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Water Productivity Enhancement through controlling the flood inundation of the surrounding region of Navsari Purna river, India

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Abstract

Water productivity may carry different meanings to different people, and may differ between but also within groups of water users. The term water productivity is used exclusively to denote the amount of the product over the volume of water diverted. This research paper presents one-dimensional hydrodynamic modeling of a steady flow analysis on the Purna river of the Navsari region, India. ArcGIS and HEC-RAS software were used to find out water level at different cross-section in 62 km stretch of river reach. Carto DEM of 1-arc second resolution was pre-processed in ArcGIS v10.5 to extract the cross-sections for hydraulic modeling. Hydrologic Engineering Centre's- River Analysis System (HEC-RAS v5.0.7) software was used to carry out the analysis of hydraulic parameters for past flood data. Total 246 cross-sections were analyzed to check the carrying capacity of the 62 km stretch of the river for the peak flood discharge of the years 2004 and 2005. The results show that around 40% of the total cross-sections were not having the capacity to safely pass the flood discharge. So, construction of retaining walls, embankments, stone-pitching, and detention ponds were suggested to prevent the flood inundation of the surrounding region. The study presented in this paper would be helpful in the infrastructure planning for decision-makers to prevent the loss due to floods in low-lying areas.

Keywords: ArcGIS; Flood; Flood Delineation; HEC-RAS; One-dimensional Model; Water Productivity Enhancement

INTRODUCTION

Water productivity may carry different meanings to different people, and may differ between but also within groups of water users. The term water productivity is used exclusively to denote the amount of the product over the volume of water diverted (Chowdhary *et al*., 2016). The occurrence of high-intensity rainfall leads to flooding of the river. Flood has become a serious threat to human being's life and property (Mehta *et al*., 2013; Patel, 2018; Mehta *and* Yadav, 2020; Yadav and Mangukiya, 2020). Floods have affected the loss of human life, damage the property, destruction of crops, and deterioration of health conditions owing to water-borne diseases. One-dimensional (1-D) hydraulic models are used to forecast the floods and water levels in the river and floodplain. (Mehta *et al*., 2020; Horritt *and Bates,* 2002). A set of equations are solved simultaneously to estimate the discharge and water depth at different cross-sections using boundary conditions in 1-D hydraulic models for steady flow analysis (Timbadiya *et al*., 2011. 2013). Boundary conditions and channel geometry data are important inputs for developing hydrodynamic models. Vegetation cover, watershed, and topographical characteristics can also be considered. Generally, structure data like dams, weir, and bridges are not considered in the study of one-dimensional hydrodynamic models (Mehta *et al*., 2013). In the present, one-dimensional hydrodynamic models are an important tool to generate flood hazard maps for

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disaster management, and to design the height of a flood wall on the river bank to reduce damages in flood-prone areas (Parhi *et al*., 2013; Ahmad *et al*., 2016; Demir and Kici, 2016). The peak flow of extraordinary large floods that occur during a period of systematic record is a controversial problem for flood frequency analysis (FFA) using traditional methods (Heidarpour *et al*., 2017). River flood risk map prediction is a combination of hydrological modelling, hydraulic modelling, river flood visualization and river flood risk mapping (Alaghmand *et al*., 2012).

The main reasons for the floods are the prevailing natural ecological systems in the country, such as heavy rainfall with temporal and spatial variations, highly silted river systems and inadequate capacity to carry high flood discharges, inadequate drainage to transport rainwater quickly to streams and rivers (Chabokpour *et al*., 2020). Many times, typhoons and cyclones also cause floods. Flash floods are caused by steep and highly erodible mountains, particularly in Himalayan ranges. The average rainfall in India is 1150 mm with significant variation across the Country. The annual rainfall along the western coast and the Western Ghats, