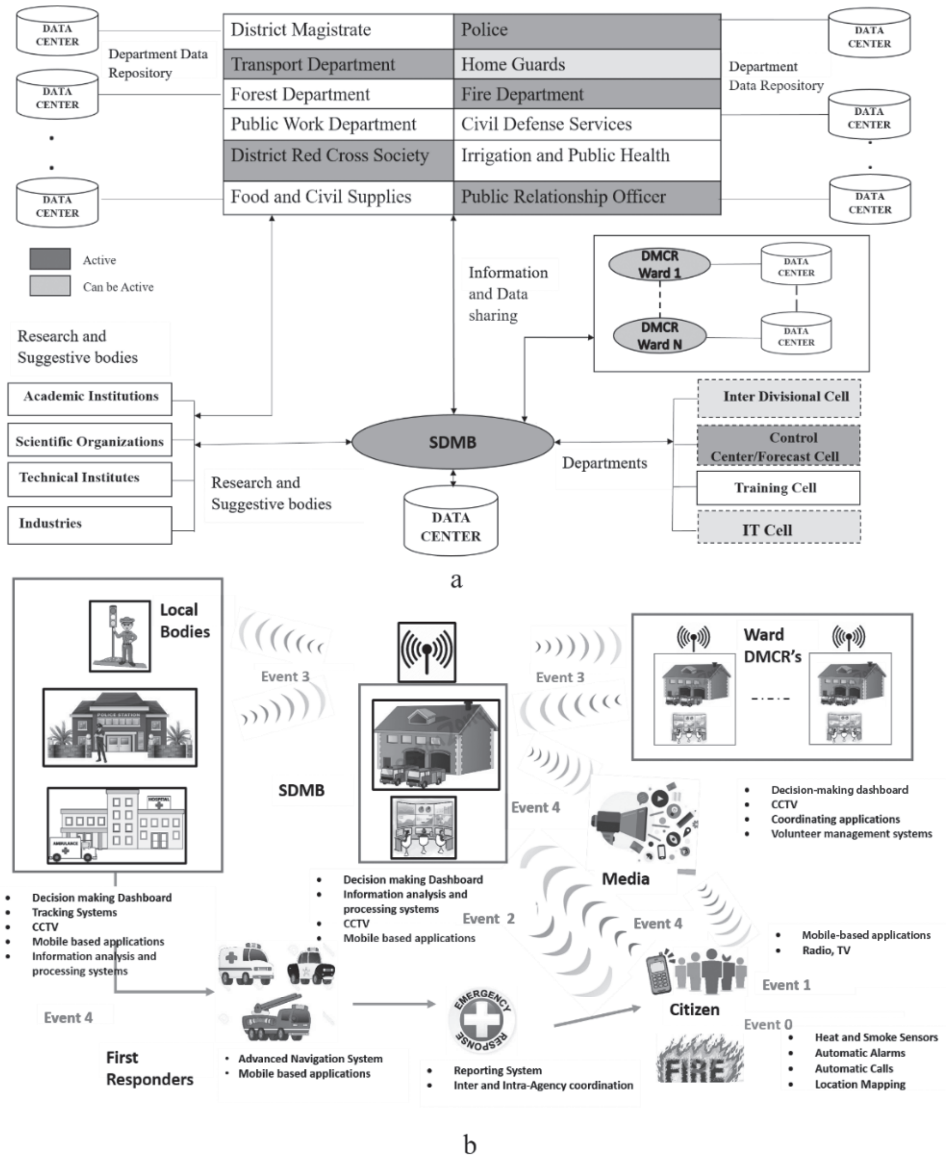

Figure 1: (a) Proposed SDMB; (b) working scenario of the involved entities according to the proposed solution during a fire breakout

The forecasting cell receives disaster-related data that can be used to predict any unusual events to alert the citizens and concerned organisations. The role of the introduced in-house IT cell is to develop and support ICT-based systems by considering local aspects. One of the challenges faced by the current working structure is the decentralisation of resources and combining their effort in information acquisition and sharing for decision-making during the disaster. The training cell is introduced in the framework to address this challenge. The human resources from various backgrounds in the interdivisional cell make it a common platform for solution development. The cell shall work on various data formats used across the agencies to provide outcomes. One of the difficulties is the transition of existing ULBs from existing working structure to a new one. The addition of new bodies and their coordination with the existing bodies also holds the key for an implementable solution. To address the concern, the solution retains most of the existing ULBs and their attributes. The SDMB ensures coordination among all the ULBs. A single channel for information transfer in the supervision of SDMB makes the coordination easier for the ULBs.

The Expected Working Scenario of SDMB during a Fire Event

This section presents an expected working scenario of the discussed SDMB and the involved stakeholders during a fire event. Figure 1(b) shows the events and the information exchange details between the stakeholders. As the fire event occurs, the sensors available on the incident space will transmit information about location, floor, resident data, temperature, etc., to SDMB (Event 0). The information is also broadcasted to the users and the decision makers through the mobile application, CCTV or a phone call for immediate action (Event 1) and (Event 2). This enhances the credibility of received data. SDMB broadcasts the information to various local bodies, ward DMCR, disaster volunteers, and Quick Response Team (QRT) (Event 3). Functionalities like navigation, dynamic update of the event information by local bodies, and the citizens help decision makers, rescuers, and victims in route planning and various other decision-making. Local bodies like hospitals update the status of beds and doctors using ICT systems. Victims and rescuers exchange real-time information like the current floor, the location of rescuers, responders, etc., which helps in the efficient rescue process and can save many lives. SDMB also broadcasts the information to the media for making citizens aware of the real-time situation (Event 4). The reader must note that not all the mentioned technology has been implemented in the paper. Some of the technologies as per the presented working scenario are applied in the fire drill discussed in the next section.

System Testing in a Fire Drill

This section introduces the developed mobile and web-based system, and its implementation in a fire drill as per the working guidelines of SDMB. A detail literature survey about various disaster apps and their classification is done by Tejassvi, Karnatak, and A. de By (2014). These applications lack the disaster implementation scenario and functionalities, thus are less preferred by the citizens. Our system is in-line with the recommendations and suggestions provided by the citizens and city managers during the surveys.

Implementation Environment

To develop an ICT-based system, it was essential to identify the key areas that need to be addressed during the disaster. An iterative process of gap identification, system development and testing in the fire drill is performed. Based on the survey (Section 3.1) with the officials of DMCR, Maharashtra Fire Services (MFS), and the citizens functionalities of an ICT system are identified for development.

Two mobile applications have been developed, one for the victims and another for the rescuers to serve rescue operations and relief management. The victim application was installed in a close group of 25 citizens, and 7 rescuers used the rescue application. The central database is used to store, exchange, and analyse the real-time data transfer between victims, first responders, rescuers, and decision makers. The Google-based navigation system is used in the applications. The mobile application needs GPS signals for location services, network services for making calls and sending text messages, and internet access to use maps and weather services.

Victim or citizen application has two modules; victim and volunteer module. The victim module has the following functionalities:

- A victim can send emergency SMS.
- A victim can send auto SMS about his/her location to the registered numbers.
- A victim can visualise rescuers; broadcast the messages to the nearest rescuers; contact the rescuers, police stations, hospitals; and navigate using the navigation window.
- A victim can inform his/her emergency requirements to the rescuers.

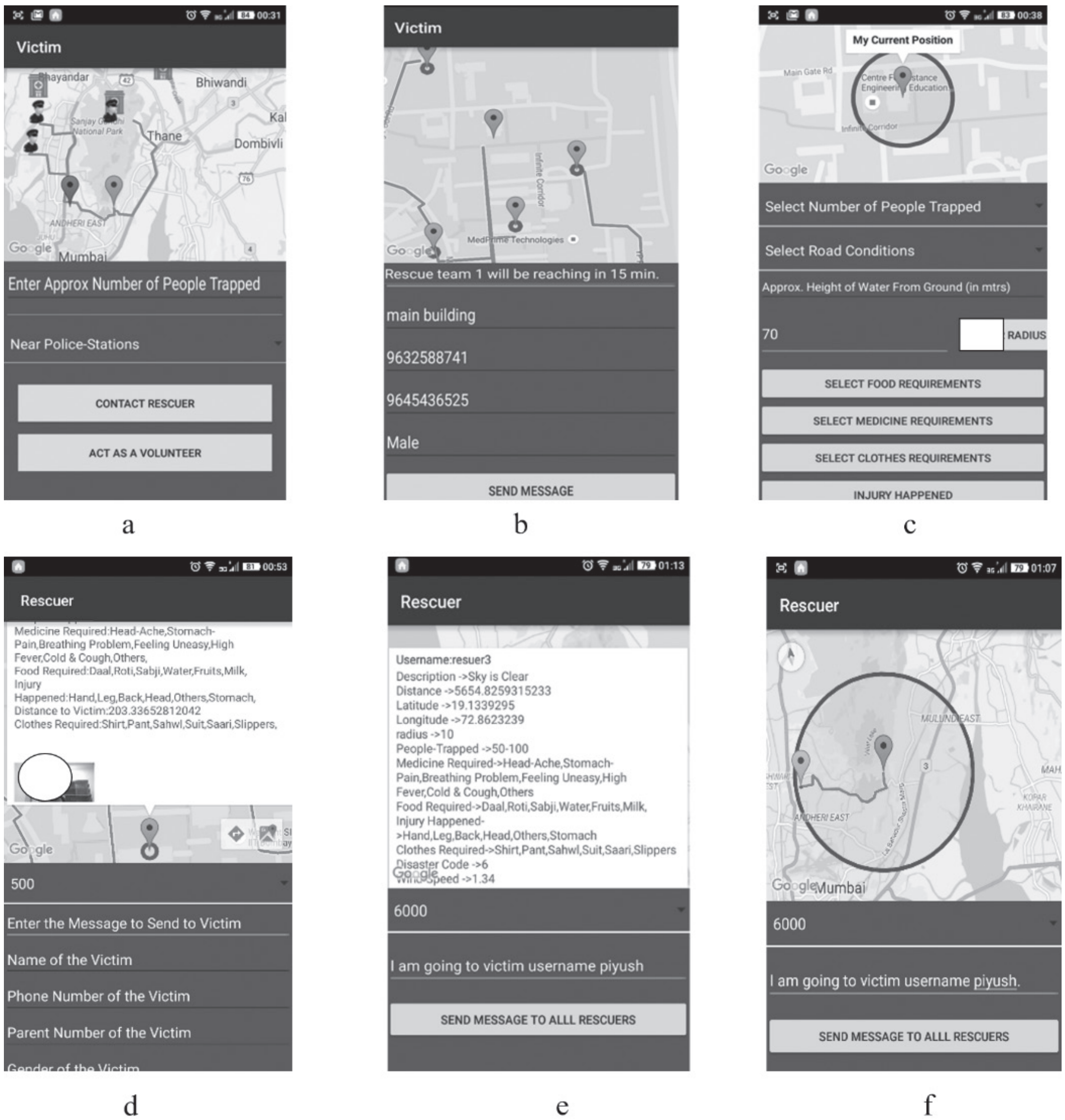

Figure 2: (a) Hospital's, rescuer's, and police station's information with location; (b) rescuer's status, broadcast message (rescuers and decision makers) and navigation on victim's interface. (c) Act as volunteer interface on victim's interface; (d) rescuer interface for interacting with victims and getting information; (e) rescuer interface for broadcasting information to other rescuers; (f) information and navigation broadcast to near rescuers

In the second module, citizens can act as a volunteer and provide supportive services during the disaster. All the information is stored in a common data centre, which helps all the actors like decision makers and rescuers aware of all the proceedings in the real-time. This helps in quick and better decision-making. Figure 2(a), Figure 2(b) and Figure 2(c) show the interfaces of the discussed functionalities. Figure 2(d) shows the interface of the rescuer application. Using the interface, the rescuer can track the information sent by victims. They can also send a message to the victim using send message functionality. Figure 2(e) and Figure 2(f) show the coordination between rescuers, where a rescuer can select victims and the broadcast crucial message and navigation information to other rescuers for rescuing victims. The application also has an interface to report the information related to the dynamic aspect of the incident like wind velocity, temperature, people rescued, and people trapped.

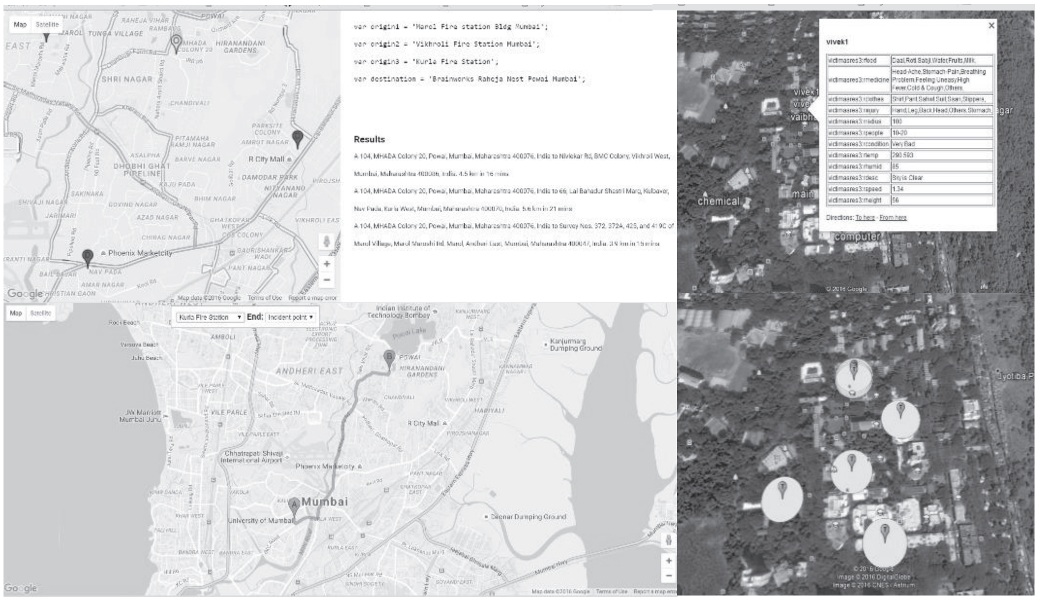

Figure 3: Web-based dashboard for decision makers showing real-time information

Figure 3 shows the web dashboard developed for decision makers in SDMB. It is used to visualise and analyse the real-time data transfer. It also shows the real-time data related to the nearest fire stations and navigation information of the first responder vehicles. The dashboard displays all the data exchange between rescuers and victims, data reported by rescuers in the real-time environment for quick decision-making. The data set collected can be used in community awareness, training of human resources, and better planning.

