Application of Geo-Spatial Technique for Flood Inundation Mapping of Low Lying Areas

Dhruvesh P. Patel and Prashant K. Srivastava

Abstract Flooding is one of the severe disaster causes mass demolition of properties and affected human lives. In hazardous flood of year 2006, 90–95 % of Surat city, India, was under water and so that local planner as well as decision makers need accurate information on the spatial distribution, magnitude, depth of flooding and land use affected by such floods. Surat city is majorly partitioned into seven different zones named north zone, east zone, central zone, south zone, south-east zone, south-west zone, and west zone. Purpose of this study is to determine inundation of water in low laying areas of west zone. By procedure of Geo-reference along with Ground Control Point (GCP) and GPS points, 0.5 m interval contour map for west zone is introduced. Digitization of contour through GIS software and Digital Elevation Model (DEM) of West Zone through ArcGIS software is carried out. Probable submergence area for rescue work is also scrutinized. Graph of submergence area of West Zone according Town Planning Scheme (TPS) versus water level and flood Inundation map are generated which specify that West Zone and its TPS are low lying areas in Surat whose 20–25 km^2 area will be submerge when water level exceeds 12 m height (MSL). The accuracy and validation of DEM is calculated by comparison with actual observed data at the time of flooding.

Keywords Digital elevation model · Flood · Inundation mapping · RS & GIS · Vulnerability

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1 Introduction

Flood is defined as extremely high flow of water from river, lake, pond, reservoir or any other water body, wherein water inundates outside of the water body area. Flood may also occurs when the sea level rises extremely or above the coastal lands due to tidal sea and sea surges. The flooding of homes, industrial areas, and amenities in recent years, along with an appreciation of the likely consequences of climate change, has brought the issue of flooding to the attention of the media and the general public (Wright et al. 2008). On the global scale, storms and floods are the most destructive of natural disaster and cause the greatest number of deaths and property loss (Casale and Margottini 1999; Sadrolashrafi et al. 2008). Flooding and flash flooding poses serious hazards to human populations in many parts of the world. Surat, the study area, is one of the cities of state Gujarat, India and has been frequently affected by flood in river Tapi. Due to augmented industrialization in and around Surat, the population is reached up to 50.64 lakh in year 2011 which was 28.76 lakh in year 2001. Surat has experienced three major flood events in recent past in year 1994, 1998 and 2006 which caused heavy loss of property and human lives. In year 2006, large amount of water spilled from low rise river sections resulted into flood and 90–95 % Surat city was under submerge up to 4–5 m (Patel and Dholakia 2010; Joshi et al. 2012; Patel et al. 2012b). This unprecedented flood in Surat caused damages of over Rs. 21,000 crores approximately.

High resolution, high accuracy topographic data sets are becoming increasingly available for flood prediction studies in a number of countries (Bates et al. 2003). Remote Sensing, Geo graphical Information System and Global Positioning System has been demonstrated to be a useful tool in mapping flood extent (Horritt and Bates 2001; Horritt et al. 2001) and hence for validating numerical inundation models (Horritt and Bates 2002). Various methodologies or approaches have been adopted by researchers in relevant flood research in the period 1997–2010 (Islam and Sado 2000; Kresch et al. 2002; Pistocchi and Mazzoli 2002; Sutanta 2002; Tralli et al. 2005; Wright et al. 2008; Andrysiak and Maidment 2000). Flood inundation models commonly require four key data items: (1) topographic data to construct the model grid; (2) bulk flow or stage data to provide model inflow and outflow boundary conditions; (3) an estimate of the effective friction parameter for each model cell; and (4) a source of validation data (Wright et al. 2008). The elevation information in a digital format using image matrix in which the value of each pixel is associated with a specific topographic height is called DEM, is a computerized representation of the Earths relief in 3D (Patel and Dholakia 2010; Patel et al. 2012a, b). Triangulated Irregular Networks (TIN), regular grids, contour lines and scattered data points (Sulebak 2000) are some methods usually used for generating DEM.

Using DEM as an input, flood risk map, flood hazards map, geomorphologic map, Vulnerability analysis, damage estimation and risk assessment, hydraulic modeling, flood inundation and storm-tide flood-inundation maps can be generated

(Islam and Sado 2000; Kresch et al. 2002; Pistocchi and Mazzoli 2002; Sutanta 2002; Tralli et al. 2005; Wright et al. 2008; Andrysiak and Maidment 2000; Patel and Dholakia 2010). Two-dimensional flood inundation models are widely used tools for flood hazard mapping and an essential component of statutory flood risk management guidelines in many countries (Neal et al. 2012). Noman et al. (2001, 2003), Agnihotri and Patel (2008), Patel et al. (2012a) also described the two primary inputs to any automated floodplain delineation process in 3D, which are creation of a water surface using Geo-referenced water level points and DEM. The flood depth map is obtained by subtracting the DEM from the water surface.

Generation of DEM, flood inundation map and submerge area of West Zone (Stage-area submerge curve) are prepared and also verified in this study.

