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2-D Unsteady Flow Modelling and Inundation Mapping for Lower Region of Purna Basin Using HEC-RAS

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ABSTRACT

Present investigations utilize two-dimensional flow modelling abilities of (HEC-RAS) Hydrologic Engineering Centres River Analysis System for flood inundation mapping in the downstream area of Purna basin, exposed to recurrent flooding. Floods are natural disasters, which cause loss of life and damages to properties and nature. 2-D Hydrodynamic model is utilized to assess geomorphic viability of floods in downstream side of Purna basin. In this research study, downstream region geometry of Purna river basin, the flood plain of the study area and historical observed flood data of unsteady flow have been used to develop the 2-D hydrodynamic model. For analysis of flooding, a reach of 20 km of river situated downstream of Purna River basin has been considered. Point-by-point fundamental terrain data is taken from a Digital Elevation Model (DEM) of 30-meter resolution image and is utilized to produce the (2D) two-dimensional flow area and stream geometries. River flow information like daily discharge during rainy months, slope available along the river reach from Mahuva gauging station close to Navsari city is utilized for the unsteady flow modeling. Depth of water, velocity distribution and water surface height obtained after 2D flow simulation are utilized to decide the degree of flooding. RAS-mapper is an effective tool in HEC-RAS, which can be utilized for inundation of research area. For unsteady flow analysis, each time step was done based on inflow hydrograph using RAS mapper tool in HEC-RAS, which gives the spatial distribution of the river flow. The outcomes from this research examination can be utilized for disaster management, flood management, early warning system by authorities in addition to infrastructure growth decisions.

INTRODUCTION

The issues of expanding environmental carbon dioxide fixations in the Earth's atmosphere is analysed and the conceivable future climatic changes which may result considering such issues. As the amount of CO_2 prone to be discharged into the environment because of fossil fuel combustion, the normal increments of other greenhouse gases that impact the world's radiation spending plan, how and when climatic changes can be distinguished, and the anticipated changes in ocean level coming about because of global warming (Bolin et al. 1989). Environmental change is required to quicken water cycles and, in this way, boost the accessible renewable freshwater resources (RFWR) that as it may, fluctuations in occasional forms and the expanding likelihood of extreme events may balance this impact. Diminishing current vulnerability will be the initial step to get ready for such foreseen changes (Oki et al. 2006). The research depicts an appraisal of the ramifications of climate change for worldwide hydrological administrations and water assets. By 2025, it is assessed that around 5 billion individuals, out of an all-out populace of around 8 billion, will live in nations suffering from water pressure (Arnell 1999). The Inter-governmental Panel on Climate Change (IPCC) ventures that more prominent fluctuation and precipitation force will build flooding risk in numerous territories on account of environmental change (Ishiwatari 2010). The ascent in worldwide temperature expands the risk of the flood disaster. Radiative impacts of anthropogenic fluctuations in atmospheric structure are relied upon to cause atmosphere fluctuations, specifically an escalation of the worldwide water rotation with a subsequent increment in flood hazard (Milly et al. 2002). Each year, flooding causes a catastrophic effect on the population, environment, economy, and everywhere throughout the world. Federal Emergency Management Agency (FEMA) has of late refreshed their flood-plain standard according to the high-level official request in 2015 on the Federal Flood Risk Management Standard. This examination joins the recently refreshed floodplain mapping standard in the flood hazard appraisal of roughly 11.3 km stretch of the Patapsco River close Ellicott City, U.S (Thakali et al. 2017). Hazard can be built up as a well-characterized strategy for taking care of flood risk because of man-made, ecological and natural risks, of which floods are a delegate. Flood risk management plans, described at three level say project planning, project design, and the real expense of a structure, are assessed and contrasted and the advantages from the strategic scheme (Plate 2002). Of late, the tsunami in South East Asia triggered approximate 220,000 passing which makes it likely a standout amongst the most appalling floods. Amid the International Decade of Natural Disaster Reduction (IDNDR) from 1990 to 1999, it was valued that the past worldview of "flood assurance" was wrong (Schanze 2006).