Feedback from the Stakeholders Post-Implementation

A detailed qualitative survey among the citizens, rescuers, and the participating authority members was conducted. The citizen sample size consists of the age group 17 to 60 years with 40 per cent females. The survey focuses on the usefulness of functionalities, their relevance to the disaster situations, and responder's response. 72 per cent of the responders were married and responsible to report on behalf of their family members. To keep the implementation process closer to the realistic scenario, optional use of the application during the drills was conveyed to the users. Still, a high percentage (86 per cent) of the users used the installed app during the drill. It was encouraging to see that about 77 per cent of the people were satisfied with the implementation of the application and mentioned it as a great help during the drill. A total of 68 per cent users were able to contact the rescuers in less than 2 minutes, while 22 per cent of the users received a delayed response (over 2 minutes), and 10 per cent of the users were not able to contact in the threshold time of 5 mins, due to resource constraints. The implementation of ICT system met the expectations of the users. 72 per cent of the people wanted to use the system in future, while 22 per cent out of the remaining 28 per cent of users were not certain about their choice. One of the reasons for the higher user satisfaction has been the quick response of the decision makers and the information transfer using the system. This was evident from the fact that as much as 75 per cent of the users were satisfied with the application functionalities and its implementation while 15 per cent of the remaining stressed on more functionalities for future use. A separate survey was also conducted for the authorities and the rescuers about the usefulness and scope of ICT services in disaster scenarios. The response of the authorities confirmed the successful implementation of the system. They benefited from the response and rescue modules during the fire drill operations. It can be beneficial in managing the much-required coordination among the stakeholders.

Conclusion and Recommendations

Many Indian cities lie in high disaster-prone zones. We argue that disaster management and its support areas are underfocused and lacks the required roadmap for service delivery.

We participated in fire drills to understand the working process of the current system and related agencies. On the basis of the drill, surveys with the stakeholders and existing literature we identify the need for a dedicated disaster management body with ICT support. A solution is proposed in the form of Smart Disaster Management Body (SDMB). A mobile-based application along with a web-based system is developed and implemented in a fire drill under the supervision of city managers to study the feasibility of ICT in disaster management. We tested the working of SDMB in the drill and conducted post-implementation surveys to deduce the efficiency of the system. More than 100 citizens and city managers were surveyed to understand their response about ICT and its use in disasters. In the implementation phase of the system, 25 citizens, 7 rescuers and the concerned authorities were involved. Results show that around 75 per cent of the citizens were satisfied with the response and functionalities. While 15 per cent out of the remaining 25 per cent suggested more functionalities as the driving force to use such a system in the future, rescuers and authorities also reported better coordination and access to the data.

Any solution must equally benefit every person regardless of the socioeconomic conditions. Results show that ICT, if accessed by every class of the society, can help in bridging the gap of disaster-based service delivery. It will be early to say that a similar system will work across various cities based on a single implementation scenario, and a larger scale implementation is required to achieve more clarity. However, the results discussed in the paper provide way forward strategies that can be used to develop efficient disaster management systems.

References

Alawadhi, Suha, Armando Aldama-Nalda, Hafedh Chourabi, J. Gil-García, Sofia Leung, Sehl Mellouli, Taewoo Nam, Theresa Pardo, Hans Scholl, and Shawn Walker. (2012). "Building Understanding of Smart City Initiatives." *Electronic Government*, 40–53.

Alazawi, Zubaida, Mohmmad B. Abdljabar, Saleh Altowaijri, Anna Maria Vegni, and Rashid Mehmood. (2012). "ICDMS: An Intelligent Cloud Based Disaster Management System for Vehicular Networks." In *Communication Technologies for Vehicles*, edited by Alexey Vinel, Rashid Mehmood, Marion Berbineau, Cristina Rico Garcia, Chung-Ming Huang, and Naveen Chilamkurti, 40–56. Lecture Notes in Computer Science. Springer Berlin Heidelberg.

Aqib, Muhammad, Rashid Mehmood, Aiiad Albeshri, and Ahmed Alzahrani. (2018). "Disaster Management in Smart Cities by Forecasting Traffic Plan Using Deep Learning and GPUs." In *Smart Societies, Infrastructure, Technologies and Applications*, edited by Rashid Mehmood, Budhendra Bhaduri, Iyad Katib, and Imrich Chlamtac, 139–54. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering. Springer International Publishing.

Arfat, Yasir, Muhammad Aqib, Rashid Mehmood, Aiiad Albeshri, Iyad Katib, Nasser Albogami, and Ahmed Alzahrani. (2017). "Enabling Smarter Societies through Mobile Big Data Fogs and Clouds." *Procedia Computer Science* 109: 1128–33. https://doi.org/10.1016/j.procs.2017.05.439.

Batty, Michael. 2013. "Big Data, Smart Cities and City Planning." *Dialogues in Human Geography* 3 (3): 274–79. https://doi.org/10.1177/2043820613513390.

Chong, Miyoung, Abdulrahman Habib, Nicholas Evangelopoulos, and Han Woo Park. (2018). "Dynamic Capabilities of a Smart City: An Innovative Approach to Discovering Urban Problems and Solutions." *Government Information Quarterly* 35 (4): 682–92. https://doi.org/10.1016/j.giq.2018.07.005.

Chourabi, Hafedh, Taewoo Nam, Shawn Walker, J. Ramon Gil-Garcia, Sehl Mellouli, Karine Nahon, Theresa A. Pardo, and Hans Jochen Scholl. (2012). "Understanding Smart Cities: An Integrative Framework." In, 2289–97. IEEE. https://doi.org/10.1109/HICSS.2012.615.

FICCI. 2016. "India Risk Survey 2015.". http://ficci.in/Sedocument/20328/India-Risk-Survey-2015.pdf.

Kumar, Vaibhav, Krithivasan Ramamritham, and Arnab Jana. (2019). "Resource Allocation for Handling Emergencies Considering Dynamic Variations and

Urban Spaces: Fire Fighting in Mumbai." In *Proceedings of the Tenth International Conference on Information and Communication Technologies and Development - ICTDX '19*, 1–11. Ahmedabad, India: ACM Press. https://doi.org/10.1145/3287098.3287099.

Lee, Jungwoo, and Hyejung Lee. (2014). "Developing and Validating a Citizen-Centric Typology for Smart City Services." *Government Information Quarterly* 31 (June): S93–105. https://doi.org/10.1016/j.giq.2014.01.010.

Mhaske, Sumedh Yamaji, and Deepankar Choudhury. (2010). "GIS-Based Soil Liquefaction Susceptibility Map of Mumbai City for Earthquake Events." *Journal of Applied Geophysics* 70 (3): 216–25. https://doi.org/10.1016/j.jappgeo.2010.01.001.

m-indicator. n.d. "M-Indicator Now in a New Avatar - The Hindu." Accessed December 19, (2017). http://www.thehindu.com/news/cities/mumbai/m-indicator-now-in-a-new-avatar/article18460041.ece.

Mishra, Arun Pratap, Anjan Sen, and Ashok Kumar. (2017). "Exploring Potentials and Challenges in Making Smart Cities in India: A Case Study of Allahabad City, Uttar Pradesh." In *Sustainable Smart Cities in India*, 123–42. The Urban Book Series. Springer, Cham. https://link.springer.com/chapter/10.1007/978–3-319–47145–7_8.

MoCIT, DeitY, and GoI. (2016). "Digital India." New Delhi: DeitY. http://www.nio.org/nio/uploads/digital-india-ebook.pdf.

Mumbai Fire Brigade. (2014). "Fire Hazard Response & Mitigation Plan." Municipal Corporation of Greater Mumbai. http://www.mahafireservice.gov.in/Site/PDFs/NewsEvents/FireHazardResponseMitigationPlan/MillenniumCityMitigationPlan/mumbai_mitigation_plan.pdf.

Nam, Taewoo, and Theresa A. Pardo. (2011). "Conceptualizing Smart City with Dimensions of Technology, People, and Institutions." In *Proceedings of the 12th Annual International Digital Government Research Conference: Digital Government Innovation in Challenging Times*, 282–91. ACM. http://dl.acm.org/citation.cfm?id = 2037602.

NASSCOM. (2016). "The Future of the Internet in India." NASSCOM. http://www.communicationstoday.co.in/images/reports/20160820-nasscom-the-future-of-the-internet-in-india-19082016.pdf.

NDMA. (2016). "Standard Operating Procedure for Disaster Management NDMA." Ministry of Home Affairs.

Pal, Indrajit, and Tuhin Ghosh. 2014. "Fire Incident at AMRI Hospital, Kolkata (India): A Real Time Assessment for Urban Fire." *J Bus Manag Soc Sci Res* 3: 9–13.

Sharma, Divya, and Sanjay Tomar. (2010). "Mainstreaming Climate Change Adaptation in Indian Cities." *Environment and Urbanisation* 22 (2): 451–65. https://doi.org/10.1177/0956247810377390.

"Smart City Mission, GoI." 2015. (2015). http://smartcities.gov.in/content/.

Tejassvi, Tanya, Harish Chandra Karnatak, and Rolf A. de by. (2014). "An Android Application to Support Flash Flood Disaster Response Management in India." Thesis, Dehradun: Indian Institute of Remote Sensing.

Wentz, Larry. (2006). "An ICT Primer: Information and Communication Technologies for Civil-Military Coordination in Disaster Relief and Stabilization and Reconstruction." NATIONAL DEFENSE UNIV WASHINGTON DC CENTER FOR TECHNOLOGY AND NATIONAL SECURITY POLICY.

Diagnosing the Mumbai Floods by Integrating Technical and Political Economy Approaches: Interdisciplinary Analysis of the Failure of the Storm-Water Drainage System of Mumbai

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ABSTRACT: This paper integrates technical and political economy approaches to unravel the complex reasons underlying flooding in the city of Mumbai. In diagnosing the flooding in the city of Mumbai, this paper proposes that the flooding is caused by the technical failure of city's storm-water drainage (SWD) system during the flood event. The paper takes the 'technical view' in proposing that this failure is rooted in certain causal physical factors or barriers that adversely affected drain, junctions, and outfall facilities in city's SWD system.

In sum, the paper identifies and discusses the major physical factors or barriers that affected Mumbai's SWD system during the flooding events. It presents the 'political economy' analysis of these physical barriers and traces their roots. In doing so, it identifies and discusses the following: the main actors, their problematic actions, motivation underlying the actions, and the nature and scale of economic and/or political power wielded by these actors. These powers are seen as adversely affecting the capacity of the central administration of MCGM to curb or control the causal physical causal factors rooted in the problematic actions of the respective actors. Finally, drawing from the political economy analysis, the paper presents some concrete policy and governance-related recommendations for the central administration of MCGM to help it successfully handle and control these physical causal factors. The paper concludes by emphasising the need to integrate the technical as well as political economy approach in addressing critical issues like Mumbai floods.

KEYWORDS: strengthening disaster governance, floods disasters, mega cities, resilience, urban infrastructure, legal policy and institutional frameworks agency coordination, government approach

Introduction

Background

A major aspect of water resources management that has been overlooked in the discourse of water pertains to water and disaster. The destructive potential of water has been recorded in history and it dates back to biblical times. However, experiences from recent years have recorded a sudden spike in the occurrence of number of catastrophic events related to floods and droughts throughout the world (Gopalakrishnan, 2013).

According to the report published by UNISDR (2011), between 2000–2010, out of the total natural disasters that occurred (4241), 87 per cent (3705) of these disasters were water-related(floods, droughts, storms, extreme weather, etc.). Out of 2482 million

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people affected by the natural disasters during that period, 96 per cent (2388 million) were affected by the water-related disasters. In addition, out of the total damage of USD 1002 billion, 76 per cent (USD 762 billion) was done by water-related disasters alone. The human and economic impact of water-related disasters are far more severe than any other form of natural disaster. One major type of water-related disaster which has had the most significant impact is the occurrence of floods.

Floods alone have accounted for 51 per cent (1910) of the number of water disasters occurring (3705), 45 per cent of the total natural disasters (4241) and have affected more than 1100 million lives, which is more than 45 per cent of the total lives affected by water-related disasters. India too has been affected adversely due to the occurrence of catastrophic flooding events (Gopalakrishnan, 2013).

India's average annual economic loss due to disasters is approximately USD 9.8 billion, out of which, more than USD 7 billion is due to floods alone. The 26 July 2005 incident in Mumbai resulted in death of more than 1000 people with an estimated economic loss of USD 2 billion (Anand, n.d.). The worst affected areas were the low-lying areas of Kurla, Dharavi, and other scanty slums where more than 50 per cent of the city's population resides. Majority of deaths were recorded in these areas with people dying due to building collapses, drowning, and other waterborne epidemics encountered after the water receded.

With more than 24 million people residing in Mumbai – the financial capital of the country, possessing a total wealth of over USD 82 billion (Anand, n.d – it is critical to understand the factors that contribute to the periodic flooding situations so that appropriate measures can be shaped to efficiently address them.

With this in mind, on 19 August 2005, the State Government of Maharashtra appointed a Fact Finding Committee to study the Mumbai Floods under the chairmanship of Dr. Chitale, former Secretary of Irrigation, Government of India. The committee submitted its 350-page detailed report in April 2006, providing a long list of technical as well as policy and governance-related recommendations. Many research and policy documents provided diagnoses and prescriptions, which largely remained within the disciplinary boundaries (Gupta 2007, Parthasarathy 2015).

However, again in the year 2017, the severe flooding ravaged the city and brought it to standstill for two days, causing about 14 direct and 21 indirect casualties. It was clear that, even after the passage of 12 years, the city was not ready to deal with floods. It is this realisation that prompted the research resulting in this paper.

Conceptual Scheme and Structure of the Paper

The basic logic of any storm-water drainage (SWD) system is presented in Figure 1. As shown, the SWD system collects the runoff (i.e., water that did not deep through) generated within a catchment region after a rainfall event. It then carries this runoff water through a system of drains and junctions to an appropriate water body wherein the collected and transported runoff is released through the outfall facility. Thus, the SWD system has the following main elements or components: runoff, network of drains (network of both natural and constructed), junctions in the network of drains, and outfall facilities.

This paper integrates technical and political economy approaches to unravel the complex reasons underlying flooding in the city of Mumbai by focusing on the functioning of the storm-water drainage (SWD) system in the city. It takes the technical view in proposing that the flooding in the city is rooted in the poor technical performance or failure of the SWD system. It takes the 'technical view' by proposing that this failure – on a very physical or material plane – is rooted in certain causal physical factors or barriers that lead to poor technical performance of one or more of the abovementioned components or elements of the city's SWD system. It is envisaged that these causal physical factors or barriers adversely affect the technical performance of the SWD system in one or more of the following four main ways: (i) by reducing the capacity of the network of drains, (ii) by reducing the capacity of junctions of the drains in the network, (iii) by reducing the capacity of the outfall facilities, and/or (iv) by increasing runoff water due to (a) decrease in the proportion of precipitated water seeping/infiltrating in the soil or (b) decrease in the water holding capacity of the soil.

