TO DEVELOP FLOOD FORECASTING APPROACH OF AHMEDABAD CITY, GUJARAT, INDIA

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Contents

1. Abstract:

Flood is disastrous for developing countries, its assessment are important for flood risk management. Ahmedabad is largest city and former capital of Gujarat and included under the 100 Smart city project of India is situated 151.6 km downstream for Dharoi dam. The city has experienced floods in the year 1973, 1983, 1988, 1991, 1993, 1998, 2003, 2004, 2005 and 2006. Going by statistics the city has experienced flood in almost consecutive three to four years. In addition, AMC has developed the Sabarmati River Front along the banks across the city which narrows the river section. Whether any study about risk of flood vulnerability has been done prior to the implementation of the project is not clear. How the river will react during flood situation is a matter of speculation for general public. Therefore, it is prime issue for Ahmedabad city to produce the accurate flood inundation map which predicts the depth and submergence areas of city. In year 2006, 8800 cumec water was released from Dharoi dam during monsoon due to continuous rainfall in the upstream of the Sabarmati River, resulting in the waterlogging and inundation in low lying area of Ahmedabad city. Gumbel's flood frequency analysis has been carried out using last 35 years annual discharge data to calculate discharge for various return periods till 100 years. The opensource HEC-RAS model is one of the most popular hydraulic models. In 2014 a new version of HEC-RAS (HEC-RAS-v5) was released including 2D capabilities and having capabilities to import geometric data from HEC GeoRAS, hence used in present study to develop 1 D and 2D hydrodynamic model.

Present study describes the formation of 1D and 2D hydrodynamic model using DEM generated cross sections of river for flood mitigation studies. 1D hydrodynamic model is generated for 38 km length of Sabarmati River from Chiloda Bridge to Vasana barrage covering two most important cities of Gujarat state, i.e. Ahmedabad and Gandhinagar. The River geometry has been generated using Cartoset-1 stereo image with 10 m grid interval. The cross section of the river has been derived at every 200 m using HEC GeoRAS software and validated with data collected from state and central government departments as well as field survey. The boundary condition for upstream and downstream has been fixed and model is simulated for flood event of year 2006 under the unsteady flow conditions. As an outcomes, the discharge, water surface elevation, velocity and flow area has been derived. Afterward the simulated flow and stages at known section is compared with the observed data and shows a significant correlation. When water begins to overflow it becomes a 2-D phenomenon and hence 2-D modeling is applied for flood modeling. The present study is applied the new HEC-RAS-v5 to simulate the August 2006 flood event in the Sabarmati River. Stimulation showed many areas of the city getting inundated due to this event. It also provides important information like maximum depth and

flow velocity of the flood. Model was run from 18th August, 2006, 18:00 hours to 23rd August, 2006 23:00 hours. Maximum depth, Velocity, inundation area and WSE observed has been mapped for prepaing flood inundation probability maps which can be utilized for flood mitigation and management for Ahmedabad city. Present case shows the application of a HEC-RAS and HEC-GeoRAS open source software in prediction of a river stages and probability of inundation area, hence applicable for flood mitigation and management in developing countries under a scarcity of data, fund and skilled human resources. An evacuation plan for inhabitants can be fixed based on flood inundation maps.

2. Brief description on the state of the art of the research topic:

Flood is surplus water inundated due to insufficient capacity of rivers to carry a high volume of water from the upstream area within their banks following heavy rainfall [1]. India has witnessed total 649 disasters from 1915 to 2015, among which 302 disasters was caused by the flood which accounted approximately 47% of total disasters took place in India in the last 100 years [2]. Among all the natural catastrophic events occurs worldwide, floods are the most recurrent and destructive to social, economical and environmental aspects of the vicinity. In India, among all natural hazards, river floods are most recurrent and often destructive causing extensive losses of infrastructures, cultivation, transportation, community health, livestock and human lives [3].

In recent decades, the use of Geographic Information System (GIS) along with the hydraulic model has been used effectively for flood management and forecasting. GIS being capable of representing topographic features and hydraulic model being efficient in simulating flow for various return periods, all together they both give very good results, which can be further used for preparing flood risk and hazards maps. [4]. Nowadays researchers are using various hydraulic models in combination with GIS to simulate water flows. Many software packages like DWOPER, FLDWAV, MIKE-11, ISIS, SOBEK, CCHE2D, TUFLOW, Infoworks-2D, RiverFLO-2D etc. have been widely applied for simulating 1D and 2D flow in rivers [5] [6]. Researchers like, [7] and [8] have developed a stage-discharge relationship using 1 dimensional MIKE 11 hydrodynamic model for lower Tapi river, India and Brahmani river, India respectively. Among all the available hydrologic models, freely available HEC-RAS [9] model is very handy means for forecasting of likely flood events to occur in future and used worldwide for flood prediction and management [10]. HEC-RAS is efficiently used worldwide to develop various and flood risk assessment and management for rivers like, Pahang River, Malaysia [11] , Mert River, Turkey [4], Martil River, Northern Morocco [12], Al Kahlaa and Hilla

Rivers of Iraq [13] [14] and many more. Also in India HEC-RAS based hydrodynamic model has been effectively developed for many rivers like Mahanadi [15], Tapi [7] [16]and Yamuna [17]

The existing literature shows that many researchers are used 1D and 2D HEC-RAS hydrodynamic modeling for flood simulation analysis. 1D modeling can help to predict the stages of the river while 2D modeling can give best results in terms of inundation and spread of water, which can be utilized to develop the flood warning and forecasting system [9]. For both 1D and 2D HEC-RAS models, precise geometry of river is prime requirement. At present, very few surveyed cross sections are available for development of hydrodynamic model in India. Due this reason very few case studies are available to carry out the 1D and 2D flow simulation through HEC-RAS modeling. The case of Sabarmati River has been presented in this paper for flood stages assessment at different locations for flood management in lower Sabarmati catchment. It is also necessary for future flood protection work. Presently, there is no such hydrodynamic model is available for Sabarmati river for prediction of stages at Ahmedabad and Gandhinagar cities for different release from Dharoi dam. In this study, an attempt has been made to simulate the year 2006 flood occurrence using HEC-RAS hydrodynamic model under the unsteady flow condition for Sabarmati River, whereas geometric of the river is produced by 10 m grid interval Cartoser-1 DEM using a HEC GeoRAS tool.

