Journal of Geomatics Vol 9 No. 2 October 2015

Estimating water surface elevation using HEC-RAS in lower Tapi basin

N. Goswami[1], P.K. Gupta[2] and Ajai[2]
[1]K.S.School of Business Management, Gujarat University, Ahmedabad
[2]Space Applications Centre, ISRO, Ahmedabad
Email: goswaminandita@gmail.com

(Received: Jul 29, 2015; in final form: Oct 15, 2015)

Abstract: In this study, the Hydrologic Engineering Centre's River Analysis System (HEC-RAS) model is parameterized for studying water surface elevation of the nearly 110 km stretch of lower Tapi basin (LTB) river from Ukai dam to Surat city. Parameters such as channel capacity, longitudinal profile, discharge from Ukai dam etc. have been used to simulate the river water surface elevation and the extent of inundated area in the study area. Model has been calibrated for unsteady flow during 2004 and simulation is performed for prediction of water surface elevation for different return periods. Model was tested for water surface elevation over a gauging site (Ghala) with high value of Nash-Sutcliff coefficient (0.86) indicating the model is well calibrated.

Keywords: Water surface elevation, Stream flow, Lower Tapi basin, HEC-RAS

1. Introduction

Water level elevation changes with the flow and it is an important input for prediction of inundation pattern based on terrain topography. River Tapi experienced about 26 heavy floods during 1876 to 2013. The flood in the year 1968 was unprecedentedly high (discharge 44174 cumec) causing loss of life, damage in infrastructure. In 1994 and 1998 also flood in this area affected Hazira town and its nearby areas. Due to incessant rainfall in the upper catchment area of river Tapi in Maharashtra and Madhya Pradesh, inflows to Ukai dam started rising from 23000 to 34000 cumec for few days in 2006 and nearly 90% of Surat city and surrounding towns and villages were inundated. Many organisations like IMD, ISRO, CWC, Central Water Power and Research Station (CWPRS) are involved in studying the flood phenomena of Tapi river using different technique and models. A simulation study of floods along the lower Tapi river has been carried out by Timbadiya et al.(2014). Agnihotri et al. (2011) have also studied lowerTapi catchment and proposed modification of the cross section of river Tapi. It is important to use different hydraulic model to get better perspective to study flood and associated changes. Hydrologic Engineering Centre's River Analysis System (HEC-RAS) allows to perform steady and unsteady flow in the river. In this study hydraulic model HEC-RAS has been used to simulate water surface elevation for lower Tapi river for different return period's flows.

2. Study area

Tapi is a river in central India. It is one of the three rivers in Peninsular India that runs from east to west. Tapi river originates at Multai of Satpura range in Betul district of Madhya Pradesh at an elevation of 752 m above mean sea level (MSL) and flows through Maharashtra and Gujarat before joining the Arabian Sea. The length of the river is about 724 km. The Tapi river basin may be divided into three distinct parts: upper, middle and lower basins. Upper Tapi basin is up to Hathnur [confluence of Purna with the main Tapi (29,430 km^2)], middle Tapi basin is from Hathnur up to the Gidhade gauging site (25,320 km^2) and lower Tapi basin (LTB) is from the Gidhade gauging site up to the sea (10,395 km^2). The annual rainfall for the upper, middle and lower Tapi basins for an average year is 935 mm, 631 mm and 1042 mm, respectively. The present study concentrates on the 110 km stretch of the river between Ukai dam (Lat. 21.25^0 N, Long. 73.59^0 E) and Surat (Lat. 21.1700° N, Long. 72.8300° E). There are many rapids in the reach downstream of Ukai. The river bed falls by about 7.5 m at Kakrapar and the slope of river bed in this reach is about 1/2000. The width of the river varies from nearly 350 m to about 800 m. The study area has one reservoir Ukai. During monsoons, Tapi river is frequently in flurry and occasionally causes havoc in the plains at lower reaches. Fig. 1 shows the Landsat satellite image of LTB with important places including Central Water Commission (CWC) maintained gauging sites.

