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Hazard and Vulnerability in Urban Flood Risk Mapping: A case study of Chennai city, India

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Abstract*—Chennai has been the center of trade and commerce from ages. But with the recent high urban growth rates the damages have outweighed the gains. The city is witnessing floods very frequently and this has encouraged us to take up the study to create the risk zones within the city. The present study aims to generate the hazard, vulnerability and the risk profile maps of the city at ward level using remote sensing and GIS techniques. The analysis shows that land use land cover change caused by urban expansion increased the flood risks of Chennai. Furthermore, the authors observed that urbanization increases the exposure to flooding and flood depth in the study area which plays a greater role in flood risk. Urbanization and changes in the land use land cover changes leads to increase in flood risk and exposure. The land development generally occurs by infilling in the natural drainage and vegetation prevailing in the region. This leads to water clogging and man-made flooding during high intensity short duration rainfall. So in such situations proper urban planning is essential which considers proper drainage system for channelizing excess water flow.

***Index Terms*— Chennai, floods, urbanization, hazard, vulnerability**

I. INTRODUCTION

Flood and flood related problems have created detrimental effects all over the world in recent decades. In India most of the major cities are prone to flooding due to improper growth and land development activities [1]. As per the Census 2011, urbanization levels in India have risen from 27.81% in 2001 to 31.16% in 2011 [2]. To accommodate more urbanized spaces wetlands, vegetation, agricultural plots have been converted to built-up in urban and peri-urban areas. This leads to increase in impervious surfaces causing higher the flooding frequency [3]. The prevailing drainage systems in cities are incapable of handling the high volumes of rainfall in short span [4,5]. There have been numerous flash floods in major metro cities that caused heavy damages in economy, loss of life, and disruption of transport system [6]. In recent times heavy rainfall lead to flooding in Chennai (2015), Mumbai (2017) and Bangalore (2017). Different towns and cities have different degrees of exposure to flood hazards and in general, flood damage is affected by environmental, economic, social, and even political factors. Many of the world's cities are hotspots of risk from extreme weather events and levels of risk in many cities are likely to grow due to a combination of population growth and development and rising intensities of extreme weather events. There is an immediate need to protect human and natural resources loss caused due to flooding [7]. Maintaining economic and hydrological coordination are becoming more and more difficult [8]. Hence managing risks from extremes will be a crucial component of adaptation planning. With each passing day the impact of flood is becoming more intense due to increase in frequency and scale. Moreover, high population pressure and poor living conditions of developing nations make them most vulnerable to flood disasters [9,10,11]. These, in turn, have increased the flood risk and resulted in damages and casualties [12].These changes are also altering society's ability to respond to hazard events. Low income populations living in informal settlements persist in neighborhoods without basic facilities and with increasing risks of losses from extreme environmental hazards. Adaptive capacity is defined as the potential or capability of a system to adjust, via changes in its characteristics or behavior, so as to cope better with existing climate variability, or with changes in variability and mean climatic conditions [13].The adaptive capacity inherent in a system represents the set of resources available for adaptation, as well as the ability of those who need to adapt to deploy these resources effectively, and their willingness to do so [14]. Adaptive capacity can be thought of as being of two kinds – 'specific' adaptive capacity and 'generic' adaptive capacity. Specific adaptive capacity refers to certain adaptation interventions and capacities that are geared specifically for reducing the impacts due to a particular climate hazard [15].

A. Flood risk zone mapping

In recent times of technological advancements, the remote sensing and Geographic Information System (GIS) have proved beneficial in research by providing useful tools for mapping floodplains and flood disaster risks for creating efficient and useful disaster management planning [16]. GIS platform have led to successful integration of remote sensing data, flood hazard data, and data on socio-ecological indicators generate flood vulnerability and risk maps for a given area [17]. Recently, as global warming continues, abnormal weather phenomena include precipitation and high temperatures occur frequently, leading to various environmental problems, including localized downpours, flooding, drought and heat waves, that could cause many casualties [18]. Floods can incur an enormous economic cost, particularly in city centres that comprise high levels of urban infrastructure that includes buildings and transportation facilities [19,20].Because of the irreducible and huge damages to road, rail, bridges, electricity, water, phone services, the functionality of entire cities can become paralyzed; therefore, the provision of adequate flood-protection and flood-prevention measurements is urgent. To rapidly prevent the damage from a flood, an advance-warning system and prompt action by governments and institutions are needed. As mentioned, a flood could cause the loss of human life or injury, so a flood policy including the improvement of pumping stations and water facilities should not be an afterthought [21].The prevention measures should include the establishment of countermeasures using the information on flood-prone areas; therefore, to minimize the damages from floods, a vulnerability assessment is needed to determine the priority areas according to the flood vulnerability, and it could be derived from previous flood damages. In studies on natural disasters, various data are usually needed but it is not easy to obtain suitable data [22].For a flood study, the factors that significantly affect a flood are vegetation type, soil type, and geological, geomorphological and hydrological characteristics. The acceleration of a flood could be caused by the reckless destruction of nature by human beings [23] indiscriminate development, over-harvesting and deforestation are examples. By using these factors with a geographic information system (GIS), the studies of flood areas calculate and evaluate the effects of floods.