3. Definition of the Problem:

The average rainfall of Ahmedabad is about 98.2 cm. Infrequent heavy torrential rain causes flood to the Sabarmati River and the city has experienced floods at every two to three years interval. Ahmedabad reach a record high flood level at 47.45 m at Subhash Bridge on 19th and 20th August, 2006 exceeding the past record level of 44.09 m in year 1993. The city remains flooded for two to three days. Except small hilly areas of Thaltej Tekra the entire city is flat makes the inundation condition worse. The flood was concentrated in the areas of Bapunagar, Naroda, Dani limada, part of Paldi, Ghatlodiya, Khanpur and Vadaj area.

For this study, after discussion with officials of state irrigation department and Ahmedabad municipal corporation followed by literature review the problem is defined as that release of heavy discharge of 8800 cumec (approximately 3 Lac Cusec) from Dharoi Dam along with rain falling parallel in Ahmedabad and other in between Cities, made difficult to dispose accumulated water in the City result in water logging in low lying area of city.

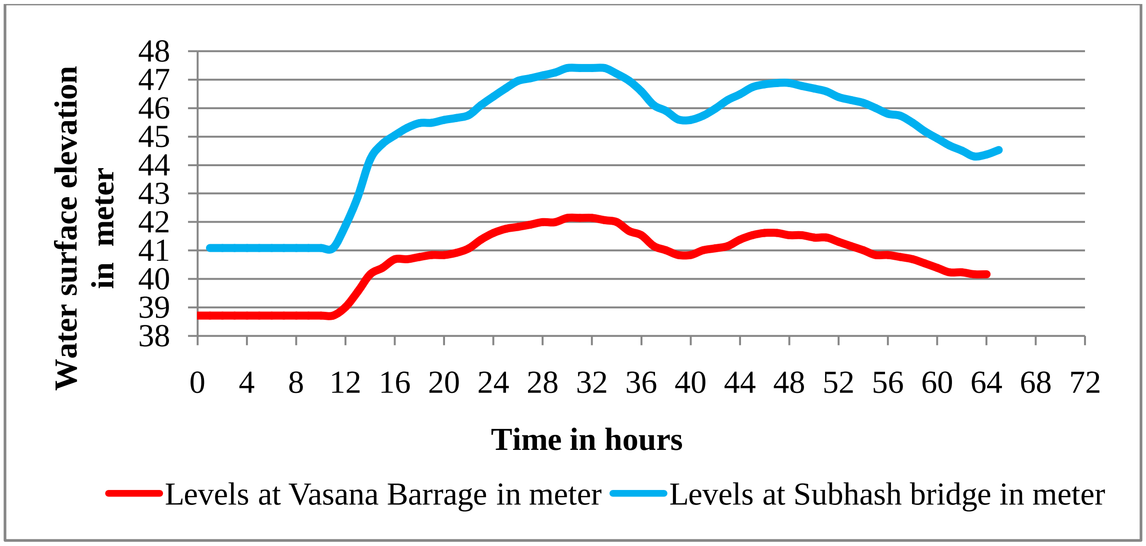


Fig. 1 Hydrographs at Subhash Bridge and Vasana Barrage for flood event of year 2006

Figure 1 shows graphical representation of year 2006 flood event in which flood hydrographs at Subhash Bridge and Vasana Barrage has been shown. High flood level of Subhash Bridge and Vasana Barrages are 45.34 m and 41.76 m. As it is clearly visible from flood hydrographs that stage and discharges at Subhash Bridge and Vasana barrage are in nearly equal or in surplus of their high flood levels.

4. Objectives:

- To develop 1 D unsteady model of Sabarmati river to predict stages at various locations along the study area
- Compare and analysis effectiveness and applicability of ALOS 30m grid and Cartoset 1 of 10m grid DEM for generating river geometry data for hydrodynamic modeling in HEC RAS
- To develop 2 D hydrodynamic model of Sabarmati river for flood inundation mapping
- To calibrate manning's roughness coefficient for study reach of Sabarmati river
- To analyze stages of river for various return period using 1 D steady hydrodynamic model
- To develop flood inundation probability maps for Ahmedabad city for preparation of framework for flood forecasting and warning system.

5. Future scope:

- To prepare the emergency action plan for Ahmedabad city for flood warning and mitigation management.
- Flood inundation map is useful for the local planning authority, engineers, rescue management system for planning for flood vulnerable areas
- Identification of the gap in the available infrastructure for prioritization of implementation of new infrastructure and plan for appropriate rescue system.
- It will be useful for the decision making process for all urban infrastructure development.

6. Original contribution by the thesis:

The present approach will reduce the modeling complexity of 1D and 2D modeling and fill the gap for required modeling data sets. It also accelerates the modeling approach in such a way that it will be a very useful tool for hydraulic engineers to apply for 1D and 2D hydrodynamic modeling. The HEC-RAS model has been simulated in steady condition for discharge calculated from Gumbel's flood frequency analysis for various return periods of 20, 25, 30, 50, 60, 75 and 100 years which can be utilized for future urban and infrastructure planning in city. The calculated hydraulic parameters from 1D and 2D HEC-RAS models can be utilized by planners and decision makers in designing flood protection approach and flood inundation maps even with the limitation of physically surveyed data. The sensitivity analysis and calibration of model gives the most suitable manning's roughness for study area. Also the comparative analysis of DEMs of 30 m and 10 m resolutions can be utilized as per the requirement and significance for deciding cross section interval for producing geometric data using HEC GeoRAS. This work becomes a beacon light for researchers and decision-makers to envisage a decision-making system in data scare areas.

7. Methodology of Research and Results:

The study has started by surveying literature about flood history of Sabarmati River and Ahmedabad city followed by various hydrodynamic models and its application for flood mitigation and management practices in recent decades. A study of flood history and Gumbel's flood frequency analysis has been done for last 35 years before development of hydrodynamic model. It has been observed from literature study that generally all research works done are by taking mostly physically surveyed geometric data or by collecting surveyed data from concern government agencies. During data collection from various state and central government departments like SWDC, CWC and AMC it has been faced and observed that the availability of latest and authentic surveyed data specially required for development of hydrodynamic model is a major problem. Hence, DEM generated geometric data has been used in this study for simulation of 1D and 2D HEC RAS hydrodynamic models. The sensitivity analysis has been done for calibration of manning's roughness coefficient. Two different DEMs of resolutions 30m and 10m has been used to simulate model and simulated values of stages at Subhash bridge gauging site has been compared with actual values to study and analysis effect of 200m and 300m cross section spacing for both the DEMs of 30 m and 20m resolutions.