2 Study Area and Datasets

2.1 Tapi Basin

Tapi is the second largest westward draining inter-state river after mighty Narmada, having its source at Multai, Betul district, Madhya Pradesh, India. The Tapi basin is the northern most basin of the Deccan plateau and is situated between North latitudes 20–22°N and East longitude 72–78°E approximately (CWC 2000–2001). Tapi basin is basically divided into three zones, viz. Upper Tapi Basin (UTB), Middle Tapi Basin (MTB) and Lower Tapi Basin (LTB). The river has a total length of 724 km, out of which the last lap of 214 km is in Gujarat state and it meets an Arabian Sea in the Gulf of Cambay approximately at 19.2 km west of Surat city. Tapi covers an area of, approximately, 51,504 km^2 (79 %) in Maharashtra, 9,804 km^2 (15 %) in Madhya Pradesh and 3,837 km^2 (6 %) in Gujarat state.

2.2 Surat City

Surat is situated between latitude 21°06′N–21°15′N and longitude 72°45′E–72°54′E, on the bank of river Tapi and having coastline of Arabian Sea on its west. Surat falls in Survey of India map number 46C/15, 16. Tapi River and Surat city with zone boundary is shown in Fig. 1. Surat city lies at a bend of the river Tapi, where its course swerves suddenly from the south-east to south-west. From the right bank of the river, ground rises slightly towards the north but the height above Mean Sea Level (MSL) is 13 m. The topography is controlled by the river which is flat in general but having gentle slope from north-east to south-west.

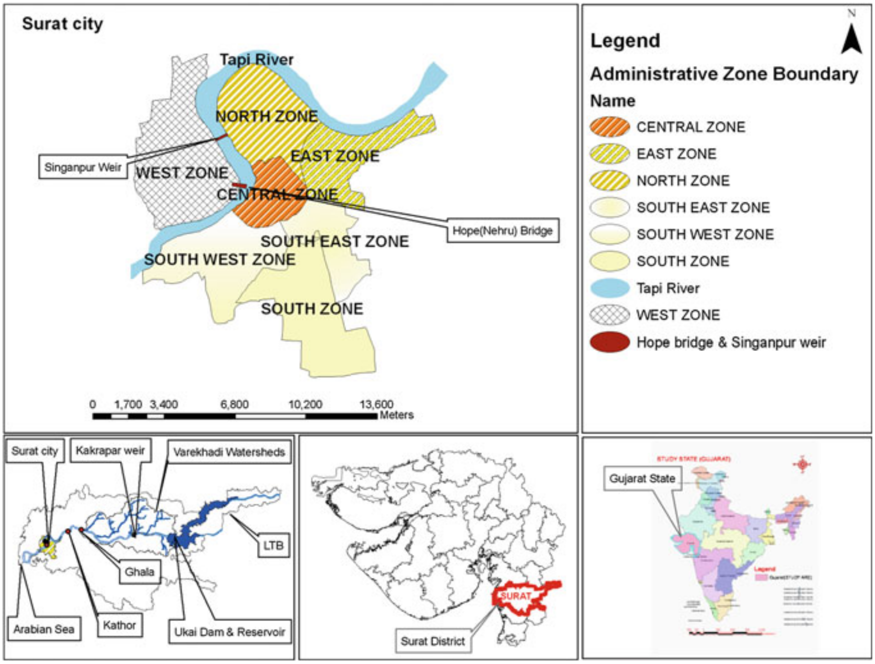

Fig. 1 Location map of LTB, Ukai dam, Varekhadi watershed, Kakrapar weir, Ghala, Kathor, Singanpur weir, Hope (Nehru) bridge, Surat city with administrative zone boundary

2.2.1 Geology and Soil Conditions

Study area can be divided into two geomorphic units namely, coastal and alluvial. The coastal area represents marshy shoreline with an extensive tidal flat stretch intercepted by estuaries. Alluvial deposited by Tapi has formed the alluvial area which is covered by recent alluvium of quaternary age. The alluvial plain is characterized by flood plain of the Tapi and Mindhola River where there is a thick alluvial cover. The alluvial plain merges into a dry, barren, sandy coastal area. The coastal area around the river is covered by mud. The alluvium consists of sand and clay layers.

2.2.2 Ground Water Table

Pre and post monsoon water levels of different open wells in and around Surat during year 1970–2006 indicated that an average rise in water level is about 1.85 m and average standard deviation of rise in water level is about 0.93 m. The ground water level generally rises 2–5 m during monsoon period (June–October) while during the rest of the year, it drops down to 5 m and even up to 10 m at some locations.

2.2.3 Climate

The climate of Surat can be broadly divided into four seasons namely summer, rainy, autumn and winter. Duration of summer season is of 3 months, from March to May, rainy from June to September, autumn in October–November and winter from December to February.

2.2.4 Temperature and Rainfall

Summer season in study area is quite hot with temperature ranges from 37.78 to 44.44 °C. The climate is pleasant during the monsoon while in autumn it is temperate. Winter is not so cold but the temperature in January month ranges from 10 to 15.5 °C. The average annual rainfall of the city is 1,143 mm.

2.2.5 Demography/Population in the Study Area

With the beginning of 20th century, Surat had started developing its sub-urban areas namely Udhna, Athwa, Fulpada etc. along with the various corridors opened up through various gates in the radial pattern. The city was originally established on the south-eastern bank of the river Tapi with a castle at the eastern bank and a custom house at the northern side of the castle. In the beginning, the activities were concentrated within the inner wall which had been constructed in year 1664. At that time, the area of the city within this inner wall was 178 hectors. The evolution of the city from 1494 to 2004 AD is shown in Fig. 2.