Additionally, as of now ecological and local arrangements in numerous nations are beginning to move from flood assurance to flood hazard management (Dworak & Görlach 2005). Geospatial techniques are very useful to detect the flooding events through combine approach of Arc GIS and HEC-RAS.(Pathan & Agnihotri 2019a)

Decision support system (DSS) is a significant tool for decision makers throughout various period of flood organization to mitigate the major flood and develop different models like economic, forecasting and hydrodynamic to connect with each other and share information which play a crucial role for decision makers (Ahmad & Simonovic 2006). The vision of FEMA's is to fill in as an impetus that drives expanded understanding and proactive activity to help individuals in networks to reduce their losses from natural risks. To fulfil this vision, FEMA subsidizes three Hazard Mitigation Assistance (HMA) programs. Flood risk relief estimates are any manageable moves made to decrease or dispose of long-term hazard to individuals and property from future fiascos. With the continuous event of an outrageous event in urban zones, floodplain maps and flood models have become necessary for disaster authorities to mitigate flood (Knebl et al. 2002). One dimensional modelling approach has given an accurate outcome for determining flooding at different cross sections of the Purna River basin (Pathan & Agnihotri 2019b).

Now a day's different water resources models are utilized to simulate the flooding phenomena, to quantify risk and damage estimation and to help the decision-making procedure with respect to the forecast and counteractive action of floods (Todini 1999). Different examinations have exposed the ability of globally accessible adaptation of 2-Dimensional numerical simulation methods (Johns et al. 1971, Vojinovic 2013). Comparison between 1-Dimensional model over a 2-Dimensional model shows more difference in HEC-RAS when unsteady flow has been carried out; results show almost 200m horizontal difference in inundated area at high discharge (Alho et al. 2008). Generally, the results obtained from 1-D models are not accurate for the flat or flatter flood plain areas, in this way, numerous 1-Dimensional hydrodynamic models are supplanted by 2-Dimensional hydrodynamic models (Merwade et al. 2008). In spite of the fact that there is enormous vulnerability of the qualities of flood events, 2-Dimensional numerical investigation suggests an approach to all the more likely describe the flood. Hydrologic Engineering Centre- River Analysis System (HEC-RAS) hydrodynamic model has been generally utilized related to Environmental System Research Institute (ESRI), HEC-GeoRAS and Arc-GIS programming for 1-Dimensional investigation and mapping of a flood extent. The most recent adaptation, HEC-RAS 5.0.1 offers the independent ability to accomplish 2-Dimensioanal directing and capacities to fully examine and mapping of flood inside the RAS mapper in HEC-RAS model itself. Research examination investigates the 2-D presenting limit of HEC-RAS to show the Purna River around Navsari region, which is exposed to flooding during high discharge. The most recent capacities of RASmapper in HEC-RAS are used for the improved mapping of the floodplain periphery by using past flood information of the Purna River. The objective of the research study is to accomplish unsteady flow analysis, set up a flood inundation map of the study area and to plot the flood inclined territories by utilizing the 2-dimensional hydrodynamic modelling and inundation mapping capacities of most recent variant of HEC-RAS 5.0.1. Computational techniques are very effective in flood management to identify flooding scenarios at different reaches of the study area (Pathan & Agnihotri 2019c).

MATERIALS AND METHODS

Research Study Area

Navsari region lies on floodplain in the periphery of Purna. The length of Purna river considered is about 20 km for research. The river basin starts from Saputara near Maharashtra. Purna river floodplain has centroidal facilitate of 200º41' to 210º05' North latitude and 720º45' to 740º00' East longitudes. The purpose behind choosing this study area is the regular occurrence of flood events, affecting densely the populated urban area around it. The absolute catchment locale of the Purna basin is 2433 km^2. Location map and google map of the research area are as shown in Fig 1. and Fig 2 respectively. Catchment area distribution of Purna River is given in Table 1.

Digital Elevation Model (DEM) of 30-meter resolution is utilized for building the terrain of the research area in RAS-mapper tools (HEC-RAS), acquired from Indian Space Research Organization Bhuvan (ISRO BHUVAN). High resolution images are downloaded from Google earth, the water level and river discharge information of yearly and daily scales are gathered from Central Water Commission

Table 1: Catchment area distribution of Purna River.

Sr. No.	State	Catchment area (km^2)	% of the total catchment area
1	Gujarat	2373	97.61
2	Maharashtra	58	2.39
3	Total	2431	100.00