7.1 Gumbel's Flood Frequency Analysis

After studying literature regarding flood history of Sabarmati River and Ahmedabad city, the flood frequency analysis has been carried out using Gumbel's flood frequency analysis. In this analysis, annual peak discharge of past 35 years from 1981 to 2015 has been considered and following Gumbel's steps mean, standard deviation has been calculated. Flood flow for different return periods has been calculated using Gumbel's co-efficient K, mean and standard deviation. The graph has been plotted for return period versus flow discharge and best fit function for this graph comes out as 5^{th} order polynomial having R^2 as 0.995. This function has been used further in study to calculate future discharge for various return periods to run 1D steady flow in HEC RAS.

7.2 HEC-RAS Modeling

For this study integration of Arc Map 10.0.1, HEC GeoRAS 10.0 and HEC-RAS 5.0.1 has been used to create geometric data and simulation of 1D and 2D hydrodynamic models of Sabarmati River. Cartoset 1 DEM 2.5 m stereo image with 10m grid interval has been used for creating geometric data. Following figure 3 shows general modeling concepts considered for this research.

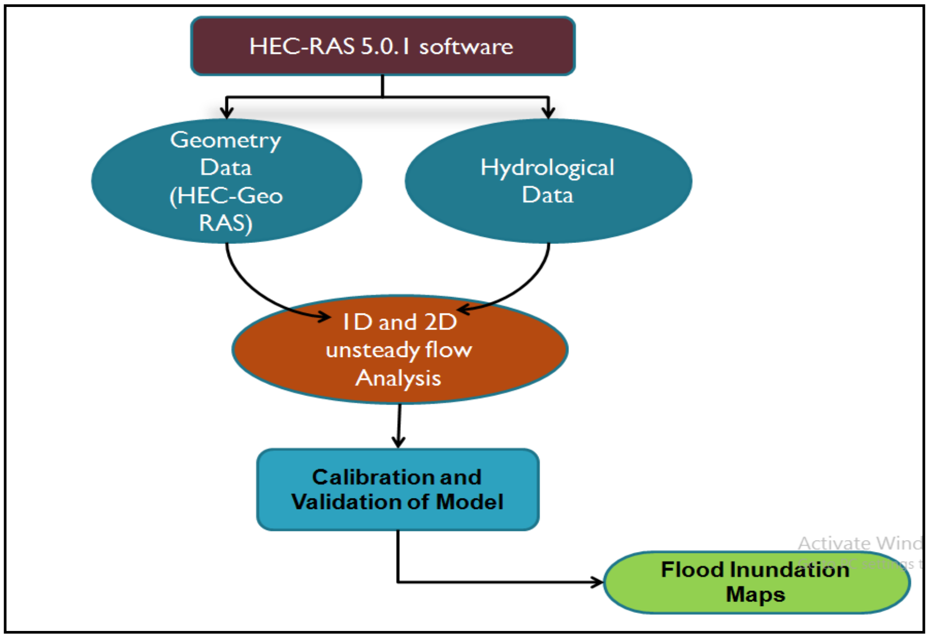


Fig. 2 Modeling concept adopted in research

The 1D hydrodynamic HEC RAS model is simulated for unsteady condition to study and compare the stages of Sabarmati River in a patch of Chiloda Bridge to Vasana Barrage. For simulation of efficient hydrodynamic model, geometry of river is prime input. It has observed, almost all the 1D modeling; geometry has been prepared by both surveyed cross section or in a combination of surveyed data and freely available DEMs. Generating the geometry through surveyed cross section is time-consuming and labours techniques. In addition, it needs high concentration during modeling, unless it has chances to generate faulty geometry in modeling work. As shown in methodology flow chart in figure 2, elevation data at every 200 m interval for the entire length of 38 km of study area has been extracted using HEC Geo Ras open source software using 10 m grid Cartoset-1 DEM. Various RAS layers like, stream centre line, bank lines, flow path lines and cross section cut lines are generated and digitized. All the layers have been assigned with respective attributes and reach code. Cross sections cut lines are delineated automatically by assigning 200 m interval and width of 1200m considering maximum width of river reach. Total of 190 numbers cross sections are generated to represent river geometry of 38 km study reach. All the RAS data are saved in GIS format in desired location. Further, extracted river cross sections will be imported in HEC-RAS and prepared river geometry for 1D flow simulation.

In HEC RAS, flow hydrograph at Chiloda Bridge and normal depth at Vasana Barrage is given as upstream and downstream boundary conditions respectively. The 1D model is calibrated for Manning's roughness coefficient in range between 0.015 to 0.045 for year 2006 and validated for year

2007 as per guideline of DRIP, Govt. Of India and Chow (1959). The 38 km long study reach has a very gentle slope. As there is no sharp curvatures has been observed, effect of meandering has been neglected by providing expansion and contraction coefficient as 0.3 and 0.1 respectively. Simulation of model under unsteady condition will give result in terms of water surface elevation, discharge, velocity, flow area, energy gradient slope. Figure 4 shows steps involved in simulation of 1D unsteady model.

