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Original paper

Impact of Climate Change and Land Use Change on Coastal Areas: A Case Study Thane, India

Shivkumar S. Pujari [1] * and Abhay S. Wayal [1]

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Abstract Changes in land use patterns and increased occurrence of extreme rainfall events and sea level rise are now serious concerns for urban coastal flooding. Thane city faces frequent flooding problem every monsoon and now its frequency and inundation area are increasing. Therefore, the objective of this study is to develop a flood hazard map taking into account the combined effect of land use change and climate change. In this study, the effects of land use land cover (LULC) changes over the past 25 years (1995-2020) and for next 30 years were examined. The obtained result indicates that since 1995 the built-up area has increased by 27.47% in past 25 years, and it will further increase up to 55.99 % for next 30 years. It means that Thane city is rapidly urbanizing. The increasing built-up area and increasing rainfall intensity events and sea level rises, increases the peak runoff. The obtained result in present study indicates that peak runoff in past 25 years due to land use changes increased by 11.5% and it will further increase up to 31.8 % for next 30 years including climate change effect. This means that Thane city has faced water logging problem in the past and will face water logging problem in the future. In the present study, Storm CAD software was used for hydraulic analysis of major drains while ArcGIS software was used for land use change analysis, flood prone area development and flood hazard mapping. The result of this analysis indicates that inundation area in past 25 years increased to 9.15% and it will further increase up to 14.03 % for next 30 years. This means that Thane city currently facing waterlogging problem in 6.211 km^2 and will face waterlogging problem up to 9.604 km^2 in future. It is expected that the developed flood hazard map may assist decision-makers or/to relevant authorities, particularly for storm water planning and water-related concerns to minimize the number of lives and property lost due to repetitive flood disasters in Thane city.

Keywords: Urbanization; Climate change, Land use land cover change, Flood hazard map

[1] Civil and Environmental engineering, Veermata Jijabai Technological Institute
* Corresponding author email: pujarishiv@gmail.com

1. INTRODUCTION

Over the last few decades, there has been a dramatic increase in global interest in urban flood risk as the frequency of flooding and the damage caused by urban flood events has risen (Al-Awadhi, *et al*. 2017). Uncontrolled urban development affects the performance of urban drainage system and rises the risk of flooding (Pervin, *et al*. 2020). Increasing flood events in urban areas are not only caused by heavy rainfall but also result from changes in land use patterns, low terrain, and unplanned urbanization (Shahapure, *et al*. 2011). Over the past few decades, land use & land cover (LULC) change has become one of the major causes of urban flooding, so proper research is urgently needed to explore their relationship and future consequences (Thapa 2021). Sea level changes is one of the main impacts of the recent trend of climate change (IPCC 2014). The adding trend of climate change are increasing the occurrence of irregular and high intensity rainfall events. Rapid urbanization and climate changes are the major causes of coastal urban flooding (Shahapure, *et al*. 2011). In recent years, increased frequency of urban flooding has caused huge loss of life and property and had a devastating impact on the economy. India has witnessed devastating floods like Mumbai in the year 2005, Srinagar in 2014 and recent in Chennai and many parts of Kerala.

The geographic focus of our city is the coastal city, Thane, India because of the same nature of problems here also rises flooding problem near creek vicinity area such as rapid urbanization, heavy rainfall in monsoon, High tide. Thane has 17 major drains, of which 8 are below sea level, 6 are above mean sea level but below high tide level, and just 3 are above high tide level. Hence, whenever heavy rainfall coincides with high tide levels, water accumulates in the area surrounding the creek in Thane city (Gupta 2007). Waterlogging has an adverse impact on various important infrastructure and services, such as roads, transportation, education, and healthcare (Hariyali Team 2006). Now this city faces repetitive water logging problem every year near the creek vicinity area. Even though future flood disasters cannot be avoided, the extent of their damage can be minimized by creating appropriate flood countermeasures (Dewan, *et al*. 2006). Therefore, a need to identify and delineate flood prone areas, mainly depending on today's changing hydrological conditions is necessary (Zope, *et al* 2016). Hence, flood hazard map could give an idea for possible spreading range of flood depth and can be used as a useful tool to prevent flood damage by creating holding pond, pumping station, adequate flood protection walls, early warning systems, and evacuation strategies etc. (Tingsanchali & Karim 2005).

The primary objective of this present study is to evaluate the LULC change between 1995, 2005, 2020 and City development plan (DP) in Thane city. Then to examine the impact of LULC change, high tide level variation and high rainfall intensity on flood peak runoff. As well identification of increase changes in flood inundation areas due to LULC and climate change. Then prepare flood hazard map for Thane city.

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2. STUDY AREA

Thane is a metropolitan city in Maharashtra, India (Figure-1). The city placed at190 10' 19” N to 19° 14' 56” N and 72° 55' 50” E to 73° 00' 32” E have an area of 81.97 km^2 (CDP 2005) & (Chacko, *et al*. 2012). As the border of Thane city is adjacent to Mumbai city, the city has been urbanized rapidly. The population was 1890000 according to the 2011 census and ranked 15th most populated city in India. Geographically, Sanjay Gandhi National Park and Ulhas creek are located to the northwest of Thane city, while Thane city is bounded by Thane creek to the east and Mumbai city limits to the south. Thane’s urban development shows in a South- North direction, like moving from the inner city to the outskirts.