2.3 Hydraulic Structures at LTB

The LTB contains hydraulic structures namely Ukai dam, Kakrapar weir and Singanpur weir. Details of these structures are as under.

2.3.1 Ukai Dam

The Ukai dam is located about 30 km U/S of the Kakrapar weir and about 95 km U/S of Surat city, originally approved by the planning commission of government of India in 1969 and the construction of the dam was completed in 1973 (Fig. 3). The Ukai reservoir at its FRL of 105.15 m (345 ft.) has a live storage capacity of 7,369 Mm^3 with water spread of about 600 km^2 and maximum length of about 112 km. The reservoir is expected to attain Maximum Water Level (MWL) of 106.99 m (351 ft.) while passing the Probable Maximum Flood (PMF) of 59,747 m^3/s (21.16 lakh cusecs). Ukai dam is a composite dam with a maximum

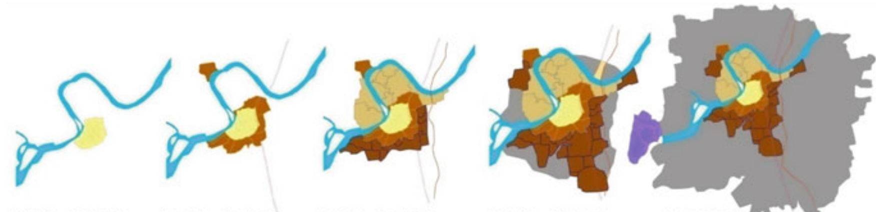

Fig. 2 Evolution of Surat city from year 1494 to 2004 (*Source* SMC, vision 2020)

Fig. 3 Ukai Dam

height of about 80.7 m above its deepest foundation level. The total length of dam is 4,927 m, out of which 4,058 m is earthen dam of zoned fill type. Masonry gravity dam, including the 425 m long spillway and the power dam occupies the remaining length. The spillway, located in the left bank of the river, is provided with 22 no. of radial crest gates of 15.55 m × 14.78 m (51 ft. × 48.5 ft.) size. The maximum discharge capacity of the spillway at its MWL is 46,270 m^3/s (16.34 lakh cusecs) while the corresponding discharging capacity of the spillway at FRL is 37,860 m^3/s (13.37 lakh cusecs). The power house, located at the toe of the dam on the left side of the spillway, is equipped with four units of 75 MW each and generally operates as a peaking station. The water released from the dam to powerhouse is picked up at the Kakrapar weir in downstream for firming up the irrigation in the Kakrapar canal system. For the purpose of flood protection and moderation, a reservoir operation schedule is prepared by CWC, New Delhi, for the monsoon period. The overall behavior of Ukai dam in last 34 years during the flood in river Tapi, is shown in Fig. 4. The massive flood years are 1959, 1968, 1978, 1979, 1994, 1998 and 2006. Ukai reservoir provides protection against heavy floods to an area of 827 km^2 on the downstream (D/S). Later, by constructing the flood embankments on both the banks of the river Tapi, between Kathor and Surat, it provides protection to an additional area of 230 km^2. Thus, the Ukai reservoir and the flood embankment, together provide protection to

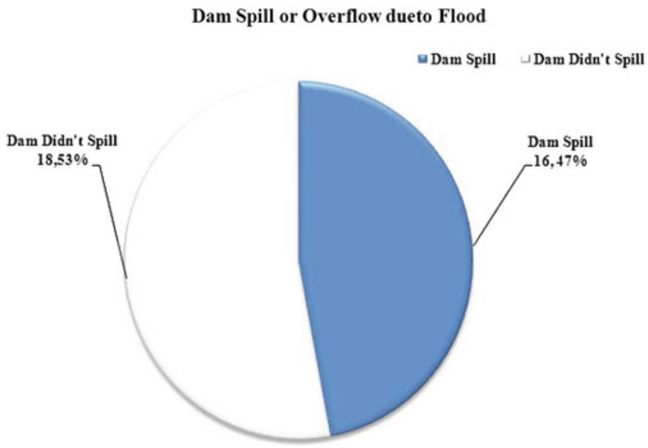

Fig. 4 Behavior of Ukai Dam

1,057 km^2 of land area, saving approximately 2 million inhabitants residing in greater Surat region around river banks. Flood embankments are designed for uniform river discharge of 24,069 m^3/s (8.5 lakh cusecs). The Safe carrying capacity of river at Surat is estimated to be 11,326 m^3/s (4.0 lakh cusecs).

