

Floodplain Delineation Using HECRAS Model—A Case Study of Surat City

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Abstract

Surat city, the commercial capital of Gujarat state, India is situated at latitude 21° 06' to 21° 15' N and longitude 72° 45' to 72° 54' E on the bank of river Tapi and is affected by flood once in every five years since last hundred years. Present study describes the application of HEC-RAS model with integration of GIS for delineation of flood plain. Digital Elevation Model (DEM) of Surat city is used as main input for flood inundation mapping. River section near Nehru Bridge is used as sample case to simulate flood flow. Discharges equal to food return period for 25 and 32 (worst flood year) have been used for investigation of flood scenario. Outcome of the research clearly indicates that most of the area of the Surat city is submerged for a depth of 2.5 to 4.0 m when the discharge released from Ukai dam equals to return period of 32 years (25768.09 Cumecs).

Keywords

Surat, Flood, River Tapi, Return Period, HEC-RAS

1. Introduction

Flood is one of the serious natural hazards in the world. On the global scale, storms and floods are the most destructive of natural disasters and cause the greatest number of deaths [1]. Intense rainfall, drainage congestion, imperviousness of ground surface, and bank erosion are primarily responsible for causing flooding [2]. In India about 400,000 square kilometres of land is flood prone, which is about 12% of the total geographical area of 3,280,000 square kilometres. About 120,000 square kilometres of the flood-prone land has been provided with some reasonable protection against floods by providing flood embankments, drainage channels, etc. [3]. Various hydraulic parameters like velocity, slope and others like channel roughness are the most important because they are highly variable as they depend on factors like channel irregularities and alignment, surface roughness, vegetation cover [4]. Obstruction in river, changes in shape and size of river along with its length, sedimentation, bed

load are also affect to predict discharge [5]. Applying GIS techniques, flood visualization can be easily generated which could be useful for flood mitigation and planning of the basin. HEC-RAS and HEC-GeoRAS models are very useful and have the capability for generating flood delineation and estimating hydraulic parameters [6].

2. Study Area

The Tapi originates from Multai in Betul district of Madhya Pradesh, India at Latitude $20^{\circ}07'$ to $22^{\circ}N$ and Longitude $72^{\circ}41'$ to $78^{\circ}12'E$. The river has a total length of 724 kilometers, out of which the last lap of the 214 kilometers is in a Gujarat state and ultimately meets the Arabian Sea in the Gulf of Cambay approximately 19.2 kilometers west of Surat [7]. The portion between Ukai Dam and Arabian Sea is known as Lower Tapi Basin (LTB), consisting of Surat city. The Tapi river basin in Gujarat, encompassing an area of about 65950 square kilometers [8] covers parts of Surat district. The topography in LTB comprises narrow valley and a gently sloping ground [9]. The LTB receives an average annual rainfall of 1376 mm, and these heavy downpours along with reducing discharge carrying capacity of the river sections, encroachment, and siltation result into devastating floods in and around the fastest growing city Surat. The average slope of the river in LTB is 1 in 1760; the river enters the flat and fertile lands of Gujarat, low banks near Nehru Bridge causes periodic overflow resulting in extensive flood damages. In 1978 Surat Urban Development Authority (SUDA) was established including Surat Municipal Corporation (SMC) area, covering a total area of 722.00 square kilometers. The city is divided into seven zones namely the West zone, the South-West zone, the South-East zone, the South zone, the Centre zone, the East zone and the Centre zone. The map of Surat city with zone boundaries, river Tapi and the LTB can be seen in Figure 1.

3. Datasets

This study required two types of data sets, hydrological data for river analysis and spatial data for GIS operations. Surat Irrigation Circle (SIC) measured river Tapi after 2006 flood. River Tapi measured from Ukai Dam to Arabian Sea by taking interval of about 400 m along its length and the reduced level were taken at interval of 10 m across its width for each river section. All 308 river cross sections with details like bed and bank level, velocity, gauge level at the time of measurement, etc were collected from SIC. For river analysis, the gauge and the discharge data were collected from State Water Data Centre (SWDC) and Central Water Commission (CWC). In order to find out discharge according to flood return period, observed discharge data from the year 1978-1979 to 2013-2014 were collected. For generating DEM, contour map of scale 1: 50,000 was collected from Survey of India (SOI) department. Satellite image of CARTOSAT-I was used for flood delineation analysis.