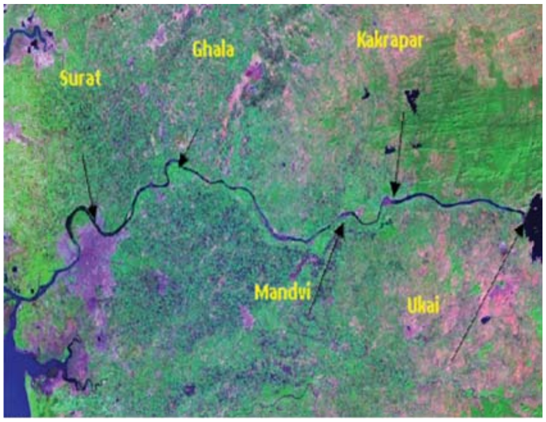

Figure: 1 Landsat satellite image of Lower Tapi Basin (LTB) with important places

© Indian Society of Geomatics

3.0 Data used

3.1 Digital Elevation Model (DEM)

SRTM DEM (Shuttle Radar Topography Mission Digital Elevation Model) of 90 m resolution is considered for terrain with coordinate system and projection (source: earth explorer website). Geographic projection was changed to UTM 43N WGS84.The reason for using SRTM DEM is that its vertical accuracy is more than any other DEM over the flat regions (Forkuor and Maathuis 2012).

3.2 Daily discharge and water levels

Ukai dam daily discharge and water surface elevations (Ghala gauging site) have been collected from Executive Engineer's office, Ukai division No. 1. Flow varies from few thousand to approximately 36000 cumec in the LTB considering 50 years return period.

3.3 River cross sections

Boundary geometry for the analysis of flow in natural streams is specified in terms of ground surface profiles (cross sections). Cross sections are perpendicular to the anticipated flow lines and extend across the flood plain. Cross sections are requires at locations where changes occur in discharge, slope, shape or roughness. Longitudinal profile of Tapi river along with cross section for 264 locations from Ukai dam to beyond Surat city were collected from the Superintendent Engineer's Office, Surat Irrigation Circle, Surat. Data was used to define the geometric model in the HEC-RAS.

3.4 Other data

Discharge data for different return period from 2 to 50 yrs were collected from River Engineering Laboratory (2009). The discharge (cumec) for the above return periods are shown in the Table 1. Runoff data for the model testing periods i.e. July-August 2004, are taken from previous work on HEC-HMS (Hydrologic Engineering Centre's Hydrologic Modeling System) simulations in the LTB (Goswami et al., 2013).

4.0 Methodology

HEC-RAS has been used to perform unsteady/steady flow simulations. HEC-RAS use the general form of the section-averaged Navier-Stokes equations which are based on the conservation of mass and momentum (Brunner, 2010). User interacts with HEC-RAS through GUI.HEC-GeoRAS, the extension of ARCGIS, comprises of procedures, tools, utilities that allow user to create geometric data (river centreline, flow path, bank lines, cross sectional cut lines and their attributes etc.) from digital terrain model (DTM) and complementary datasets. These data is imported to HEC-RAS. The results from HEC-RAS can also be exported and processed and viewed in HEC-GeoRAS (Cameron and Ackerman, 2011). Runoff data have been added as lateral flow to the HEC-RAS model. After setting up the model, unsteady flow simulations are done by defining the boundary conditions such as Ukai dam discharges and normal depth for upstream and downstream, respectively. Model was tested using the observed vs. simulated water surface elevations for the gauging site (Ghala) over the LTB. Statistical indicators such as model efficiency (Nash-Sutcliff coefficient) and coefficient of determinations have been used to test the performance of the model. Further, tested model was applied in steady flow mode for the prediction of river water surface elevations for different return periods flow in the study area. Approach followed in this study is presented in Fig. 2.

Table1: Details of the flow associated to different return periods

Return period (years)	Discharge (cumec)
2	11048
5	19271
10	24715
15	27787
20	29937
25	31594
30	32942
50	36697