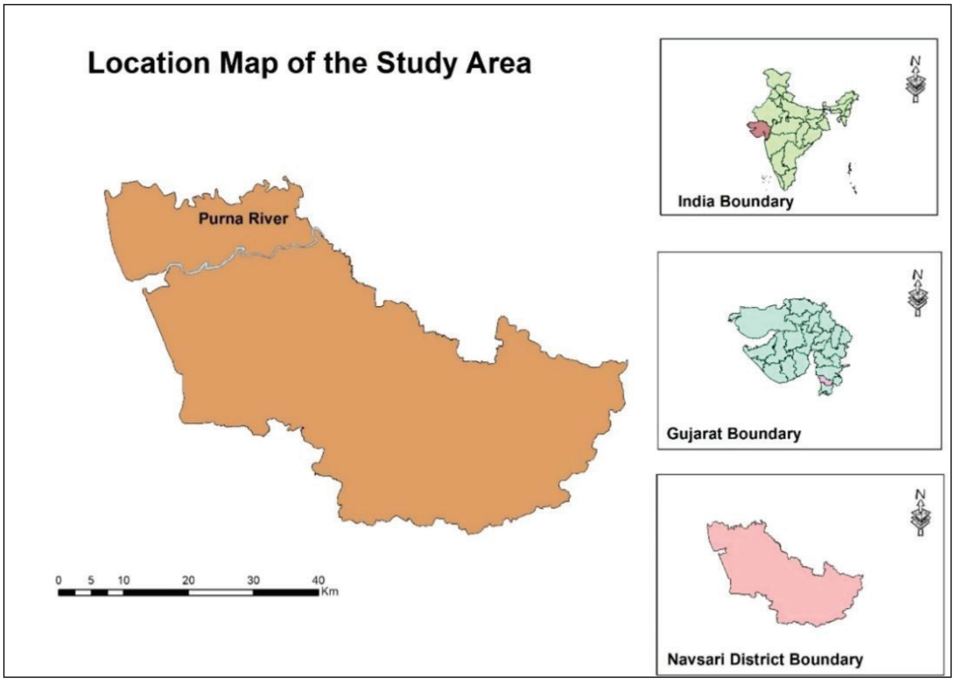

Fig. 1: Location map of study area.

(C.W.C), State Water Data Center (SWDC), Gandhinagar and Irrigation Department.

Methodology

Digital Elevation Model (DEM) of 30-meter resolution taken from ISRO Bhuvan is imported to HEC-RAS software. Now, from Tools menu in RAS-Mapper, create terrain from selected Digital Elevation Model (DEM) which is then used in RAS-Mapper to work on the hydrodynamic properties and building up the geometry of 2-D flow region of study area. Moreover, cell size of 200 m × 200 m was provided, which are created along the selected 2-D flow area of the River of the study area. Now, we utilize the geometric pre-processing tools in Ras-Mapper for creation of hydraulic properties of each cell of the reach.

Manning's roughness coefficient is allocated for the 2D area, considered for the research area in RAS-mapper. The allocated land cover value and corresponding Manning's n value are shown in Table 2.

For unsteady flow simulation in RAS-mapper, provide upstream and downstream boundary conditions of the area of the river. For upstream, Mahuva gauge station hydrograph is used for simulation, and in the downstream normal depth of channel slope (0.000425) is used as boundary condition. The created geometric layer for 2D area of river with the used boundary conditions are mentioned in Table 2 and Fig. 3.

In this research study, daily discharge data is used for two flooding events of time intervals 29th June 1976 to 26th September 1976 and from 21st July 2004 to 26th September 2004. As per past flood data, most severe flooding events occurred in Purna basin on 31st July 1976 with a peak discharge of 4380.2 m^3/s and on 04th August 2004 with a peak discharge of 8836 m^3/s. Upstream hydrographs used in check for the two flooding events are shown in Fig. 4. and Fig. 5.

Flood inundation mappings for years 1976 and 2004 events are plotted in RAS-mapper for peak discharge. For better visualization in mapping, google earth layers can be