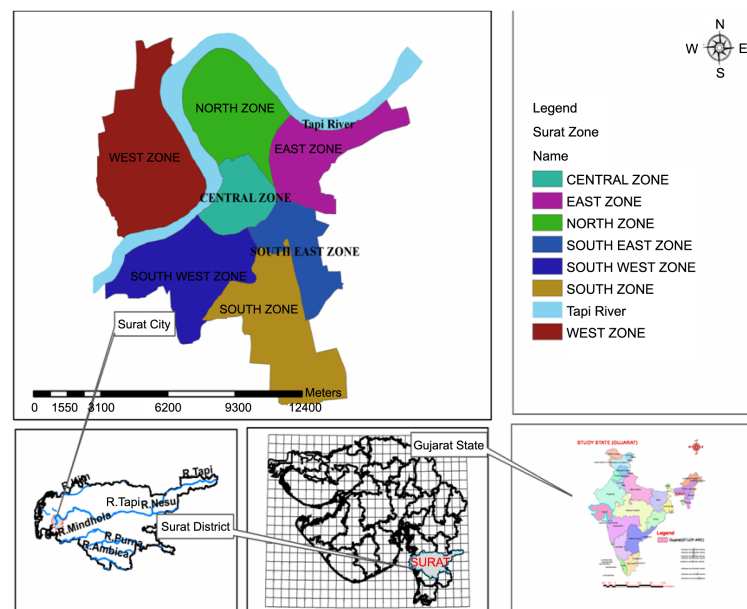


Figure 1. Study Area—Surat city-River Tapi-Lower Tapi Basin.

ArcGIS and open source softwares such as HEC-RAS and HEC-GeoRAS were used for flood hazardous mapping.

4. Methodology

GIS and Remote Sensing provide a broad range of tools for determining areas affected by floods or for forecasting areas likely to be flooded due to high river water levels. DEMs are increasingly used for visual and mathematical analysis of topography, landscapes, and landforms, as well as modeling of surface processes [10] [11]. A DEM offers the most common way of showing topographic information and even enables the modeling of flow across topography; a controlling factor in distributed models of landform processes [12]-[14].

In this study, a DEM of Surat city was prepared using ArcGIS. Contour map of scale 1:50,000 of the study area was scanned at 400 dots per inch (dpi) resolution to convert it into image. The scanned image was georeferenced and overlaid on the satellite image of the study area. Necessary operations like buffering were carried out for adjustment. Contours were digitized by line tool and errors like dangling, overshoot, undershoot and silver polygon were removed to make DEM accurate. Spatial and temporal data were inter-linked through ArcGIS and customized data base management system. 3D Analyst tool was used to convert digitized contours into Triangulated Irregular Network (TIN). Interpolation was done to convert vector data (TIN) into raster data (DEM). In order to study flood scenario considering discharge equal to return period of 25 and 32 year HEC-RAS and HEC-GeoRAS software were used. One of the major capabilities of HEC-RAS is to perform steady flow water surface profile, is intended for calculating water surface profile for steady gradually flow. The steady flow component is capable of modeling subcritical, supercritical and mixed flow regime water surface profile. In present work steady flow analysis was applied to calculate water surface profiles for gradually varied flow condition. Calculations in HEC-RAS model were carried out by solving one dimensional energy equation as written in Equation 1. Hence losses due to energy are evaluated by Manning's equation and expansion and contraction multiplying by change in velocity head

$$y_1 + z_1 + \frac{a_1 v_1^2}{2g} + h_e = y_2 + z_2 + \frac{a_2 v_2^2}{2g} \quad (1)$$

where, y_1, y_2 = Depth of water at cross sections,

z_1, z_2 = Elevation of the channel,

a_1, a_2 = Velocity weighting co-efficient,

v_1, v_2 = Mean velocity,

g = Gravitational acceleration,

h_e = Energy head loss.

