

Hydrological impacts of land use–land cover change and detention basins on urban flood hazard: a case study of Poisar River basin, Mumbai, India

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Abstract Flooding in urban area is a major natural hazard causing loss of life and damage to property and infrastructure. The major causes of urban floods include increase in precipitation due to climate change effect, drastic change in land use–land cover (LULC) and related hydrological impacts. In this study, the change in LULC between the years 1966 and 2009 is estimated from the toposheets and satellite images for the catchment of Poisar River in Mumbai, India. The delineated catchment area of the Poisar River is 20.19 km². For the study area, there is an increase in built-up area from 16.64 to 44.08% and reduction in open space from 43.09 to 7.38% with reference to total catchment area between the years 1966 and 2009. For the flood assessment, an integrated approach of Hydrological Engineering Centre-Hydrological Modeling System (HEC-HMS), HEC-GeoHMS and HEC-River analysis system (HEC-RAS) with HEC-GeoRAS has been used. These models are integrated with geographic information system (GIS) and remote sensing data to develop a regional model for the estimation of flood plain extent and flood hazard analysis. The impact of LULC change and effects of detention ponds on surface runoff as well as flood plain extent for different return periods have been analyzed, and flood plain maps are developed. From the analysis, it is observed that there is an increase in peak discharge from 2.6 to 20.9% for LULC change between the years 1966 and 2009 for the return periods of 200, 100, 50, 25, 10 and 2 years. For the LULC of year 2009, there is a decrease in peak discharge from 10.7% for 2-year return period to 34.5% for 200-year return period due to provision of detention ponds. There is also an increase in flood plain extent from 14.22 to 42.5% for return periods of 10, 25, 50 and 100 years for LULC change between the year 1966 and year 2009. There is decrease in flood extent from 4.5% for 25-year return period to 7.7% for 100-year return period and decrease in total flood hazard area by 14.9% due to provisions of detention pond for LULC of year 2009. The results indicate that for low return period rainfall events, the hydrological impacts are higher due to geographic characteristics of the region. The provision of detention ponds reduces the peak discharge

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as well as the extent of the flooded area, flood depth and flood hazard considerably. The flood plain maps and flood hazard maps generated in this study can be used by the Municipal Corporation for flood disaster and mitigation planning. The integration of available software models with GIS and remote sensing proves to be very effective for flood disaster and mitigation management planning and measures.

Keywords Land use–land cover change impacts · Hydrological modeling · Flood plain and hazard maps · Detention basin

1 Introduction

Soil permeability, change in land use–land cover (LULC) and topographical alterations are the three major watershed characteristics which affect the rainfall runoff process (Saghafian et al. 2008). Flooding, a natural disaster, impacts on life of people, infrastructure, economy and overall growth of the city (Hammond et al. 2013). Impact of LULC change on hydrological process is the main reason for urban flooding (Stonestrom et al. 2009; Wagner et al. 2013). Many people settle down in urban areas in search of employment, trading or business that alter the land use to satisfy their needs. By 2050, 75% of world's population is estimated to be living in urban areas (UN 2008; Miller et al. 2014; Zope et al. 2016). Thus, LULC change results in scarcity of land for urban infrastructure such as provision as well as widening of existing drainage system (DeFries and Eshleman 2004). Coastal urban megacities like Mumbai have limitations on discharge capabilities of the drainage system due to the tide levels as well as backwater problems (Gupta 2007; Gupta and Lokanadham 2008). For assessment of LULC, toposheet and satellite images provide suitable spatially distributed information (Miller et al. 2002; Seeber et al. 2010; Wagner et al. 2013). In hydrological studies, LULC change and its hydrological impacts on design of drainage system are the major topics of research in the recent years (Amini et al. 2011; Chen et al. 2009; Fox et al. 2012; Sayal et al. 2014; Zope et al. 2016). Ali et al. (2011) analyzed the impact of LULC change on hydrology by using HEC-HMS model with integration of GIS platform in the context of land use scenario. Kalantari et al. (2014) used distributed hydrological model to study the changes in peak flow and runoff due to changes in LULC of six catchments.

Sayal et al. (2014) investigated the impact of LULC change at sub-catchment level on the peak discharges. Zope et al. (2015) have assessed the impact of LULC change on urbanization with reference to spatial and temporal variation in one of the catchments of Mumbai, India. For the sustainable growth of an area, LULC change monitoring in space and time is the major issue and challenge in developing countries (Rawat et al. 2013). Quan et al. (2010) analyzed the impact of LULC in Pudong New Area, Shanghai, between the years 1994 and 2006. The results showed that for assumed 200-mm daily precipitation, the average flood depth increased by 13.19 mm between these periods. The encroachment of hutments and infrastructure along the alignment of the river and drainage system to satisfy the needs of human beings are the main cause of flooding in metropolitan cities like Mumbai, India (Zope et al. 2015). For a better flood mitigation and prevention of flood disaster, it is necessary to have proper understanding about the impact of LULC and urbanization on surface runoff (Shi et al. 2007).