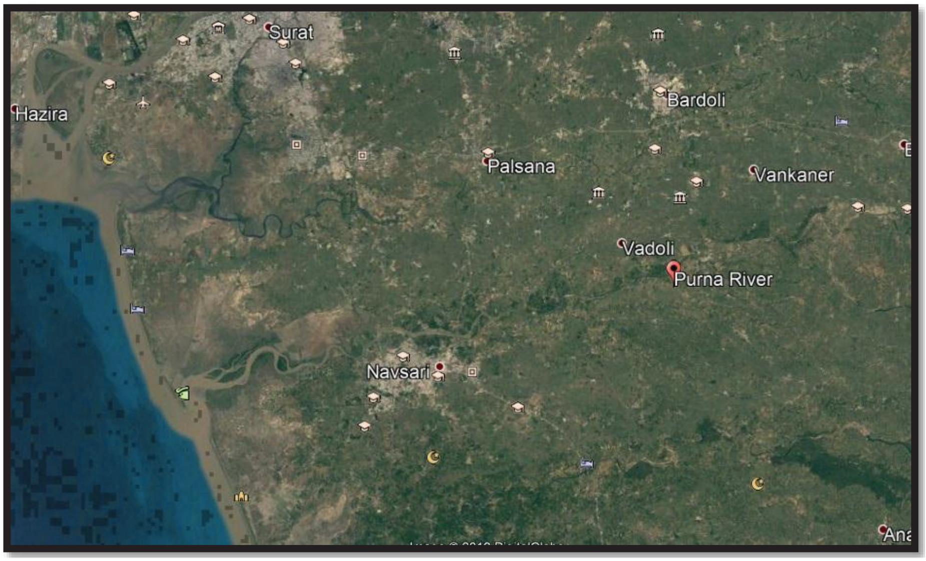

Fig. 2: Google map of study area.

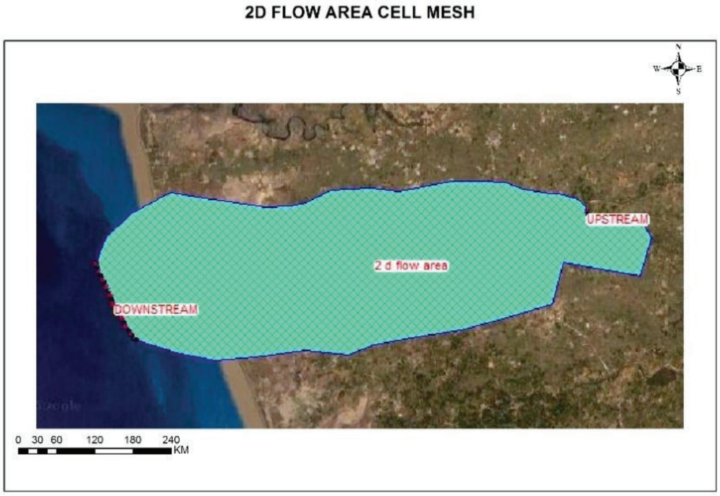

Fig. 3: Generated geometric layer with 2D flow area cell mesh.

Table 2: Manning's n for the channel (Chow 1959).

Type of Channel and Description	Minimum	Normal	Maximum
Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

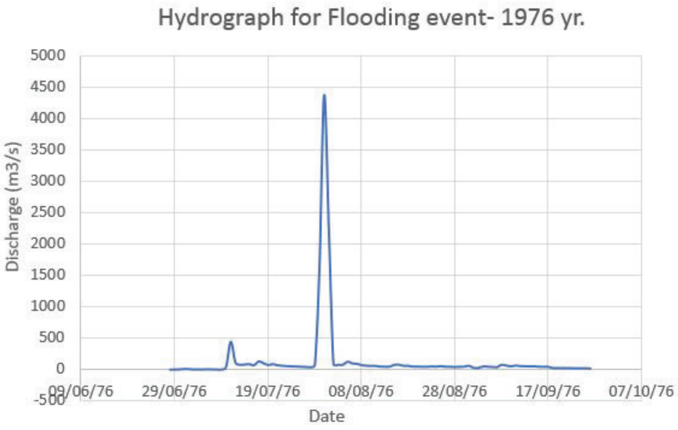

Fig. 4: Hydrograph for flooding event-1976 yr.

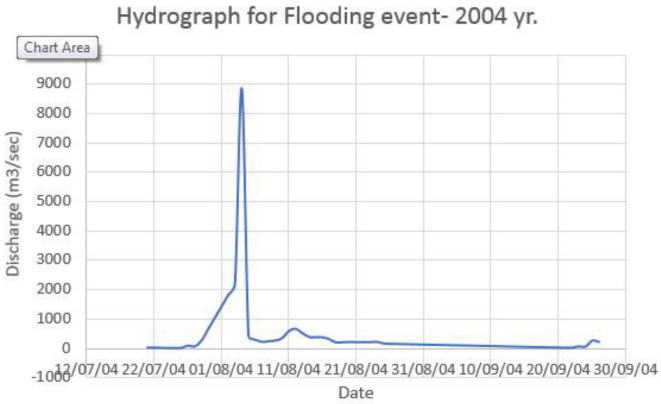

Fig. 5: Hydrograph for flooding event-2004 yr.