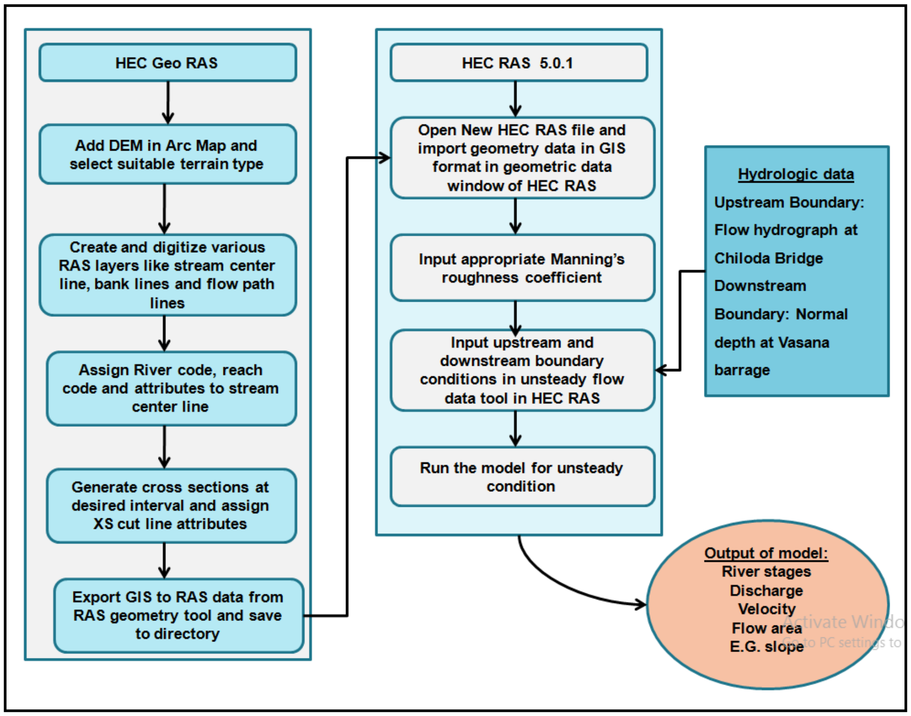
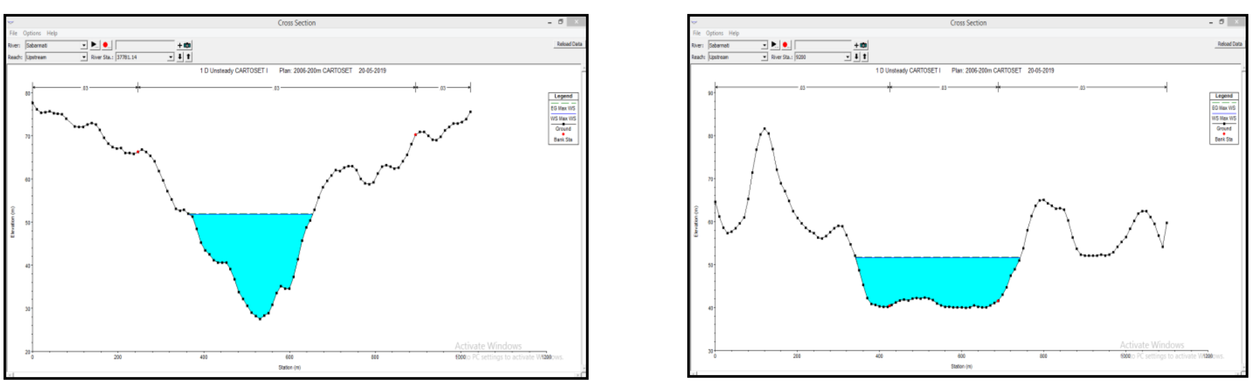


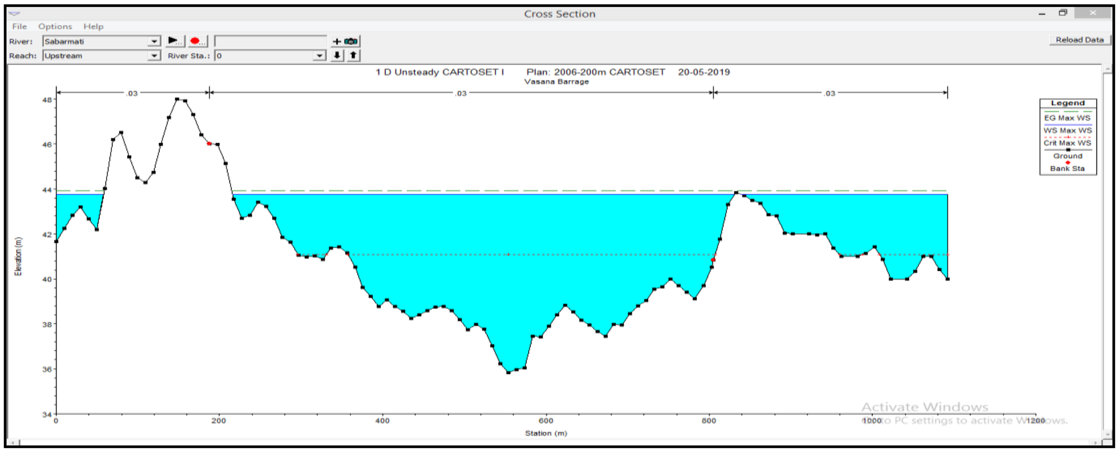
Fig. 3 Steps involved in simulation of 1D unsteady HEC-RAS model

As sown in Figures 4, results in terms of stages, discharge, velocity, flow rate for each cross sections and other outputs such as x-y-z profile plot and rating curve has been obtained after simulation.



(a) Chiloda Bridge (upstream boundary)

(b) Subhash Bridge (validation site)



(C) Vasana Barrage (downstream boundary)

Fig. 4 (a), (b), (c), Cross section profiles at various locations along study area after simulation

Observed and simulated stage hydrographs at Subhash Bridge for year 2006 and year 2007 are compared and found to be in good and satisfactory match for manning's roughness 0.030. Among all simulated parameters, river stages have been considered and compared with observed values at Subhash Bridge gauging site in terms of mean difference, mean absolute difference and RMSE with observed value as shown in Table 1 below.

Table 1 Calculation of root mean square error (RMSE), average absolute difference and average difference of water surface elevation at Subhash Bridge gauging site

Flood Year	RMSE	Avg. absolute Difference (in meter)	Avg. difference
2006	1.65	1.49	-1.44
2007	1.66	1.41	-0.97

Also, as shown in Fig. 5 and 6, analysis of water spill from right bank as well as left bank has been done using simulated results of water surface elevation for year 2006 flood data.