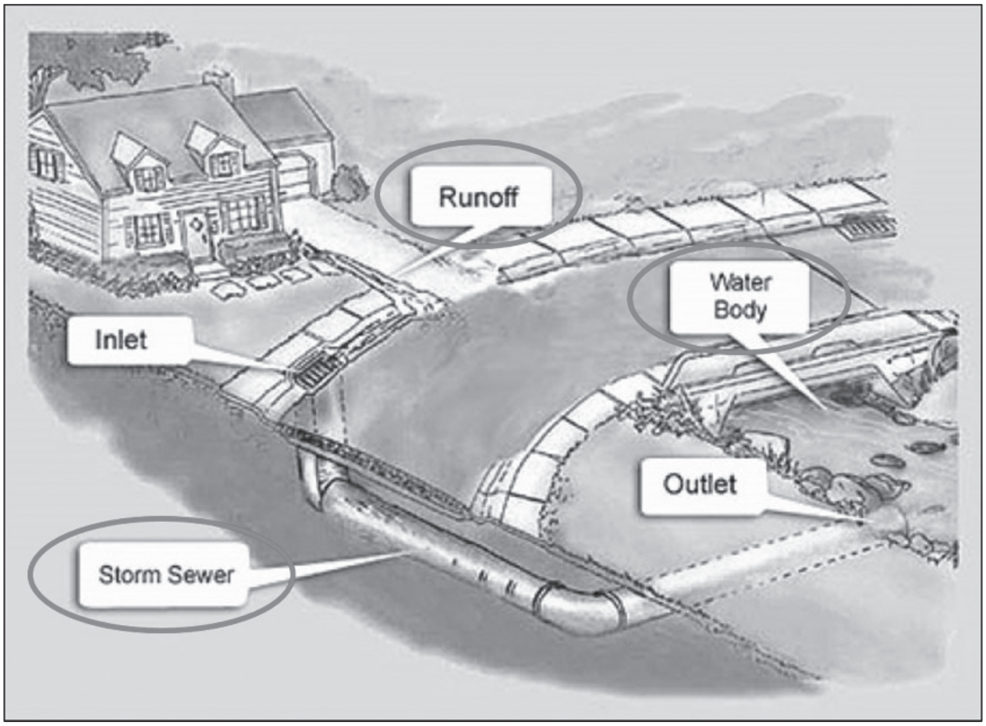

Figure 1: Basic logic of storm-water drainage system

Source: https://goo.gl/images/NE212H

Coming to the structure of the paper, in the second section after this introduction, the paper identifies and discusses the major physical factors or barriers that were identified as affecting Mumbai's SWD system during the flooding events in one or more ways out of the four ways mentioned above. The third section presents the 'political economy' analysis of these physical barriers and traces their roots. In doing so, it identifies and discusses the following: (i) the main factors involved in making of each of these physical factors, (ii) the problematic actions of these factors that directly or indirectly result into creation of these physical factors, (iii) motivation of these actors underlying their problematic actions, (iv) the nature and scale of economic and/or political power wielded by these actors. These powers are seen as adversely affecting the capacity of the central administration of MCGM to curb or control the causal physical causal factors rooted in the problematic actions of the respective actors. Using this diagnostic analysis, the last section of the paper presents some concrete policy and governance-related recommendations for the central administration of MCGM to help it successfully handle and control these physical causal factors.

The discussion in the paper relies mainly on the academic and policy literature as well as interviews of officials, academics, researchers, activists, and media persons.

Physical Factors Affecting Performance of SWD System in Mumbai

This section identifies and discusses 10 major physical factors or barriers which adversely affect the effective functioning of the SWD system in the city of Mumbai. This is based on two sources of information: literature and interviews of experts, officials, and other stakeholders. The section also identifies the level of effect on (or the importance of) flooding of the city for each of these causal physical factors or barriers. Table 1 presents key feature of these ten causal physical factors or barriers.

Widespread Use of Paver Blocks and Concretisation in Public and Private Premises

Covering of surfaces with paver blocks results in increased coefficient of imperviousness, which increases the runoff coefficient. Similarly, concretisation of the areas previously covered by soil also cause increase in the runoff. The increase in area of covered surfaces reduces the quantity of water seeping into the ground, hence increasing the quantity of runoff (Bhagat et al., 2006). Paver block technology provides many advantages including reusability, easy removal and relaying, and costs. Both these factors were considered having minor effect on the flooding of the city in comparison with the other factors.

Increase in Built-Up Area (Residential and Commercial)

Like most big cities, Mumbai experienced very high speed of urbanisation in the last two decades, which results in the alterations in landscape due to construction of urban infrastructure (K. Gupta, 2007). There has been a significant and fast-paced increase in the built-up area to accommodate the growing population. The increased built-up area has resulted in drastic reduction in the green zones and open spaces through which water could infiltrate (Bhagat et al., 2006). This was seen as one of the factors having major impact on the flooding of city by experts.

Table 1: Key Features of Causal Physical Factors or Barriers

Causal Physical Factor/Barrier	Level of Effect/Importance for Flooding in Mumbai	Modes of Impact on SWD System in Mumbai
Widespread Use of Paver Blocks and Concretisation in Public and Private Premises	Minor	Increase in Quantity of Runoff Water
Increase in Built-Up Area (Residential and Commercial)	Major	Increase in Quantity of Runoff Water
Increased Construction of (Covering of Surfaces with) Roads	Medium (City Level) Major (Local Level)	Increase in Quantity of Runoff Water
Mixing of Construction Waste, Debris, or Garbage in the Soil	Medium	Increase in Quantity of Runoff Water
Faults in Design of Drains, Junctions, and Outfall Facilities	Medium	Reduction in Carrying Capacity of Drains, Junctions, Outfall Facilities
Improper Construction of Drains, Junctions, and Outfall Facilities	Major	Reduction in Carrying Capacity of Drains, Junctions, Outfall Facilities
Ill-maintained, Dis-repaired, and Silted Drains, Junctions, and Outfall Facilities	Critical	Reduction in Carrying Capacity of Drains, Junctions, Outfall Facilities
Obstruction due to Utility Lines	Medium (City Level) Major (Local Level)	Reduction in Carrying Capacity of Drains, Junctions, Outfall Facilities
Silting and Choking of Drains Due to Garbage or Sewerage	Critical	Reduction in Carrying Capacity of Drains, Junctions, Outfall Facilities
Encroachment of Illegal Structures on Drains, Junctions, and Outfall Facilities	Critical	Reduction in Carrying Capacity of Drains, Junctions, Outfall Facilities

Increased Construction of (Covering of Surfaces with) Roads

The rise in the level of roads due to frequent resurfacing has resulted in creation of low-lying areas adjacent to the roads which face the issue of flooding and water clogging during heavy rainfall (K. Gupta, 2005). In addition, according to the experts, covering of road side drains during road construction was also a major issue behind localised flooding. Further, gradual increase in the road level due to continuous resurfacing often creates difficulties for the adjoining premises. According to experts this factor has medium-level impact on flooding especially at the city level, though it may become a major factor when it comes to local-level flooding.

Mixing of Construction Waste, Debris or Garbage in the Soil

The soil characteristics (infiltration capacity and porosity) of a region is one of the governing factors in determining the quantity of precipitated water infiltrating in the ground (Chitale Committee, 2006). Due to addition or mixing of debris (i.e., construction waste), the capacity of soil to accommodate or hold the rain water reduces, which results in increased runoff quantity. According to the regulations established by the municipal corporation, it is the responsibility of the contractor to ensure proper disposal of the construction debris outside municipal limits. As per the change in the policy, approval for construction can only be provided by the municipal corporation when the builders provide a debris certificate indicating the safe disposal of construction waste. In the opinion of experts, this has medium level of impact on flooding of the city.

Faults in Design of Drains, Junctions and Outfall Facilities

According to the Chitale Fact Finding Committee Report, in case of urban drainage, the local intensity of precipitation is important than the average annual precipitation. However, in case of Mumbai, the channel size of the drains were designed on the basis of annual precipitation. In addition, no common hydrological criteria has been followed in designing the storm-water drainage system. The issues due to the design failures and lacunas were accepted by the experts as unavoidable human errors. But with access to latest modelling software, they agreed that the probability of having a design failure is reduced considerably. Some alterations were made in the design practices after the Chitale Committee Report pointed out the lacunas. These included change in the value of runoff coefficient from 0.5 (before 2006) to 1 in the current development plan. Overall, this factor has medium-level impact on flooding in the city.

Improper Construction of Drains, Junctions and Outfall Facilities

Improper construction of the storm-water drains cause distortion in the design of the SWD system and significantly affect the effective functioning of the SWD system. Often, it also leads to structural damages. Both these factors have an adverse effect on the carrying capacity of the drains. In addition, due to improper gradient provided during the construction, issues related to water-logging and local flooding have been experienced in some areas (Dixon et.al, 2008). Though it is the responsibility of the contractor to carry out proper construction, the MCGM officials carry responsibility of inspection and approval of work. This factor has a major level impact on the flooding of the city as per the expert interviews.

Ill-Maintained, Dis-repaired, and Silted Drains, Junctions and Outfall Facilities

Negligence in repair and maintenance of existing storm-water drains has resulted in reduced carrying capacity of the drains, which became evident during the 26/7 incident (Dixon et al., 2008). Although the experts considered this as one of a critical factors contributing to the flooding of areas, it is often left to contractors who are held responsible for their negligence in the cleaning process. The cleaning of the storm-water drains is supposed to be carried out throughout the year with majority of the cleaning completed before the monsoons (60 per cent). The contractor is responsible for the de-silting and dumping of silt outside the municipal limits. In case of open drains, cleaning process can be carried out using machines like front-hoe excavator or other earth removing machines. However, in case of closed pipe drains (mainly in the city area), manual labour is used along with extensive use of suction pumps. In order to check the conditions of the drains, timely structural audits are expected to be carried out by the ward-level authorities with catchment engineers and local officers responsible for highlighting the dilapidated drains. If drains are not repaired, maintained, or desilted properly, issues such as flow obstruction, spilling of water, and improper disposal of water might arise.

Obstruction Due to Utility Lines

Any obstruction in the storm-water drains system drastically reduce its carrying capacity. Floating material and objects get entangled in such obstructions and result in partial or complete blockage. The results can be disastrous in case of closed drains due to the difficulty faced in identifying the choked areas. The waterways of cross drainage works/bridges in the island city and in the suburbs have been blocked by encroachment and crossing of service lines, which has resulted in reduction of cross-section area of the storm-water drains at those places (Chitale Committee, 2006). According to the experts, the level of impact created by this factor is medium from the perspective of the entire city, but is major from the perspective of local-level flooding.

Silting and Choking of Drains Due to Garbage or Sewerage

According to Gupta (2005), in Mumbai, most of the trunk drains have become structurally unsafe and have had their hydraulic capacity reduced by 40 per cent to 60 per cent due to garbage and silt. Nearly 60 per cent of the city's population resides in informal settlements called slums. There are no amenities of collection, storage, and removal of waste generated by them due to limited access, nature, and frequency of generation of refuse in slums (Chitale Committee, 2006). Although regular manual de-silting is carried out, the laborers do not go more than 5 m away from the manholes, which are spaced at 50 m to 100 m from each other, leaving long silt dunes and garbage piles between the manholes. Experts consider this as one of the critical factors for control of flooding in the city.

Encroachment of Illegal Structures on Drains, Junctions and Outfall Facilities

Illegal encroachment on manholes, drains, junctions, open areas (including areas with mangroves) has resulted in severe damage to the SWD system in the city. Encroachment on open areas has resulted in lack of land for constructing planned holding ponds, which reduced the overall carrying capacity of the SWD system. Due to illegal settlements and encroachments along the length of the drains, the cross-section of the drains is reduced, resulting in reduced carrying capacity. In addition, encroachment obstructs the work of cleaning of storm-water drains. The area under the mangroves serves as a cushion against the tidal waves, which, when encroached by illegal settlements, fails to fulfil this role. This results in ingress of tidal waters into the city areas during high tides. Due to its scale and proximity to major arterial drains, encroachment is considered as a critical factor for control of flooding in the city.

Diagnosing the Roots of the Physical Factors

This section presents the diagnosis of the roots or genesis of the physical factors identified and discussed in the previous section, which adversely affected the smooth functioning of the SWD system in the city of Mumbai during the flooding events. The diagnosis essentially involves the 'political economy' analysis of these physical barriers in terms of the following steps: (i) identification of the main factors involved in making of each of these physical factors, (ii) identification of the problematic actions of these factors that directly or indirectly result into creation of these physical factors, (iii) understanding motivation of these factors underlying their problematic actions, (iv) identifying the nature and scale of economic and/or political power wielded by these factors. These powers are seen as adversely affecting the capacity of the central administration of MCGM to curb or control the causal physical causal factors rooted in the problematic actions of the respective actors.

Increase in Use of Paver Blocks and Concretisation in Publicly Owned Premises

Public sector officials indulge in use of paver blocks and concretisation, mainly because these technologies provide convenient and cost-effective solutions to their problems pertaining to management of their estates and also help them earn some revenue by renting these premises. However they do not possess much political or economic power over the MCGM administration. It was found that MCGM has not prepared any well-articulated and concrete policy on these two issues.

Increase in Use of Paver Blocks and Concretisation in Privately Owned Premises

Owners of private sector premises, such as individual owners or committee members of housing societies, make use of these technologies because these technologies provide convenient and cost-effective solutions to many of their problems of estate management and they often use such spaces for earning income. But these owners of private premises are not difficult to deal with for the central administration of MCGM.

Increase in Area Covered by Buildings (Residential and Commercial)

The city of Mumbai is known for its high real prices comparable to other global metropolises. In Mumbai, the real estate development is largely controlled by very powerful, national-level corporate developers though there is some presence of medium-scale developers in distant suburbs. The high real estate prices provide motivation for making use of every inch of land and build more and more. Simultaneously, they make these developers politically and economically very strong players, who are beyond the capacity of the central administration of MCGM to effectively regulate. Involvement of the state government's urban development department further makes it difficult for MCGM to control these players.

Increased Construction of Roads

The large-scale building activity creates the need/demand for and provides the rationale for construction of more and more roads. Hence, the powerful corporate developers indirectly support road construction. However, key aspects of actual planning and construction of roads – such as location, technology, economics, tendering procedures, quality – and hence impact of roads on city's SWD system are senior municipal councilors, top-level officials of MCGM, and contractors. All these players wield significant political and economic power over the MCGM administration.

Mixing of Construction Waste or Debris in the Soil

This factor is largely driven by local actors such as small- or medium-scale developers or the property owners and contractors involved in repairs of residential, commercial, or industrial properties. They are expected to carry this debris to sites designated by regulations, which are at some distance from the city. Instead, these actors dump the debris at nearby convenient places, mostly open spaces and natural drains, mixing the debris with the soil in these places. The reasons underlying such illegal actions of these actors include pure ignorance of regulation, lack of easy access to transportation or disposal sites, or pure selfish reason of avoidance of costs. These factors are small-scale operators, and their political or economic power vis-à-vis to MCGM administration is insignificant.