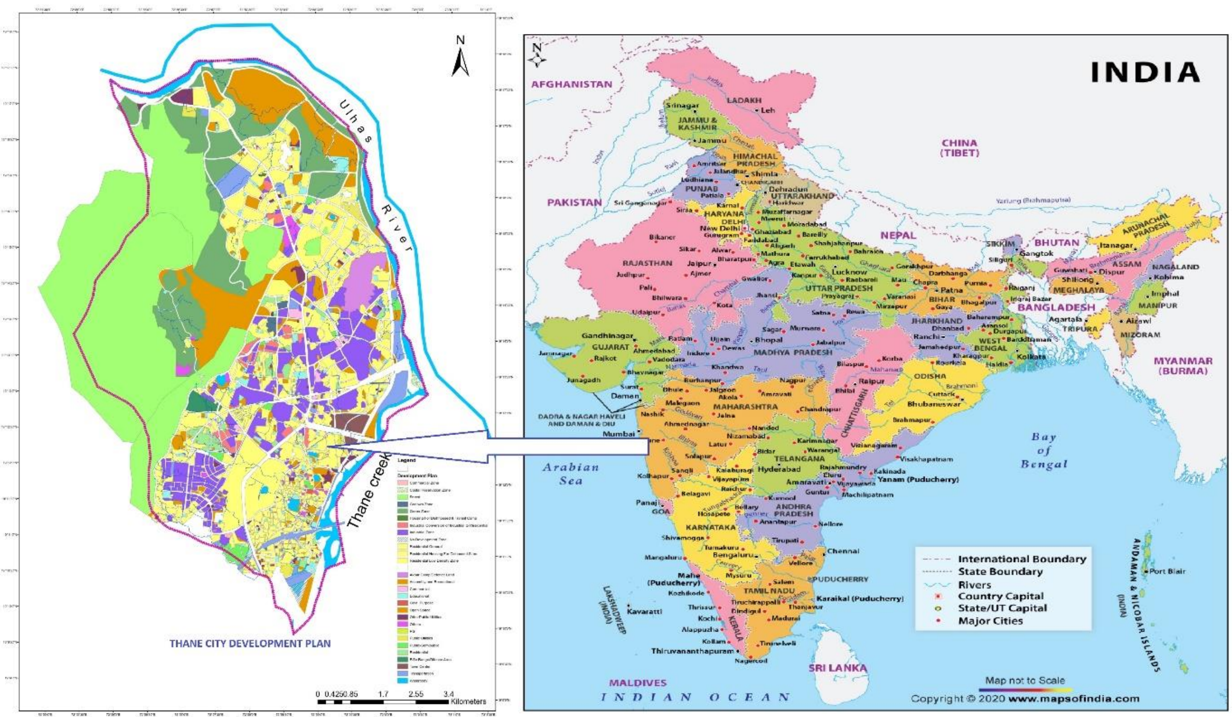

Figure 1. Location map of Thane city

Thane city has 10 km long creek front (Thane creek and Ulhas creek). City has roadside drains and minor drains discharging surface water into major drains or directly into the creek. Major drains 1-7 comes under phase -I region and meets Thane creek while major drains 8 to 16 comes under phase-2 region and joins the Ulhas creek. Phase -I region is the main area of the city and Phase- II region is the outskirts of the city where huge development is going on.

The Thane municipal corporation disaster management department has identified a list of 9 locations that experience critical waterlogging every year, including Chikhalwadi, Vandana takies area, Ram Maruti Road near Shivprasad hotel, Below CIDCO railway Bridge, Panama company near teen haat naka, Debinoir society, Vindhavan society, Shrirang society, Glendail society near Bai. Nath pai road, Edenwood society Bai. Nath pai road (Hariyali Team 2006).

3. DATA COLLECTION, MATERIALS AND METHODS

There are three main factors that affect flooding in coastal cities: LULC change, rainfall and semidiurnal tidal variations. Continuous per day high and low Tide data for 10 years (2009 to 2018) of Thane salt Bandar and Kasheli Bridge tide gauge stations were collected from Maharashtra Maritime Board (MMB) Mumbai. Continuous observed hourly rainfall data for the period 1969 to 2018 was collected from India Meteorological Department (IMD) in Pune. Landsat images from 1995 and 2005 were taken from the United States Geological Survey (USGS) Earth Explorer website while ESRI Inc. website provided 2020 Landsat images, these images were used for the analysis of LULC changes. Thane municipal corporation has provided a city development plan prepared for next 30 years, *i.e*., up to 2050, contour topo-sheet, catchment boundaries of major drains, hydraulic report and drawings of all major drains

3.1 Rainfall and Tidal Analysis

Global climate change is increasing irregular and high intensity rainfall events that may further increase the risk of flooding in the future, so the rainfall intensity duration frequency (IDF) relationships need to be improved to consider today's changing hydrological conditions. Today Thane city uses old IDF relationships even though increases the evidence of heavy rainfall events and repetitive waterlogging. All the major drains in Thane city are designed based on rainfall analysis by Gumbel's EV-I method for 10 years return period, which does not consider the effect of climate change. The recent climate change study indicate that rainfall intensity is likely to increase in next 30 years *i.e*. 17% in 2019-2028, 25% in 2029-2038 and 32% in 2039-2048 (Pujari & Wayal 2022).

In the present study, City development plan has been prepared for next 30 years, Hence the projected IDF curve for 10 -year return period for next 30 years (2048) has been used for the hydrological analysis (Figure-2).