B. Flood hazard mapping

Exposure refers to the socio-economic components, including human and manufactured capital as well as natural ecosystems that are exposed to climate risk. A flood hazard map defines the area at risk and indicates the hot spots where the flood events are likely to occur. Flood hazard mapping forms the basic tool for flood preparedness and mitigation activities, including flood insurance programs. The purpose of flood hazard mapping is to promote proper and prompt evacuation actions for local residents, by providing them with early warning of flood risk and evacuation. Land use planning and development should consider the flood hazard area and degree of flood risk in order to minimize the damage to lives, infrastructure, property and environment. Moreover, flood hazard zone maps give a clear picture about the inundation area and intensity of flooding; thereby it creates awareness to the community. It is necessary for the stakeholders to know about the variation in flood hazard and behavior so that a coordinated approach can be provided on how best the flood plains can be managed. In order to prepare the flood hazard map, thematic maps of the annual rainfall, size, slope of the watershed, gradient of the main stream, drainage density, soil types, land use of the watershed, communication line and other infrastructure are prepared using the ArcGIS software. Flood hazard mapping and vulnerability assessment of coastal areas can be generated combining the land use data and elevation data using geographical information system tools. This enables the policy makers with better information to manage disasters beforehand. This also leads to better policy implementation. The authorities responsible for flood protection are provided with an excellent tool to manage disasters well in advance. In addition, land use policy might be adopted on basis of the study result [24].

The rest of the paper consists of study area in section 2, data and methodology in section 3 followed by results in section 4, last section deals with the conclusion.

C. Study Area

The study area is coastal megacity Chennai, which is the capital of Tamil Nadu. Chennai is also one of the four metropolitan cities of the Indian sub-continent. It is situated in the southern Coromandel coast of India spanning between 12°09´, 80°12´NE and 13°09´, 80°19´NE. The weather is mostly tropical humid-climate with rainfall during the north-east monsoon (October–December). Mean annual average rainfall of the study area is 1300 mm while the mean maximum and minimum temperature ranges between 37°C in summer and 24°C in winter. The total area of the city is about 174 sq. km. The city is experiencing population growth of an average of 25% per decade (CMDA, 2007). The Bay of Bengal is situated in the eastern side of the city coastline while Thiruvallur and Kanchipuram districts surround the other sides of the city boundary. The population of Chennai city and Chennai urban agglomeration/metropolitan area are 4.6 and 8.6 million respectively as per 2011 census. The Chennai Metropolitan Area(CMA) consists of Chennai city, 5 municipalities, 24 other urban local bodies and 27 rural local bodies, covering an area of 1189 sq. km. The tremendous growth in its industrial, educational, and health sectors have led to the tremendous population growth in this region. Chennai has been given names like ‘‘Detroit of India’’ and ‘‘Gateway to South India’’ due to the fact that it is the largest industrial centre in South India (U.S. International Trade Commission, 2007). With a population of 4.6 million, Chennai is now the fourth largest city in India, and according to Tholons (2013), Chennai ranks fifth among the top outsourcing destinations in the world. It is the home of many large manufacturing and IT companies that attracts professionals from all over India as well as foreign expats. In addition, many skilled and unskilled labourers migrate to Chennai in search of job opportunities. However, a portion of this migrant rural population ends up living in slums [26]. According to the Census of India (2011), 28% of the urban population in Chennai lives in slums. The process of urbanization in India gained stimulus in 1970s with the advent of industries was followed by globalization in 1990s along with the liberalization in 1991. In 1991, there were 23 metropolitan cities in India, which increased to 35 and 46 in 2001 and 2011 respectively [2]. Some of the prominent ones are Delhi, Mumbai and Chennai [27]. In the last 20 years, the rate of urbanization in Tamil Nadu has been rapid. As per 1991 Census, only 34.15% of the total population in Tamil