Integration of GIS and remote sensing with hydrological and hydraulic models proves to be a very effective and powerful tool for assessing the impact of LULC on surface runoff spatially as well as temporally (Hathout 2002; Herold et al. 2003; Lambin et al. 2003; Serra et al. 2008; Dewan and Yamaguchi 2009). Remote sensing with GIS is very useful for developing source information and as a decision-making tool in a variety of urban applications (Gatrell and Jensen 2008; Jensen and Cowen 1999; Zeilhofer and Topanotti 2008; Dewan and Yamaguchi 2009). Suriya and Mudgal (2012) carried out study of Adyar River, Chennai, India, and presented the impact of LULC change on urban runoff. They also developed flood plain and flood hazard maps. Salimi et al. (2008) integrated the hydraulic simulation model HEC-RAS with GIS for delineation of flood depth and extent for the catchment of Zaremroud River in Iran. The results revealed that for flood plain management, integration of hydraulic simulation with GIS is very effective. Adikari et al. (2010) demonstrated the importance of flood hazard disaster management in urban planning. Water resource planners and designers use GIS as an essential tool to develop integrated flood model and watershed management spatial decision support system (Xu et al. 2001; Tayler et al. 1999; Choi et al. 2005; Aziz et al. 2003; Werner 2001; Boyle et al. 1998; Green and Cruise 1995; Dewan et al. 2006). The developed urban flood hazard maps can be used as a tool for mitigation planning and to identify the areas of the city which needs additional infrastructure (Büchle et al. 2006; Fernandez and Lutz 2010; Owrangi et al. 2014; Zope et al. 2016). Sowmya et al. (2015) developed flood vulnerability maps for Cochin City, India. The analysis was performed using multi-criteria evaluation approach with GIS environment using remote sensing images. They found that the major factors of flooding are the blockage of drain and tidal influences.

Occurrence of flood hazards cannot be prevented, but the intensity can be reduced by providing effective flood control strategies (Mitchell 1999; Dewan et al. 2006). Sowmya et al. (2015) generated flood vulnerability maps for Cochin City in India and found that about 8.6% of the total area of the city falls under very high vulnerable zone. In many urban areas, detention basins act as a part of best management practices as well as sustainable drainage system, which reduces peak discharge, controls quality and quantity of storm water runoff. Detention basins also reduce flood extent and flood risks (Jones 1990; Moglen and McCuen 1990; McEnroe 1992; Yeh and Labadie 1997; Lee and Li 2009; Lodhi and Acharya 2014; Gul et al. 2010). Lee and Li (2009) investigated the influence of detention basin on residential properties and its policy implications. Natural basins in the city area which are acting as natural detention or retention basin should be protected in future. Such spaces should be reserved as sustainable natural detention basin in the development plan of the city for flood control. No development should be allowed by reclaiming these spaces in future.

The main objectives of the present study are to analyze the impact of LULC change spatially and temporally on the peak flood discharge for the catchment of Poisar River basin, in Mumbai city, India, for different return periods. The variation in LULC change is assessed between the years of 1966 and 2009. Flood hydrographs are generated using HEC-HMS for different flow and land use conditions. Detention basins are proposed to assess the impacts on reduction of flood peak discharge, flood plain extent and flood hazard extent. Flood hydrographs, flood plain maps and hazard maps for different flow conditions with and without provision of detention basins are developed for the 1966 and 2009 land use conditions. The hydrological and hydraulic models are integrated with GIS and remote sensing to develop the flood plain and hazard maps. The proposed flood plain and hazard maps can be effectively used by the Municipal Corporation of Greater Mumbai for flood mitigation and disaster planning.

2 Description of the study area

The Poisar River catchment is located in the western suburbs of Mumbai city, India (Fig. 1). It is located between latitudes of $19^{\circ}10'0''\text{N}$ and $19^{\circ}14'0''\text{N}$ and longitudes of $72^{\circ}49'0''\text{E}$ and $72^{\circ}55'0''\text{E}$. The average elevation of the catchment is 8 m above the mean sea level (MSL) (FFC 2006; WAPCOS 2007; Zope 2016; Zope et al. 2016). The location map of the study area is shown in Fig. 1. The river originates from the Sanjay Gandhi National park, a hilly area in Mumbai. The river discharges at Malad creek into the Arabian Sea, which is the vital point in terms of tidal influence. The river has a length of 8 km and includes five tributaries as shown in Fig. 2. The middle and lower reach of the river is fully developed. The average elevation in the upper reach of the system is 21.0 m, the middle reach is 8.0 m, and the lower reach is 2.0 m above MSL. At some parts of the river, along the alignment of flow path, the banks are encroached with hutments. These hutments prevent a smooth flow path of the river (FFC 2006; WAPCOS 2007). The river passes through the railway track, western express highway and consists of cross-culverts. The blockage due to floating materials at these culverts and its cleaning are the main issues during the rainy seasons.

3 Materials and methods

3.1 Database preparation

For the present study, the rainfall data of Santacruz rain gauge station in Mumbai, which is nearby the study area, were collected from the Indian Meteorological Department (IMD)