In the Thane city area, all Major drains 1-7 meet Thane creek while major drains 8 to 16 joins the Ulhas creek and hydraulic depth of water level in all major drains mainly depends on the variation of the tide levels. On 26th July 2005 in Thane created unpredictable situation due to extreme rainfall coinciding with highest tide level (MMRDA 2006). In the present study 10 years tidal data was analyzed and found 2.97 m is Mean high water springs level (MHWS) for Thane Salt Bunder and 2.06 m for Kasheli bridge location. The Sixth Assessment Report published by United Nations' Intergovernmental Panel on Climate Change has estimated that Mumbai can witness a sea-level rise of around 0.58 meters by 2100, the highest in India. Mumbai Climate change action plan 2022 indicates that Mumbai along with 11 other Indian coastal cities will witness sea level rise of 0.1-0.3 m over the next three decades due to climate change (MCCAP 2022). Therefore, in the present study extreme tide level of 3.3 m at Thane Slate Bander and 2.3 m at Kasheli Bridge have been considered for tidal back water analysis (Pujari & Wayal 2022).

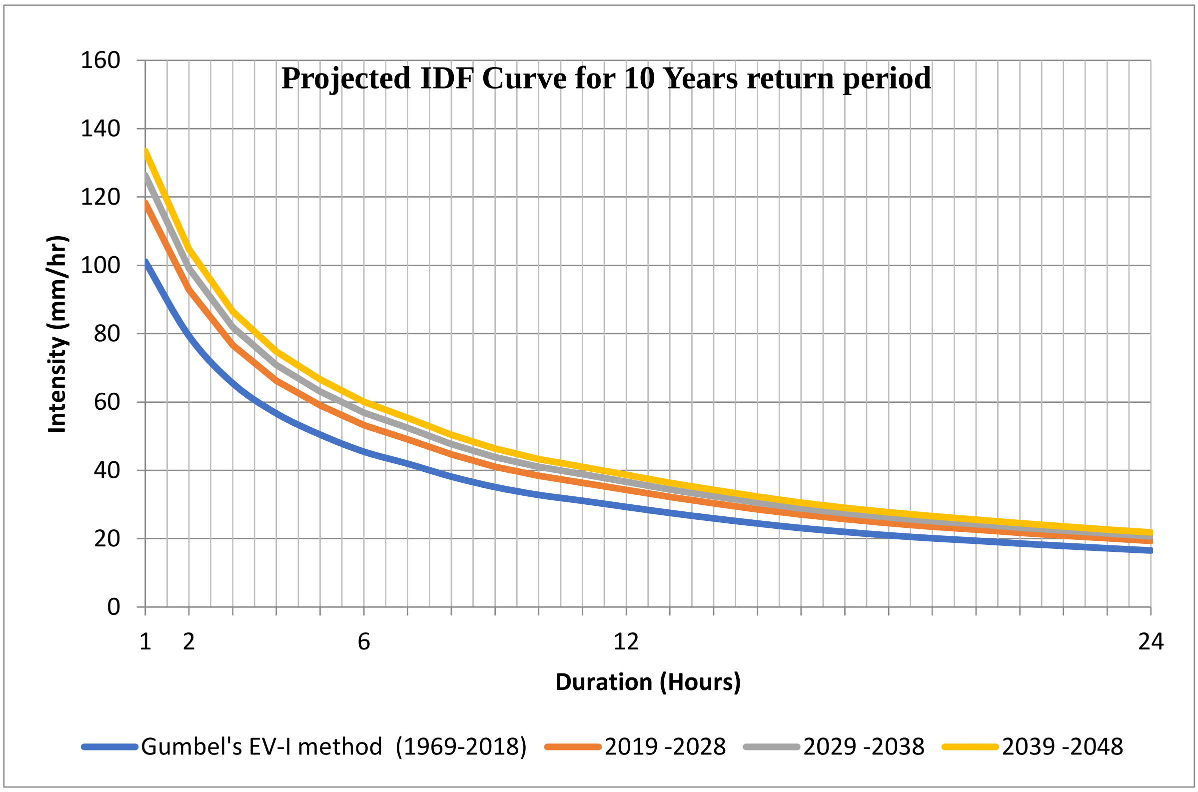

Figure 2. Projected IDF curve for Thane city

3.2 Land Use Land Cover Analysis

Thane city has an area of 81.97 km^2 of which major drains cover 68.46 km^2 of catchment area. In the present study, to assess LULC changes between 1995, 2005, 2020 and DP. Landsat satellite images were used for classification and analysis of various LULC classes. Land use land cover (LULC) changes were analyzed by ArcGIS 10.3.1 software. Each Landsat images were georeferenced by the WGS 84 datum and the Universal Transverse Mercator (UTM) Zone 43 North coordinate system and then Landsat images were processed and converted into five classes namely forest, open land, built-up land, waterbodies and mangroves. After that each LULC class was then compared. The rate of change of LULC from 1995 to 2020 was calculated by dividing the percentage change of LULC between the two periods by the number of years (25 years). The city development plan shows various land use types, but in this study, land use types are classified into five classes: open land, built-up land, water body, mangroves, and forest. Open spaces are denoted as open land. Commercial zones, godown zones, housing for dishoused individuals and transit camps, industrial conversion of industrial to residential areas, industrial zones, general residential areas, low-density residential areas, defense lands, assembly and recreational areas, commercial, educational, government, and other public utilities, public semi-public areas, and town centers and transportation are denoted as built-up land. Water bodies are denoted as water bodies. Forest and green zones are denoted as forest land, while coastal reservation zones and no development zones are designated for mangroves.

3.3 Flood Runoff Modeling

Rational method is used for calculating flood peak runoff (CPHEE 2019). The rational equation is expressed as:

$$Q_p = 10CIA \qquad 1$$

Where

Qp - Peak runoff m^3/hr.