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Nadu was classified as urban but in 2011, it has augmented to 48.45%, there was a sharp increase of 14.3%. As per 2011 Census data, in the last decade growth in industrial and manufacturing sector has contributed to high inflow of people from rural to urban areas in Tamil Nadu has led as compared to other states. Tamil Nadu holds the first place in terms of most urbanized states with 48.45% of its population living in urban areas whereas Kerala, Maharashtra and Gujarat follows the lead. The development resulted in rapid economic and industrial growth as investment flowed from both national and international investors. Chennai (Capital of Tamil Nadu) has growth rates higher than the all India rate in case of manufacturing sector. The surplus labour from the agricultural sector and transforming cities into an industrial labour sector was because of the new pull production mechanism [28]. The reality is not very appealing as this unsustainable steady development at the expense of nature would prove expensive for mankind. The city has become one of the most preferred locations for not only students due to many educational centres and colleges but also workers (skilled and unskilled). With time the migrant population eventually prefer to stay back and this has given rise to which we might say “Modern Job Town Home”. Urbanization has been an important driver of increased flood risk in the city and it makes the drainage systems of the city are now inadequate to cope with heavy rainfall. Coastal cities face higher flood risks in situations where there is lack of proper spatial and urban planning [29]. The Chennai Metropolitan Area (CMA) covers 1189 km^2 which comprises of three districts, namely Chennai district, Thiruvallur district and Kancheepuram district. There are 15 zones in Chennai city (Figure 1) and it is divided into 200 wards (Table 1, Figure 2). In the year 2015 the floods went out of control and Chennai city was officially declared a disaster city on December 2, 2015 [31].

Zones and wards of chennai city

TABLE I. ZONES AND WARDS OF CHENNAI CITY

Zones	Zone Names	Wards
1	Thiruvottiyur	1-14
2	Manali	15-21
3	Madhavaram	22-33
4	Tondiarpet	34-48
5	Royapuram	49-63
6	Thiru Vi Ka Nagar	64-78
7	Ambattur	79-93
8	Anna Nagar	94-108
9	Teynempet	109-126
10	Kodambakkam	127-142
11	Valasaravakkam	143-155
12	Alandur	156-167
13	Adyar	170-182
14	Perungudi	168,169,183-191
15	Sholinganallur	192-200

Source; Chennai Corporation (http://chennaicorporation.gov.in/zone/index.htm)