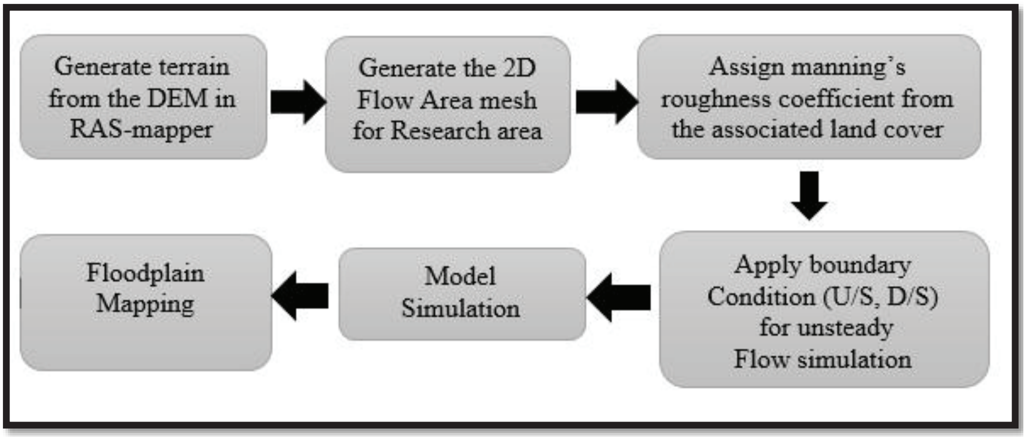

Fig. 6: Conceptual 2D model diagrams for floodplain mapping in HEC-RAS.

imported into RAS-mapper. The outline of methodology is shown in the Fig. 6.

RESULTS AND DISCUSSION

Over the 2D flow area considered in this study, a total of 15,221 cells are generated for the year 1976 flooding event and 9207 cells are generated for the year 2004 flooding event, for the 20 km river reach. Terrain information used for 2D flow area of research zone is from the geometry editor tools in HEC-RAS.

In this research work, for the study area considered, the computational time interval for the model is taken as 6 hours and output interval of the model is taken as 1 day for both flooding events with cell sizes of 200 m × 200 m used for analysis. Using a lesser value of time intervals and smaller cell sizes can produce better results, but the simulation would take more effort to complete. Initial condition of river reach for the study area was supposed to be wet for unsteady flow analysis in HEC-RAS. After considering all conditions, the entire mesh is filled up till warm-up period and when simulation is finished, fill up all cells of the river reach as open channel flow implementing diffusion wave equation in which finite volume approximation is considered.

Hydraulic properties of every cell must be assigned before doing the analysis in RAS-mapper. RAS-mapper has good capability for making hydrodynamic properties of every mesh generated in each cell, which in turn depends on the terrain data considered in the study area and their Manning's "n" values.

The 2D output results can be observed in the form of inundation area, velocity and water surface elevation profile within RAS Mapper tools in HEC-RAS.

Comparison of 1976 and 2004-Year Flood Depth Map

It is observed that in the 1976-year flood, the depth of flooded water at Purna River Bridge, Navsari is 20.550 m and in 2004-year flood, depth of flood water is 23.490 m (Fig. 7 & 8). We have simulated both flood year data in RAS-mapper

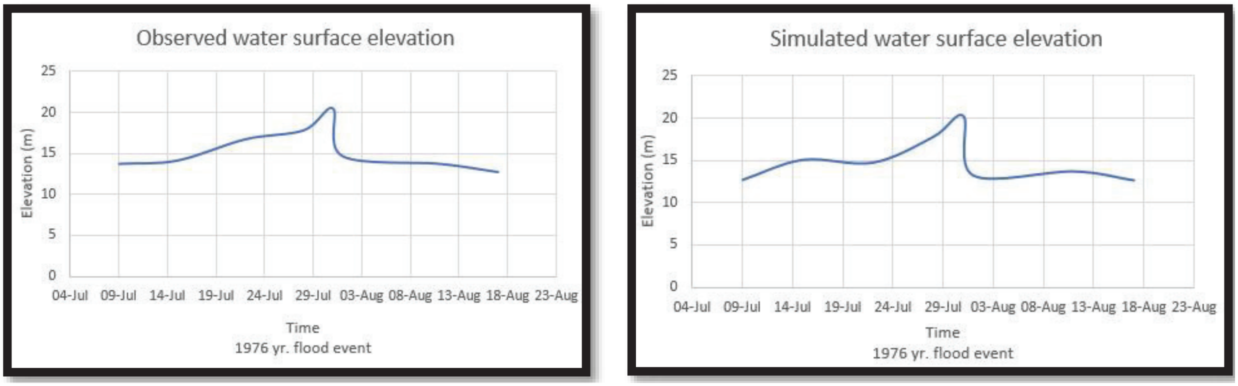

Fig. 7: Observed vs simulated water surface elevation for 1976 yr flood event.