C - Coefficient of runoff,

I - Intensity of rainfall mm/hr.

A – Area of catchment Ha

The Rainfall Intensity obtained by IDF curve is used for Peak flow calculation. As per IRC: SP-50-2013, page no. 45 indicates that inlet time used in actual practice may vary from 5 to 10 minutes (IRC-50, 2013). So, in present study inlet time is considered as 10 min for roadside drains and for Major (Natural drain) is calculated by Federal Aviation Administration (FAA) method shown in Equation 2, it comes 25 min. The Peak flow is calculated by using Equation 1. Bentley Storm CAD software is used to analyze stormwater drainage networks for different land use changes and IDF curves, considering free-fall and backwater effect scenarios at the outfall point.

$$I_t = \frac{0.218[1.1 - c]L^{0.5}}{S^{0.333}} \qquad 2$$

Where, I_t is Inlet time in minutes, c is runoff coefficient, Length of surface flow in meter and s is surface slope in percentage (%).

This Storm CAD software simulates dynamic routing in a storm water system by numerically solving the St. Venant equations. Because tidally influenced creeks frequently produce backflow into coastal systems, it is crucial to apply dynamic wave routing when modelling coastal systems (Sadler, *et al*. 2020). Rainfall intensities of 10 years return periods by Gumbel's EV-Method were provided as input to the model for 1995, 2005, 2020 and DP land use pattern and projected rainfall IDF is provided as input to DP to analyze climate change impact. Similarly, Runoff coefficient shown in table 1 is as per CPHEEO guidelines (CPHEEO 2019). The actual survey data for all major drains like alignment, drain alignment, left and right banks elevation, Invert Level, width of drain, runoff coefficient and manning's roughness coefficient 0.018 were taken as inputs to the model. Then land use changes in 1995, 2005, 2020 and DP was analyzed using hydraulic model. The hydraulic water level obtained from the hydraulic model for 10 years return period was exported to ArcGIS and then the actual ground level and hydraulic water level were analyzed through ArcGIS to identify the inundation areas for land use conditions of 1995, 2005, 2020 and DP.

Table 1. Runoff coefficient for study area

Sr. No.	Land use types	Runoff coefficient 'C'
1	Forest land	0.20
2	Open Land	0.60
3	Built up land	0.95
4	Water body	0.90
5	Mangrove	0.30

3.4 Flood Inundation and Flood Hazard Map

A significantly longer return time is used to build minor dams and airport drains (100 years and above), where there is a significant risk of life in case of failure. But a 5 or10-year return period is used to construct urban roadside drains where the cost of failure is small. However, the existing drainage system is adequate for 5 to 10 years return period flooding events, but for longer return period existing drains are not of sufficient capacity to carry the higher return period flooding events. Therefore, in present study only 10 years return period is used for finding inundation areas.

By using ArcGIS model flood extent and flood depth were estimated based on changing land use conditions and then identify flood inundation areas. The primary information used for creating the flood hazard map are the generated flood inundation areas and its depth. The step-by-step process used to create the flood inundation areas and flood hazards maps shown below.

1. Export hydraulic water level generated from model flood hydrograph.
2. Post process export hydraulic water level from Storm CAD and topo survey level in ArcGIS.
3. Identify inundation areas for development plan (2050) land use conditions.
4. To identify the maximum flood extent, all flood inundation areas for various flow and land use conditions were combined.
5. Create a raster map with the combined flood extent at its highest.
6. Generate flood Hazard map.

4. RESULTS AND DISCUSSION

4.1 Land Use Changes

Changes in land use land cover affect hydrological processes leading to flood condition (Chen, *et al*. 2009). The change in LULC status in 1995,2005, 2020 and DP studied by using ArcGIS software to digitize the land use map. In this study land use types used for the analysis are open land, built-up land, waterbody, mangroves and forest. Figure - 3, Figure - 4, Figure - 5 and Figure-6 represent the land use maps generated for the years 1995, 2005, 2020 and DP, respectively. Table 2 illustrates the change in land use type between 1995-2020 and DP.

The analysis of result indicates that, over 10 years (between 1995 and 2005) there was an increase of about 6.62% in built-up area and a decrease of 8.07%, 0.13% and 3.46% in forest, open land and mangrove respectively. However, over 15 years (between 2005 and 2020) there was an increase of about 19.56% in built-up area and a decrease 29.37%, 18.93% and 36.30% in open land, waterbodies and mangroves respectively. Overall, in 25 years the built-up area has increased by 27.47% while the open space, forest, waterbodies and mangrove areas have declined by about 29.46%, 8.07%, 18.93% and 36.30% respectively. Similarly, in the next 30 years, as compared to 2020, the built-up area will increase by about 22.37% and forest, open land, waterbodies and mangroves will decrease by 9.78%, 37.60%, 84.46 and 56.24% respectively. That is since 1995 the built-up area has increased by 55.99% while the open space, forest, waterbodies and mangrove areas will decline by about 17.06%, 55.98%, 87.40% and 72.13% respectively. The result of this analysis recommends that the annual rate of change in built-up area has increased by 1.09%, while open land decreased by 1.17 percent and mangroves decreased by 1.45 percent, indicating significant change in land use compared to the more natural land cover that existed in 1995, and will continue for next 30 years as per DP. Hence, overall analysis indicates that there has been rapid urbanization in Thane city area at least in the last 25 years and also in coming period.