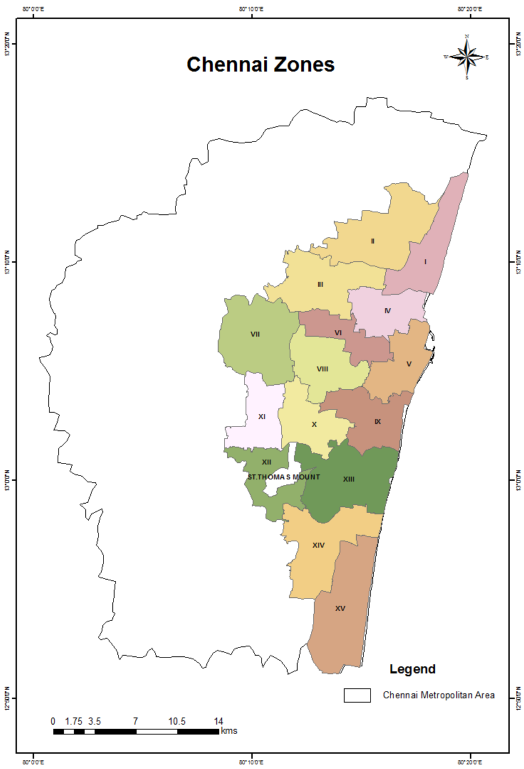

Fig. 1 Chennai Study Area

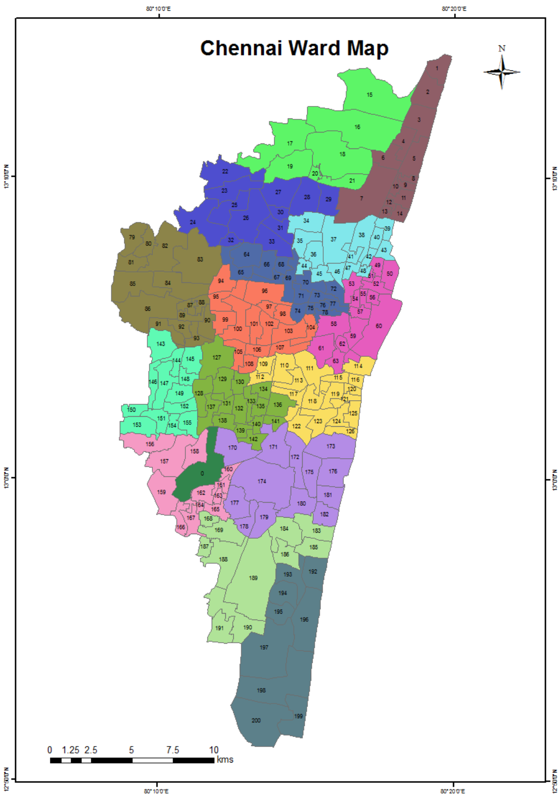

Fig. 2. Chennai Study Area

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Previous flood studies on Chennai

Author	Objective	Study Area	Method
Glaser et al. (2008)	Dynamics of Pallikaranai marshland in South Chennai	Pallikaranai Marshland	Geo-communication and geo-visualization
Gupta and Nair (2010)	Flood risk management of Chennai city	Chennai Metropolitan Area	Technical report of a national level study accomplished in India covering 8 important cities
Suriya and Mudgal (2012)	Urbanization-induced flooding	Thirusoolam watershed	Geospatial Hydrologic Modeling Extension models
Suriya et al. (2012)	Flood damage assessment	Velachery, Chennai	Focus group discussion, stakeholder meeting, questionnaire survey
Mariappan and Devi (2012)	Coastal vulnerability assessment	10km stretch of Chennai caost	GIS Techniques
Mishra (2016)	Flood monitoring of Chennai 2015 floods	Chennai city	Remote sensing
Muneerudeen (2017)	Map and site investigation	Chennai city	focus group discussion, questionnaire survey
Seenirajan et al. (2017)	Flood monitoring and risk analysis of Chennai flood 2015	Kanchipuram District	GIS integrated with multicriteria decision analysis (MCDA)
A.R Assessment (2018)	Flood damage assessment	Chennai city	Rapid Assessment of 2015 Chennai floods
Dhiman et al. (2019)	Review Article	Surat, Mumbai, Chennai and Kolkata, which are the most populated coastal cities in India.	review article provides an assessment regarding quantification, management and climate change impacts of flood risks

D. Data and methodology

Remote Sensing and Geographic Information System greatly helps in generating flood risk maps considering the hazard and vulnerability functions of risk elements [41]. In order to generate the risk maps of Chennai city, prior to that hazard and vulnerability maps have to be generated (Figure 3). There are various factors that were considered in each creation. The projection and resolution of the collected data is WGS84 UTM Zone 44 N and 30 m respectively. Flood hazard maps have been developed Digital Elevation Model (DEM) data, distance from the sea and water bodies (Table 3). To process the flood hazard, vulnerability and risk map of Chennai city, datasets containing the administrative boundary map was needed. For the Digital Elevation Model (DEM) was retrieved using ASTERDEM data from USGS earth explorer. Land classification was done using image from Sentinal 2B with 10 m resolution. The satellite image was dated June, 15, 2019. For the administrative boundary and rivers the files were taken from DIVA- GIS free source. The sea coastline was digitized using the Google Earth then the kml file type was converted to shape file using ArcGIS 10.2.2. Further the urban land use land cover map of Chennai city was overlaid with the flood hazard map to decipher the relationship between human development and flood exposure. Land use or land cover map has been generated from the Sentinal 2B satellite images (10m resolution) using supervised classification in ArcMap 10.2.2 and population density data was used to create vulnerability map. The supervised classification was a two-step process: training and accuracy verification stage. False colour composition of bands 3,2 and 1 were used to perform the supervised classification process in order to generate the land use land cover map. The City boundary was taken as the study area and it comprises of 15 zones and 200 wards within it. The area of the Chennai city boundary is 426 km² whereas the CMA has an area of 1189km2. The land use land cover of CMA was classified in 1:50000 scale. LULC classes depend on the features of the specific study area. As per the USGS guidelines, the identified classes by supervised classification are: built-up area, agricultural land, vegetation, water body, open/shrub, others. But for this study, the land cover was only classified into urban and non-urban areas.