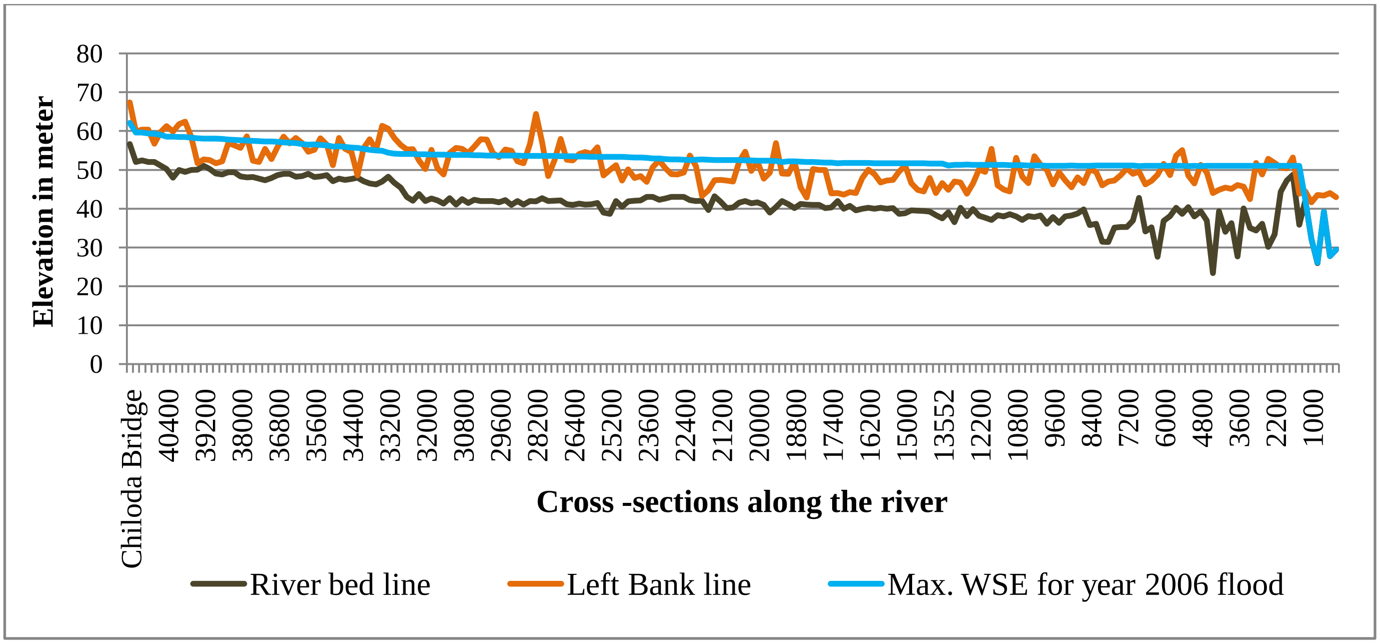


Fig. 5 Comparison of simulated water surface elevation with left bank for year 2006 flood

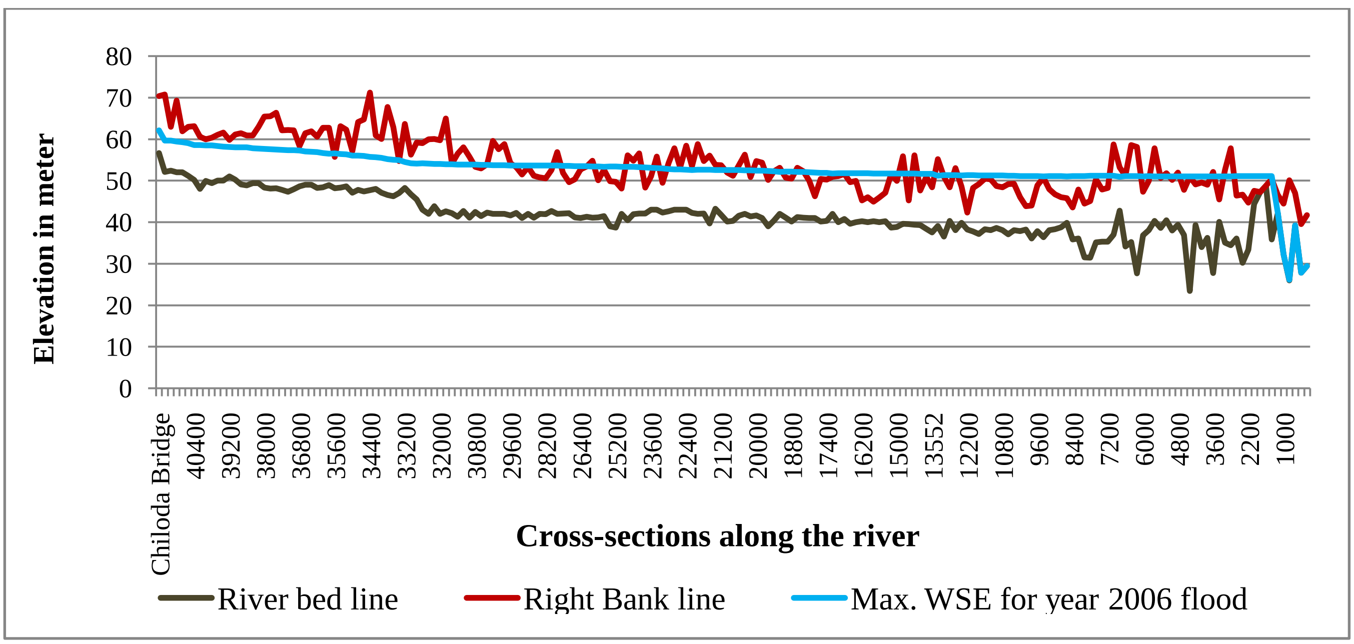


Fig. 6 Comparison of simulated water surface elevation with right bank for year 2006 flood

The analysis of water spill from both the banks shows that for flood event of year 2006, for the left bank 129 cross sections out of 197 (65.48 %) and for the right bank 95 cross sections out of 197 (48.22%) were inundated. This results had been compared with actual conditions of year 2006 flood event, comes out to be in satisfactory match.

The 1D model just computes water surface elevation and how deep that water is going to get. It does not determine the direction. That is quite insufficient to actually determine which direction that water's going to go, which the 2D modeling can be very useful to in reality determine which direction the flow going to go. HEC-RAS 2D has a GIS interface and applies the finite volume method to solve unsteady flow equations that describe the two-dimensional [18]. The fundamental concept underlying 2D modeling is to divide the river and neighbouring floodplain areas into a set of individual cells called grid cells or 2D flow cells. Each grid cell contains elevation and roughness data to represent the ground surface elevation and friction effects along the ground surface. The interface between two grid cells is called a cell face. The ground geometry at a face is composed of the ground elevations found from the GIS cells. Hydraulically, a cell face is the same as across-section. The ground geometry is known since it is provided by the GIS cell information. As a result, hydraulic properties like, cross-sectional area, wetted perimeter, hydraulic radius and conveyance can be computed for any water surface elevation. In addition, since the topography within a grid cell is known, then a relationship between the storage volume in the grid cell and the water surface elevation can be developed. This is known more commonly as a stage-storage curve. A water surface elevation is computed at each grid cell for each point in time. The size of the grid cells defines the resolution of the model and model results. For this research 10 m grid Cartoset 1 DEM is used to create terrain and 2D flow area is delineated on this terrain with 10 m computational mesh. Following figure 7 shows steps involved in development of 2D HEC-RAS model.