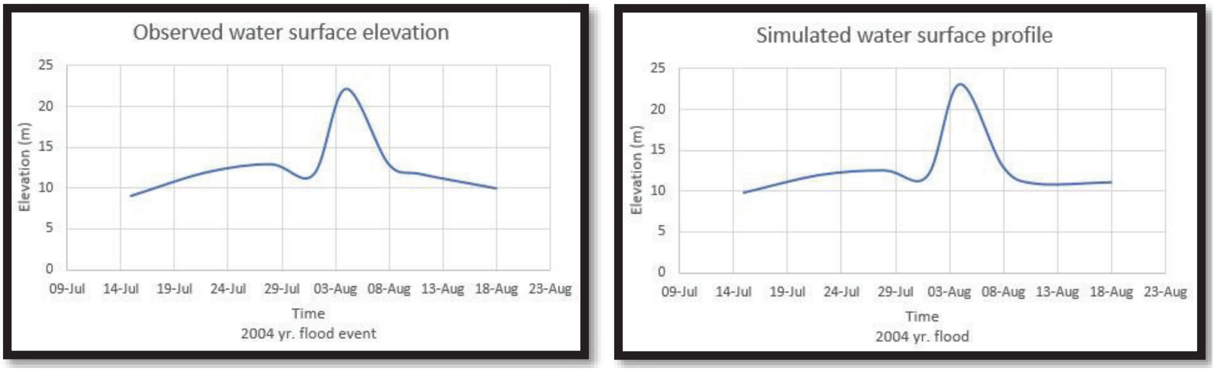

Fig. 8: Observed vs simulated water surface elevation for 2004 yr flood event.

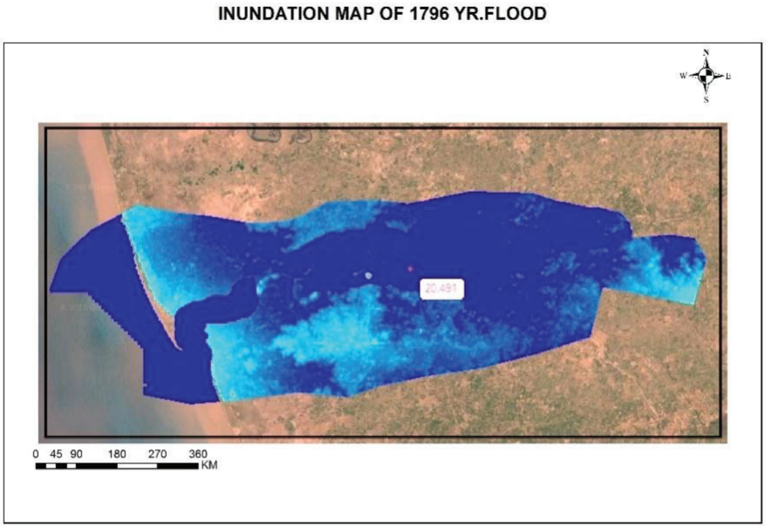

Fig. 9: Inundation map of 1976 year flood

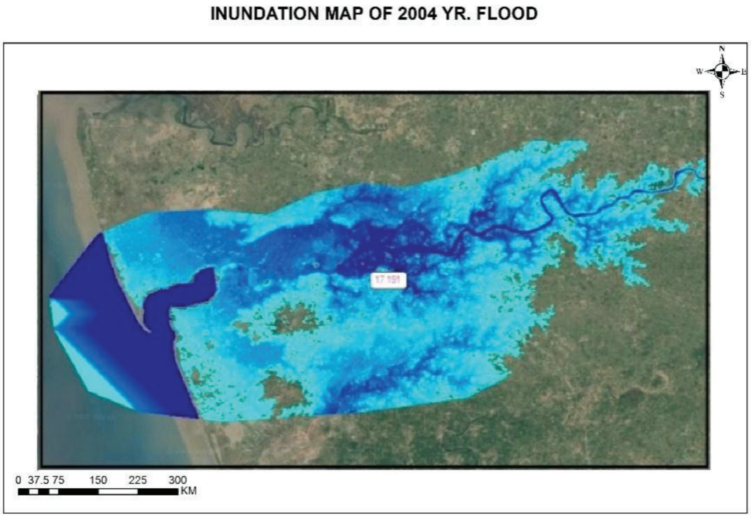

Fig. 10: Inundation map of 2004 year flood.

and developed the inundation map for both 1976-year flood depth and 2004-year flood depth and are shown as in Fig. 9 and Fig.10.