Well known standard step method was used to compute water surface profile from one river cross sections to the next by solving the above equation. Since HEC-GeoRAS uses functions associated with ArcGIS like Spatial Analyst and 3D Analyst, make sure that these extensions are enabled before loading it. Any hydraulic or hydrologic modeling in aid of GIS environment involves three steps Pre-processing of data, Modeling phase, and Post-processing of data. For Pre-processing, DEM of Surat city was used as main input in order to create RAS layers like stream centre line, bank lines, bank stations, flow path centre lines, XS cut lines and others. River centre line was used to establish the Tapi basin network; line tool was used to digitize centre line, left and right bank, flow paths etc. Cross-sections cut lines are one of the key inputs to HEC-RAS and these cross-sections cut lines are used to extract the elevation data from terrain to create a ground profile across channel flow. However certain rules must be followed while digitizing cross section cut lines. Before exporting GIS data to HEC-RAS, Manning's value assigned to individual cross sections according to different land use types. When the data was exported, it created two files namely .xml and .sdf, which were used for further operations in HEC-RAS. In order to check quality of data graphical cross sections editor tool was used for individual cross sections. To define downstream boundary conditions, normal depth was taken as 0.001 before running HEC-RAS. After successful simulation, HEC-RAS output of the work was exported to ArcMAP for post-processing in order to create flood delineation of the study area. DEM and selected river cross section can be seen in [Figure 2](#).

5. Result and Discussion

Steady flow was simulated for river Tapi considering its length of 24 kilometres entering at the East zone and

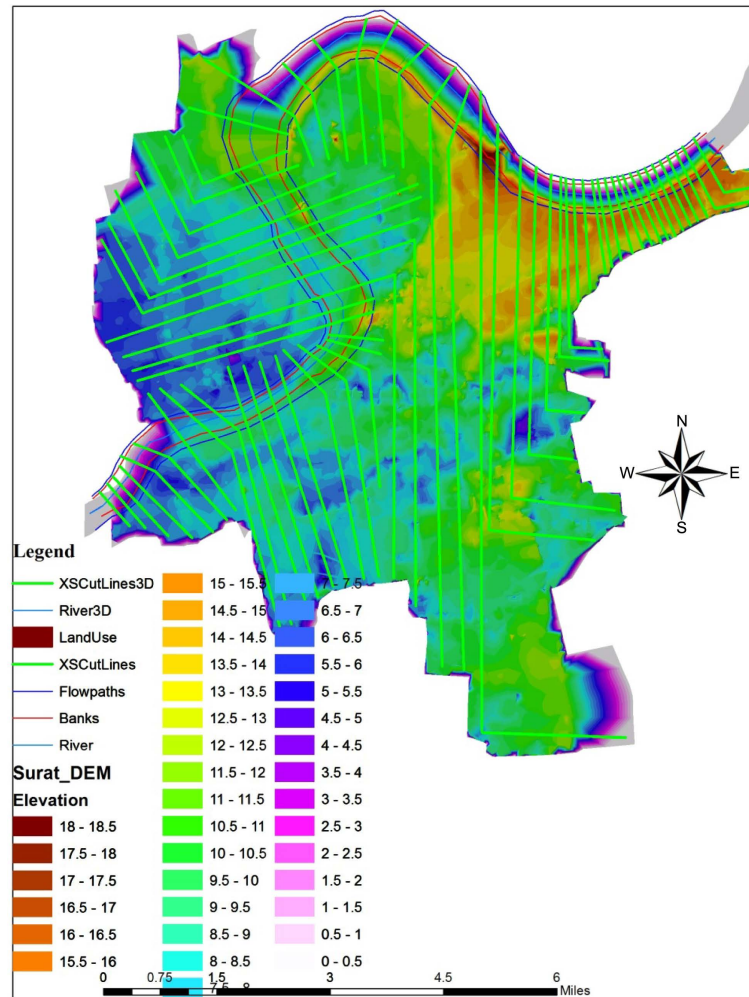


Figure 2. DEM of Surat & Tapi, and cross section cut-lines.

existing from the West zone. DEM was generated at 0.5 m contour interval by performing various steps like scanning, georeferencing, digitalization, conversion of data from vector to raster etc. For precise results, reliability of the DEM was checked by conducting GPS survey and was found reasonably good. The HEC-GeoRAS was used in conjunction with 3D Analyst for interpolation of DEM data and tool Spatial Analyst for proper displaying of the cross sections. From RAS Geometry, all RAS layers had been prepared as discussed in methodology and then after RASGIS import file was generated for required hydraulic simulation in HEC-RAS model. Gumbel’s probability method was used to calculate peak flow for return periods of 5 years interval. Table 1 shows magnitude of peak flow for 5 to 35 years return period.