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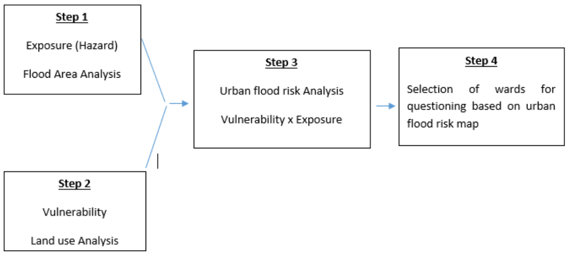
Chennai Study Area



Source: Park and Won (2019)

Table 3. Generation of hazard map of Chennai

Factors	Data Source	Ranking	Weightage
DEM (Figure 4 and Figure 5)	Using ASTERDEM data from USGS earth explorer 30m resolution	3: low altitude (0-6 m) 2: Medium altitude (6-20 m) 1: High altitude (20 – above)	40
Distance from the sea (Figure 6)	Digitised from Google Earth followed by processing done in Arcgis 10.2.2	3: 0-500 m 2: 500-1000 m 1: > 1000 m	30
Distance from the river (Figure 7)	Digitised from Google Earth followed by processing done in Arcgis 10.2.2	Into same three rankings based on the generated Euclidian distance	30

Author calculation

Table 4. Generation of Vulnerability map of chennai

Factors	Data Source	Ranking	Weightage
Population density (Figure 8)	Census 2011	High : 3 Medium :2 Low :1	55
Land use land cover	Land classification using image from Sentinal 2B with 10 m resolution	Urban : 2 Non – Urban: 0	45

Author calculation

II. RESULT AND DISCUSSION

Urbanization and changes in the land use land cover changes leads to increase in flood risk and exposure. The land development generally occurs by infilling in the natural drainage and vegetation prevailing in the region. This leads to water clogging and man-made flooding during high intensity short duration rainfall. So in such situations proper urban planning is essential which considers proper drainage system for channelizing excess water flow [43]. For generating the risk map of Chennai, both the hazard (Figure 10) and vulnerability (Figure 11) were given equal weightage. As cities growth and development becomes stagnant and saturated the flood damages should decrease due to flood protection systems but in reality due to more human and financial resources in the area the damages are higher than before. Similarly flood infrastructure might not have been in place in rapidly urbanizing suburban areas, leading to higher flood damage [44]. Earlier studies have testified a positive relationship between population density and flood hazards [45,46]. While some previously developed affluent city areas may have effectively reduced flood damage, it was typically higher in suburban areas that underwent rapid urban development without adequate infrastructure. The probability of flood damage is high in the initial stage of rapid urbanization, but a variety of preventive measures, including river area maintenance, successfully reduced flood damage as urbanization stabilizes. More detailed studies are needed to be undertaken to evaluate the prevailing flood infrastructure, plans and policies to check their adequacy to handle flood situations due to extreme weather events and climate change [47]. In this study a detailed ward level flood risk map has been developed that provide means for identification of flood prone areas and categorize it into low, medium and high flood risk zones,

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where flood risk management and adaptation interventions can be targeted (Figure 12). Locations closer to the rivers have higher hazard values as compared to the other places. Hence urban centres with rivers flowing through them are highly susceptible to flood hazard which leads to higher physical and economic damages if not checked [48].

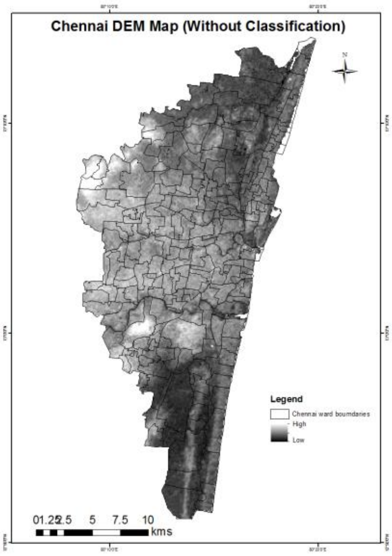

Fig. 4. Chennai city elevation map

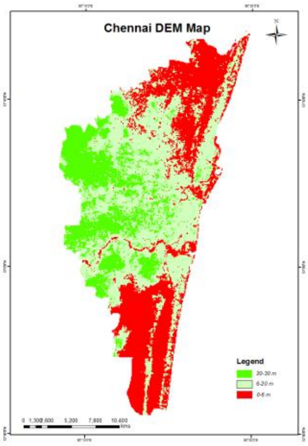

Fig. 5 Chennai city elevation map (after classification)