Comparison of 1976 and 2004-Year Flood Velocity Map

It is observed that in 1976-year flood, velocity of flood water was 3.13 m/sec at Purna River Bridge, Navsari and for 2004-year flood, velocity of flood water was 2.57 m/sec. We have simulated both flood year data in RAS mapper and developed velocity maps of both 1976-year flood and 2004-year flood as shown in Fig. 11 and Fig.12.

CONCLUSION

This analysis is meant to lead 2D unsteady flow simulation using HEC-RAS 5.03 in downstream of Purna River, Navsari city. For the stream of 20 km reach, stream hydrograph of 1976-year flood event, occurred between 29th June 1976 and 1st December 1976 and for 2004-year flood event, occurred between 22th June 2004 and 29th September 2004 are routed. Assessment of unsteady flow conditions for the stormy month just as flooding event is completed. From the analysis, following conclusions can be drawn.

- During the study period, the maximum depth of water found was 19.976 m and maximum velocity of water

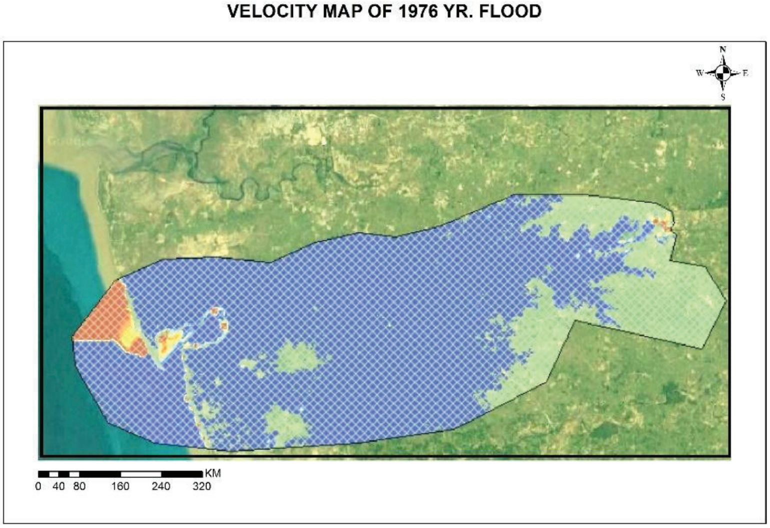

Fig. 11: Velocity map of 1976 year flood.

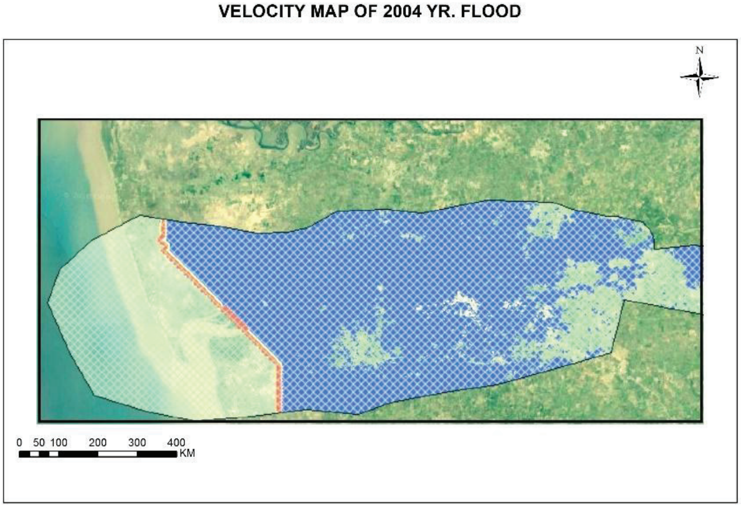

Fig. 12: Velocity map of 2004 year flood.

found was 0.4 m/s for 1976 year flood event with a peak discharge of 4380.20 m^3/sec, the maximum depth of water found was 21.325 m and maximum velocity of water was 0.038 m/s for 2004 year flood event with a peak discharge of 8836 m^3/sec at the Purna River Bridge, Navsari.

- When maximum discharge of 8836 m^3/s is routed, areas near Purna River Bridge like Viraval, Jalalpur are found to be inundated. The highest flood level reached was 24.8 m.
- To develop flood warning and using this information for protecting areas of Navsari district from inundation.