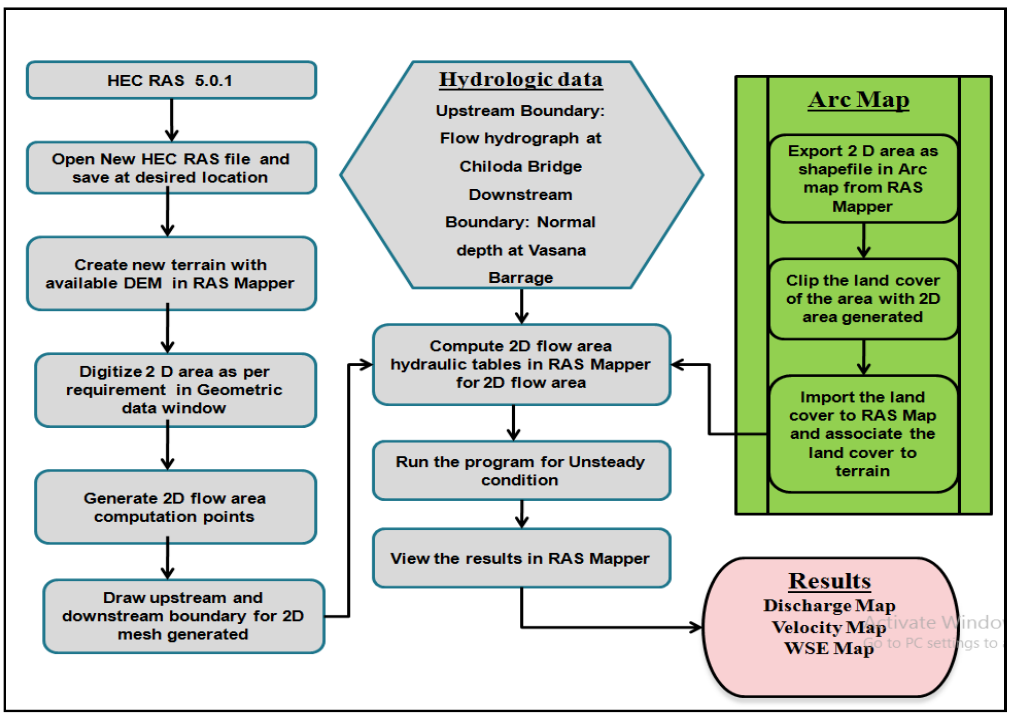


Fig. 7 Steps involved in simulation of 2D unsteady HEC-RAS model

The value of Manning's roughness coefficient n is also a vital parameter that can be used in calibration of the two-dimensional model. In land cover map, manning's roughness values have been specified as per guideline of DRIP, Govt. Of India with various land use categories like wasteland, agriculture, plantation, built up areas of high, medium and low intensity, river, canal, water bodies etc. in land cover layer. This land cover layer with relevant manning's roughness co-efficient has been associated with terrain data of study area which results in association of a Manning's roughness value with each computational cell faces as shown in figure 8.