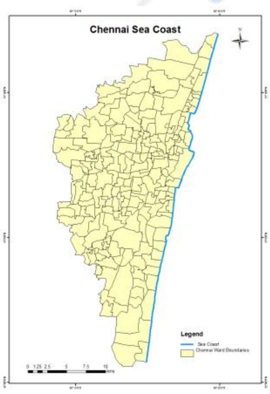

Fig. 6 Chennai city coastline

Fig.7 Chennai city rivers

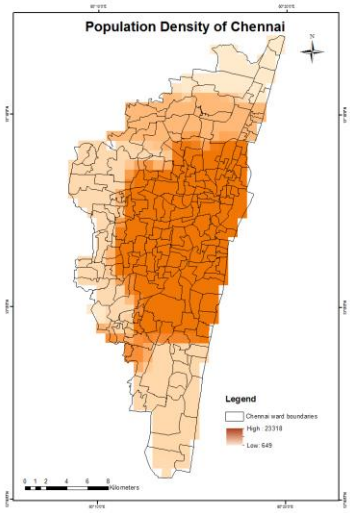

Fig. 8 Chennai population density map

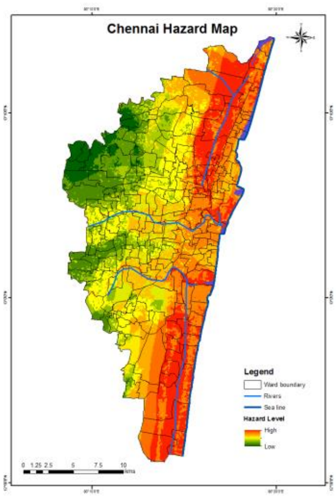

Fig. 9 Chennai hazard map

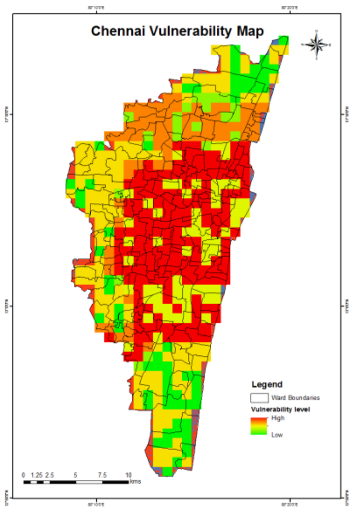

Fig. 10. Chennai vulnerability map

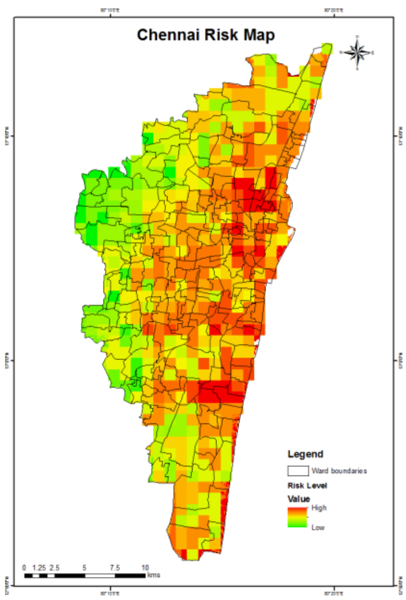

Fig. 11 Chennai risk profile map

III. CONCLUSION

The flood risk study of Chennai has showed the city risk profiles under three classes which can be used to educate the common people residing in the city. This knowledge will create an awareness among the masses enabling them to adopt resilient measures to cope with the recurring floods of Chennai. Even at the policy level these maps can be used target the wards based on their level of flood riskiness.

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REFERENCES

[1] Singh, P., Sinha, V. S. P., Vijhani, A., & Pahuja, N. (2018). Vulnerability assessment of urban road network from urban flood. International journal of disaster risk reduction, 28, 237-250.

[2] Census of India, 2011. Provisional Population Totals, Government of India.

[3] Huong, H. T. L., & Pathirana, A. (2013). Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. Hydrology and Earth System Sciences, 17(1), 379.

[4] Nair, K. S., 2009. An assessment of the impact of climate change on the megacities of India and of the current policies and strategies to meet associated challenges. Fifth Urban Research Symposium

[5] Avinash, S., 2016. Flood related disasters: concerned to urban flooding in Bangalore, India. International Journal of Research in Engineering and Technology, 03(16), pp. 76-83

[6] Guhathakurta, P., Sreejith, O. P., & Menon, P. A. (2011). Impact of climate change on extreme rainfall events and flood risk in India. Journal of earth system science, 120(3), 359.