2.3.2 Kakrapar Weir

The scheme comprises of an Ogee shaped masonry pick up weir constructed across the Tapi River near Kakrapar, Surat district, Gujarat. Kakarapar weir (Fig. 5) is situated 30 km away from Ukai dam at D/S and is built for irrigation purpose in nearby area. It is 621 m long with 14 m height and having catchment area about 62,801 km^2. It leads a maximum discharge of 38,228 m^3/s from its Ogee type of spillway. The weir is having 442 km^2 reservoir area, where the gross storage capacity is 51.51 Mm^3 and the effective storage capacity is 36.51 Mm^3. Two canals take off from right and left bank of weir by canal head regulating work. Right canal is 219.74 km (including main canal, branches canal, minor and major distributaries) long and having the discharge caring capacity 70.23 m^3/s (main canal). It covers the gross command area of $100{,}220 \times 10^4$ m^2 and culturable command area of $58{,}745 \times 10^4$ m^2. Same way, the left canal is 296.91 km (including main canal, branches canal, minor and major distributaries) long and having the discharge caring capacity 85.63 m^3/s (main canal). It covers the gross command area $247{,}000 \times 10^4$ m^2 and culturable command area $145{,}335 \times 10^4$ m^2. This project was commissioned in the year 1954 as stage-I of the Ukai project-3.

Fig. 5 Kakrapar Weir

Fig. 6 Singanpur Weir

2.3.3 Singanpur Weir

Singanpur causeway (Fig. 6) cum weir was constructed in 1995 with cost of Rs. 31 crores on river Tapi near Singanpur–Rander village. The length of bridge is 580 m, out of which, 98 m is gated portion and the remaining is ungated. The bridge has 16 span and length of each span is 6.20 m. Length of retaining walls is 80 and 100 m for left and upper side respectively. The design discharge of the weir was estimated as 680 m^3/s (24,000 cusecs) with designed HFL of 16 m in U/S and 14 m in D/S. The foundation of the bridge is open integrated and substructure with reinforced cement concrete abutments and piers.

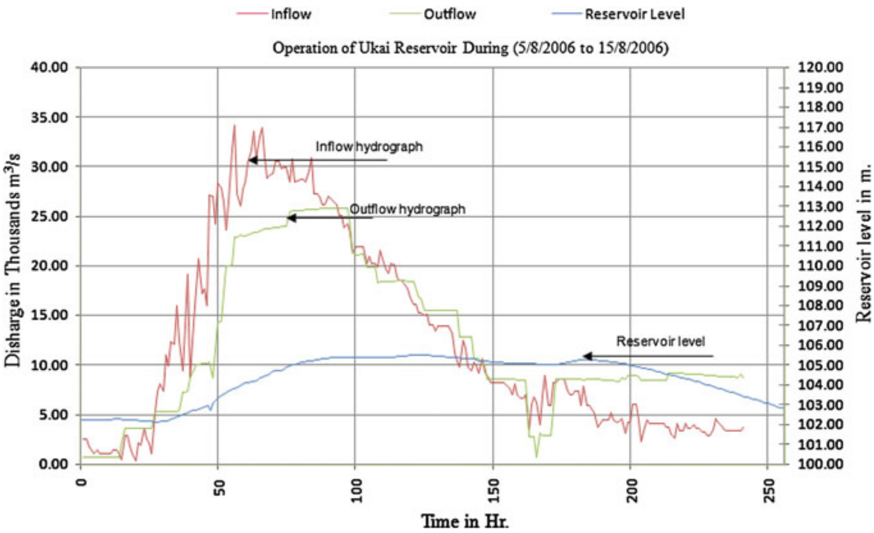

Fig. 7 Operation (inflow/outflow) of Ukai reservoir, 2006

2.4 Flood Event 2006

2006 flood had created disaster in Surat city and surrounding areas which falls in semi-arid and arid agro-climate region. Flood event during 7–14th August in year 2006, resulted in mass devastation of lives and belongings damage worth INR 21,000 crores in Surat and Hazira twin city. For several weeks, whole society was lifeless and many diseases were reported in city (Patel and Srivastava 2013). Operation of Ukai reservoir during 5 days of August, 2006 is shown in Fig. 7. As indicated in graph, the water level rise continuously from 102.108 m (335 ft.) to 105.344 m (345.62 ft.) as maximum, after 4 days. The Ukai reservoir was having large catchment area and due to constant inflow, the large volume of water accumulated in it. The graph shown indicates that on 7th August, compare to inflow, water released from dam was very less, almost half. The dam operation during 10 days of August 2006, combining inflow–outflow and reservoir level, is shown by hydrograph. The inflow in the dam was continuously fluctuating for first 20 h from 05/08/2006 and then suddenly rose up to 16,423 m^3/s (5.8 lakh cusecs), whereas the outflow from the dam was below 5,663 m^3/s (2 lakh cusecs) for that period. Next 36 h, from 07/08/2006 afternoon, were very critical and during that period the inflow touched to 33,980 m^3/s (12 lakh cusecs) which is the maximum in the recent flood history and to manage the situation, the water released from the dam was about 25,768 m^3/s (9.1 lakh cusecs) for 24 h (Table 1). The inflow was then down to 12,742.42 m^3/s (4.5 lakh cusecs) and out flow was maintained almost same.