Addition of Garbage in the Soil

This factor is largely driven by two sets of actors. First, the citizens who do not dispose of their household or commercial garbage through the facilities provided by MCGM system, and, instead, dump it locally. They indulge in such behaviour due to various reasons: ignorance, lack of effective and/or easy access to municipal system, or apathy. The second set of factors are street-level employees of MCGM or its contractors, who fail to collect the garbage and allow it to get piled up or buried in open spaces. The reasons underlying this behaviour by MCGM employees are lack of adequate equipment, excessive work load, or apathy, while the MCGM contractors try to reduce their costs. Both these sets of actors, however, lack political or economic power when compared with the central MCGM administration. However, the number of citizens involved in such behaviour is very large and they are spread out and dispersed across the city. This makes it extremely difficult for MCGM to enforce the existing regulations on these actors.

Faults in Design of Drains, Junctions and Outfall Facilities

There is a separate design cell in the SWD department of MCGM, which prepares the technical designs of various components of the SWD system, viz., drains, junctions, and outfall facilities. However, the officials from this department were quite non-cooperative to the researchers. They are employees of MCGM and hence the power held by them vis-a-vis MCGM administration is not significant. However, they manage to escape accountability and responsibility of their performance due to lack of appropriate internal or external mechanisms of accountability in the MCGM system.

Improper Construction of Various Elements of SWD System

Construction of various elements of SWD system is executed through a set of contractors, operating at small, medium, and large (i.e., national and international) scale. The design and execution of tenders are under the control of the top-level municipal officials. Members of certain committees (mainly Standing Committee and Improvements Committee) of the elected body of MCGM are involved in making decisions on award of these contracts. Monitoring of the actual construction work and quality assurance are the responsibility of the middle-level officials of SWD department of MCGM. The political functionaries making decisions are said to be influenced by the political and economic interests at the individual as well as party levels. They also influence the process of design and execution of the tenders. The top-level officials involved in tendering are said to be under pressure from these political actors and often are willing or unwilling accessories to their decisions.

These political functionaries in MCGM and top-level officials involved in tendering process and decision-making wield tremendous political and economic power. It was reported that these functionaries are key elements in the political power structure in the city and also wield extra-legal muscle power. All this makes it impossible for the MCGM to control or regulate this causal physical factor.

Ill-Maintained, Dis-repaired, Silted or Choked Drains, Junctions or Outfall Facilities

It was reported that there are two sets of factors involved in the repair, maintenance, and desilting operations of the drains and other facilities (junctions and outfall facilities) in SWD system. Some small-scale and local-level repair and maintenance tasks are handled by the SWD department. Similarly, the repair and maintenance of equipment like pumps is handled by the departmental staff. However, a large number of repair, maintenance, and desilting tasks are contracted out by MCGM to a variety of contractors having differing levels of capabilities and scales of operation. The design and execution of tenders and decision-making is handled by political functionaries and top-level officials of MCGM in the same manner as explained above.

Though the internal staff handling the small-scale repair and maintenance tasks is not powerful in face of the MCGM administration, the political functionaries and top-level officials involved in tendering process and decision-making wield tremendous political power as explained before.

Utility Lines Obstructing Drains, Junctions, or Outfall Facilities

Many private and publicly owned utilities lay their lines (mainly from electrical, water, telephone, gas, and optic-fiber lines) along or across drains, junctions, or outfall facilities of the SWD system. Most utility companies contract out this job of laying and maintain lines. Often, these contractors and their sub-contractors, in order to save on costs and time, do not follow the safe practices and prescribed by rules, causing obstruction to the SWD system. These utility companies and their contractors do not wield significant power vis-à-vis MCGM administration. It was told that MCGM has prepared a set of rules for laying the utility lines. However, the officials did not make a copy of these rules available to researcher. The rules also require that the local-level MCGM office certify that the laying work is done as per the rules before returning the deposit of the contractor. However, on ground, these inspection and certification tasks are not taken seriously by local-level officials.

Choking of Drains, Junctions or Outfall Facilities Due to City Garbage

Four sets of main players are involved in causing this choking. First, the residents of the city, mainly from the informal (both legal and illegal) settlements spread across the city. These residents do not make proper use of the formal MCGM system of garbage disposal, which leads to choking of the SWD system. The main reasons guiding this behaviour of residents are ignorance, apathy, and often lack of easy and adequate access to proper garbage disposal facilities. These local residents do not have much power vis-à-vis MCGM administration.

The second set of factors are the contractors hired by MCGM to collect the garbage from garbage bins in communities and dispose it off at the designated sites. These contractors and their employees fail to carry these operations in an effective manner. The main reasons underlying this failure are apathy and cost-cutting. The third set of factors are the municipal officials who fail to discharge their responsibilities of monitoring of the work of contractors and enforcing the terms of contract. The reasons for their failure include apathy, corruption, and work pressures. These officials responsible for monitoring and enforcement are said to be “small fries” when compared with the other interest involved.

The fourth set of factors are the senior political functionaries and top-level officials of MCGM who are involved in design, award, and execution of tenders for hiring these contractors. Their interests, powers have been discussed previously. The contractors by themselves do not have much power; however, once the contract is awarded to them, they are protected by the top-level political and administrative functionaries. However, it was reported that some contractors have eliminated competition and have developed monopoly on the strength of their long-established relationship with the decision makers and top-level officials of MCGM. They also have evolved effective business practices over years and possess intimate knowledge of the operations of MCGM and that of the garbage disposal.

Sewerage and Garbage from Illegal Settlements

The concern here is that the sewerage and garbage from the illegal settlements cause silting and choking of drains, junctions, and outfall facilities. These illegal settlements located mainly on the fringes of the city are the outcome of a complex web of factors and forces. These include the national-level factors such as fast-paced urbanisation caused by the mass exodus from rural areas to the metro cities like Mumbai. These also include the political and economic interest of local mafia and local municipal councilors who put up and protect the illegal settlements. The analysis of the issues involved is much beyond the scope of this paper. The problem is further aggravated by the formal policies of MCGM and informal practices of the political functionaries which deny civic amenities including garbage disposal and sanitation to these illegal settlements.

It is certainly beyond MCGM’s power to regulate the onslaught of migrants arriving in large number to Mumbai cities. The political and economic interest of local actors like local mafia and local municipal councilors constructing and protecting these illegal settlements do receive protection from city-level political leaders and officials in exchange of political and economic benefits. There is a significant role of SLBs in spread of these illegal settlements who experience very strong pressure from local- and city-level political functionaries to turn a blind eye.

Encroachment on Drains, Junctions or Outfall Facilities

The encroachments or illegal extensions of old structures or construction of new structures in illegal as well as informal but regularised settlements often result in the obstruction to drains, junctions, SWD system in the city. The main factors involved are the local residents who receive protection from local politicians. While in some cases the ward-level officials of MCGM act as accessories, their efforts to control such encroachment through legal measures often are frustrated due to clogging of the local judicial system and delay in judicial actions for decades. The local-level political and economic actors like local municipal councilors and local mafia constructing and protecting these illegal settlements do receive protection from city-level political functionaries and local officials in exchange of political and economic benefits. Though the policies for controlling and removing encroachments are there in place for decades, their enforcement has proved to be near impossible due to a variety of reasons mentioned before.

Discussion and Recommendations

This section presents recommendation to the central administration of MCGM for effectively handing and curbing of the physical causal factor adversely affecting performance of SWD system in the city. These recommendations emerge from the political economy analysis of the causal physical factors, which is presented in the previous section. The problematic physical factors identified and discussed in previous sections are divided here in three main groups: (i) factors that MCGM central administration can remedy (ii) critical problems that are partially remediable, (iii) problems that are practically irremediable. The discussion and recommendations is organised as per this grouping of factors.

Factors Remediable by MCGM

Though both the factors are considered as having minor impact on flooding, there is need for preparing clearly spelled-out policy instruments to regulate the widespread use of paver blocks and widespread concretisation of soil-covered areas in public and private premises. Some stakeholders opined that even if there were such policies, the problems would persist mainly because of lack of interagency coordination between MCGM on one hand and other public agencies on the other. In the case of these two problems in premises owned by private agencies, it was feared that ward-level and street-level functionaries of MCGM would either look at these with apathy or see this as another opportunity for corruption. In all these cases, the central MCGM administration is capable of making policies and enforcing them in order to curb both these factors.

Similarly, in view of the limited political and economic powers of the local-level factors involved, it is possible for the MCGM central administration to effectively implement the existing polices regulating the disposal of construction debris and waste. Regarding the problem of mixing of garbage, especially plastic, in soils, it partially is a problem created by lack of internal accountability within the MCGM structure in the case of its street-level employees and its contractors. The street-level employees also face hurdle like excessive workload and lack of proper equipment. The central administration of MCGM should be able to tighten up these systems and provide necessary relief and facilities to employees. The problem is also rooted partially in the ignorance, apathy of citizens, their lack of access which can be handled by measures like awareness campaigns, provision of easy availability of disposal facilities, and enforcement.

Coming to the faulty designing of various components of the SWD system, the MCGM central administration should strengthen internal accountability of the design cell in the SWD department through measures like peer technical reviews and third-party audits of the designs. If necessary MCGM may also seek inputs and training from expert institutions in the city. The problems created by utility lines can be handled by effective implementation of the existing policies and strengthening the monitoring and enforcement functions carried out of MCGM staff.

In conclusion, it could be said that, taking the strategic view, the measures to deal with the first category of problems are low-hanging fruits, which MCGM administration should focus on. Though they are difficult to remedy, in view of their critical importance for the city, MCGM administration should make a concerted attempt to address and try to remedy these factors at least partially. The problems from the third category, as indicated, are beyond the control, and hence, practically irremediable for the MCGM. The administration and the city seems to have to live with them.

Critical but Partially Remediable Problems

This category includes, first, the problem of ill-maintained, dis-repaired, and silted SWD system components. It is seen as critical factor in addressing the problem of flooding of the city, but it is also rooted in the city-level powerful political and economic interests, though the stakes of these interests are somewhat limited as compared with those involved in infrastructure construction. This combination of critical nature and low stake makes it necessary and possible for the central administration of MCGM to attempt to handle this problem. One of the necessary measures would be making the tendering process and its decision-making more rational and transparent in order to reduce the influence of the interests involved.

The second problem in this category is that of 'Choking of Drains and Other Elements of SWD System due to Garbage'. This factor is seen as critical by most stakeholders for controlling flooding in the city. Though the city-level powerful interests are involved here, their stakes in tendering of the garbage disposal contracts are small as compared with their stakes in SWD infrastructure projects. This provides a window of opportunity to the central administration of MCGM to at least partially try to reign in the garbage contractors and address this critical problem.

The third factor in this category is the problem of silting and choking created by massive illegal settlements near the outfall areas of SWD system. The central administration of MCGM has no control over the broader and larger factors causing massive influx of migrant population in the city from different parts of country and even from Bangladesh. It also has hardly any control on the nexus between the local political interest and city-level leadership of political parties involved in protection of these settlements. However, the MCGM administration can try to tactically address this problem by providing garbage disposal and sanitation services to these settlements.

Similar is the nature of the forces underlying the problem of encroachment of the illegal or regularised structure on drains and other facilities in the SWD system. Here again the MCGM administration has little control on the local political and economic interests supported by city-level leadership of most political parties. As a result, MCGM may find difficult to take effective action against the illegal encroachments at large scale. But, considering the critical importance of this factor for flooding of the city, MCGM should make an effort to take focused action on the encroaching illegal structures that are especially causing blockage of main drains, junctions, and outfall facilities.

Practically Irremediable Problems

As mentioned previously, there are certain problems which are caused by national- or international-level forces or factors that are simply beyond the central administration of MCGM. These include the continuous increase in built-up area under residential and commercial buildings in the city.

Apart from these, there are certain factors which are traced to the powerful city-level political economy interests of city-level political leaders and functionaries, city or state-level units of political parties, or top officials in the city or state administration. It is extremely difficult for the central administration of the MCGM to address these problems effectively. Such factors include, first, the increased and in appropriate planning and construction of roads, which has medium-level impact on flooding especially at city level. Second, though it is said to have major impact of flooding of the city, the improper construction of various components of the SWD system influenced by city-level powerful political economy interest are difficult to curb for the MCGM central administration as these interest have huge stakes in construction of these infrastructure projects.

Conclusion

Thus, the paper shows that the technical failure of the storm-water drainage system in the city of Mumbai persisting over for at least last 15 years is primarily rooted in diverse political economy forces and factors operating at different levels, from the international and national levels to local wards and street levels. This clearly indicates the irrelevance and futility of the emphasis laid at present on techno-fixing measures by the MCGM administration and the state government of Maharashtra. There is need to take an integrated view for addressing the persistent problem of floods in Mumbai. It would involve acknowledging the political economy roots of these apparently technical problems and making diligent efforts to work on improvements in the policy and governance spheres, while employing technical remedies.

References

Anand, V. (n.d.). Mumbai Floods 2005 to 2017. available at and accessed on :18/01/2019 https://www.mitkatadvisory.com/blogs/mitkat-advisory/mumbai-floods-br-2005-to-2017

Bhagat, R., Guha, M., & Chattopadhyay, A. (2006). Mumbai After 26/7 Deluge: Some Issues and Concerns in Regional Planning. *Population and Environment*, 27(4).

Chitale M. (2006). Final Report of Fact-Finding Committee on Mumbai Floods. available at and accessed on : https://www.scribd.com/document/293669664/Fact-Finding-Committee-on-Mumbai-Floods-Vol1

Dixon, R.W., Malini, B. H., & Ayyalasomayajula, B. (2008). Description and Impacts of the Mumbai Monsoon Flood of July 2005. *In Proceedings of the applied geography conferences* (Vol. 31, pp. 162–165).

Gopalakrishnan, C. (2013). Water and Disasters: A Review and Analysis of Policy Aspects. *International Journal of Water Resources Development*, 29(2), 250–271.

Gupta, K. (2005). The Drainage Systems of India's Cities. *Waterlines*, 23(4), 22–24.

Gupta, K. (2007). Urban Flood Resilience Planning and Management and Lessons for the Future: A Case Study of Mumbai, India. *Urban Water Journal*, *4*(3), 183–194.

Parthasarathy, D. (2015). Informality, Resilience, and the Political Implications of Disaster Governance. *Pacific Affairs*, *88*(3), 551–575.

Conceptualising 2Rs: Risk and Resilience – The Case Study of Mumbai

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ABSTRACT: Urban spaces are expanding rapidly in the developing world today. The urban expansion has been horizontal more than vertical. Cities are indeed crucial spaces and more people have been attracted to the glare of city life. However, the kind of urban development which Indian cities have experienced is rather unplanned and haphazard. Risk is a very comprehensive term. However, urban risk can't be observed in isolation as there exist manifold risks. Population explosion, decreased man-land ratio, lack of housing, limited resources leads to congestion, poor living conditions and increased pressure on land. Indeed the impacts on natural and human environment are visible.

Borrowing the concept of Pressure and Release model, with multidimensional vulnerabilities, dynamic pressure, and unsafe condition, there's 'Progression of Vulnerability' that takes place in cities which ultimately leads to disasters in cities. Flooding, terrorism, building collapse, cyclonic storms, accidents or seismicity, and other hazard is at the doorstep planning to ring the bell to enter the city space in the present times.

This research builds upon the case study of Mumbai. The risks of this complex urban landscape are the subject matter of this research. This study attempts to comprehensively state the risk associated with the city and analyse the resilience of the city Mumbai. It would also attempt to look at how urban governance and risk governance operate and contribute in enhancing the resilience of the city.

KEYWORDS: coping capacity, risk, resilience, Mumbai, urbanisation, vulnerability

Introduction

Cities are a world of wonder, offering a plethora of opportunities and facilities. These are crucial spaces on the earth, considered to be 'powerhouses of economic growth' and 'catalyst for inclusion and innovation' (Ban Ki-Moon, 2016). Over past century world has evidently witnessed phenomenal growth of urban areas. Today, half of the world's population lives in cities. This urban development which has been quite rapid has led to subsequent implications on various fronts. Environment, living conditions, and human health are few facets which have faced enormous challenges in the contemporary urban scenario. Pertaining to generation of various kinds of risks, urban development has indeed intersected with various imperatives of demographic trends, material gains, social struggles and modernisation.

This urbanisation has originated challenges of overpopulation, crowding, degradation of environment, scarcity of resources and decreased man-land ratio. Subsequently this has led to emergence of various kinds of risks. Physical risks might range from stampede, water-logging, accidents and pollution. Social risks can be witnessed as marginalisation, deprivation, poor living conditions, crime and violence, and other related factors. Thus, these manifold urban risks can be seen as diverse as nature of rare and

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routine risk. On the other hand, sustainable cities are seen as a future of the world. Resilience, which is ability to withstand after-shocks of risk, is aspired to be achieved by the Urban Governance throughout the globe. However, there's a huge gap in theory and practice.

Megacities in the developing world are considered as 'global risk areas' (Kraas, 2008). UN's Sustainable Development Goals also considers the cities under its umbrella. The Goal 11 of SDGs envisages to 'Make cities and human settlements inclusive, safe, resilient and sustainable'.

In India, the case is no better because urban expansion here is an ongoing process. With increased rural to urban migration, cities in India have expanded horizontally as well as vertically. This paper tries to build upon the case study of Mumbai, the capital city of Maharashtra. The city has been analysed from the lenses of risk and resilience. The last section tries to bridge the gap of conceptualisation and ground realities. The analysis of risk and resilience relationship through example of the city of Mumbai is critical to this research.

2Rs: Risk and Resilience

Risk and resilience are two sides of the same coins which never meet. Risk reduction, mitigation and risk-free society can only be imagined when resilience is achieved. Without presence of risk, resilience stands nowhere.

Risk as a concept originated from a non-environmental context. The notion of risk in a small economy is capitalistic where the discourse is all about taking risk between opportunities and danger. Risk however in disaster management context is technically defined as a function of vulnerability and hazard, 'the probability of harmful consequences, or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable/capable conditions. Conventionally risk is expressed by the equation Risk = Hazards x Vulnerability/Capacity' (UNISDR, 2004). According to Ortwin Renn, the definition of risk therefore consists of three elements: 'outcomes that have an impact upon what human's value; the possibility of occurrence (uncertainty); and a formula to combine both elements".

However, risk as a concept has a wider connotation. It cannot be constrained into the ivory tower of academic discourses. Evidently risk impacts the lives and livelihoods of people globally. Risk is integral to modern society in contemporary world which has been an area of interest to scholars who have been inspired for studying foundation of modernisation and the genesis of governance structures with respect to coping with the uncertainties in a world full of unforeseen possibilities (Renn, 2008).

Resilience according to United Nations Office for Disaster Risk Reduction (UNISDR) stands for, 'the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions'. While the Rockefeller Foundation's 100 Resilient Cities project defines resilience as 'the capacity of individuals, communities, institutions, businesses and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience…Simply put, resilience enables people to bounce back stronger after tough times, and live better in good times'.

However, resilience can be seen closely associated with coping capacity which is considered to be an inherent feature or capacity of a community or system from unusual, rare and adverse situations. Hence, it can be seen as the higher the coping capacity, the more is the resilience to withstand the aftershocks hazards and disasters.

Turner and Singer puts forth the idea that 'the concept of 'resilience' needs to be seen as a panacea to the negative impacts of change, whether gradual or sudden, whether man-made or through "natural disasters", and as a proponent of the positive effects of growth' (Turner & Singer, 2014). According to this notion, resilience stands as a positive and fine practice which is steady yet ongoing and evolves over time. Indeed, resilience is an ever-growing process which exists in all periods of disaster cycle. It is a proactive approach which inspires to prepare, mitigate, prevent and adapt. It provides a scope for risk assessment, vulnerability mapping and moving towards risk reduction. Also, resilience stands for various connotations such as economic resilience, social resilience and structural resilience.

The scope of resilience has increased over time. The Sendai Framework for Disaster Risk Reduction brings forth a strong case of risk reduction with specific targets. The connotation of 'Bounce Back Better' strongly presents the case of resilience in post-disaster scenario.

Pressure and Release (PAR) Model is a conceptual underpinning in the disaster management discourse. It elaborates how due to the existence of the root causes, dynamic pressure and unsafe conditions, there's a Progression of Vulnerabilities. This is further explained to be creating a situation that leads to the disaster like scenarios in the already existing hazardous atmospheres.

Thus in the Urban scenarios, the multidimensional vulnerabilities, dynamic pressure and unsafe condition have been found leading to the 'Progression of Vulnerability'. In the already hazard-prone zones, the mounting vulnerabilities ultimately transforms into disasters. Flooding, terrorism, building collapse, cyclonic storms, accidents or seismicity and other hazard is at the doorstep planning to ring the bell to enter the city space in the present times. The dynamic pressure, along with increasing unsafe conditions, leads to exponential increase in the urban risk.

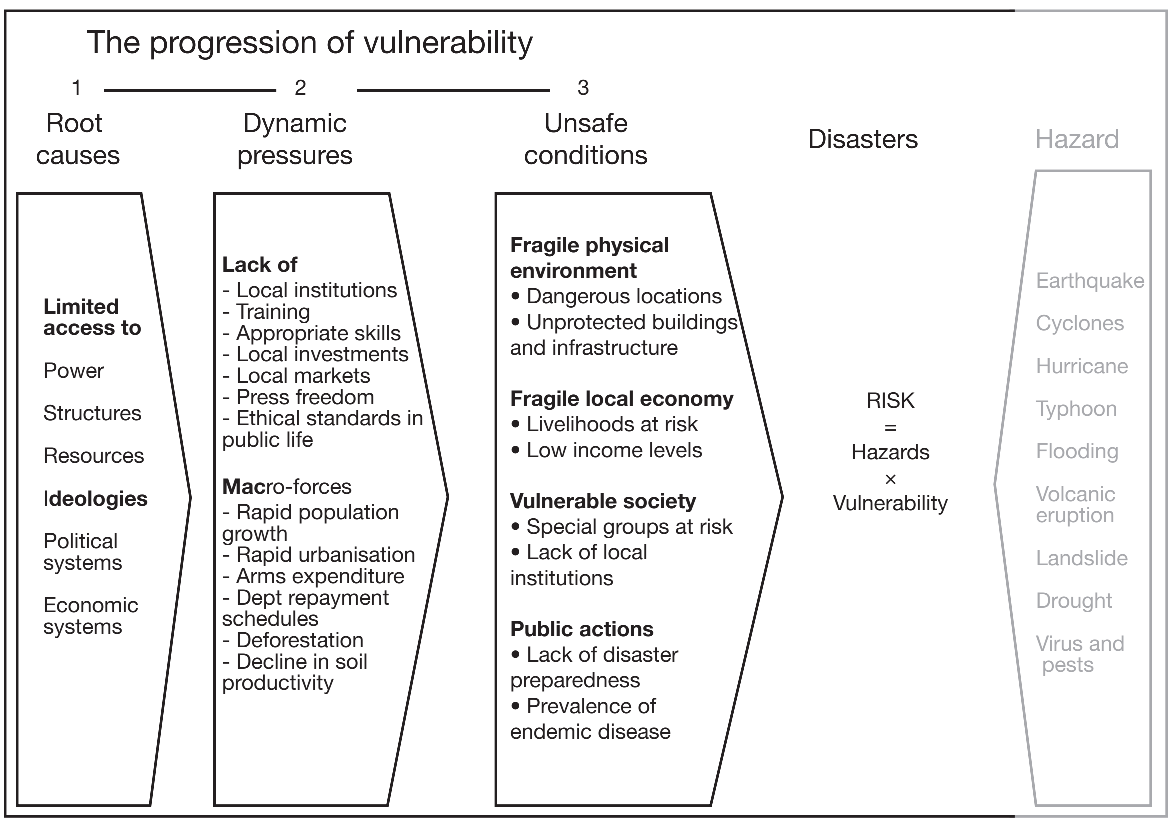

Illustration 1: The Pressure and Release (PAR) Model (*Source: https://link.springer.com/chapter/10.1007/978–94–024–1283–3_8*)

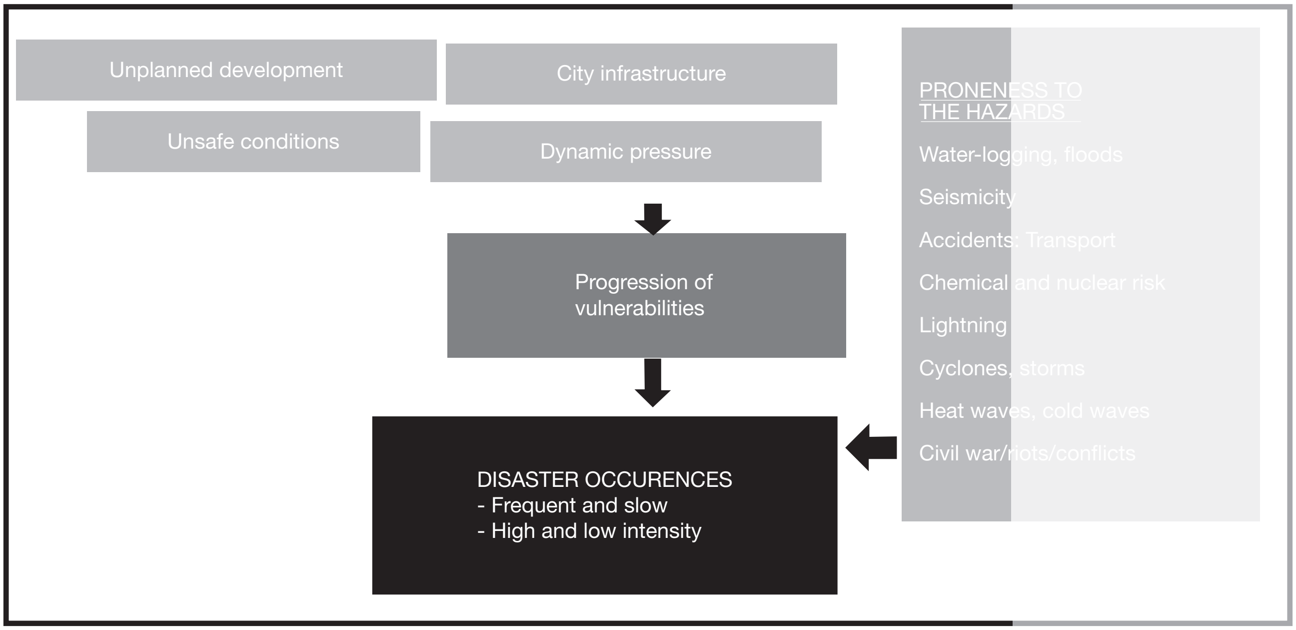

Illustration 2: Depiction of how disasters in urban setting occur, adapted from PAR Model;

Source: Created by Author

Understanding Risk and Resilience through the Case of Mumbai

Considered to be the city of dreams, Mumbai has historical roots. There was a time when it was a fishing village and later got colonialised. From British times to the industrialisation and becoming the financial capital of the country, the city has grown manifold times in last few centuries. While tracing the story of Mumbai, its existence from seven islands to reclamation of land in creating the giant megacity can't be undermined. Mumbai's population density is the highest in the country and even higher than many mega-cities of the world.

Mumbai has experienced phenomenal growth, since its industrial expansion. Several favourable conditions of cheap labour, access to raw material, proximity to market and its coastal location contributed in the setting up of the Mills and industrial growth bloomed in the city. by 1980s and 1990s Mumbai had become not only economic concentration of the country but also a global player.

Mumbai has always been a city on the run. From Dabbawalas to men with suitcases, everyone has a hectic schedule here. The Mumbai sub-urban railways commonly referred as the 'local' is the lifeline of the city whose delay will be equivalent to the delay of the city. The traffic on the roads is no less; getting struck on the Monday morning is a common expectation. People belonging to the different strata of society in this city, live and work together, equally indulging and contributing in the economic activities and financial growth. Mumbai hence fits in as a 'paradox agglomeration' (Davis, 2006). Since here the paradoxes are visible from remarkable high rises and colonial infrastructure which coincide closely with huge clusters of slums. The richest of people live lavishly, whereas the slum dwellers and middle class struggle to survive in the country's most expensive city. In 2009 the Globalisation and World Cities Study Group named Mumbai an 'Alpha world city'—a city considered to have a tangible effect on global affairs both socially and economically.

Risk and Uncertainties Present in Mumbai

Mumbai faces multi-hazard risks ranging from the incessant monsoon rains, floods, earthquake, storm surge, riots, terrorism, building collapse, chemical, nuclear and other accidents. Many incidents have ripped the city apart but it has uprooted from the past experiences and has tried to bounce back better. However, there are several risks which haunt the people and city on routine and rare cases. Some of these are elaborately explained as follows:

IDENTIFIED RISKS IN MUMBAI

Based upon the past incidences	Future possible threats
▪ Rains and flooding	▪ Sea level rise
▪ Scarcity of water	▪ Climate change
▪ Seismic risk	▪ Hazardous -waste accumulation
▪ Chemical & nuclear accident	▪ Maritime security
▪ Building collapse	
▪ Riots and terrorism	
▪ Other routine risks	

Illustration 3: List of identified risks in Mumbai, based upon past incidences as well as future possibilities

Source: Created by Author

The above-mentioned risks have been identified and enlisted to indicate the existing risks and future threats which the city of Mumbai can face. Each risk can be elaborated separately in the context of Mumbai and the reasons for why these risks mount on the city. This section further presents few of the prominent risk factors precisely.

Rains and Flooding

The city experiences high amount of rainfall every year in the monsoon season. However, pertaining to the urban expansion that has occurred in the city, concretisation has locked percolation capacity of the land. The open spaces have been lost too.

The experiences of the city with the incessant rains have been quite worse over the years. The 2005 monsoon which flooded the whole megacity has been remembered as a classic example of the risks with which Mumbai and its residents live with. Water-logging on the roads, railway line and everywhere else chokes the city in monsoon and brings it to a halt. This has been story of each year now. There have been many instances when city residents have got struck in their offices and mid-way due to sudden flooding. The floods indeed break down the backbone of the municipal authority of Mumbai and its civic management plans.

The first Urban Disaster Management Plan for Mumbai was prepared in late 1990s by Government of Maharashtra which identified flooding as a significant risk. Since Mumbai is reclaimed land carved out of seven islands, the natural landscape and environmental setting have been disturbed by the reclamation. Several ecological studies have found that the island structures allowed an easy passage of the monsoon rains which the reclamation blocked and hence the water gets trapped in the landmass, logs the roads and chokes the city. The Mumbai DMP identifies 10 sections along the Central Railway and 12 along the Western Railway prone to serious flooding along with 235 flooding points within the city (GoM 1999). Pot holes during this time is another danger which affects the life in the city.

Kalpana describes this situation, 'Every monsoon hundreds of people in the city are killed - by disease, by crumbling buildings, by retaining walls built to protect precariously perched slum settlements that collapse, and by flooding. There is no romance in the monsoon for half the city that lives in impermanent or dilapidated housing' (Sharma, K. 2011).

Seismic Risk

Mumbai falls in the Seismic Zone III and is highly prone to the earthquakes. The last recorded earthquake of highest intensity was in 1951 which was recorded as VIII magnitude on the Richter scale.

Chemical and Nuclear Accidents

Mumbai is prone to chemical and nuclear explosions. The Victoria dock explosion due to the SS Fort Stikine in 1944 killed up to 6,000 and devastated an area of 1.2 sq km in the heart of the city. Recently in August 2018 the fire which broke out in BPCL Refinery Plant shocked the whole city. The location of chemical refineries, Rashtriaya chemical fertiliser (RCF) and Bhabha Atomic Centre increases the risk factors.

Building Collapse

Manisha Chalana describes, 'The city of Mumbai provides an ideal location for looking at how the existing vernacular environments are transforming in the face of rapid globalisation'. Though the urban infrastructure has transformed in the city, old infrastructure has been used for long. This has been leading to several building collapse incidents. Mumbai's building are largely aged, dilapidated and partially engineered, implying that it does not meet contemporary standards of building safety (Sinha and Adarsh 1999). The incident which took place in Ghatkopar, August 2017, was dreadful of all.

Riots and Terrorism

Communalisation of politics and civic life is a way of life in Mumbai. The regionalism and religion centric politics of vote bank have been a unique kind of risk which city faces. The 1992 riots which started post-Babri Masjid demolition had worse effects on life and livelihood. There also exists intertwined complications of communal politics and terror outfits. Consequently it gave rise to another series of violence that was perpetrated in the city as serial bombing in 1993. These bomb blasts are considered to be a response to the 1992 violence.

The communal riots and terror attacks of 1992–93 were not the only threats that city has faced so far in its history. This has been followed by train bombings in 2006, attacks in 2008 and serial bomb blasts in 2011. The 26/11 attack of 2008 had bought havoc as the terrorists targeted prime locations of South Bombay. S. Muralidharan describes the post- 26/11 as, 'collective trauma' that people of Mumbai and whole nation went through.

The question of safety and fears of insecurity looms over the face of city. Tight policing and installation of private security systems at many places in the city doesn't suffice the needs. The coastal security lays a main threat, till date.

Other Daily Risks

Kalpana Sharma puts forth that 'Mumbai have posed questions once again about the vulnerability of the city to terrorist attacks. But everyday life is itself terrifying for the majority in Mumbai' as she refers to erosion of sense of citizenship in the city, divisive politics and daily risks which are a lag to development or betterment of city.

The fleet of public transportation system available in the city is unequally proportioned to the size of the city. Many have to travel in the bone-crushing crowd, face traffic and hang on the doors of buses and trains. On several instances it has been reported how people die because of hanging on the doors of Mumbai sub-urban trains popularly known as 'Locals'. Daily commute is hence a risk which people of the city face.

Regionalism and Maratha identity have been asserted in the city times and again by the majority Maratha community which is supported by the political roots too. The migrant communities face challenges of language, non-cooperation and exclusionary behaviours which create mental stress to people who come to city seeking better life and livelihood.

Climate Change and Possibilities of Sea Level Rise

Today whole world has been caught with the danger of climate change. Mumbai has also been experiencing this. The sea level rising has been experienced by many parts of the globe. Mumbai also sits on the verge and might have to experience it in the times to come. Mumbai being a coastal city also has a future possibility of coast turning as inhabitable, a phenomena evident in Oceania.

Hazardous Waste Accumulation

The dumping grounds of the city, which stores the waste of the huge mega-city of Mumbai, generates hazardous situations for the people around. It is the cost cities have to bear for stepping up the ladder of development and material progress. The concern is grave as the hazardous waste accumulation sites put pressure on the urban ecology as several poisonous gases are released from it. The proximity of human life to the dumping areas can lead to catching of severe diseases too.

Deonar dumping ground, opened in 1927, is Asia's biggest dumping ground which grows by 4000–5000 tonnes of garbage every day. In several researches it has been found that proximity to this dumping ground has affected health of residents of highly populated Mumbai's 'M East' Ward (Free Press Journal, 2017). There have been instances when it has caught fires too, which has been hard to control. Dumping ground in Mulund is the second largest landfill in the city of Mumbai which has been in existence since 1967.

Bombay High Court in February 2016 had also ruled out to close the Deonar and Mulund dumping grounds in the city after observing that both of these have reached a saturation point (TOI, 2018). However initiatives to scientifically dispose the waste have been proposed, much awaits in the line for ground realities to change.

Poor Living Conditions

Mumbai is one of the densely populated cities in terms of population. The high man-land ratios is both boon and ban for the city. Nearly half of the population of the city lives in squatter settlements, slums or chawls. Lack of adequate and affordable housing compels people to live in dense network of small and dingy houses. Those slum dwellers also contribute to the economic activities equally.

The slum dwellers who engage in informal sector undergo and live with risks in all seasons. They face socio-economic and political vulnerabilities. One of the most expensive cities in the world, Mumbai offers a world of disparity within its own territorial limits. The sky scrapers located in proximity with squatter settlements bring in the picture of marginalisation and exclusion. The lack of access to safe drinking water and sanitation make them more vulnerable to health and environmental hazards.

The Millennium Development Goal Report 2010 brings out the fact that in India, 97 per cent of urban dwellers have access to safe water, despite the fact that only 30 per cent of urban dwellers posses access to better sanitation facilities. Though, the definition of 'better' is a subject of debate in itself.

The developmental planning of the city has failed to incorporate the housing schemes or the resettlement plans for these slum dwellers who continue to live on the private and governmental lands.

Critical Analysis

Conceptualisation of risk and resilience doesn't come easy when ground realities are considered. There are manifold urban risks that surround the urban spaces. Similarly, urban resilience has a multifaceted underpinning, since cities are complex entities. Generally any city is surrounded by manifold kinds of risks. Thus, there are many facets to be addressed and several measures to be introduced. Urban resilience policies have not been seen as uprooted as a preventive approach. Throughout the world urban resilience has emerged first as a reactionary approach from where it transformed. Though in India, this transition is still in process.

The above pen picture of risks existing in Mumbai provides a deeper understanding of urban complexities. In this case of Mumbai's routine and rare risk, Urban Governance has played a role. It should be noted that the flood risk is taken sincerely by the Bombay Municipal Corporation (BMC) and other concerned authorities.

S.W.O.T. Analysis

Strengths, Weakness, Opportunities and Threats (S.W.O.T.) Analysis of Mumbai's hazard risk and state of resilience has been conducted by the researcher after thorough review of city's profile, ground realities and assessment of its capacity.

STRENGTHS	WEAKNESS	OPPORTUNITIES	THREATS
Urban governance	High population density and congestion	Satellite towns and planned expansion	Water logging and major flooding
Geographical location and interconnectedness	Decreased man-land ratio; scarcity of resources	Economic advantages	Accidents: transport, chemical and nuclear
Social fabric: multi-cultural with secular thread	Pollution and ecological destruction	Rain waters	Climate change and possibilities of sea level rise
Few well-preserved ecological hotspots	Unplanned expansion (drainage, waste)	Human resources	Human health: infections/epidemics
Old historical past	Crime, violence and politics	Coping capacity	Riots and terrorism
	Poverty		Maritime security

Illustration 4: Strengths, Weakness, Opportunities and Threats Analysis of Mumbai's hazard risk and state of resilience (this is just an indicative list);

Source: Created by Author

- Strengths of Mumbai city exists in the risk management that city has been trying to cope with. The Urban Governance of the city through BMC and other authorities have been critical to the city. The geographical location of the city is however of the foremost importance; located on the coast the city has been inter-connected to the globe through waterways. Jawaharlal Nehru Port and other harbours of the city makes the city a place of strategic location. These ports can play a crucial role during the times of emergency. The social fabric of the city is multi-cultural, diverse and secular, which binds the city in one thread. There exist many well-preserved ecological hotspots in the city which includes Sanjay Gandhi National Park too.

  The city of Mumbai has faced many hazardous incidents and disasters over the years. Each incident had been a lesson for the city, and with each incident, city has withstood. Resilience is hence strength of this city.
- Weakness of Mumbai city can be depicted in many facets such as overpopulation which has led to decrease in man-land ratio and increased human density. The resource crunch is a consequent trouble which is further leading to the mismanagement of resources rather than optimal utilisation. Pollution and ecological destruction are quite evident due to unsustainable practices in the city. Protection of mangroves had not been done in the proper manner. The management of waste is poor; the dumping grounds have become the hazardous sites. Air quality levels in the city are deteriorating too in the present times.

  The unplanned urban expansion of the city over the years had been haphazard.

  Especially the urban sprawl and spread of huge slum area like Dharavi has happened quite rapidly.

This growth has given birth to water-logging, unhealthy sanitation, poor drainage and conditions of lack of waste management.

The inequalities in the city are startlingly high; the income divide is steep and abrupt too. Poverty levels in the city are high as well. Often referred as the underbelly of the crime world, Mumbai city faces threats from the deeper nexus of violence, crime and politics.

- Opportunities in front of Mumbai city are many. The city being the economic capital owns economic advantage and houses human resources who can contribute in the city's peace and prosperity. The Satellite Towns of the city like Navi Mumbai are more critical for the city in the present times. Heavy rain water the city receives can be an opportunity which can help in reducing the problems such as water scarcity through the tapping of rainwater. Many other factors give the city opportunity to grow and become risk-free.
- Threats in front of Mumbai city are quite diverse. Biggest of all is the probability of occurrence of major flooding and water-logging. The occurrence of accidents of transport vehicles are more routine threats. Chemical and nuclear accidents threaten the life in the city. The presence of petro-chemical industries and institutes like Bhabha Atomic Research Centre make Mumbai more vulnerable. Public Health concerns remains a future risk as spreading of deadly infections or epidemics can be rapidly and equally damaging to the city. Climate change and rising sea levels are two possible phenomena which puts the city at risk. The existing international relations, crime-politics nexus and divides based on religion put city at the risk of riots and further terrorist activities.

The SWOT Analysis has been done on a limited extent; however, there can be many other factors which are not considered here. The past incidents and future possibilities have been the basis to highlight the key strengths, weaknesses, opportunities and threats in front of the Mumbai. The scope of risk and resilience hence can be closely observed from the clear demarcations that this analysis sets.

Mumbai: A Risk Society

In the academic discourse the concept of 'risk society' has come up time and again. Urban societies too have been referred as 'risk society' by various scholars including Ulrich Beck who have argued that industrialisation of society itself produces risk. According to Beck, these risks are different: global in nature, high impact, unseen and 'open to social definition and construction'. However, Beck's notions have been critiqued. His belief that there's a contention between traditional and late modern risk is not widely accepted. He characterises risk as unseen and global. These notions have been countered on several grounds. Risks are mostly unprecedented and are most often localised too.

Additionally, it is often believed that cities have higher resilience to absorb the after-shocks of disasters and other kinds of risks. Mumbai's case shows a similar picture wherein the city has experienced many kinds of shocks from natural and human-induced disasters. It has however come up from these shocks and moved on each time. 'Business as usual, irrespective of drought, plague, famine or riot has been Mumbai's hallmark through the great cotton boom of the mid-19th century to becoming one of the greatest megacities of the early 21st century' (Revi, A 2005).

Conclusion

'Mumbai is not resilient; it is a city without choices. Resilience is not a choice here; it is a necessity, essential for survival in a city where almost everyone is scrambling for space, for air, for water, for food, for work, for shelter' (Sharma, K 2011).

In the present era, Urbanisation can't be restrained. It's a process which is equated with development and is hence desired by people who don't reside in big cities. Mumbai is one of the most risk-prone cities in the country. It has stood with time to withstand many kinds of emergencies that have hit this land. Can Mumbai be considered a "Resilient City"? – is one of the major questions that remains yet to be answered.

City scale mitigation measures are necessary for the city of Mumbai. Multiplicity and deep interconnections between the challenges posed to and by urbanisation – political, economic, ecological, social and cultural needs to be addressed carefully. High cost options can't be sought; they will give some of the solid reasons for bringing resiliency in the city. Other cities of the world have built from their experiences of disasters. Mumbai needs to do that homework too by linking the urban risk reduction programmes with initiatives like Urban Renewal Programme or SMART cities programme to address both natural and human-induced hazards. Risk assessment and vulnerability mapping as a base study should aid in development planning and risk-informed decision-making. Re-examining urban governance, ward and neighbourhood level, community-based initiatives should be introduced. Urban development, housing and infrastructure planning, renewals for the lowest strata would be an urgent need. Risk communication channels for disseminating the early warnings through telecommunication systems can be sought. Comprehensive, ward-wise disaster management plans should be formulated with dedicated plans and procedures, including information of the emergency equipments, volunteers and helplines.

Administrative rules and legislation are important means and measures with which urban risk can be checked and managed. However, the role played by non-state actors is of equal importance. The private organisations, educational institutions and non-governmental organisations are some of the key players in this process. While, it's the community which lives at risk and should be considered and involved in risk reduction planning programmes generating public awareness through sensitisation campaigns, mobilisation programmes would create preparedness among the larger public.

Indeed, risk reduction needs to be integrated with the development planning. Since all these issues are interwoven so well, they necessarily need to be addressed together. For moving towards a risk resilient society, sustainable practices should be essentially followed in planning as well as in practice at all levels in all, not only in Mumbai but largely in the world.