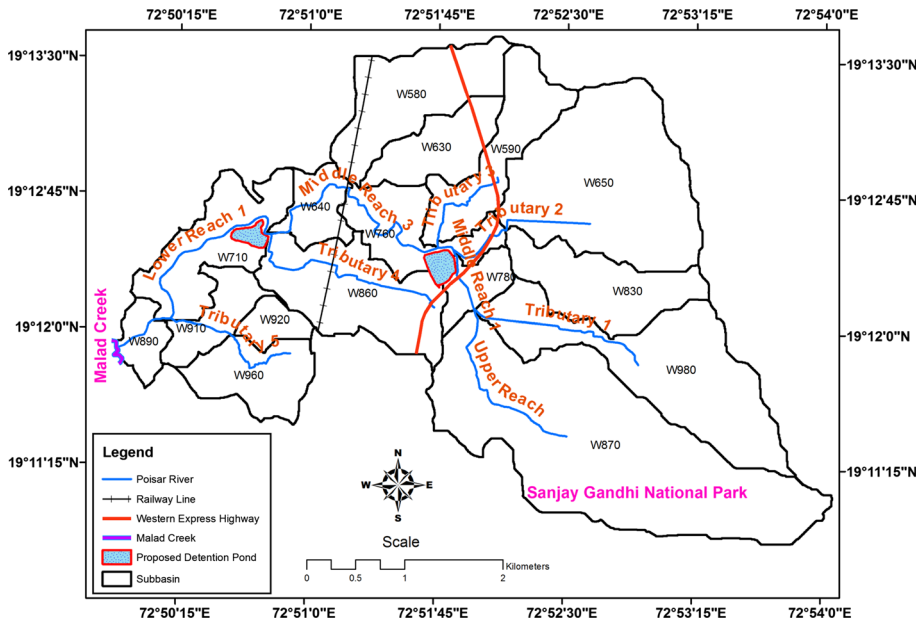


Fig. 1 Location map of the Poisar River catchment

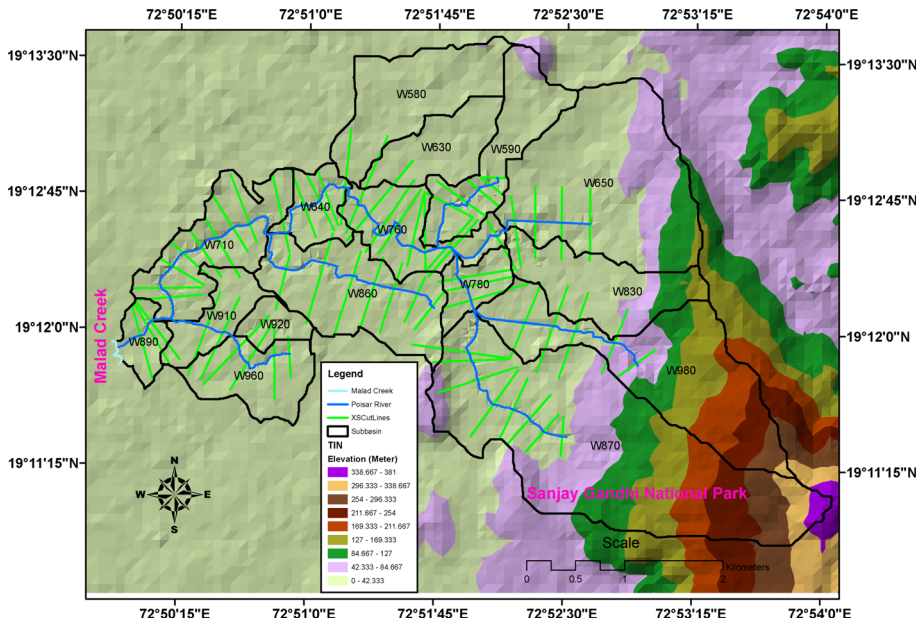


Fig. 2 River geometry with tributaries

and the Municipal Corporation. The data length for daily rainfall was from year 1901 and for hourly rainfall was from year 1969. Rainfall depths for different return periods were calculated by performing statistical analysis (Kulkarni et al. 2014; Zope et al. 2015, 2016). These rainfall depths were used as input for hydrological and hydraulic modeling. Toposheet No. 47 A/16 surveyed in the year 1966 and satellite image from IRS-P6/L-4 of year 2009 with resolution of 5.8 m were collected. Actual surveyed data along the alignment of the river were collected from Municipal Corporation (Zope et al. 2016). The methodology used in this study is presented in the form of flowchart in Fig. 3.

For catchment delineation, the Shuttle Radar Topography Mission (SRTM) (<http://srtm.csi.cgiar.org>), digital elevation model (DEM) was used. However, the river network generated by using this DEM does not match with the actual river network. Therefore, actual surveyed data points along the river path were collected from the local Municipal Corporation. These points were replaced from the SRTM DEM, and new modified DEM was generated (Fig. 4). The river network generated from this DEM coincides with present river network. HEC-GeoHMS software package as a geospatial hydrological modeling extension of ArcGIS 9.3.1 software has been used for delineation of the catchment boundary (USACE 2010). The catchment delineation was carried out using a series of steps employing the terrain processing tool of the HEC-GeoHMS software (Knebl et al. 2005). The total delineated catchment area of the Poisar River is 20.19 km², and it consists of 16 sub-catchments as shown in Fig. 1.

The LULC map for year 1966 was prepared by using the Toposheet No. 47 A/16 surveyed in the year 1966. Another LULC map for the year 2009 was generated from Indian Remote Sensing (IRS) satellite P6/L-4 image of March 2009. ERDAS Image 9.0 software with maximum likelihood classification method was used to extract the LULC data (Zope 2016; Zope et al. 2016). The change in LULC between the year 1966 and year 2009 was assessed for the classes categorized as built-up land, open land, vegetation and