[7] Field, C. B., Barros, V., Stocker, T., Qin, D., Dokken, D., Ebi, K., ... & Tignor, M. (2012). IPCC, 2012: Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 30(11), 7575-7613.

[8] Hanson, S., Nicholls, R., Ranger, N., Hallegatte, S., Corfee-Morlot, J., Herweijer, C., & Chateau, J. (2011). A global ranking of port cities with high exposure to climate extremes. Climatic change, 104(1), 89-111.

[9] Shrestha, B. B., Okazumi, T., Miyamoto, M., & Sawano, H. (2016). Flood damage assessment in the P ampanga river basin of the P hilippines. Journal of Flood Risk Management, 9(4), 355-369.

[10] Dewan, A. M., & Yamaguchi, Y. (2008). Effect of land cover changes on flooding: example from Greater Dhaka of Bangladesh. International Journal of Geoinformatics, 4(1), 11-20.

[11] Dewan, A. M., & Yamaguchi, Y. (2009). Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. Applied geography, 29(3), 390-401.

[12] Liu, W., Chen, W., & Peng, C. (2014). Assessing the effectiveness of green infrastructures on urban flooding reduction: A community scale study. Ecological Modelling, 291, 6-14.

[13] Adger, W. N., Brooks, N., Bentham, G., Agnew, M., & Eriksen, S. (2005). New indicators of vulnerability and adaptive capacity. Norwich: Tyndall Centre for Climate Change Research.

[14] Brooks, N., & Adger, W. N. (2005). Assessing and enhancing adaptive capacity. Adaptation policy frameworks for climate change: Developing strategies, policies and measures, 165-181.

[15] Sharma, U., & Patwardhan, A. (2008). An empirical approach to assessing generic adaptive capacity to tropical cyclone risk

in coastal districts of India. Mitigation and adaptation strategies for global change, 13(8), 819-831.
[16] Nyarko, B. K., Diekkrüger, B., Van De Giesen, N. C., & Vlek, P. L. (2015). Floodplain wetland mapping in the White Volta river basin of Ghana. GIScience & Remote Sensing, 52(3), 374-395.
[17] Merz, B., Thieken, A. H., & Gocht, M. (2007). Flood risk mapping at the local scale: concepts and challenges. In Flood risk management in Europe (pp. 231-251). Springer, Dordrecht.
[18] Kim, D., Jung, H. S., & Baek, W. (2016). Comparative analysis among radar image filters for flood mapping. Journal of the Korean Society of Surveying, Geodesy, Photogrammetry and Cartography, 34(1), 43-52.
[19] Lee, M. J., Kang, J. E., & Kim, G. (2015). Application of fuzzy combination operators to flood vulnerability assessments in Seoul, Korea. Geocarto international, 30(9), 1052-1075.
[20] Klaus, S., Kreibich, H., Merz, B., Kuhlmann, B., & Schröter, K. (2016). Large-scale, seasonal flood risk analysis for agricultural crops in Germany. Environmental Earth Sciences, 75(18), 1289.
[21] Vojtek, M., & Vojteková, J. (2016). Flood hazard and flood risk assessment at the local spatial scale: a case study. Geomatics, Natural Hazards and Risk, 7(6), 1973-1992.
[22] Cao, C., Xu, P., Wang, Y., Chen, J., Zheng, L., & Niu, C. (2016). Flash flood hazard susceptibility mapping using frequency ratio and statistical index methods in coalmine subsidence areas. Sustainability, 8(9), 948.
[23] Chang, H. S., & Chen, T. L. (2016). Spatial heterogeneity of local flood vulnerability indicators within flood-prone areas in Taiwan. Environmental Earth Sciences, 75(23), 1484.
[24] Bhuiyan, S. R., & Al Baky, A. (2014). Digital elevation based flood hazard and vulnerability study at various return periods in Sirajganj Sadar Upazila, Bangladesh. International journal of disaster risk reduction, 10, 48-58.
[25] Tholons (2013). 2014 Tholons top 100 outsourcing destinations: Rankings.
[26] Viswanathan, V., & Tharkar, S. (2010). Can the divide be bridged: Overview of life in urban slums in India. Indian journal of community medicine: official publication of Indian Association of Preventive & Social Medicine, 35(1), 198.
[27] Mohan, M., Pathan, S. K., Narendrareddy, K., Kandya, A., & Pandey, S. (2011). Dynamics of urbanization and its impact on land-use/land-cover: a case study of megacity Delhi. Journal of Environmental Protection, 2(09), 1274.
[28] Turok, I., & McGranahan, G. (2013). Urbanization and economic growth: the arguments and evidence for Africa and Asia. Environment and Urbanization, 25(2), 465-482.
[29] Ranger, N., Hallegatte, S., Bhattacharya, S., Bachu, M., Priya, S., Dhore, K., ... & Herweijer, C. (2011). An assessment of the potential impact of climate change on flood risk in Mumbai. Climatic change, 104(1), 139-167.
[30] Glaser, S., Glaser, R., Drescher, A., Pfeiffer, C., Schliermann-Kraus, E., Lechner, M., & Vencatesan, J. (2008). Geo-communication for risk assessment and catastrophe prevention of flood events in the coastal areas of Chennai.
[31] Bhuvana, N., & Aram, I. A. (2019). Facebook and Whatsapp as disaster management tools during the Chennai (India) floods of 2015. International journal of disaster risk reduction, 39, 101135.
[32] Gupta, A. K., & Nair, S. S. (2010). Flood risk and context of land-uses: Chennai city case. Journal of Geography and Regional Planning, 3(12), 365.
[33] Suriya, S., & Mudgal, B. V. (2012). Impact of urbanization on flooding: The Thirusoolam sub watershed–A case study. Journal of hydrology, 412, 210-219.
[34] Suriya, S., Mudgal, B. V., & Nelliyat, P. (2012). Flood damage assessment of an urban area in Chennai, India, part I: methodology. Natural hazards, 62(2), 149-167.
[35] Mariappan, V. N., & Devi, R. S. (2012). Chennai coast vulnerability assessment using optical satellite data and GIS techniques. Int. J. Remote Sensing GIS, 1(3), 175-182.
[36] Mishra, A. K. (2016). Monitoring Tamil Nadu flood of 2015 using satellite remote sensing. Natural Hazards, 82(2), 1431-1434.
[37] Muneerudeen, A. (2017). Urban and landscape design strategies for flood resilience in Chennai city (Master's thesis).