Bibliography

Aromar Revi. (2005). Lessons from the Deluge: Priorities for Multi-Hazard Risk Mitigation. Economic and Political Weekly, 40(36), 3911–3916. Retrieved from http://www.jstor.org/stable/4417103 (Revi, A 2005)

Bhalerao, S. (2018). Fire at Mumbai's Deonar dumping ground still not doused. Hindustan Times. 27th March 2018. Retrieved from: https://www.hindustantimes.com/mumbai-news/fire-at- mumbai-s-deonar-dumping-ground-still-not-doused-six-fire-tenders-on-spot/story-4j5dhjpp5hWBUzbaoHgK0K.html

CHALANA, M. (2010). Slumdogs vs. Millionaires: Balancing Urban Informality and Global Modernity in Mumbai, India. Journal of Architectural Education (1984), 63(2), 25–37. Retrieved from http://www.jstor.org/stable/20778805

Davis, M. (2006): Planet of slums. London.

Elliott, J., & Frickel, S. (2013). The Historical Nature of Cities: A Study of Urbanisation and

Hazardous Waste Accumulation. American Sociological Review, 78(4), 521–543. Retrieved from http://www.jstor.org/stable/23469226

Keck, M., & Etzold, B. (2013). Risk and Resilience in Asian Megacities. Erdkunde, 67(1), 1–3. Retrieved from http://www.jstor.org/stable/23595351

Kennedy, Loraine and Marie-Hélène Zérah (2008): "The Shift to City-Centric Growth Strategies: Perspectives from Hyderabad and Mumbai", Economic & Political Weekly, 43 (39), pp 110-

Ki-moon, B. (2016). World Cities Report, Urbanisation and Development: Emerging Futures. World Cities Report, UN Habitat.

Kraas, E (2008): Megacities as global risk areas. In: Marzluff, J.; Endlicher, W; Alberti, M.; Bradley, G.; Ryan, C.; Zum Brunnen, C. and Simon, U. (eds): Urban ecology. An international perspective on the interaction between hu mans and nature. New York, 583—5

Madeline Alford. (2012). Mumbai, India: The Metamorphosis of a City. World Literature Today, 86(3), 5–5. doi:10.7588/worllitetoda.86.3.0005

Malu, Preksha (2017). What It means to live near Mumbai's Deonar Dumping Ground. Homegrown Online Media Publication. 13th March 2017. Retrieved from: https://homegrown.co.in/article/800250/what-does-it-mean-to-live-near-the-deonar-dumping- ground

Mehrotra, S., Rosenzweig, C., Solecki, W. D., Natenzon, C. E., Omojola, A., Folorunsho, R., et al. (2011). Cities, disasters and climate risk. Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network. Cambridge, U.K.: Cambridge University Press.

Mishra, S. (2017) Mumbai: Deonar dumping yard is affecting health of residents, say doctors. Free Press Journal. 7th November 2017. Retrieved from:
https://www.freepressjournal.in/mumbai/mumbai-deonar-dumping-yard-is-affecting-health- of-residents-say-doctors/1165877 (Free Press Journal, 2003)

Murthy, S. (2012). Land security and the challenges of realizing the human right to water and sanitation in the slums of Mumbai, India. Health and Human Rights, 14(2), 61–73. Retrieved from http://www.jstor.org/stable/healhumarigh.14.2.61

Muralidharan, S. (2008). Mumbai, Militarism and the Media. Economic and Political Weekly, 43(49), 15–18. Retrieved from http://www.jstor.org/stable/40278257

PTI. (2018). Garbage dumping ground in Mumbai permanently shut. Times of India. 1st October 2018. Retrieved from: https://timesofindia.indiatimes.com/city/mumbai/garbage-dumping- ground-in-mumbai-permanently-shut/articleshow/66028407.cms (TOI, 2018)

Sharma, R. (2010). Mega Transformation of Mumbai: Deepening Enclave Urbanism. Sociological Bulletin, 59(1), 69–91. Retrieved from http://www.jstor.org/stable/23620846

Sharma, k. (2011). Wounded Mumbai. Economic and political weekly, 46(30), 12–14. Retrieved from http://www.jstor.org/stable/23017998

SOOD, A. (2013). Urban Multiplicities: Governing India's Megacities. Economic and Political Weekly, 48(13), 95–101. Retrieved from http://www.jstor.org/stable/23391470

Turner, M., & Singer, R. (2014). Urban Resilience in Climate Change. In Von Schorlemer S. & Maus S. (Eds.), Climate Change as a Threat to Peace: Impacts on Cultural Heritage and Cultural Diversity (pp. 63–82). Frankfurt am Main: Peter Lang AG. Retrieved from http://www.jstor.org/stable/j.ctv2t4cvp.8

UNISDR, (2007) 'Terminology: Resilience' (The United Nation Office for Disaster Risk Reduction, 30 August 2007) www.unisdr.org/we/inform/terminology

Vidyadhar (2005). Mumbai Floods: The Blame Game Begins. Economic and Political Weekly, 40(34), 3714–3716. Retrieved from http://www.jstor.org/stable/4417041

World Cities Report (2016), Urbanisation and Development: Emerging futures. UN Habitat.

Wisner B, Blaikie P, Cannon T, Davis I (2004) At Risk: Natural Hazards, People's Vulnerability and Disasters, 2nd edn. Routledge, London, 471p

WHO/UNICEF (2012) Joint Monitoring Programme for Water Supply and Sanitation, Progress on Drinking Water and Sanitation, pp. 44–45.

Flood Hazard and Vulnerability Assessment of a Mega Urban Coastal City: A Case Study

P. E. Zope[a] and T. I. Eldho[b]

ABSTRACT: Flooding is one of the most common severe natural hazards that occur nowadays frequently all over the world. For appropriate flood disaster management and mitigation plan, proper knowledge of flood plain extent, flood hazard, flood vulnerability and risk assessment for different flow conditions is very essential. Coastal cities like Mumbai are more vulnerable to floods due to scarcity of land, limitations on the horizontal growth and limitations on the discharge capabilities of the drainage system due to tail water levels. The main focus of the present study was to investigate the impact of urbanisation on floods using integrated flood modeling approach, flood hazard mapping and assessment of flood vulnerability. The catchment of the Mithi River which is one of the major rivers in Mumbai is considered as the case study. For the considered catchment, flood plain and flood hazard maps for different flow conditions were prepared. Flood vulnerability maps with social indicators and infrastructural indicators including all important critical facilities have been generated. Flood hazard and vulnerability analysis with generation of maps provide important tools for disaster management planning and evacuation system planning during the floods.

KEYWORDS: urbanisation, urban flooding, flood hazard map, flood vulnerability, disaster management

Introduction

Migration of people from rural to urban area has increased the population of the urban cities drastically during the recent years. To satisfy the needs of the increased population, there is change in land use and land cover due to infrastructural growth. As such due to the increase in impervious areas in urban catchments, the intensity of peak discharge of runoff is increasing drastically. Human lives, property and infrastructure are on high risk due to extreme intensity of rainfall and flood events occurring nowadays around the world. Also due to changing hydrologic conditions and also change in rainfall pattern, severe flood events may occur in future (Zope et al., 2012; Zope et al., 2016a). Floods being the natural disaster cannot be avoided totally but proper flood mitigation and risk management can be achieved to minimise the damage to property and loss of lives. People residing in the vicinity of the flood plains of the rivers should have proper knowledge about the consequences of flood hazard and flood risk. To assess the information about the flood vulnerability and risks, design of proper user friendly management information system is very essential (Zope et al., 2015, 2016, 2016a). As per Kron (2005), risk is the product of hazard, values at risk and vulnerability. The people residing in the flood-prone areas do not know how to respond and act instantly as against the extreme situation during the flash floods. As such risk reduction should address not only hazard reduction but also the integration of each individual process. Increase in flood event has increased the importance of insurance which

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completes the individual's financial risk management. Risk relates to losses having uncertain occurrence and size. Hazard relates to probability and magnitude of the occurrence. Exposure relates to statistics on population, socio-economic data and infrastructure (Barredo et al., 2007). Karmakar et al. (2010) in their research on flood risk assessment considered the physical, economic, infrastructure and social components of vulnerability. The infrastructural vulnerability is assessed by considering road, railway, bridges and critical facilities such as schools and hospitals. They also considered the exposure of land use and soil permeability in the flood risk assessment. Total risk was calculated considering the flood extent probability, total vulnerability including all four parameters and exposure to land use and soil. GIS technology can be effectively used to study to assess vulnerability as well as flood risk mapping (Zope, 2016). Srivastava and Shaw (2015), explored the consequences of post-disaster with respect to employment opportunities across urban, peri-urban and rural area in and around Ahmadabad, India. The two major concepts considered were "urban -rural linkage and vulnerability occupations" (Zope, 2016). The main objective of the present study was to prepare flood hazard, flood vulnerability maps with social indicators and infrastructural indicators including all important critical facilities. Flood hazard and vulnerability assessment and analysis with generation of maps provide important tool for disaster management planning and evacuation system planning during the floods.

Study Area

Mumbai being the financial capital of India and capital of Maharashtra state is developing in a very rapid way in the last few decades. Mumbai city have four main rivers mainly Mithi, Poisar, Oshiwara and Dahisar. All the rivers discharge their flow to the Arabian Sea through creeks, so they have a tidal influence effect. Study area considered for this study was Mithi River being the main River of the city. Mithi River Watershed falls between Latitudes 19^0 0' 15"N and 19^0 15' 0" N as well as Longitudes 72^0 45' 0" E and 73^0 0'0" E. Location map of Mithi River is shown in Figure 1. Origin of Mithi River is from overflow of Vihar lake and subsequently Powai lake and meets the Arabian Sea at Mahim Causeway. The total length of river is 17.8 km long, out of which the 11.8 km stretch on the upstream side have step gradient (FFC, 2006). On its way, the river flows below the airport runway for a distance of about 400 m and comes out of airport culvert near Kranti Nagar. The Mithi River flows through the city of Mumbai and forms a principal channel to discharge stormwater. Mithi River has one major tributary called Vakola River towards downstream of the catchment. A total of 16 major nallah are discharging their stormwater into the Mithi River. Besides the bank of the river, there are industrial units, storage facilities, workshop and scrap yards, which deliver untreated sewage into the river, thus polluting the aquatic system of the entire river (CWPRS, 2006; Zope, 2016).

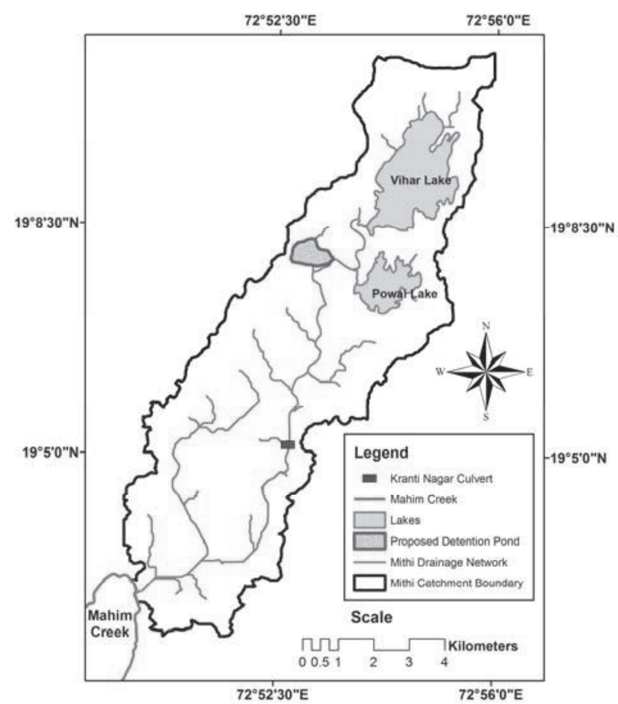

Figure 1: Location map of Mithi River catchment (Zope, 2016)

Methodology

To prepare flood disaster management and mitigation plans, it is necessary to have thorough knowledge of flood peak depths and discharges for different return periods, impact of flood control strategies to reduce the peak discharge, flood plain inundation and flood hazard extents for different flow conditions and land use conditions. Also proper knowledge of impact of flood vulnerability considering different criteria indicators such as social, physical, infrastructure, economical, environmental and ecological factors based on the study area is essential (Zope, 2016).

Flood Plain and Flood Hazard Mapping

Hydrological analysis for generation of flood hydrographs for different flow conditions and land use conditions was carried out using HEC-HMS model (Zope et al., 2015). Results obtained in the form of flood hydrographs was used in HEC-RAS model for hydraulic modelling for various flow conditions to predict the flood depths and flood extents. The results obtained in the form of flood depth and flood extent were exported as GIS format export file in ArcGIS. Flood plain maps are one of the inputs for generation of flood hazard maps. The methodology developed and described in detail by Zope et al. (2016) was used for generation of flood hazard maps for the study area.

Flood Vulnerability

Vulnerability is classified into two categories: natural and human created. Natural vulnerability is due to the occurrences of the natural hazards such as floods, earthquakes, cyclones etc., whereas human vulnerability is due to social, economic, physical, political, environmental system related to human activities (Dibben and Chester, 1999; Alcantara-Ayala, 2002). Vulnerability can be defined as capacity to be wounded (Kates, 1985; Dow, 1992). There are social, physical, ecological, economic, individual, urban vulnerabilities (Adger, 2006; Luers et al., 2003; Muller et al., 2011). In the present study, the vulnerability assessment mapping is done by considering social and infrastructural vulnerabilities. The vulnerability indicators used in this study are social indicators and infrastructural indicators.

Social Vulnerability

Social vulnerability mainly depends on the response, reaction and resistance of the people residing in that area towards the natural calamity occurred such as flood (Karmarkar et al., 2010). Before analysing social vulnerability, it is necessary to gather detailed information of the population residing in that region and the impacts of social vulnerability on them. Proper selection of social indicators is the main task in assessment of social vulnerability. In this study, as per the literature and information gathered from the local self body, for social vulnerability assessment, 16 indicators have been considered with respect to the geography of the study area. The indicators considered are as follows: total households, total population, total female population, male illiterate population, female illiterate population, total non-employee population, non-employee male population, non-employee female population, lower social class population – male, lower social class population – female, household condition, household sizes, household types, total employee population – female, households-temporary and total employee population. Data required for the analysis and assessment of the social vulnerability was downloaded from Census Department of India website and also from the help of Census Department staff (Zope, 2016). For each section, the vulnerability index (VIs) corresponding to each indicator is calculated using the following equation and results are brought to one standard ranging from 0.0 to 1.0 where lower value indicates lower vulnerable area and higher value indicates higher vulnerability (Wu et al., 2002; Karmakar et al., 2010).

$$VI_s = \frac{V_s - V_{\min}}{V_{\min_{\max}}}$$

Where $V_{\min}$ and $V_{\max}$ are the minimum and maximum values of indicator for all sections, respectively, and V_s is the actual value of the indicator for the s^{th} section (Zope, 2016).