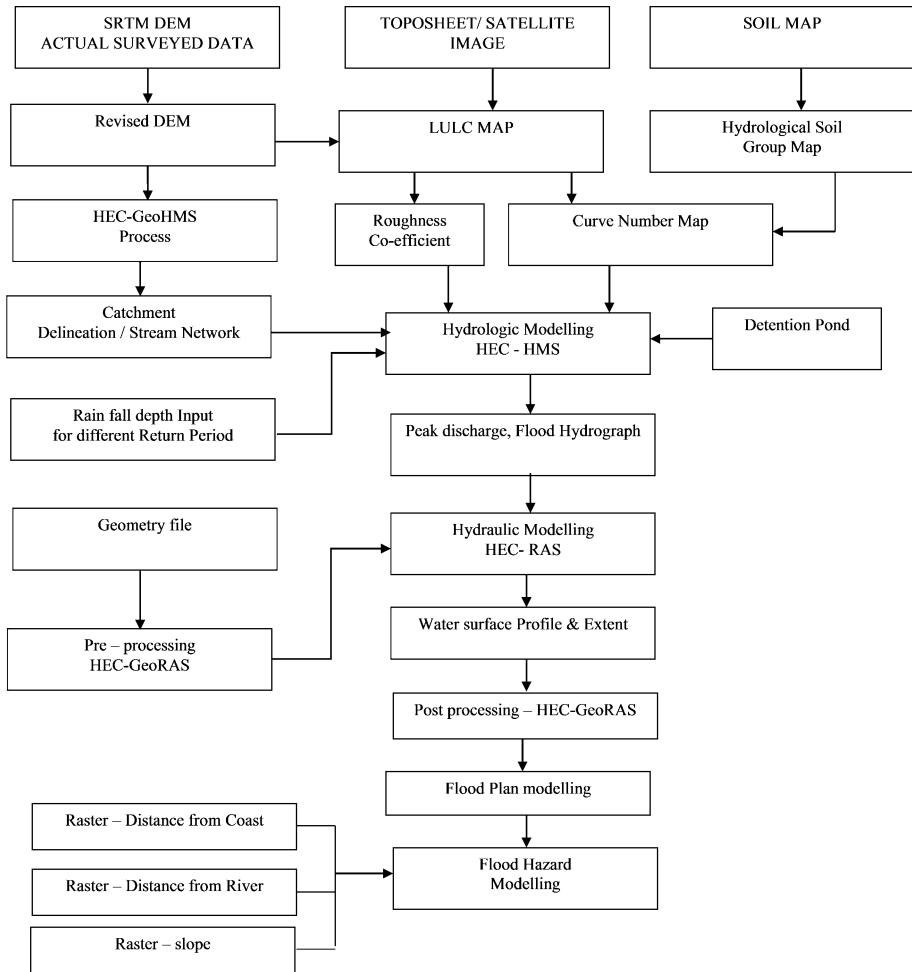


Fig. 3 Flow chart showing the methodology used in the study

water body. A Manning's roughness coefficient map (" n ") was prepared from the land use map assigning roughness values to each land use class as 0.015, 0.03, 0.1 and 0.15 to built-up land, water body, vegetation and open land, respectively (Zope et al. 2016). A base soil map was obtained from the National Bureau of Soil Survey and Land Use Planning (NBSS and LUP), Nagpur, published in the year 1995 (Zope et al. 2016). As per the LULC map of years 1966 and 2009, modified soil map for both the years was generated. The curve number (CN) maps were generated by coupling the land use map and soil map with assignment of the hydrological soil group. The curve numbers assigned to each land use category and hydrological soil group are taken from Zope et al. (2016). The composite curve numbers generated for each sub-catchment from these CN maps are used as input in HEC-HMS model for hydrological analysis (Vieux 2001; Suriya and Mudgal 2012; Zope et al. 2015, 2016).

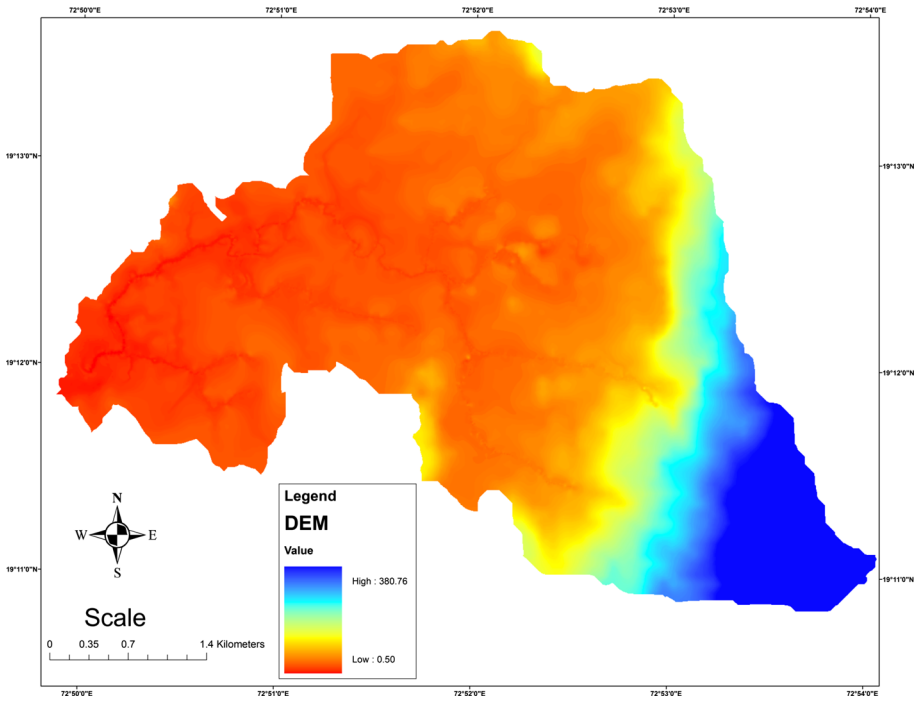


Fig. 4 DEM for the study area

3.2 Hydrological and hydraulic modeling

For generation of flood hydrographs at sub-catchment, junction and outlet level, HEC-HMS model has been used. HEC-HMS model performs hydrological as well as hydraulic simulation considering the watershed as an interconnected system (Gul et al. 2010, USACE 2010). The component consists of sub-basins, reach, junctions, reservoirs, sink, diversions, etc. (Ali et al. 2011). In this study, Soil Conservation Service–Curve Number (SCS-CN) method was used for the loss estimation and SCS unit hydrograph method for the transformation and kinematic wave method for channel routing (Zope et al. 2015, 2016). The SCS-CN method uses the following two equations (Mishra and Singh 2003; Quan et al. 2010):

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{1}$$

$$I_a = 0.2 S \tag{2}$$

Parameter S in the above equation is transformed into a dimensionless parameter CN, varying in a more conceptually logical range of 0–100 as expressed in Eq. 3 (Sahu et al. 2010):

$$S = \frac{25400}{CN} - 254 \tag{3}$$

where P = total rainfall; Q = direct runoff; and S = potential maximum retention or infiltration, also described as the potential post-initial abstraction retention (McCuen