Table 1 Flood Event, 2006

Date	Time	In-flow (m^3/s)	Out-flow (m^3/s)	Reservoir level (m)	Level at Nehru Bridge (m)
5-8-2006	8.00 a.m.	2,434.03	670.08	102.19	6.50
	8.00 p.m.	1,374.88	669.40	102.26	7.40
6-8-2006	8.00 a.m.	2,126.20	3,537.29	102.14	8.40
	8.00 p.m.	9,350.56	7,214.47	102.56	9.14
7-8-2006	8.00 a.m.	24,172.10	11,581.56	103.46	9.88
	8.00 p.m.	30,374.50	23,107.28	104.21	11.70
8-8-2006	8.00 a.m.	29,821.20	23,901.73	104.97	12.35
	8.00 p.m.	27,225.40	25,768.01	105.32	12.85
9-8-2006	8.00 a.m.	24,238.90	24,069.02	105.34	12.90
	8.00 p.m.	20,149.10	18,405.72	105.38	10.80

2.5 Data Collection

For this research work, Geo-coded Indian Remote Sensing (IRS-1D) satellite image of the study area for April 2005 from BISAG, Gandhinagar is used. Topographical sheets with the scale of 1:50,000 are collected from SOI, Ahmedabad. High resolution Google-earth images (http://earth.google.com) of the study area are downloaded for thematic maps creation. Physical measurements for the river hydraulic parameters after monsoon 2006 is collected from Surat Municipal Corporation (SMC) while the contour maps for various zones of the city at 0.5 m interval are generated using ArcGIS 9.2 software from the topographical sheets. Trimble Geo explorer XT global positioning system is used to survey the West Zone area of Surat City. In T.P. roads of West Zone and on left-right embankments of River Tapi, field survey has been performed. The water level and river discharge data from hourly to daily scales at Nehru Bridge are collected from CWC, SWDC and Irrigation department. Zonal map of the city is collected from SMC.

3 Methodology

At an early stage, ERDAS 9.1 software, Geo-referenced by ArcGIS 9.2, is used to combined image pieces of study area taken from Google-Earth. Counter map is then Geo-referenced over downloaded images (Fig. 8) and after that spatial adjustment is applied for precision. Digitized counters of 0.5 m interval through GIS software (Fig. 9) and GPS point data are integrated (Fig. 10). Temporal and spatial data are linked using GIS as well as customized Data Base Management System (DBMS). Digitized counters are then converted into TIN model using 3D analyst tool which is finally converted into DEM using spline interpolation method