Infrastructure Vulnerability

Transportation, communication, emergency shelter and services during the natural calamities play vital role in flood-risk mapping. Infrastructure indicators considered in this study are road and railway, bridges, critical facilities such as schools, colleges, hospitals, fire brigade, police stations, airport, water and waste water treatment plants.

Impact of Land Use and Soil Permeability

The change in land use and soil conditions affect the flood flow and discharge from the watershed and hence are considered as important factor in the flood risk analysis. As both the parameters are related to infiltration, they play important role in watershed modeling and flood risk analysis. Depending on the infiltration capacity, degree of importance (DI) is given to each land use class (Karmakar et al., 2010). In this study, the DI given is as follows: built-up land (0.9), open land (0.4), vegetation (0.25) and water body (0.10). Impact of land use on vulnerability and risk assessment is calculated using the following equation (Karmakar et al.,2010).

$$E_i^{land} = \sum_{i=1}^{n}\left[DI_i \times \left(\frac{A_i^l}{A_i}\right)\right]$$

Where E_i^{land} is the impact of land use on flood, DI_i is the degree of importance of land use type I, A is area under each land use type. Similarly, the impact of soil permeability is calculated using the above equation. A_i^l is denoted as area under each land use for *i*th section (Zope, 2016).

Results and Discussion

Flood plain mapping is the input and first step in preparation of flood hazard and also to perform flood risk management (Zope et al., 2015). Here the flood hazard map for the land use condition of the year 2009 and maximum rainfall return period of 100 years is generated. Flood plain extents generated for different storm flow conditions are merged to obtain the maximum flood extent. Flood hazard maps are generated by considering the maximum flood extent area, raster map generated for distance from the discharge point, slope from the river centerline and distance from the river centerline to maximum flood extent boundary. The raster map is prepared in ArcGIS using the tool "Euclidean distance" and "Cost distance" (Zope, 2016). Detailed methodology is already described by Zope et al. (2016).

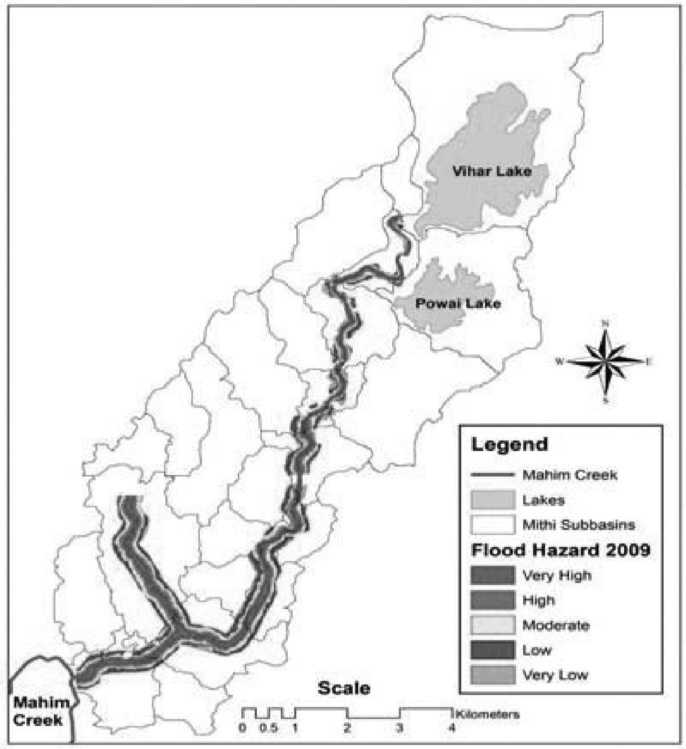

Figure 2: Flood hazard map for the Mithi River catchment for 100-year return period

Flood hazard map prepared for the study area is presented in Fig. 2. The flood hazard is classified in five categories (very low, low, moderate, high and very high) by using the first-order standard deviation method of classification. Lower value indicates higher vulnerability and vice versa. Flood hazard map prepared in this study can be used for flood disaster management planning, flood evacuation and mitigation planning. These maps can be also used by insurance organisations to decide the insurance premium based on the property falling in the flood hazard zone area (Zope, 2016).

To prepare the section-wise map for vulnerability assessment, the earlier delineated catchment boundary of the Mithi River catchment was superimposed on the section map of the census and map prepared as per section for the Mithi River catchment. The study area catchment contains a total of 18 census sections within the catchment area. After downloading the census data for all 16 social indicators from the census site, calculations of the indicator-wise vulnerability were done by using the Eq. 1. The vulnerability map for each indicator was prepared at 0 to 1 scale. Depending on the type of indicators, proper training programmes and alertness, awareness programmes needs to be arranged to minimise the vulnerability. Overall social vulnerability map was generated by averaging the vulnerability of each indicator and generated map is presented in Figure 3 (a). As per this map, areas under Sections 933 and 1978 are the most vulnerable and areas under Sections 1048 and 1255 are comparatively less vulnerable. These areas will require proper attention during the floods.

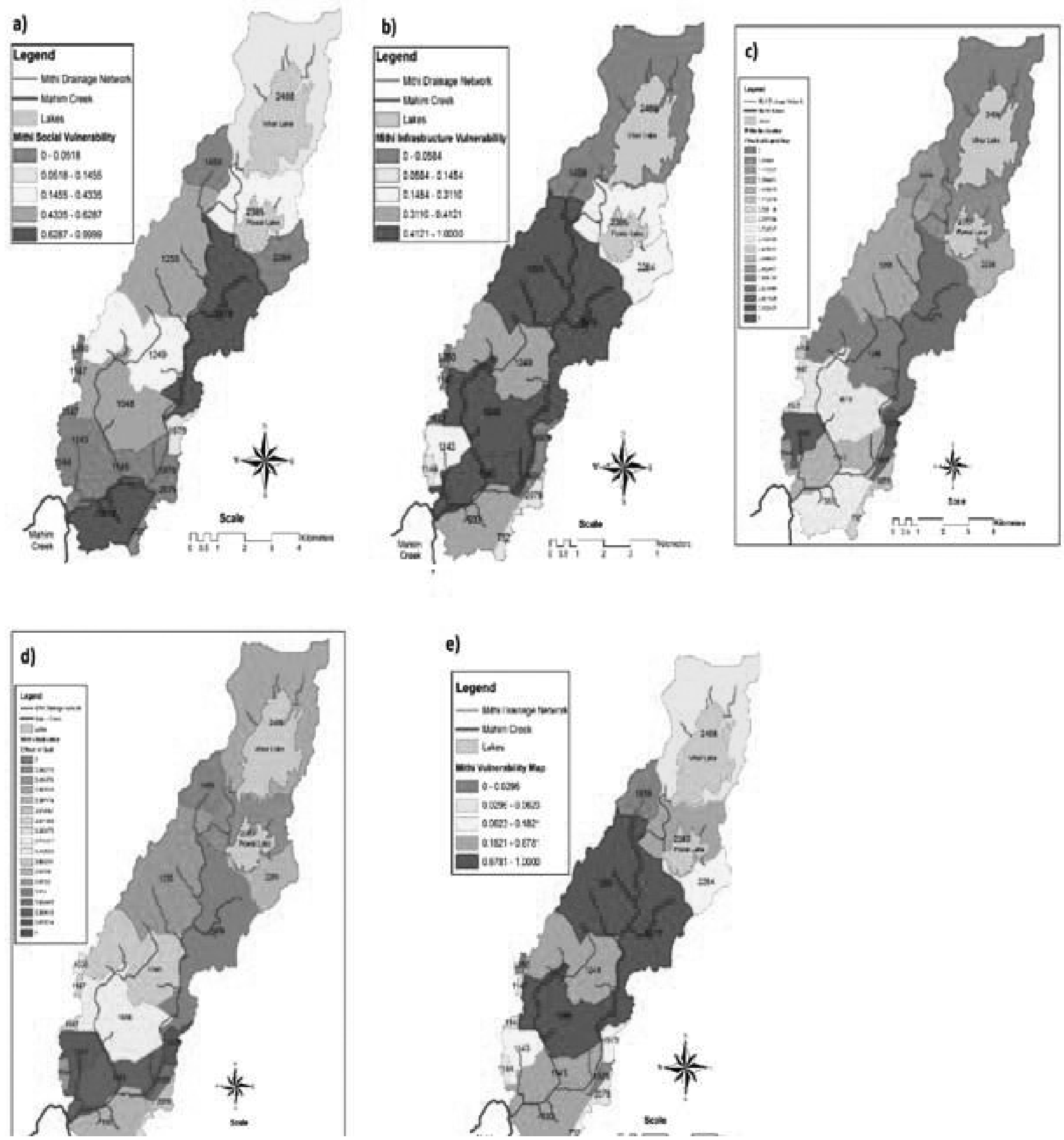

Figure 3: (a) Social vulnerability; (b) infrastructure vulnerability; (c) impact of land use; (d) impact of soil permeability; (e) total vulnerability – Mithi River catchment (indicators on a 0 to 1 scale)

Road and rail network plays a very important role in infrastructure vulnerability and flood risk analysis. If roads and railway tracks get submerged in flooding, then it will stop the movement of people as well as other goods and thus creates severe vulnerability in the region. Also bridges are very important factors along the river path. If the areas behind bridge portion get flooded during the blockage at the bridge section, entire area behind bridge portion will be under vulnerable situation. Road and rail network was digitised from the available maps from the local self body. For preparation of road and rail vulnerability map, section-wise length of the road and rail was extracted in ArcGIS and by using the Eqn. 1, calculations were done and vulnerability map for road and rail was prepared (Zope, 2016).

Figure 3 (a) represents social vulnerability map, Fig. 3 (b) represents infrastructure vulnerability map, Fig. 3 (c) and (d) represents impact of land use and impact of soil permeability maps respectively and Fig. 3 (e) represents the total vulnerability map for the study area catchment. Total infrastructural vulnerability was generated by averaging the vulnerability of all indicators. Total infrastructure vulnerability map is presented in Fig. 3 (b). As per the said map, areas under sections 1048, 1145, 1255, and 1978 are the most critical and vulnerable with reference to infrastructural activity concerns and need more attention during the flood. Comparatively areas under sections 933 and 1249 are less vulnerable. Sections having the land use type with higher infiltration capacity will be less vulnerable. Similarly, section having high permeability value will have less vulnerability.

The flood hazard map and vulnerability maps will be the main input for further generations of flood risk mapping in further studies. Further impact of land use and soil permeability can be considered for the flood risk assessment in addition to the total vulnerability. Flood plain extent and hazard maps can be used to assess the impact of flood risk zone area. Thus, the flood hazard, vulnerability maps and impact of land use and soil permeability maps prepared in this study can be used as main input for flood risk mapping in further studies.

Conclusion

The flood hazard and vulnerability maps generated in this study can be used by the local municipal corporation to identify the indicator-wise vulnerable area, and they can take precautionary measures, proper training programmes to minimise the impact of vulnerability. Flood hazard and vulnerability maps can be used further as the main input for flood risk mapping. Flood vulnerability as well as flood risk assessment and analysis with generation of maps provide important tool for disaster management planning and evacuation system planning during the floods. Thus there will be reduction in loss of human lives and also reduction in economic loss during flooding disaster. These flood hazard and vulnerability maps can be used by insurance organisations to decide the insurance criteria of the property concerned.

References

Adger, W. (2006). "Vulnerability". *Global Environmental Change*, 16, 268–281.

Alcantara-Ayala, I. (2002). "Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries", *Geomorphology*, 47 (2–4), 107–124.

Barredo, J. J., Roo, A. D. and Lavalle, C. (2007). "Flood Risk Mapping at European Scale". *Water Science and Technology*, 56 (4), 11–17.

CWPRS (2006). 1-D Mathematical Model and Desk Studies for Mitigating Floods of Mithi River in Mumbai Technical Report No. 4297 (unpublished), Khadakwasla, Maharashtra, India.

Dibben, C., and Chester, D.K. (1999). "Human vulnerability in volcanic environments: The case of Furans, Sao Miguel, Azores". *Journal of Volcano logy and Geothermal Research.* 92 (1–2), 133–150.

Dow, K. (1992). 'Exploring differences in our common future(s): The meaning of vulnerability to global environmental change' *Geoforum*, 23**,** 417–436.

FFC, (Fact Finding Committee on Mumbai Floods) (2006). State Govt. Committee Report, 31- 130, (2006). Mumbai, India.

Karmakar, S., Simonovic, S. P., Peek, A., Black, J. (2010). "An Information system for Riak- Vulnerability Assessment to Flood". *Journal of Geographic Information System*. 2, 129- 146.

Kates, R.W. (1985). 'The interaction of climate and society', in R.W. Kates, J.H. Ausubel and M. Berberian (eds.), Climate Impact Assessment, John Wiley and Sons. Chichester, UK, 3–36.

Kron, W. (2005). "Flood Risk = Hazard *Values*Vulnerability." *Water International*, 30 (1), 58–68

Luers, A., Lobell, D., Sklar, L., Addams, C. and Maston, P. (2003). "A method for quantifying vulnerability, applied to the agricultural system of the Yakie Valley, Mexico", *Global Environment Change,* 13, 255–267.

Muller, A., Reiter, J., and Weiland, U. (2011). "Assessment of urban vulnerability towards floods using an indicator-based approach - a case study for Santiago de Chile". *Natural Hazards and Earth System Sciences.* 11: 2107–2123.

Srivastava N. and Shaw R. (2015) "Occupational resilience to floods across the urban-rural domain in Greater Ahmadabad, India". *International Journal of Disaster Risk Reduction*. 12, 81–92.

Wu, S.Y., Yarnal, B. and Fisher, A. (2002). 'Vulnerability of coastal communities to sea-level rise: A case study of Cape May county, New Jersey, USA', *Climate Research,* 22, 255- 270.

Zope, P.E., Eldho, T.I., and Jothiprakash, V. (2012)**. "**Spatio-Temporal Analysis of Rainfall for Mumbai City." *International Journal of Environmental Research and Development,* 6 (3), 545–553.

Zope, P. E., Eldho, T. I., and Jothiprakash V., (2015). "Impacts of urbanisation on flooding of Coastal Urban Catchment: A Case study of Mumbai City, India". *Natural Hazards*, 75 (1), 887–908.

Zope, P. E., Eldho, T. I., and Jothiprakash V., (2016). "Impacts of Land use - Land Cover change and Urbanisation on Flooding: A Case Study of Oshiwara River Basin in Mumbai, India. *Catena*, 145(2016), 142–154. OI: 10.1016/J. Catena.2016.06.009).

Zope, P. E., Eldho, T. I., and Jothiprakash V., (2016 a). "Derivation of Rainfall Intensity Duration Frequency Curves for Mumbai City, India, *Journal of Water Resources and Protection,* 8, 756–765.

Zope PE (2016) Integrated urban flood management with flood models, hazard, vulnerability and risk assessment. Unpublished Ph. D thesis, Department of Civil Engineering, I.I.T. Bombay, Mumbai.