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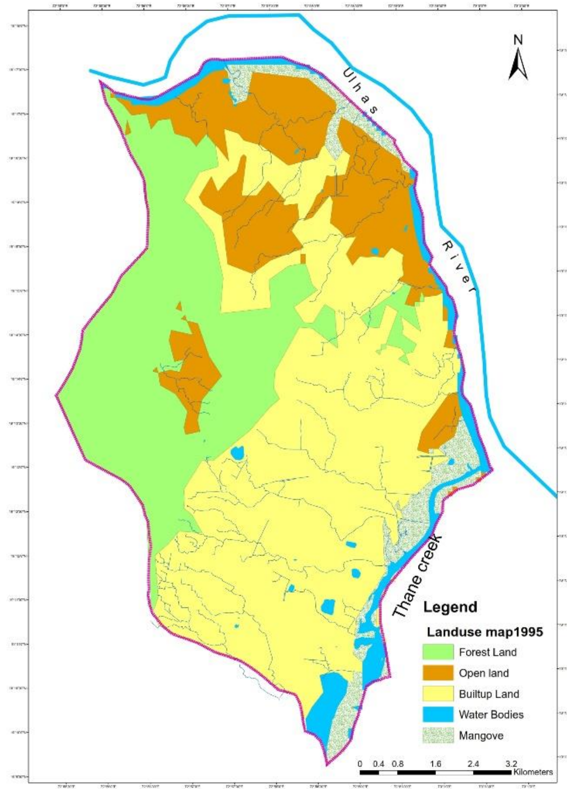

Figure 3. Land use map for the year 1995

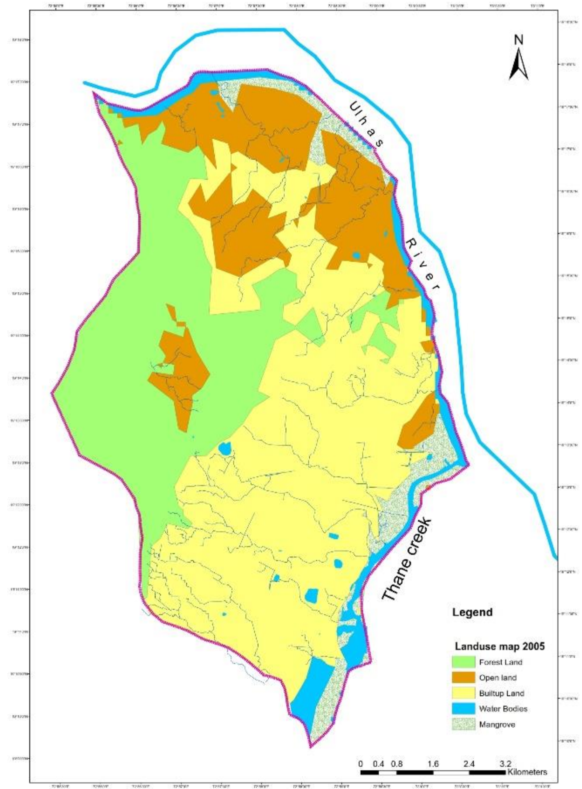

Figure 4. Land use map for the year 2005

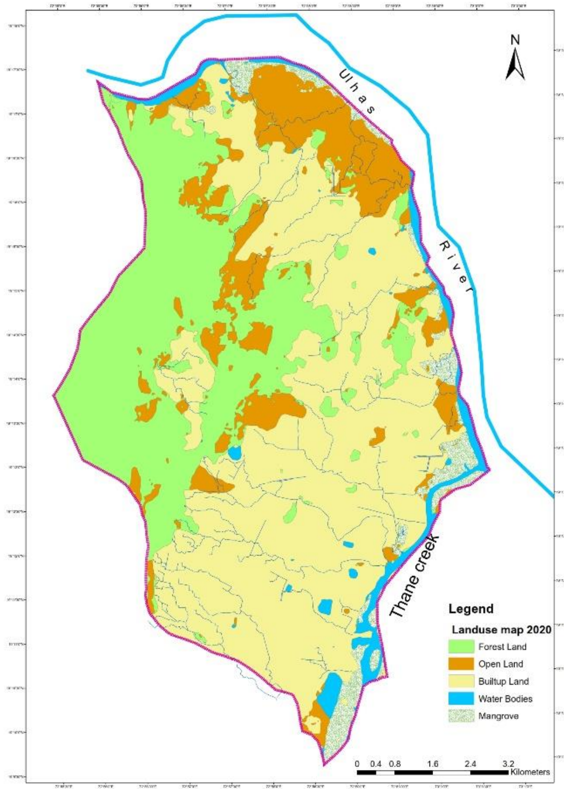

Figure 5. Land use map for the year 2020

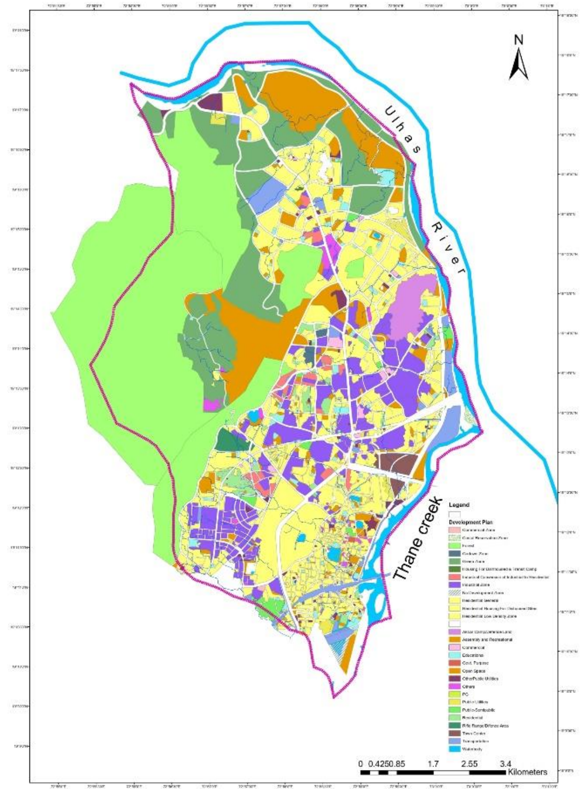

Figure 6. City Development Plan for Thane city

Table 2. Land use changes for the study area with changes between 1995, 2005, 2020 and DP