2002). Here, P , Q , I_a , F and S are in-depth or volumetric units. For different return periods, rainfall depths were derived by running the statistical analysis of daily rainfall data from year 1951 to 2009 and hourly rainfall data from year 1969 to 2009 (Zope et al. 2016). Statistical analysis was performed by using Gumbel distribution method. One-day rainfall depth having 2-, 10-, 25-, 50-, 100- and 200-year return periods was used as input in the hydrological model of HEC-HMS. In this study, two detention ponds are proposed in the catchment area of the river (Fig. 1) to reduce the downstream peak flow and also to reduce the flood extent and hazard. The volume of first detention pond is 0.42 million m^3 , and second one is 0.57 million m^3 . Mumbai, being an island city and densely populated, has scarcity of land for provision of bigger size of detention ponds. The flood hydrographs and peak discharges at each junction as well as at the outlet were generated for LULC patterns for the years 1966 and 2009, with and without considering the detention ponds. The results as peak discharge obtained at each junction from HEC-HMS are used as the input for HEC-RAS model. The geometry profile data containing river centerline, flow path, banks and cut lines were prepared using HEC-GeoRAS software. Triangulated irregular network (TIN) was used to extract the attributes of the spatial geometric data. In this study, upstream boundary condition was considered as normal depth and downstream boundary condition as tidal depth as the river discharge to Malad creek in Arabian Sea. Water surface profile and extent generated from the HEC-RAS model were used as the input for post-processing in HEC-GeoRAS model, an extension of ArcGIS for flood plain modeling map generation. Flood plain extent maps generated for different flow conditions were used as one of the inputs for generation of flood hazard maps. The flood plain and flood hazard maps were generated with and without considering the detention ponds. The results of hydrological and hydraulic modeling are discussed in detail in Sect. 4.

4 Results and discussion

4.1 Changes in LULC

The change in LULC during 43-year period (1966–2009) was assessed for the study area. LULC map for the year 1966 prepared from the toposheet is presented in Fig. 5a and for the year 2009 prepared from the satellite image is presented in Fig. 5b. Table 1 shows the variation in LULC between the years 1966 and 2009.

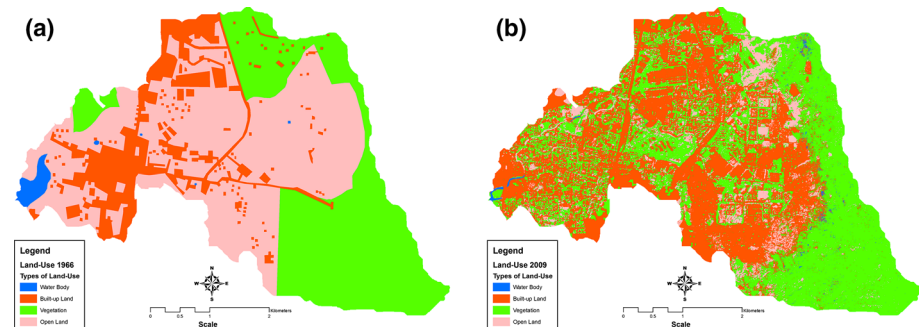


Fig. 5 Land use maps of the study area **a** 1966 **b** 2009

Table 1 LULC change between the years 1966 and 2009

S. no.	Land use type	LULC 1966		LULC 2009	
		Area (km ²)	% with respect to total catchment area	Area (km ²)	% with respect to total catchment area
1	Built-up land	3.36	16.64	8.90	44.08
2	Vegetation	7.00	34.67	9.25	45.81
3	Open land	8.70	43.09	1.49	7.38
4	Water body	1.13	5.60	0.55	2.73

From the above results, it is observed that there is substantial LULC change, specifically increase in built-up area and reduction in open spaces in the catchment. Between the years 1966 and 2009, there is decrease in built-up area at northwest and southwest part. However, at northeast and northwest as well at downstream part, built-up area is increased substantially. Thus, in overall, there is increase in built-up area from 16.64 to 44.08%, reduction in open space from 43.09 to 7.38% and reduction in water body from 5.6 to 2.73% with reference to the total catchment area. As such, there is rapid increase in urbanization in the catchment. Though there is increase in urbanization, there is no proportionate provision in infrastructural facility such as network of storm water drainage system. Also there is encroachment (hutments) along the banks of the river obstructing the flow of the river. This is one of the main causes of flooding in the area.

4.2 Hydrological impact of LULC change and detention basin

In this study, flood peak discharge and flood hydrographs are generated at the outlet of the catchment to study the effect of LULC change. Hydrological modeling was performed for the storm intensities of 2-, 10-, 25-, 50-, 100- and 200-year return periods with land use conditions of 1966 and 2009 with 1-min time step. An attempt is also made to assess the impact of detention pond on the reduction in flood peak for the land use conditions of year 2009. Table 2 shows the results obtained for peak flow discharge at outlet of the catchment

Table 2 Peak discharge for different flow and land use conditions

S. no.	Return period storm event (year)	Peak discharge (m ³ /s) at outlet			% Change in peak discharge	
		LULC 1966	LULC 2009	LULC 2009 (with detention ponds)	1966–2009	2009—(With and without detention ponds)
1	2	252.60	305.40	272.70	20.90	10.71
2	10	579.10	639.50	512.50	10.43	19.86
3	25	804.40	862.90	653.50	7.27	24.27
4	50	1042.90	1097.30	790.50	5.22	27.96
5	100	1303.70	1345.10	926.40	3.18	31.13
6	200	1597.90	1639.60	1074.10	2.61	34.49