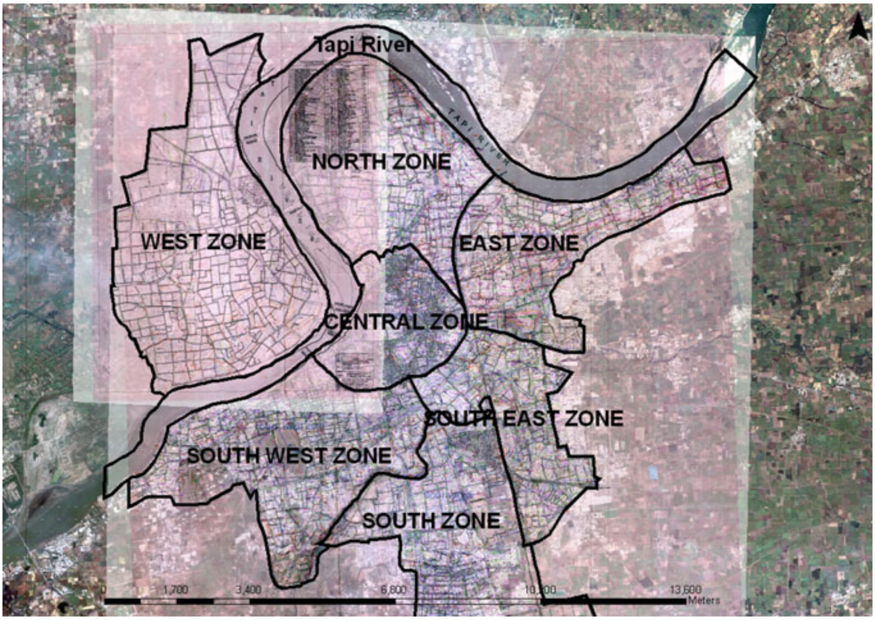

Fig. 8 Geo-referenced contour maps over Google earth image

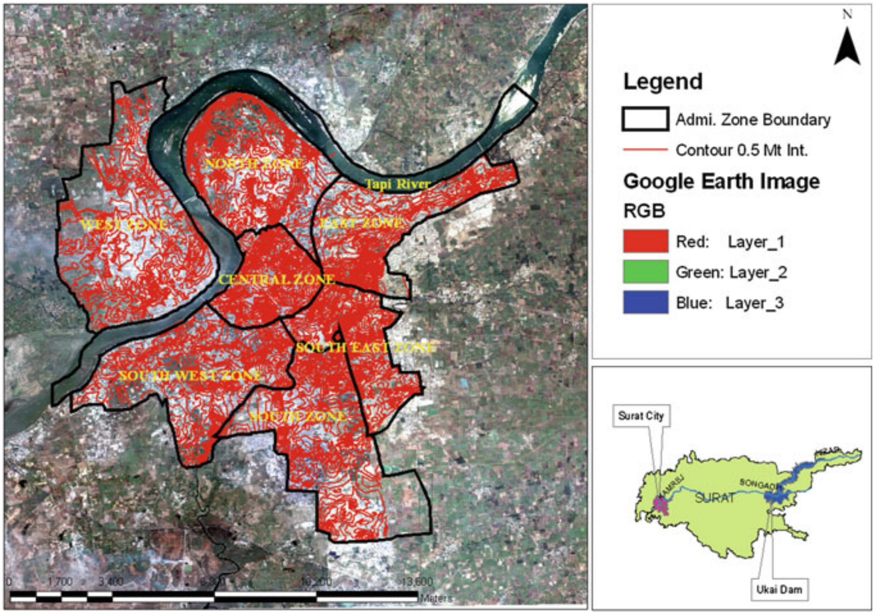

Fig. 9 Digitized contour overlying on Google earth image of Surat city

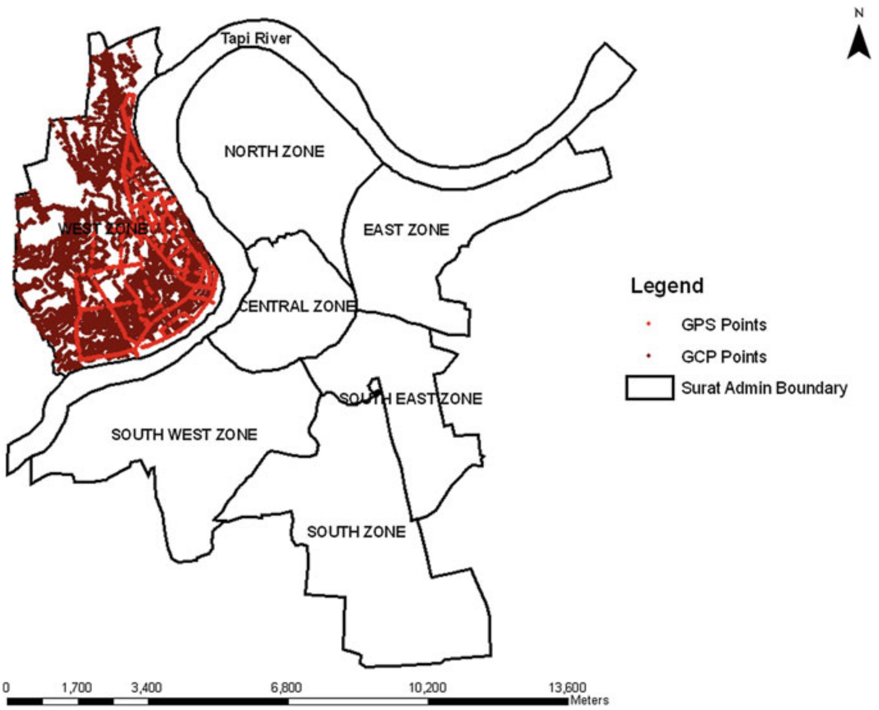

Fig. 10 GPS points and digitized contour (*GCP*) of west zone area

(Fig. 11). To find submerge areas in West Zone surface analysis is done using again 3D analyst tool. Arcscan is then applied for better visualization. For various flood potential values, areas are delineated and findings are analyzed from thematic flood inundation map for West Zone. Graph of submergence area of West zones according Town Planning Scheme (TPS) versus water level is then prepared.

4 Results and Discussion

As discussed earlier, DEM of the West Zone was generated by GPS points and collected contour map of 0.5 m interval. By considering the safe river gauge level of 7.55 m with reference to lowest bank height near Hope bridge and by applying this limit to DEM of the study area, flood inundation map is generated and shown in Fig. 12. The whole zone is segregated into 4 levels of submergence started with V1 (0–4 m RL) for very high inundation covering 0.16 km^2 area, V2 (4–8 m RL) for high inundation covering 15.15 km^2 area, V3 (8–12 m RL) for medium inundation covering 8.13 km^2 area and V4 (12 m and above) for low inundation covering 0.03 km^2 area. During the flood event 2006, observed river gauge level