Sr. No.	Land use	Area in km^2				Rate of Change of LULC (%)				
		1995	2005	2020	DP	1995-2005	2005-2020	2020-DP	1995-2020	1995-DP
1	Forest land	24.96	22.95	22.95	22.70	-8.07	0.00	-9.78	-8.07	-17.06
2	Open Land	17.24	17.22	12.16	7.59	-0.13	-29.37	-37.60	-29.46	-55.98
3	Built up land	33.40	35.61	42.57	52.10	6.62	19.56	22.37	27.47	55.99
4	Water body	1.31	1.31	1.06	0.17	0.00	-18.93	-84.46	-18.93	-87.40
5	Mangrove	5.05	4.88	3.22	1.41	-3.46	-34.02	-56.24	-36.30	-72.13

The analysis of result indicates that, over 10 years (between 1995 and 2005) there was an increase of about 6.62% in built-up area and a decrease of 8.07%, 0.13% and 3.46% in forest, open land and mangrove respectively. However, over 15 years (between 2005 and 2020) there was an increase of about 19.56% in built-up area and a decrease 29.37%, 18.93% and 36.30% in open land, waterbodies and mangroves respectively. Overall, in 25 years the built-up area has increased by 27.47% while the open space, forest, waterbodies and mangrove areas have declined by about 29.46%, 8.07%, 18.93% and 36.30% respectively. Similarly, in the next 30 years, as compared to 2020, the built-up area will increase by about 22.37% and forest, open land, waterbodies and mangroves will decrease by 9.78%, 37.60%, 84.46 and 56.24% respectively. That is since 1995 the built-up area has increased by 55.99% while the open space, forest, waterbodies and mangrove areas will decline by about 17.06%, 55.98%, 87.40% and 72.13% respectively. The result of this analysis recommends that the annual rate of change in built-up area has increased by 1.09%, while open land decreased by 1.17 percent and mangroves decreased by 1.45 percent, indicating significant change in land use compared to the more natural land cover that existed in 1995, and will continue for next 30 years as per DP. Hence, overall analysis indicates that there has been rapid urbanization in Thane city area at least in the last 25 years and also in coming period.

4.2 Effect of LULC Change on Flood Peak Discharge.

Urbanization increases the imperviousness of the ground surface leading to increase the surface runoff that can result in increasing the like hood of severe flooding during monsoon season (Shahapure, *et al*. 2011). Rainfall intensities of 10 -years return period by Gumbel's method and Projected IDF curve was used as input to the hydraulic model to understand the effect of LULC on peak runoff. Analysis has done on how land use in 1995, 2005, 2020 and DP will affect flood peak runoff. Table 3 shows the changes in peak runoff with the changes in land use conditions of 1995, 2005, 2020 and DP (2050).

Table 3. Changes in Peak discharge for LULC changes and Climate changes

Major Drain	System Rational Flow (m³/s)					Increase Rate of change of runoff in %				
	1995	2005	2020	DP	Due to Climate change DP	1995-2005	2005-2020	1995-2020	2020-DP	due to Climate change DP
1	107.2	114.3	114.3	128.4	172	6.6	0	6.6	12.4	33.9
2	94.5	94.5	94.5	96.3	128.1	0	0	0.0	1.9	33
3E	24.8	24.8	25.2	25.6	33.8	0	1.7	1.6	1.7	32
3W	43.9	45.4	47.1	47.1	60.7	3.4	3.5	7.3	0	28.9
4	15.4	15.4	15.4	15.4	20.3	0	0	0.0	0	32.1
5	106.9	110.1	110.1	110.5	135.3	3	0	3.0	0.4	22.4
6	97.1	99.9	99.9	110.9	149.2	2.9	0	2.9	11	34.6
7	136	145.4	146.8	148.2	175.2	6.9	0.9	7.9	1	18.2
8	12.9	12.9	20.8	21	28.1	0	60.7	61.2	1.1	33.5
9	68.6	76.6	79.1	82	108.9	11.6	3.3	15.3	3.6	32.9
10	76.9	80.9	88.3	104.5	139.5	5.3	9.1	14.8	18.4	33.5
11	130.9	130.9	138.7	140.9	188.5	0	6	6.0	1.6	33.8
12	39.6	40	40.8	41	56.1	1	1.8	3.0	0.7	36.6
13	60.7	60.7	71	79.6	107.3	0	16.9	17.0	12.1	34.7
13A	53	53	58.1	60.7	81.5	0	9.5	9.6	4.4	34.3
16	33.4	33.4	36.3	36.3	48.1	0	8.6	8.7	0	32.6
Yeoor hill	33.7	33.7	43.9	53.6	71.2	0	30.4	30.3	22.1	32.7
Average Increase Rate of change of runoff in %						**2.4**	**9**	**11.5**	**5.4**	**31.8**

The result of this analysis shows that the peak runoff rate increased by 2.4% during 1995-2005 due to land use changes and increased by 11.5% by 2020. Also, the peak runoff rate will increase by 5% due to land use changes in 2020-DP. Whereas climate change will increase that peak runoff rate by 31.8%. Although the change in LULC has minimal impact on peak runoff, increasing urbanization and the impact of climate change have resulted in increased peak runoff at the outlet of drains, that are heavily influenced by tidal variation. Therefore, the increase in peak runoff during periods of heavy rain and high tide are sufficient to flood in large areas.