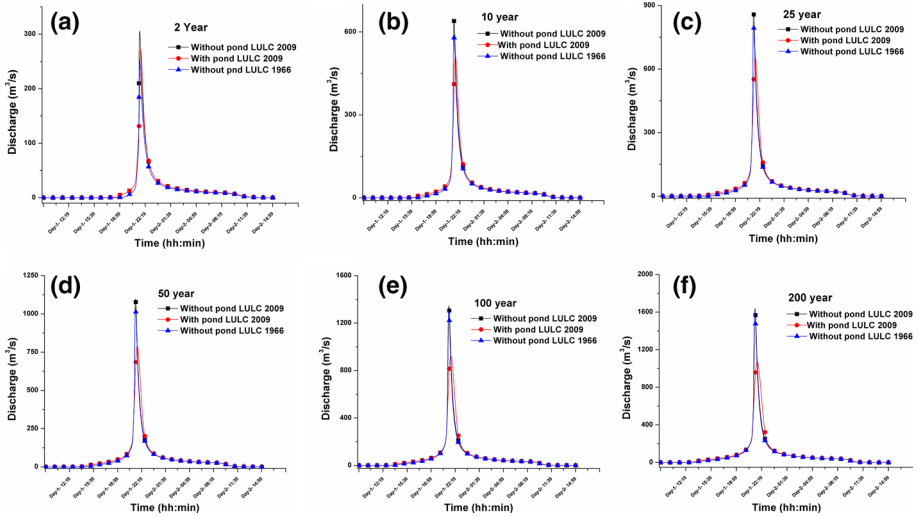


Fig. 6 Flood hydrographs at outlet a 2-year return period b 10-year return period c 25-year return period d 50-year return period e 100-year return period f 200-year return period

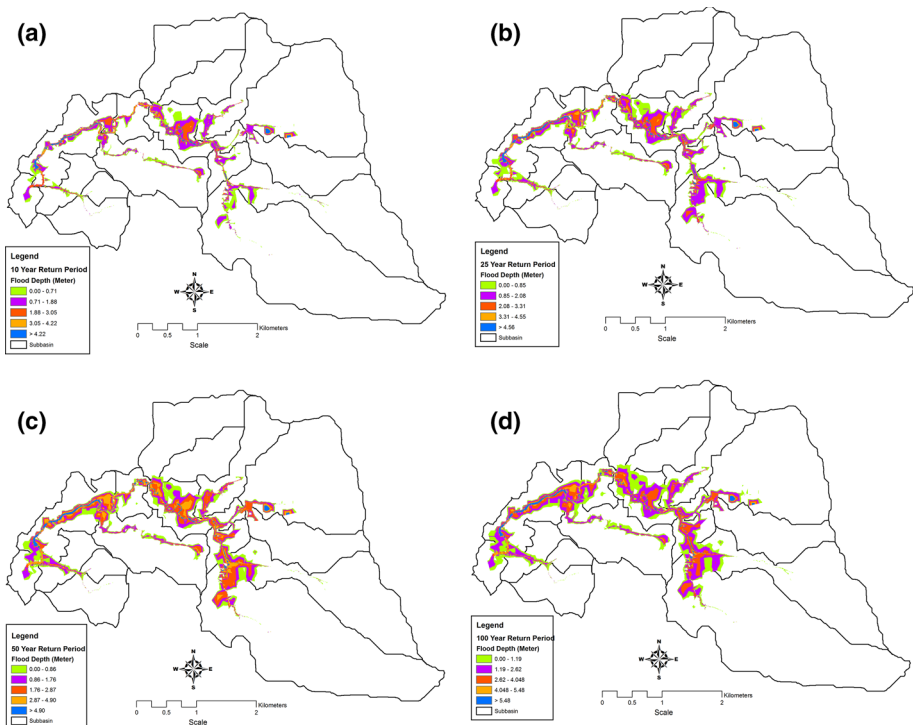


Fig. 7 Flood plain maps without considering detention ponds for LULC 1966 a 10-year return period b 25-year return period c 50-year return period d 100-year return period

for different return periods with land use conditions of 1966 and 2009. Table 2 also shows the results of peak discharges with provision of detention ponds for the land use conditions of the year 2009. The graphical representation of the flood hydrograph for different flow conditions with land use conditions of the year 1966, with and without detention ponds for the land use condition of the year 2009, is presented in Fig. 6.

From the above results, it can be observed that for the land use conditions of years 1966 and 2009, there is an increase in peak discharge of 20.9% at the outlet of the basin for a 2-year return period, whereas a 2.61% increase in peak discharge for a 200-year return period. Thus, for a lower return period, the increase in peak discharge exceeds the one for higher-year return period for the change in land use conditions between these 43 years. Here it is to be noted that present Mumbai city was formed by joining seven small islands. For Mumbai city water table is high as it is surrounded by sea from three sides. Due to high saturation level, there is less infiltration for higher return periods. These are the main causes for marginal increase in the percentage change in peak discharge for the higher return periods for the change in land use conditions (Zope et al. 2015, 2016; Zope 2016). For land use condition of the year 2009, the reduction in peak discharge at the outlet of the basin with and without considering the detention ponds for the 2-year return period is 10.71%, whereas for the 200-year return period, the reduction in peak discharge is 34.49%. Thus, there is substantial reduction in peak discharge for higher return periods with provision of detention ponds.