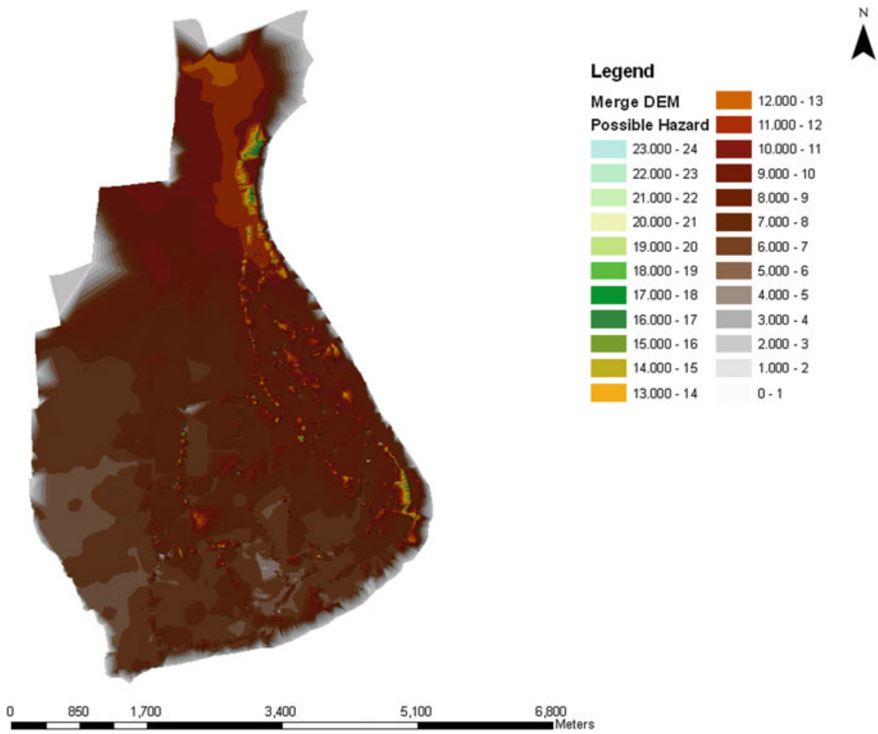

Fig. 11 Mearge TIN-DEM of west zone

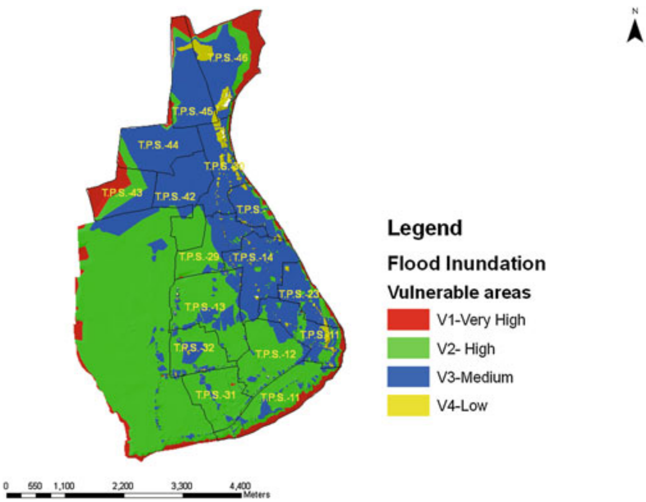

Fig. 12 Flood inundation and possible vulnerable areas of west zone Surat city

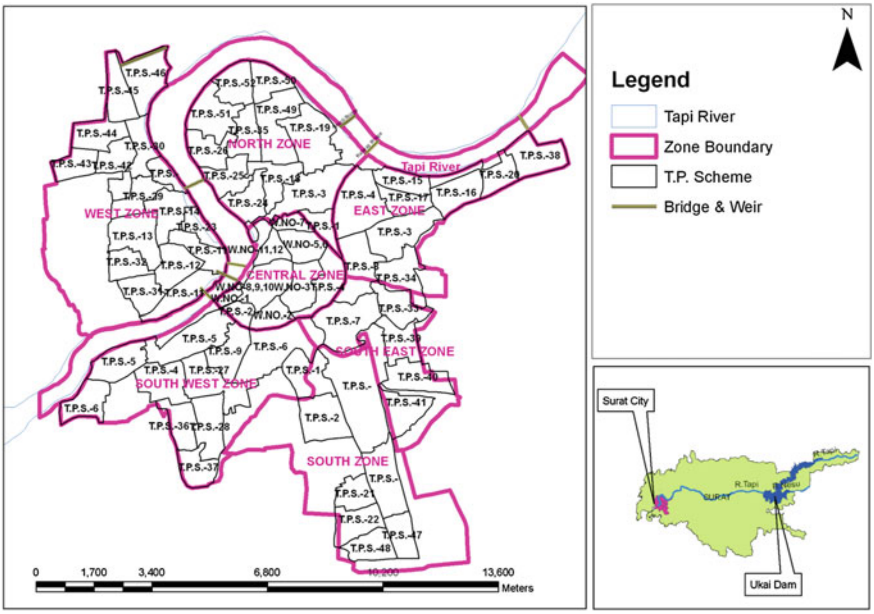

Fig. 13 Surat city map according to town planning scheme (*TPS*)

near Hope Bridge was 12.50 m. Flood inundation map indicates that areas of West Zone having reduced level above 12.50 m are safe and can survive under the same flood conditions. By comparison of the observed and calculated water levels of 2006 flood at Hope (Nehru) Bridge, it is found that the maximum water surface level in the west zone was at 4.91 m. This value is derived by subtracting lowest bank Reduced Level (RL), having value 7.55 m from 12.50 m river gauge level at Hope Bridge. For the forthcoming flood event, prediction of possible submergence can be done with reference to river gauge level, if the other conditions will remain same. By this comparison, graph of stage versus submerge areas for various TPS schemes of West Zone is plotted in which slopes of curves represent the flood inundation. In West Zone, foremost areas are Rander, Adajan, Jahagirabad-Pisad and Jahagirpura. These four renowned areas falls under different town planning scheme as intensify improvement of West Zone. Adajan was developed under TPS No. 11, 11S, 12, 13, 14, 31 and 32, Rander was developed under TPS No. 14, 23, 29 and 30 (Fig. 13, Table 2) while Jahangirabad is in TPS No. 42, 43, 44 and 45. Area of Adajan which falls under T.P. Scheme No.13 is having steep slope and it is a low lying area of this zone. Its 2.0 km^2 area was submerged when water level increased from 6 to 9 m. Similarly, area falling under TPS No. 11 S was affected at 8 m water level. Rander–Adajan area which belongs to TPS No. 14 is also a low level area and was affected by flood even at water level of 9–12 m and its 1.46 km^2 (Fig. 14) area was in submerge. Jahangirabad–Pisad, falls under T.P. Scheme No. 45, is developed at higher contour level and was affected when water