Peak flow estimated for return period of 25 and 32 years were used as case study for the steady flow data simulation. Normal depth for upstream and critical depth for downstream was considered as boundary conditions for this analysis. Manning’s value as 0.032 and 0.045 were used as channel and left-right banks respectively as input along with expansion and contraction coefficients. Stage and discharge data are observed at five stations in LTB, Nehru Bridge is one of the stations, where peak discharge observed as 25768.09 Cumecs with river level about 12.5 m. Discharge carrying capacity of river Tapi has reduced over the years [15]. For flood analysis total 67 cross section cut lines have been drawn and, considering several cross sections water surface levels for return period of 5 to 35 years have been studied. In present work analysis of water surface level for return period of 25 and 32 years were carried out on one of the sensitive cross section near Nehru Bridge. For return period of 25 years, water reaches up to height of 5.90 m and it is just below the right hand side bank height of the section as seen in Figure 3.

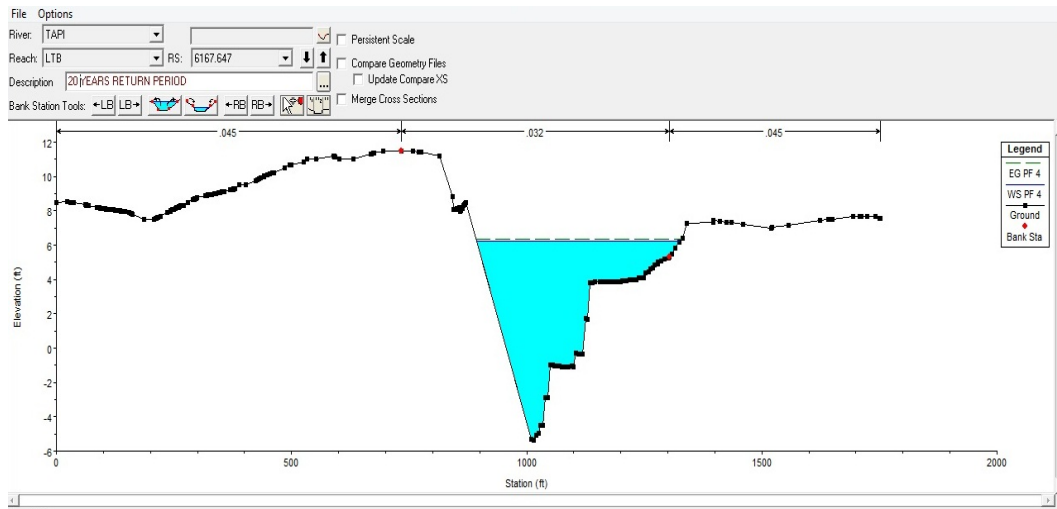


Figure 3. Water surface level for return period of 25 years.

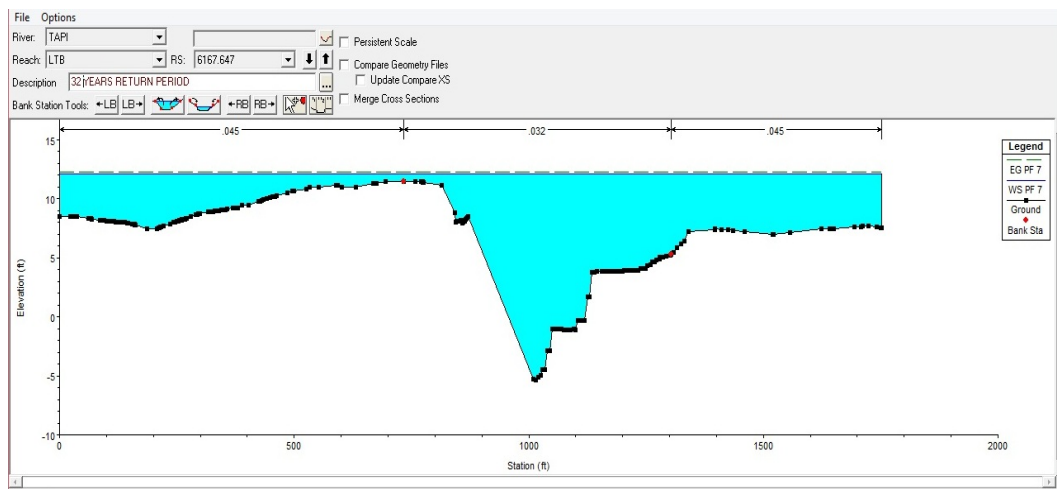


Figure 4. Water surface level for return period of 32 years.