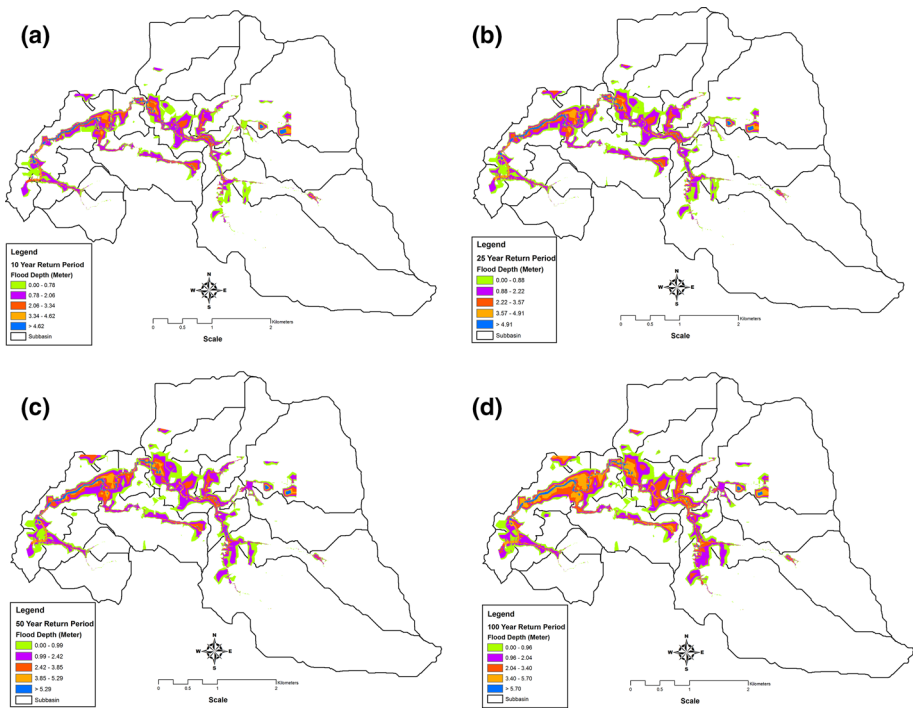


Fig. 8 Flood plain maps without considering detention ponds for LULC 2009 **a** 10-year return period **b** 25-year return period **c** 50-year return period **d** 100-year return period

4.3 Impact of LULC change and detention pond on flood plain

In the present study, flood inundation maps for LULC conditions of the years 1966 and 2009 without considering the detention ponds have been generated for 10-, 25-, 50- and 100-year return periods as shown in Figs. 7 and 8, respectively. Also the flood inundation maps for the land use condition of the year 2009 by considering the detention ponds have been generated for the 10-, 25-, 50- and 100-year return periods as shown in Fig. 9. Table 3 shows the flood inundation area with and without considering the detention pond for the land use conditions of the year 1966 and year 2009.

From the above results, it is revealed that for the LULC conditions of the years 1966 and 2009, there is increase in flood extent area by 42.5% for the 10-year return period, whereas 14.22% increase for the 100-year return period without considering the detention ponds. By considering detention ponds for land use condition of the year 2009, there is decrease in flood extent from 4.5 to 7.78% for the 10-year to 100-year return periods. Reduction in flood depth is also observed due to provision of detention ponds. Thus, provisions of detention pond reduce the flood plain extent as well as the flood depth.

4.4 Impact of LULC change and detention pond on flood hazard

In this study, the flood hazard maps for the land use condition of the year 1966 without considering detention ponds and for the year 2009 with and without considering detention

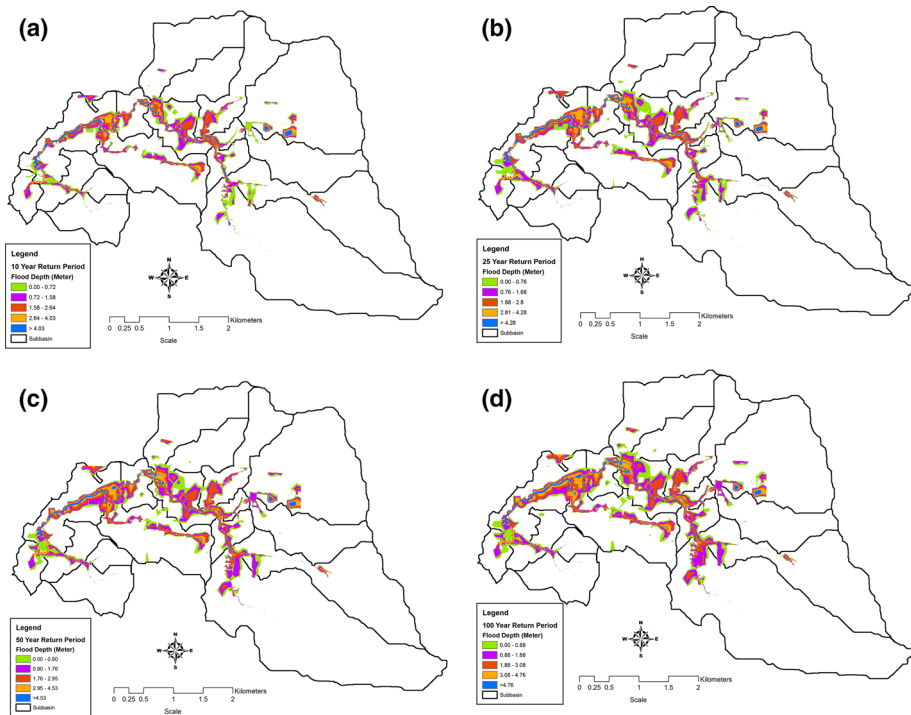


Fig. 9 Flood plain maps by considering detention ponds for LULC 2009 **a** 10-year return period **b** 25-year return period **c** 50-year return period **d** 100-year return period

Table 3 Flood plain extent area

S. no.	Return period storm event (year)	Flood plain extent area (km ²)			% Change in flood extent area	
		LULC 1966	LULC 2009	LULC 2009 (with detention ponds)	1966–2009	2009—With and without detention ponds
1	10	1.20	1.71	1.58	+42.50	−7.60
2	25	1.60	2.00	1.91	+25.00	−4.50
3	50	1.98	2.30	2.16	+16.16	−6.90
4	100	2.25	2.57	2.37	+14.22	−7.78