Table 2 Inundation area (m^2) of west zone as per the water level in m

Level in m	TPS no															
	Rander	T.P.S 11	T.P.S 11 S	T.P.S 12	T.P.S 13	T.P.S 14	T.P.S 23	T.P.S 29	T.P.S 30	T.P.S 31	T.P.S 32	T.P.S 42	T.P.S 43	T.P.S 44	T.P.S 45	T.P.S 45
	Rander	Adajan	Adajan	Adajan	Adajan	Rander-Adajan	Rander	Rander	Rander	Adajan	Adajan	Jahangirabad	Jahangirabad	Jahangirabad	Jahangirabad-Pisad	Jahangirpura
4	0	0	0	0	0	0	0	0	0	17,457	0	0	0	0	0	0
5	0	0	0	13,159	669	0	0	0	0	76,424	0	0	0	0	0	0
6	0	0	389,877	114,294	92,399	0	0	0	0	385,478	14,881	0	0	0	0	0
7	0	99,790	832,803	849,146	1,133,808	0	0	191,337	0	861,850	683,174	140,477	0	0	0	0
8	162,467	676,244	903,728	1,237,966	1,993,392	0	208,709	859,829	0	1,001,982	854,180	604,284	0	0	0	0
9	426,419	1,062,928		1,274,932	2,008,571	1,405	644,819	1,155,299	0			639,004	34,616	82,412	0	0
10	537,733	1,067,319				492,826	656,175		52,787			1,063,564	44,058	892,910	0	0
11	547,591					1,461,898			289,565			1,153,472		1,013,890	769,184	454,783
12						1,462,655			498,500						916,723	860,154
13									923,073						917,658	889,874
14									1,213,437							

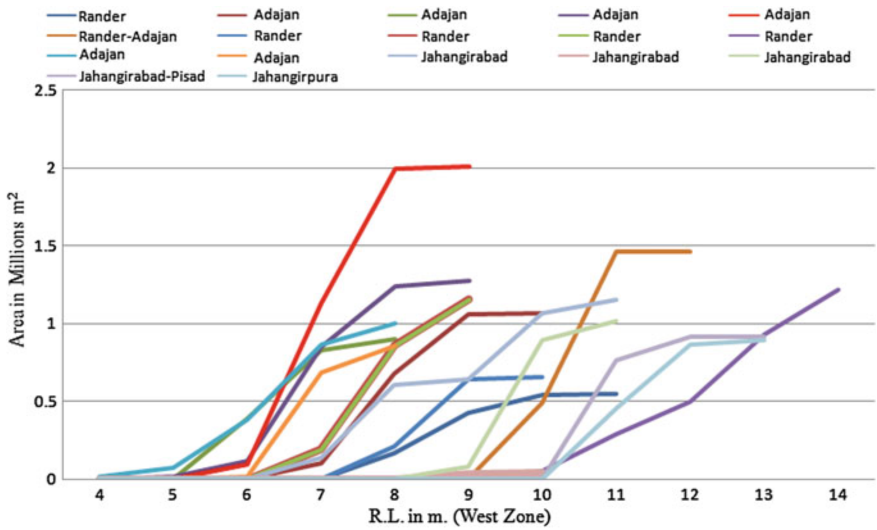

Fig. 14 Stage-area submerge curve of west zone and its TPS of Surat

level reached to 11 m. As per analysis, its about 0.92 km^2 area was in submerge. Jahngirpura follows the same characteristics as of Jahngirabad and is also a high rise area. At 13 m water level, its about 0.88 km^2 area was under water. According to the graph, Rader, Adajan are low laying areas in West Zone and for water level of 12.50 m, they were fully submerged. Comparison of this graph with the actual flood event 2006 shows that 90–95 % areas of the West Zone were submerged under water, which ultimately justify the obtained flood inundation map. It should be noted that the major parts of Adajan area, a part in the West Zone, was under water with water depth about 2–4 m.

5 Validation

For validation, Rander area is considered as case. Calculated data of inundation using software and actual observed field data are compared. As described in result, rander area was started to get affected from 4 m level and gone into submerge as level augmented. At LIC office, Rander branch, observed level was 3.65 m (12 ft.). DEM results shows that the reduced level of Rander was 8.5 m and observed gauge height at Nehru Bridge was 12.50 m and the difference between these heights is 4.0 m. For cross verification, the photographs of LIC office, Rander branch are used which indicates that the water height was about 12 ft. Noted reduced level of river section near Nehru bridge is 7.59 m. Thus, it is clear that the prediction for possible submergence of West Zone by DEM is nearby to actual observed field data.

6 Conclusion

GIS provides supplementary data in Hydrology for analysis while Digital Elevation Model (DEM) can be effectively used for simulation to get a complete model of the area. The analysis shows that West Zone is highly flood prone zone. Consequence of flood inundation was that 90–95 % area of West Zone, Surat, was under water. A steep slope in Stage-area submerge curve represents high potential of inundation while gentle slope represents a low potential. As West Zone is having low RL, it has more chances to get flooded severally. As per TPS, Rander and Adajan are low rise areas and will go under submerge at initial level of flooding. Certainly, application of Geo-spatial techniques such as RS, GIS and GPS would be the most efficient for flood inundation mapping.

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