IV. SEENIRAJAN, M., NATARAJAN, M., THANGARAJ, R., & BAGYARAJ, M. (2017). STUDY AND ANALYSIS OF CHENNAI FLOOD 2015 USING GIS AND MULTICRITERIA TECHNIQUE. JOURNAL OF GEOGRAPHIC INFORMATION SYSTEM, 9(02), 126.

[38] Assessment, A. R. (2018). Chennai floods 2015.
[39] Dhiman, R., VishnuRadhan, R., Eldho, T. I., & Inamdar, A. (2019). Flood risk and adaptation in Indian coastal cities: Recent scenarios. Applied Water Science, 9(1), 5.
[40] Dewan, A. M., Nishigaki, M., & Komatsu, M. (2004). DEM based flood extent delineation in Dhaka City, Bangladesh. Journal of the Faculty of Environmental Science and Technology, 9(1), 99-110.
[41] Park, K., & Won, J. H. (2019). Analysis on distribution characteristics of building use with risk zone classification based on urban flood risk assessment. International journal of disaster risk reduction, 38, 101192.
[42] Waghwala, R. K., & Agnihotri, P. G. (2019). Flood risk assessment and resilience strategies for flood risk management: A case study of Surat City. International Journal of Disaster Risk Reduction, 40, 101155.
[43] Bae, S., & Chang, H. (2019). Urbanization and floods in the Seoul Metropolitan area of South Korea: What old maps tell us. International Journal of Disaster Risk Reduction, 37, 101186.
[44] Cutter, S. L., & Finch, C. (2008). Temporal and spatial changes in social vulnerability to natural hazards. Proceedings of the National Academy of Sciences, 105(7), 2301-2306.
[45] Kim, Y. O., Seo, S. B., & Jang, O. J. (2012). Flood risk assessment using regional regression analysis. Natural hazards, 63(2), 1203-1217.
[46] Im, E. S., Jung, I. W., & Bae, D. H. (2011). The temporal and spatial structures of recent and future trends in extreme indices over Korea from a regional climate projection. International Journal of Climatology, 31(1), 72-86.
[47] Sakieh, Y. (2017). Understanding the effect of spatial patterns on the vulnerability of urban areas to flooding. International journal of disaster risk reduction, 25, 125-136.