Table 4 Weightage for flood hazard map derived

S. no.	Description	Weightage
1	Raster—slope from river	0.50
2	Raster—distance from river centerline	0.40
3	Raster—distance from discharge point	0.10

ponds are derived. Flood hazard maps are derived by considering the maximum flood extent area, raster map generated for distance from the discharge point, slope from the river centerline and distance from river centerline to maximum flood extent boundary. The raster map was prepared in ArcGIS using the tool Euclidean distance and cost distance. All the maps were brought to one standard by using slice tool of ArcGIS by dividing the total area into 100 zones having a similar number of cells in each zone. The final flood hazard map was generated by performing weightage overlay analysis by assigning the weightages to each raster as given in Table 4. Delphi technique was used for assigning the weightages (Lee et al. 2013). Flood hazard maps generated for the land use condition of year 1966 are shown in Fig. 10a. Flood hazard map for the land use conditions of the year 2009 with and without considering the detention pond is shown in Fig. 10b and c, respectively. Table 5 represents the statement of flood hazard area with and without considering the detention pond for the land use condition of the year 1966 and year 2009. Flood hazard area is classified into very high, high, moderate, low and very low categories. Very high indicates the higher hazard and maximum vulnerability area.

From the above results, it is revealed that in the past 43-year period, the flood hazard area in very high zone is increased from 0.068 to 0.833 km²; in low hazard zone, area reduced from 0.56 to 0.24 km², whereas the total hazard area increased by 11.34% between these periods. Thus, there is substantial increase in flood hazard area from low to very high zone and also increase in flood risk. However, for the land use of the year 2009, with and without considering the detentions ponds, there is decrease in flood hazard area of very high zone by 16.26%, decrease in high zone area by 13.19% and decrease in very low area by 23.71%. There is total 14.92% decrease in hazard area due to provision of detention ponds. Thus, provision of detention ponds not only reduces the peak discharge, flood extent and flood depth but also reduces the flood hazard area and acts as one of the important flood control measures.

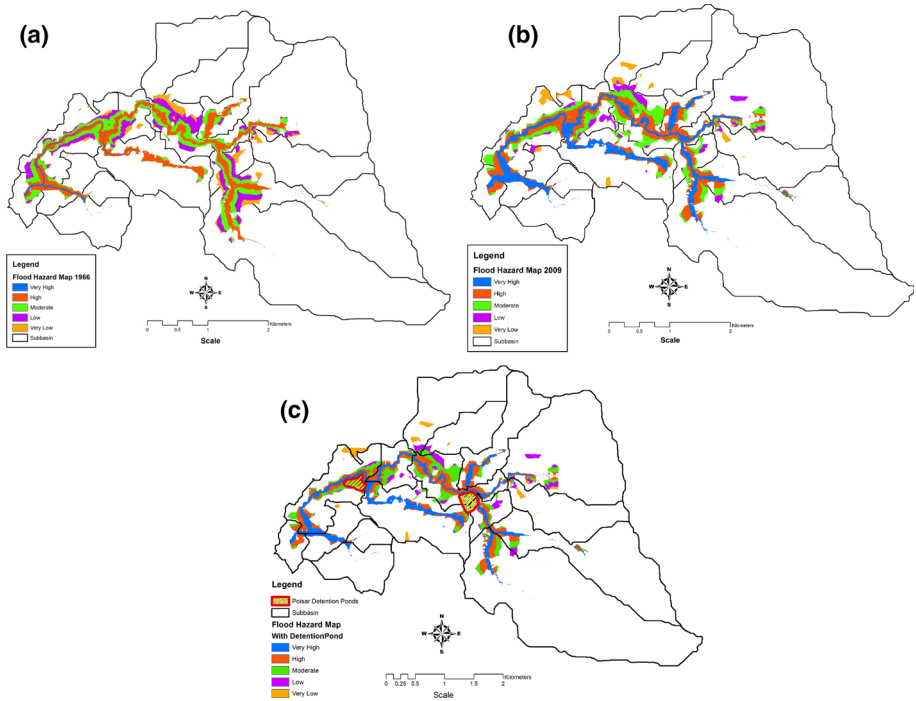


Fig. 10 Flood hazard maps **a** without considering detention ponds LULC 1966 **b** without considering detention ponds for LULC 2009 **c** by considering detention ponds for LULC 2009

Table 5 Flood hazard extent area for the study area

S. no.	Category of the hazard	Flood hazard extent area (km ²)			% Change in flood hazard extent area	
		LULC 1966	LULC 2009	LULC 2009 (with detention ponds)	1966–2009	2009—With and without detention ponds
1	Very high	0.068	0.833	0.697	+1125	−16.26
2	High	0.881	0.929	0.806	+5.46	−13.19
3	Moderate	0.799	0.660	0.556	−17.40	−15.79
4	Low	0.556	0.238	0.216	−57.19	−9.16
5	Very low	0.216	0.146	0.112	−32.41	−23.71
6	Total area	2.520	2.806	2.387	+11.35	−14.92

5 Conclusions

In the study area, effect of urbanization is the main reason for increase in the flood peak discharge and reduction in lag time. Due to rapid infrastructural development of the area, the natural places which were earlier being used as retention or detention ponds are now reclaimed to satisfy the need of urban dwellers. Also, Mumbai being a coastal city, there

are limitations on design of the drainage system. In this study, as per the LULC impact assessment between the years 1966 and 2009, there is increase in built-up land from 16.64 to 44.08% and reduction in open spaces from 43.09 to 7.38% with reference to the total catchment. Due to the impact of urbanization between these 43 years, there is increase in peak discharge from 2.61 to 20.9% for return periods of 200 to 2 years. Further, an attempt has been made to investigate the hydrological impact of provision of detention ponds on the peak discharge, flood plain extent and flood hazard extent area. It is revealed that by provision of detention ponds, there is substantial reduction in the peak discharge, flood extent and flood hazard extent area. The flood plain and flood hazard maps generated in this study will be useful to the Municipal Corporation for flood mitigation, preparedness and management planning. The flood hazard maps will be also useful to insurance organizations to decide the criteria of premium for the structures concerned in the flood and hazard zones.

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