4.3 Delineation of Flood Plain Areas

Table 4. Flood inundation areas estimated for LULC changes.

Major Drain	Drainage Area (km²)	Flood inundation Area (km²)				% Change in the flood inundation area			
		1995	2005	2020	DP (2050)	1995	2005	2020	DP(2050)
1	5.803	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
2	4.257	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
3E	1.065	0.227	0.227	0.313	0.631	21.31	21.31	29.39	59.25
3W	1.887	0.059	0.148	0.242	0.242	3.13	7.84	12.82	12.82
4	0.589	0.271	0.271	0.271	0.271	46.01	46.01	46.01	46.01
5	5.193	0.392	0.392	0.392	0.405	7.55	7.55	7.55	7.80
6	5.067	0.585	0.585	0.585	0.594	11.55	11.55	11.55	11.72
7	8.648	0.706	0.757	0.905	1.056	8.16	8.75	10.46	12.21
8	0.834	0.000	0.000	0.127	0.203	0.00	0.00	15.23	24.34
9	5.703	0.238	0.238	0.297	1.792	4.17	4.17	5.21	31.42
10	4.222	0.000	0.374	0.992	1.739	0.00	8.86	23.50	41.19
11	8.191	0.578	0.578	1.246	1.069	7.06	7.06	15.21	13.05
12	3.055	0.046	0.046	0.046	0.299	1.51	1.51	1.51	9.79
13	4.180	0.042	0.042	0.212	0.212	1.00	1.00	5.07	5.07
13A	3.527	0.000	0.000	0.385	0.385	0.00	0.00	10.92	10.92
16	3.198	0.000	0.000	0.198	0.198	0.00	0.00	6.19	6.19
Yeoor Hill	2.096	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
Total	**68.457**	**3.144**	**3.658**	**6.211**	**9.604**	**4.59**	**5.34**	**9.07**	**14.03**

Identifying flood inundation areas is the first step in dealing with flood hazards. In the present study major drains in Phase I area (1-7) affected by Thane creek tide level 3.3 m and Phase 2 (8-16) area affected by Ulhas creek tide level 2.3 m. The hydraulic analysis conducted for 10 years return period rainfall intensity and highest high tidal level back effect for different LULC conditions from 1995, 2005, 2020 and DP. The result obtained in the form of hydraulic water elevations exported to ArcGIS software for generation of the water surface. Water surface elevation and land surface elevation were analyzed in ArcGIS and

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flood zone demarcation was done by marking polygons. The obtained inundated areas due to land use changes between 1995, 2005, 2020 and DP are tabulated in table 4. The result of analysis shows that the total flooded area in 1995 for this study area was 3.144 km^2 while in 2005 the total flooded area increased to 3.658 kcc and in 2020 further increased the total flooded area to 6.211 km^2. According to the DP, the total flooded area will increase to 9.604 km^2 in the next 30 years.

Thus, results suggest that inundation area in 1995 was 3.14 km^2, in 2005 was 3.658 km^2 in 2020 was 6.211 km^2 and as per DP(2050) it will be 9.604 km^2 means the inundation area in 2020 increased to 9.07 percent of the total drainage area, and in next 30 years the inundation area will further increased to 14.03 percent of the total drainage area which means that the flooded area is higher for the 2020 than 1995. The results of this analysis show that if flood provisions are not made in the future, the inundation will continue to increase.

4.4 Flood Hazard Mapping

Flood hazard map useful for ensuring an effective flood warning and disaster management mechanism as well as to establish a useful flood insurance and risk assessment program. For a city like Thane, where too limited open space is available and frequent flooding problems occur in every rainy season, it is essential to prepare flood hazard map for this area. In the present study ArcGIS and Storm CAD software were used to construct flood hazards map. Using the first order standard deviation technique of classification, the flood hazard was divided into five groups (No flood, low, moderate, high, and very high). Higher vulnerability is indicated by a lower rating, and vice versa (Suriya & Mudgal 2012). Figure - 7 shows the category-by-category vulnerability region for the LULC conditions in 2020 and DP. In the study area it observed that if surface development levels are less than the highest high tide level then these areas get affected by tidal back water flow and upstream peak runoff.

Based on a flood hazard map, the regions of CIDCO Bridge, Vindavan, Rabodi-Koliwada, Krantinagar, Majiwada village, and Chendni Koliwada in Thane (East) have been identified as flood-prone. The Thane Municipal Corporation can utilize this map to implement preventative measures in these areas during the monsoon season. In addition, when developing areas in the creek vicinity, the TMC could consider setting a minimum development level of 4.5m or above the highest high tide level to mitigate the problem of waterlogging. Additionally, the TMC could utilize storage ponds, pumping systems, and tidal gates to further address this issue.