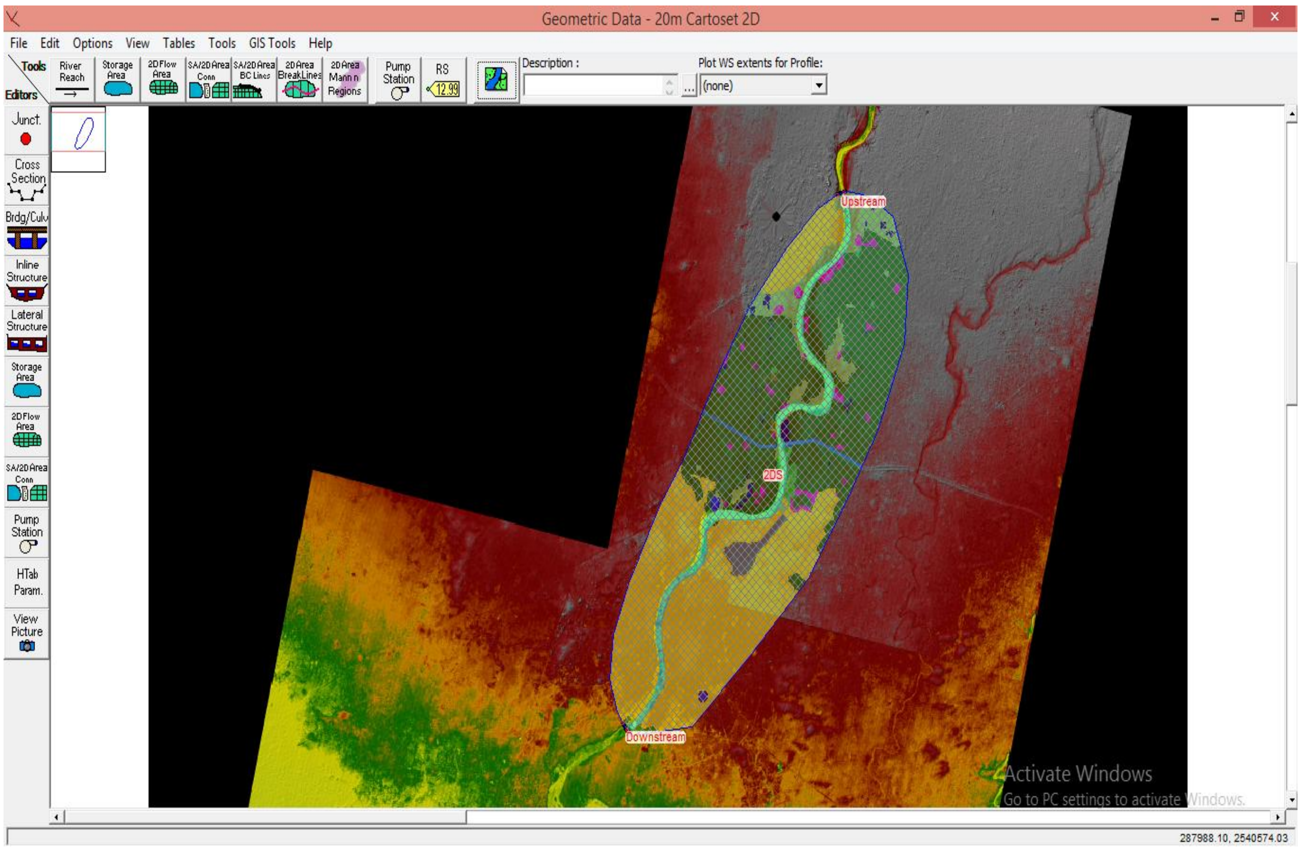


Fig. 8 2D flow area along with land cover

Flood hydrograph of year 2006 at Chiloda Bridge and normal depth at Vasana Barrage has been considered as upstream and downstream boundary conditions respectively. The 2D model has been simulated for year 2006 flood event with computational interval of 10 seconds. After simulation, various maps for parameters like discharge, velocity, water surface elevation, inundation boundary has been extracted for maximum values as shown in figure 9.

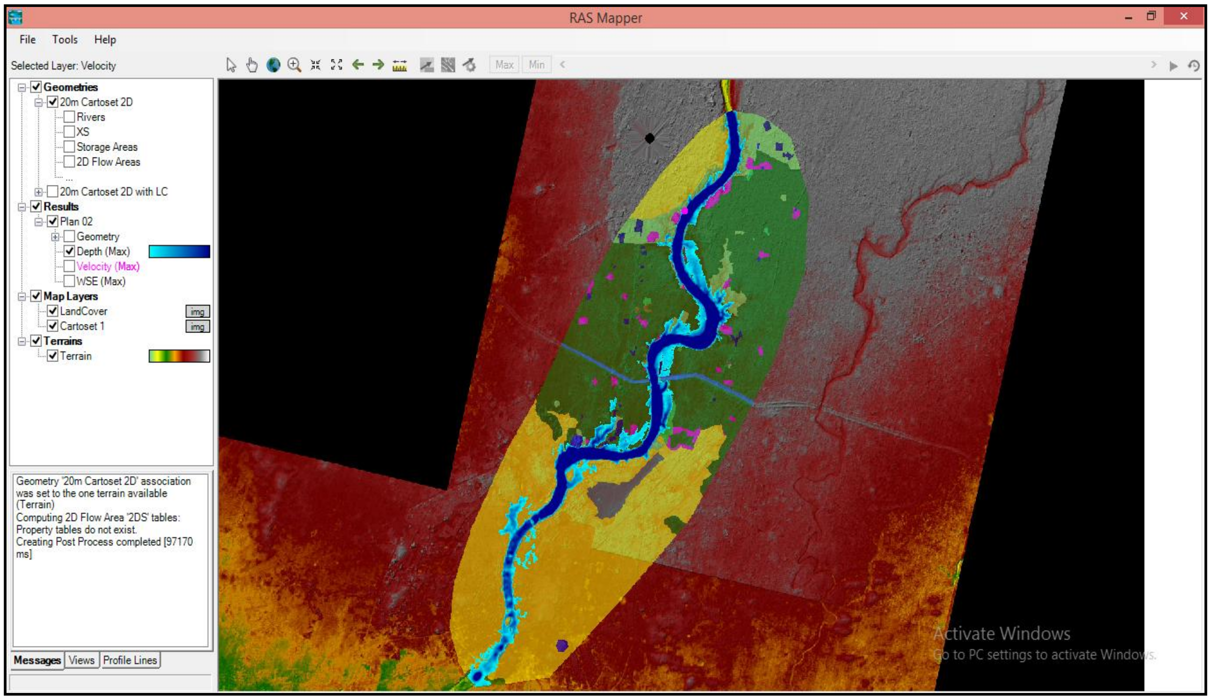


Fig. 9 Results of 2D model simulation in RAS Mapper for maximum depth

All these parameters can be extracted for specific date and time points also as per the requirement and application of model. The flood inundation probability maps have been prepared for various discharges by mapping simulated parameters with ward map of Ahmedabad city.

7.4 Sensitivity Analysis

Sensitivity of model has been analysed by comparing simulated and observed stages of river at Subhash Bridge using geometric data generated through two DEMs of 30 m resolution and 10 m resolutions along with cross section spacing of 300m and 200 m interval for year 2006 and year 2007 for manning’s roughness coefficient ranging from 0.015 to 0.045.

Observed and simulated stage hydrographs at Subhash Bridge have been evaluated in terms of statistical parameter like root mean square error (RMSE), % error, mean absolute difference and mean difference. The result shows that model is highly sensitive towards grid interval of DEM used for creation of geometric data along with the spacing of cross section interval considered. Also it has been observed that if the cross section spacing has been decreased beyond optimum value, the flow become supercritical and gives unrealistic outcomes in terms of water surface elevation.

8. Achievements with respect to objectives:

1 D and 2D hydrodynamic models have been developed using geometry extracted from Cartoset 1 DEM of 10 grid intervals and after validation of elevations at major bridge sites along the study reach founds out to be in acceptable range. The comparison of observed and simulated stage hydrographs at Subhash Bridge site shows quite satisfactory match for 1 D HEC-RAS model. Thus, objective of development of flood model for data scare region has been achieved. Calibration of Manning's roughness coefficient for year 2006 data has been done and the same is validated with year 2007 flood data. Comparative analysis of model parameter generated from two different DEMs of resolutions of 30 m and 10 m can be referred and applied for importance and requirement of model output; it can also be useful for deciding spacing of cross sections for specific DEM while producing geometric data from HEC GeoRAS. The 2D HEC-RAS model is developed and results of simulation have been further utilized for preparing inundation probability maps for city for different discharges. From developed 1D and 2D model for Ahmedabad city, flood prone areas have been identified and emergency action plan has been suggested for the same.