Table 1. Peak flow for 5 to 35 years return period.

Return Period (Years)	5	10	15	20	25	30	32	35
Peak Flow (Cumecs)	584.60	916.10	1358.04	4734.53	14,307.90	24,312.20	25,768.09	43,612.43

Considering the return period of 32 years, water surface level reaches up to almost 12.50 m and river starts overtopping from right hand side bank with great depth as well as from left bank and can be seen in Figure 4.

If discharge equals to return period of 25 years reach to the river section considered for analysis, there is no overtopping from any banks, but there are several cross sections where bank heights are comparatively low and does not contain discharge safely and get overtopped. Due to less discharge carrying capacity of those sections, water starts spilling and leading to flood in area nearer to river banks which can be seen through Figure 5.

While simulating discharge equals to flood return period of 32 years water starts spilling from both the banks and area gets flooded by different depths. Flooding area within river reach could be distinguished based on the grid layer of flood depths. DEM extracts the elevation value of each point that helps to predict probable submergence depth of respective point/area within boundary. Flood affected area as shown in Figure 6, for 32 years return period is much larger, as most of the river sections are having less discharge carrying capacity than this discharge value.

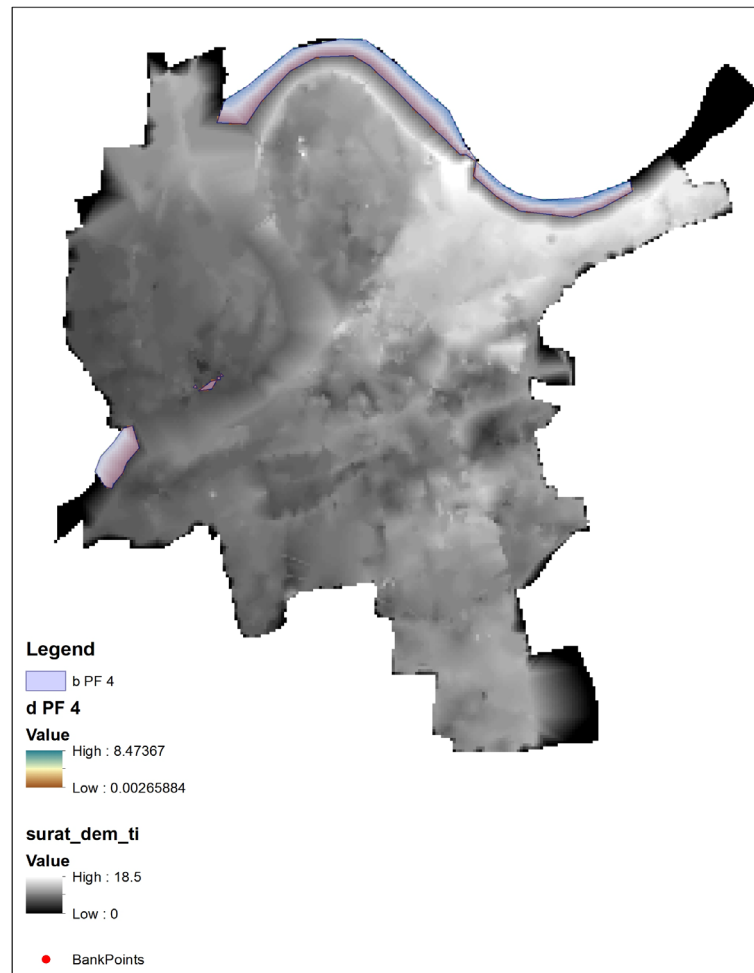


Figure 5. Flood delineation map for return period of 25 years.