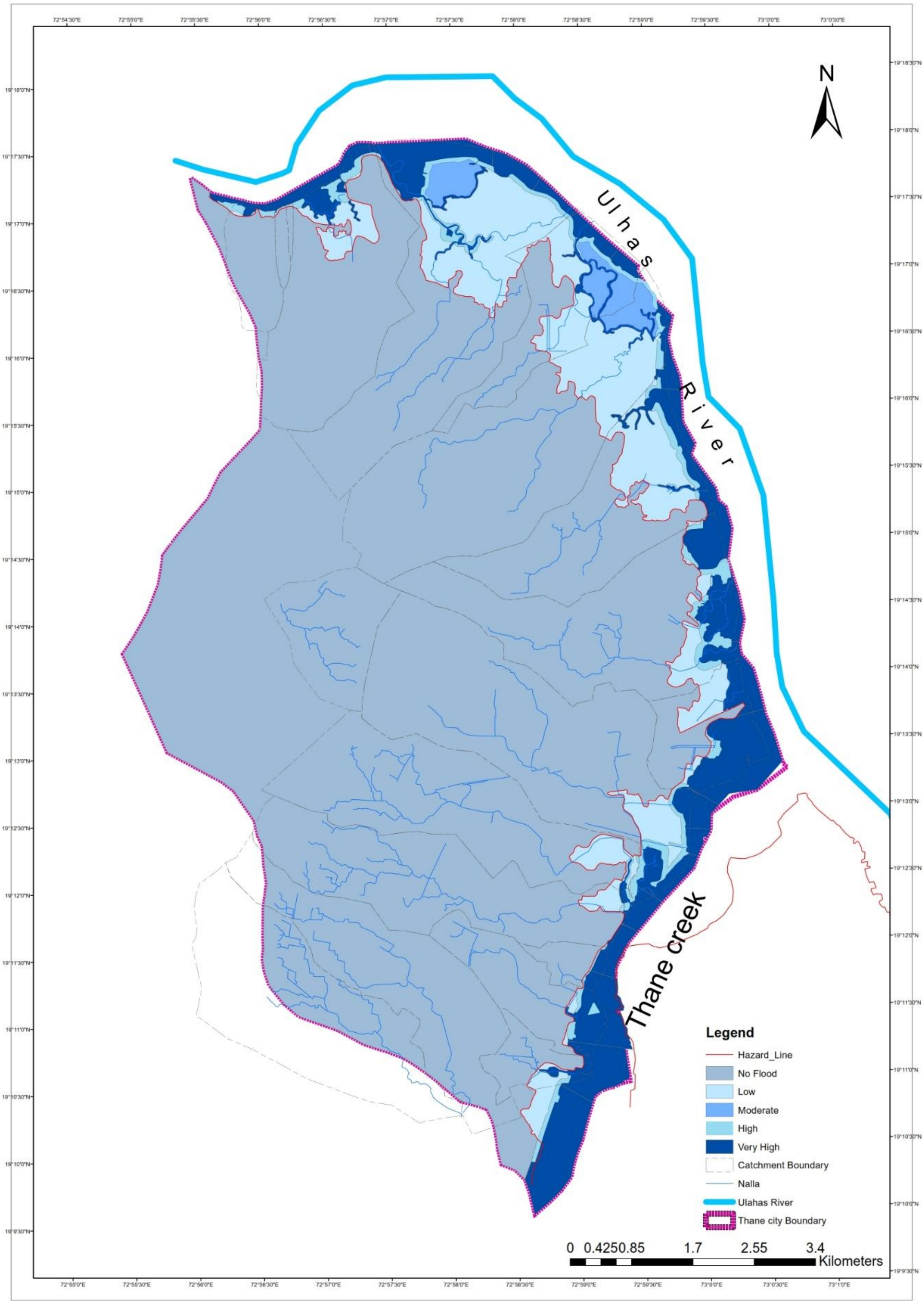

Figure 7. Flood hazard map for Thane city

5. CONCLUSION

The rapid growing urbanization, global climate changes is resulted the risk of flooding all over the world. Thane city experienced repetitive waterlogging problem every year in the creek vicinity region due to rapid change in land use changes over past 25 years, increasing upstream runoff and tide level variation. In rainfall runoff and flood inundation modelling, an integrated approach of GIS and Storm CAD hydrologic and hydraulic models was used.

For the past 25 years (between 1995 to 2020), the effects of LULC change have been examined in this study. The result of LULC analysis shows that in the last 25 years the built-up area has increased by 27.47% while the open space, forest, wetlands and mangrove areas have declined by about 29.46%, 8.07%, 18.93% and 36.30% respectively. Similarly, in the next 30 years, as compared to 1995 the built-up area has increased by 55.99% while the open space, forest, waterbodies and mangrove areas will decline by about 17.06%, 55.98%, 87.40% and 72.13% respectively. Due to this, the flow in the watershed of the drain also increases tremendously. Although the change in LULC has minimal impact on peak runoff, increasing urbanization and the impact of climate change have resulted in increased peak runoff by 31.8%. In the present study showed increase in the peak runoff during periods of heavy rainfall and high tides were found to be sufficient to flood in large areas. Further, conclude that inundation area in 1995 was 3.14 km^2, in 2005 was 3.658 km^2 in 2020 was 6.211 km^2 and as per DP(2050) it will be 9.604 km^2 means the inundation area in 2020 increased to 9.07 percent of the total drainage area, and in next 30 years the inundation area will further increased to 14.03 percent of the total drainage area which means that the flooded area is higher for the 2020 than 1995. Hence, inundation area and flood hazard map was prepared. The prepared flood hazard map can be helpful for decision-makers or/to relevant authorities particularly municipal corporation for prepare flood mitigation and early evacuation management plan during floods.

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