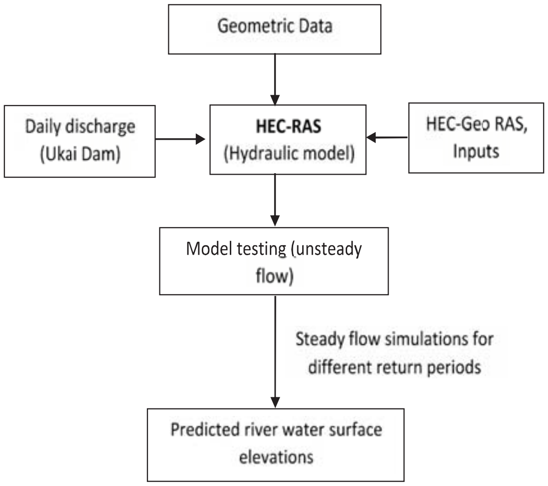

Figure 2: Approach for river water surface elevation estimation

5.0 Analysis and results

Model testing has been done by adjusting the Manning roughness parameter (model control parameter) to get the best match between the observed and simulated water levels at the Ghala. Final Manning roughness values in the study area were of 0.034 from Ukai to Kakrapad, 0.023 from Kakrapd to Mandvi and 0.025 from Mandvi to rest of the portions of the downstream. A line graph of observed and simulated river water levels is shown in Fig. 3 whereas a scatter plot at Ghala gauging site for the period 23rd July 2004 to 10th August, 2004 is presented in Fig. 4.

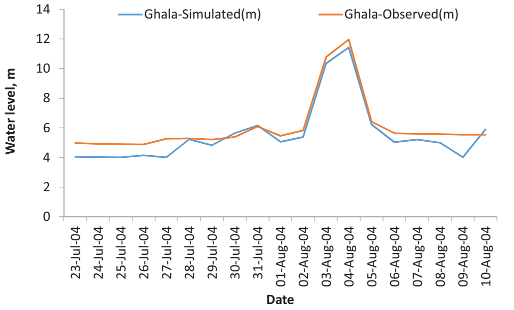

Figure 3: Observed and simulated river water levels over Ghala gauging site

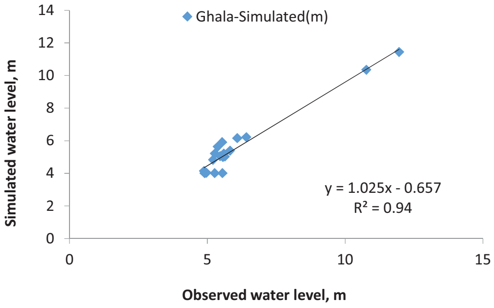

Figure 4: Scatter plot between observed and simulated river water levels over Ghala gauging site

Nash-Sutcliff coefficient is used to check the model efficiency and it is found to be 0.86. The high value of Nash-Sutcliff coefficient and coefficient of determination, 0.94 suggests that the model is well calibrated. The tested HEC-RAS model is used for steady flow analysis using discharges for the different return periods. Steady flow water surface elevation profiles obtained by considering the discharge for return period of 2yr, 5yr,10yr, 15yr, 20yr, 25yr, 30yr and 50yr are presented in Fig. 5.

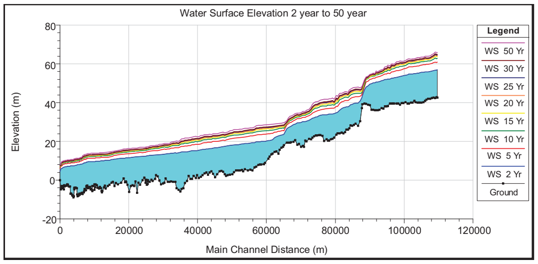

Figure 5: Water surface elevation profiles for return period of 2yr to 50yr over the from Ukai dam to Surat city (LTB)

It is observed that water surface elevation rise was 5-7 m considering discharges from 2 to 50 years return period in the upstream and middle stream regions whereas in the downstream regions water elevation rise was 3 to 4 m. Maximum water surface elevation rise is seen for the discharges during 2 to 5 years and 5 to 10 years return periods, subsequent return periods water elevation rise was smooth. This low rise in water elevation for higher returns periods is expected as the channel flow width increases significantly. Within the study area, Kakrapad, Mandvi, Ghala and Surat are considered as important locations and water surface elevation generated at these places for different return periods are shown in the Figs. 6-9.

Inundation pattern for several return period flood discharge data (2yr, 5yr, 10yr, 15yr, 20yr, 25yr, 30yrand 50yr) has also been done for the steady state simulations. Flood extent along with the depth is obtained for all these return periods. Figure 10shows the extent and depth of the inundated area for discharge associated for 50 year return period. Table 2shows the inundated area under discharges from 2 year to 50 years return period.