9. Conclusion:

The present study attempts to know efficacy and applicability of DEM generated cross sections along with HEC RAS model for estimating stages in Sabarmati River and resulted inundation in neighbouring areas using DEM extracted geometric data. After simulation of 1D and 2D hydrodynamic model of Sabarmati river flowing conclusions has been made,

- The HEC-RAS based model has potential to effectively calculate river stages for relative discharge from upstream and further utilized to update regarding flood situation in surrounding.
- The DEM extracted geometric data produced using HEC GeoRAS can be effectively used in absence of sufficient and reliable surveyed data for generation of hydrodynamic model of channel. Validation of DEM extracted data should be done at key locations for better results.
- The exactness of results is highly dependent on resolution of DEM used along with spacing of cross section produced in HEC GeoRAS. Most effective cross section spacing of 30m resolution DEM is 300 m and for 10m resolution is 200 m for respective case if the cross section spacing is further decreased, the flow becomes supercritical and model becomes unstable and giving unreal results in terms of stages and discharge.

- Model suggest that for release of discharge equal to 8800 cumec (as of year 2006 flood) from Dharoi dam, almost 65% area near left bank and 48% area near right bank are prone to inundation.
- For all the return period and relative discharge, west bank of river, consist of new Ahmedabad is more prone to water logging than east bank of river consist of old Ahmedabad city.
- Use of 2D HEC-RAS model along with precise terrain data in terms of DEM proves to be very useful and effective for preparing flood inundation probability maps. The effectiveness of 2D model can be upgraded by using more precise DEMs of 5 cm or lesser grid interval.
- The 2D HEC RAS model developed using 10 m grid Cartoset 1 DEM can generate inundation boundary maps for peak discharge of various return period which will be further utilized in preparing flood inundation probability maps for areas across the river bank showing the percentage of area inundated corresponding to peak discharge for various return periods. These maps would be helpful for initial risk assessment tasks for land use and urban planning and utilized in developing flood forecasting and flood warning system for Ahmedabad city.
- The methodology developed combining HEC GeoRAS and HEC RAS to develop hydrodynamic modeling can be used effectively to predict stages for any river in absence of sufficient geometric data.

10. List of Conferences /Journal Paper publications:

1. Paper published on the, Application of open source google image for river bathymetry delineation for 1d hydrodynamic modeling, *International Journal of Research and Analytical Reviews (IJRAR)*, Vol.6, Issue 1, March 2019, E-ISSN: 2348-1269 (UGC approved).

2. Paper published on the, Review of application of open source HEC-RAS for 1 dimensional hydrodynamic modeling - Global and Indian scenario, *Journal of Emerging Technologies and Innovative Research (JETIR)*, Volume 6, Issue 4, April 2019, ISSN-2349-5162 (UGC approved)

3. Presented paper on, River cross section delineation from the Google earth for development of 1d HEC-RAS model – a case of Sabarmati River, Gujarat, India, HYDRO-2017 International, LDCE, Ahmedabad, India, December -2017.(International conference)

4. Presented Poster on, 1D HEC-RAS hydrodynamic modeling of river flow simulation using DEM extracted river cross-sections- A case of Sabarmati River, Gujarat, India, European Geo-science Union (EGU-2018), April-2018, Vienna, Austria.

11. References:

[1] G. National Disaster Management Authority, “National Disaster Management Guidelines,” 2008.

[2] P. Tripathi, “Flood Disaster in India : An Analysis of trend and Preparedness Flood Disaster in India : An Analysis of trend and Preparedness,” no. February, 2016.

[3] J. Alam, “Flood Disaster Preparedness in Indian Scenario,” no. July, 2015.

[4] V. Demir and O. Kisi, “Flood Hazard Mapping by Using Geographic Information System and Hydraulic Model : Mert River , Samsun , Turkey,” vol. 2016, 2016.

[5] P. Taylor, “ISH Journal of Hydraulic Engineering Flood inundation simulation in Ajoy River using MIKE-,” no. December, pp. 37–41, 2012.

[6] V. Bellos, “Ways for flood hazard mapping in urbanised environments : A short literature review,” pp. 25–31, 2012.

[7] P. V. Timbadiya, P. L. Patel, and P. D. Porey, “One-dimensional hydrodynamic modelling of flooding and stage hydrographs in the Lower Tapi river in India,” *Curr. Sci.*, 2014.

[8] N. Pramanik, R. K. Panda, and D. Sen, “One dimensional hydrodynamic modeling of river flow using DEM extracted river cross-sections,” *Water Resour. Manag.*, 2010.

[9] “HEC-RAS River Analysis System Hydraulic Reference Manual,” 2016.

[10] K. Yamani, A. Hazzab, M. Sekkoum, and T. Slimane, “Mapping of vulnerability of flooded area in arid region . Case study : area of Ghardaı,” *Model. Earth Syst. Environ.*, 2016.

[11] M. K. Zainalfikry and A. A. Ghani, “HEC-RAS One-Dimensional Hydrodynamic Modelling for Recent Major Flood HEC-RAS One-Dimensional Hydrodynamic Modelling for Recent Major Flood Events in Pahang River,” no. August, 2018. page nuber ?? , check for all refernces

[12] A. Azouagh, R. El Bardai, I. Hilal, and J. Stitou, “Integration of GIS and HEC-RAS in Floods Modeling of Martil River (Northern Morocco),” no. April, 2018.

[13] A. M. Awad, “Mathematical Modeling of Unsteady Flow for AL- Kahlaa Regulator River,” vol. 05, no. 02, pp. 9–20, 2015.

[14] L. Kadhim Hameed and S. Tawfeek Ali, “Estimating of Manning’s Roughness Coefficient for Hilla River through Calibration Using HEC-RAS Model,” 2013.

[15] P. K. Parhi, “Calibration of Channel Roughness for Mahanadi River, (India) Using HEC-RAS Model,” *J. Water Resour. Prot.*, vol. 04, no. 10, pp. 847–850, 2012.

[16] D. P. Patel, J. A. Ramirez, and P. K. Srivastava, “Assessment of flood inundation mapping of Surat city by coupled 1D / 2D hydrodynamic modeling : A Case Application of New HEC-RAS 5,” *Nat. Hazards*, 2017. Add full refernce incluign all authors; page number, volume is missing

[17] N. Kumar, D. Lal, A. Sherring, and R. K. Issac, “Applicability of HEC-RAS & GFMS tool for 1D water surface elevation/flood modeling of the river: a Case Study of River Yamuna at Allahabad (Sangam), India,” *Model. Earth Syst. Environ.*, 2017.

[18] C.-H. Gary W. Brunner, *HEC-RAS River Analysis System 2D Modeling User ’ s Manual*, no. February. 2016.