As mentioned earlier, Surat city is divided in seven zones and its elevation varies from 4 m to 18.5 m from MSL. DEM shows that most of the area is lying at elevation between 8 to 12 m, and specifically the West zone and the South-West zone are relatively low compared to other zones. For discharge equals to 32 years return period water level in the section under analysis, reach to 12.5 m and start overtopping from left and right bank with depth of about 2.5 m and 4.8 m respectively causing severe flood in the surrounding area. Most of the area in the west zone was under water for a depth of flood from 3.0 to 4.5 m in the worst flood event of 2006 [16], reasonably justify flood delineation mapping.

6. Remedial Measures

The effective waterway of river Tapi has been reduced over the years due to silting. The dredging of river in certain reaches and other suitable measures can be implemented to increase the carrying capacity of the river.

Simulated water surface level at discharge equals to 32 years return period, actual bank height and bed level of most of the river cross sections out of 309 for left and right bank are shown in Figure 7 and Figure 8 respectively.

During investigation it was found that several river sections like LD 60 to LD 78 near Mugdalla Jetty, LD 21 to LD 36 near Nehru Bridge, Swami Vivekanand Bridge and Sardar Vallabhbhai Patel Bridge are very low in height and are affected badly when flood occurs in the river basin. Taking difference between water surface level and respective bank level, embankment should be raised to prevent possible submergence up to certain extent.

Investigation also indicates that compared to the left bank of river Tapi, the right bank is very low in height, and even for the same cross section the difference in the height of both side banks is significant. The graph for

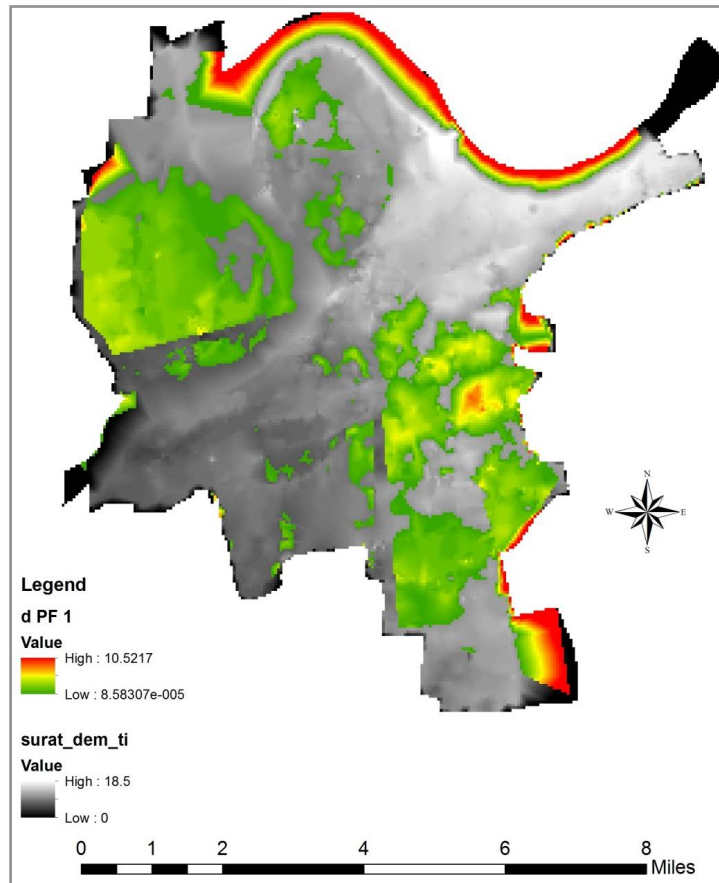


Figure 6. Flood delineation map for return period of 32 years.