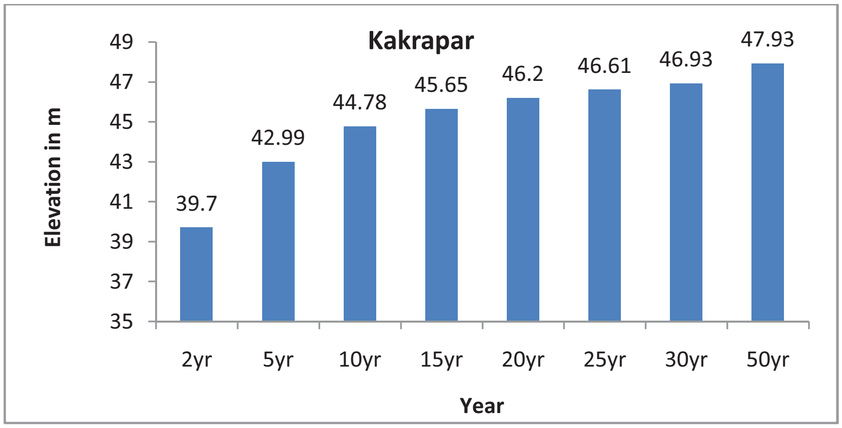

Figure 6: Water surface (WS) elevation at Kakrapar for different return period

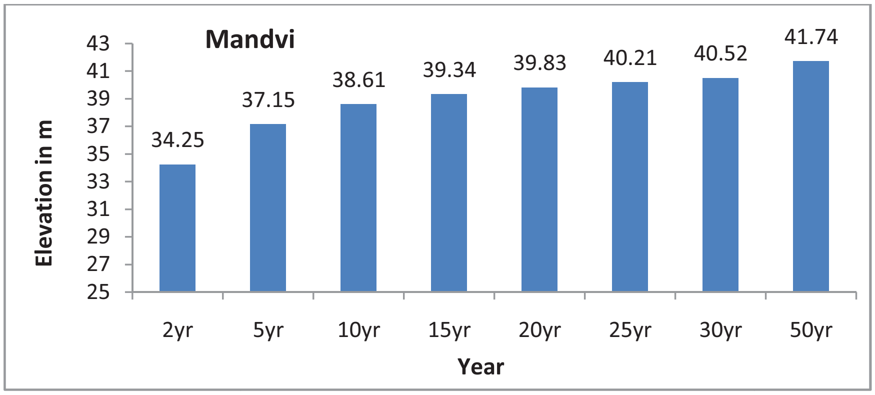

Figure 7: Water surface (WS) elevation at Mandvi for different return period

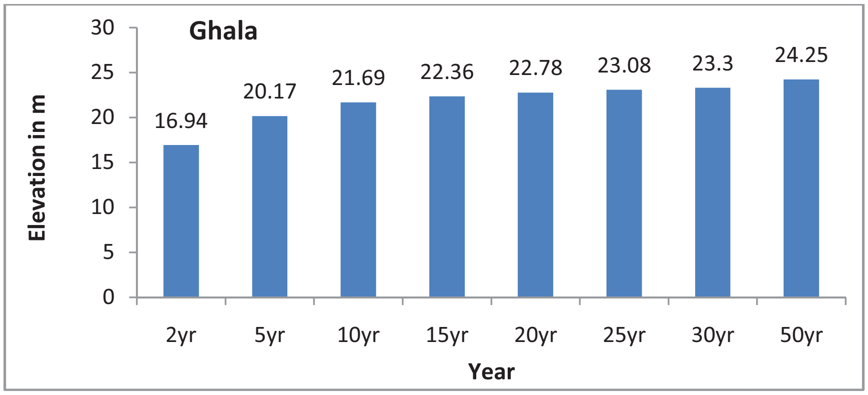

Figure 8: Water surface (WS) elevation at Ghala for different return period

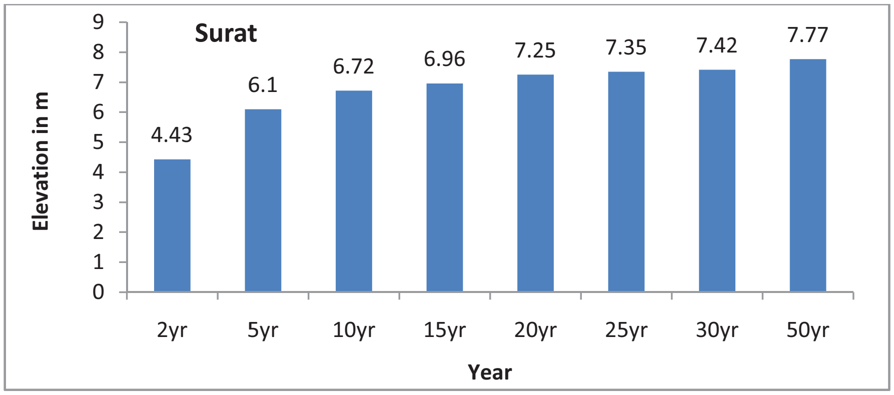

Figure 9: Water surface (WS) elevation at Surat for different return period

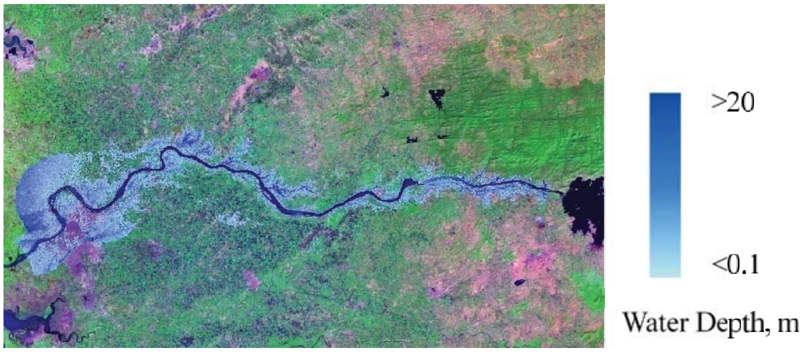

Figure 10: Fifty year return period flood extent and depth (discharge: 36697cumec; Area: 423 km^2)

Table 2: Inundated area under different return flow conditions

Return period (year)	Flow (Cumec)	Area (km^2)
2	11048	106
5	19271	193
10	24715	263
15	27787	295
20	29937	324
25	31594	345
30	32942	360
50	36697	423

It has been observed that large area is under inundation (shallow depth) in the Surat city and nearby regions, because this region comprises flat terrain, hence prone for flooding. Area under inundation varies almost linear except for the initial return periods where it jumps exponentially. Inundation area varies from 106 to 423 km^2 for the return period 2 to 50 years, respectively. The inundation pattern information corresponding to various return periods flows is highly useful for dam regulation authorities and disaster management planners.

6.0 Conclusion

Present study has focused on recreating the river flow dynamics in the lower Tapi catchment using the hydraulic model HEC-RAS, river characteristics and ancillary information. Model has been tested by comparing the in situ and simulated river water levels at the gauging station. After that tested model was applied to generate various river water surface elevation scenarios by considering the different return period flow. It was found that model is capable of reproducing the river water levels corresponding to low and high flows. Various scenarios, considering the return periods from 2-50 years, developed under the present study may be used by planners and decision makers for flood management and reservoir regulations in the LTB.

References

Agnihotri, P.G. and J.N Patel (2011). Improving carrying capacity of river Tapi (Surat, India) by channel modification. International Journal of Advanced Engineering Technology, 2(2), 231-238.

Brunner, G.W. (2010). HEC-RAS river analysis system user's manual version 4.1 (http://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_4.1 Users_Manual.pdf)

Cameron, T. and P.E. Ackerman (2011). HEC-GeoRAS GIS tool for support of HEC-RAS using ArcGIS user's manual. From http://www.hec.usace.army.mil/software/hec-georas/documentation/HEC-GeoRAS42_UsersManual.pdf

Forkuor, G. and B. Maathuis (2012). Comparison of SRTM and ASTER derived digital elevation models over two regions in Ghana - Implications for hydrological and environmental modeling: InTech.

Goswami, N., P.K. Gupta and Ajai (2013). Hydrological modelling to estimate rainfall based runoff in the lower Tapi basin. Journal of Geomatics, Vol 7 (2):158-162

River Engineering Laboratory (2009). Mathematical model studies for prediction of flow in Tapi river reach from Ukai to Hazira for design of flood embankments. Central Water and Power Reseach Station (CWPRS,), Govt. of India Technical Report No.4666, P.O. : Khadakwasla Research Station, Pune .

Timbadiya, P.V., P.L. Patel and P.D. Porey (2011). Calibration of HEC-RAS model on prediction of flood for lower Tapi river, India. Journal of Water Resource and Protection, 3, 805-811.