The outcome proposed correlates the parameter's maximum depth and velocity distribution with the past flood events. Smaller cell size and smaller computational intervals give better results but take more time to complete the unsteady flow simulation.

The process described in this study can be upgraded to facilitate analysis and better visualisation capacities. Some additional research recommended for this study are as mentioned below.

- Analysis of the Purna River may help the areas for demarcating safe and vulnerable zones based on the extent of the flood. Such analysis can also be used for the prediction of flood hazard as well as its extent.

- The peak urban runoff might also be the cause behind such unpredicted flooding, which would require additional research to validate.
- The future work can be useful for applying the methodology to produce the flood risk map of entire Navsari district.

REFERENCES

Ahmad, S. and Simonovic, S.P. 2006. An intelligent decision support system for management of floods. Water Resources Management, 20(3): 391-410.

Alho, P. and Aaltonen, J. 2008. Comparing a 1D hydraulic model with a 2D hydraulic model for the simulation of extreme glacial outburst floods. Hydrological Processes: An International Journal, 22(10): 1537-1547.

Arnell, N.W. 1999. Climate change and global water resources. Global Environmental Change, 9: S31-S49.

Bolin, B. and Doos, B. R. 1989. Greenhouse Effect. John Wiley & Sons.

Chow, V.T. 1959. Open-channel Hydraulics. MacGraw-Hill Book Co., NY

Dworak, T. and Görlach, B. 2005. Flood risk management in Europe@ the development of a common EU policy. International Journal of River Basin Management, 3(2): 97-103.

Ishiwatari, M. 2010. Climate Change Adaptation in Flood Risk Management Through Utilizing Datasets Produced by Supercomputer.

Johns, P. B. and Beurle, R. L. 1971. Numerical solution of 2-dimensional scattering problems using a transmission-line matrix. In: Proceedings of the Institution of Electrical Engineers, 118(9): 1203-1208).

Knebl, M. R., Yang, Z. L., Hutchison, K. and Maidment, D. R. 2005. Regional scale flood modeling using NEXRAD rainfall, GIS, and HEC-HMS/RAS: a case study for the San Antonio River Basin Summer 2002 storm event. Journal of Environmental Management, 75(4): 325-336.

Merwade, V., Cook, A. and Coonrod, J. 2008. GIS techniques for creating river terrain models for hydrodynamic modeling and flood inundation mapping. Environmental Modelling & Software, 23(10-11): 1300-1311.

Milly, P. C. D., Wetherald, R. T., Dunne, K. A. and Delworth, T. L. 2002. Increasing risk of great floods in a changing climate. Nature, 415(6871): 514.

Oki, T. and Kanae, S. 2006. Global hydrological cycles and world water resources. Science, 313(5790): 1068-1072.

Pathan, A. I. and Agnihotri, P. G. 2019a. A combined approach for 1-D hydrodynamic flood modeling by using Arc-GIS, Hec-Georas, Hec-Ras Interface - A case study on Purna River of Navsari City, Gujarat. IJRTE, 8(1): 1410-1417.

Pathan, A. I. and Agnihotri, P. G. 2019b. One dimensional floodplain modelling using soft computational techniques in HEC-RAS - A case study on Purna basin, Navsari District. In: International Conference on Intelligent Computing & Optimization, Springer, Cham., pp. 541-548).

Pathan, A. I. and Agnihotri, P. G. 2019c. Use of Computing Techniques for Flood Management in a Coastal Region of South Gujarat – A Case Study of Navsari District. In International Conference on Intelligent Computing & Optimization. Springer, Cham., pp. 108-117.

Plate, E. J. 2002. Flood risk and flood management. Journal of Hydrology, 267(1-2): 2-11.

Schanze, J. 2006. Flood risk management–a basic framework. In: Flood Risk Management: Hazards, Vulnerability and Mitigation Measures (pp. 1-20). Springer, Dordrecht.

Thakali, R., Bhandari, R., Kandissounon, G. A. A. D., Kalra, A. and Ahmad, S. 2017. Flood risk assessment using the updated FEMA floodplain standard in the Ellicott City, Maryland, United States. World Environmental and Water Resources Congress 2017.

Todini, E. 1999. An operational decision support system for flood risk mapping, forecasting and management. Urban Water, 1(2): 131-143.

Vojinovic, Z., Seyoum, S., Salum, M. H., Price, R. K., Fikri, A. K. and Abebe, Y. 2013. Modelling floods in urban areas and representation of buildings with a method based on adjusted conveyance and storage characteristics. Journal of Hydroinformatics, 15(4): 1150-1168.