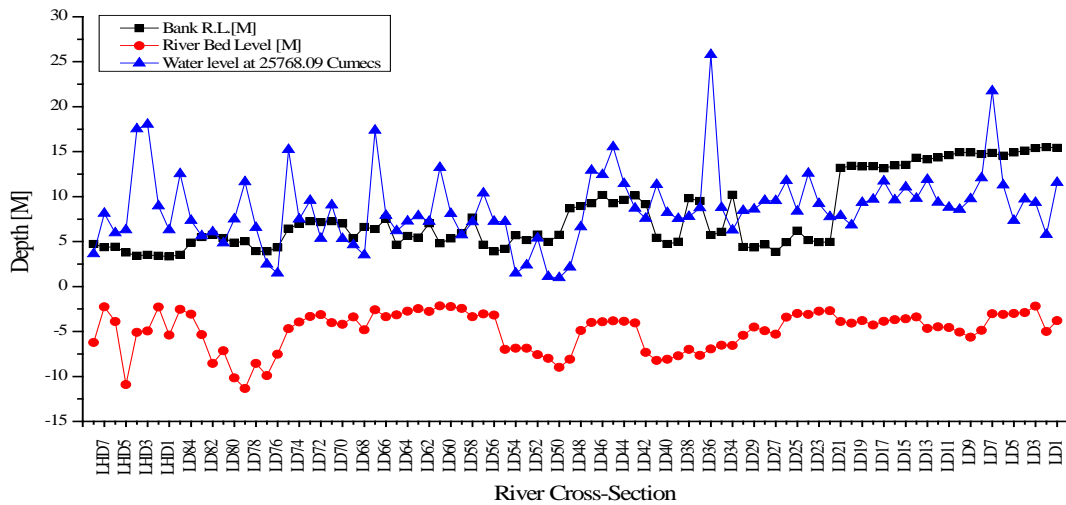


Figure 7. Left bank height & water surface level corresponding to 32 years return period.

right bank, clearly indicates that bank heights of most of the river sections are lower than water surface level at aforesaid discharge and it was also observed during flood of 2006 that the water spilled from the sections RD 20 to RD 47 causes flood in Adajan, Rander, Bhatpor, the areas which govern economy of the city. It is recommended that to minimise flood effect near such areas, bank height should be improved on priority basis along with channel dredging.

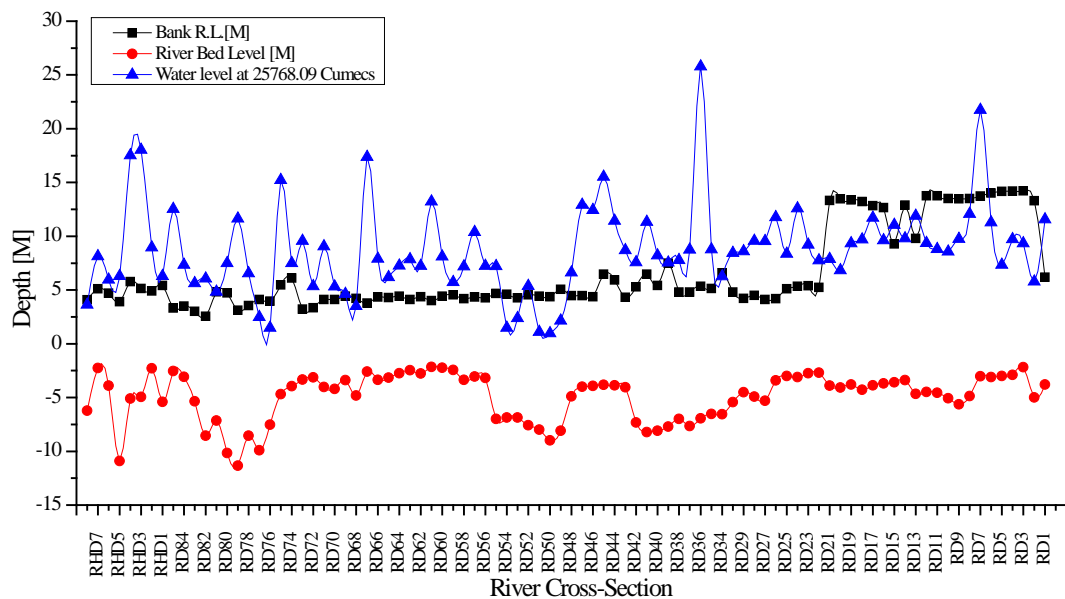


Figure 8. Right bank height & water surface level corresponding to 32 years return period.

7. Conclusion

This study has clearly shown that integration of GIS techniques and application of HEC-RAS are vital to geospatial analysis of Surat city within LTB for flood delineation. By using capabilities of the HEC-RAS, several river cross sections have been identified which can not contain discharge that is likely to come for return period of 25 years. It is also demonstrated that most of the low lying area of the city is submerged at discharge equals to return period of 32 years. Structural remedial measures have been suggested in order to prevent flood effect in low lying area of Surat city up to some extent. One of the most important lessons learnt from the study is that the use of GIS for the undertaking of flood simulation can improve accuracy and can also prove cost-saving for floodplain delineation.

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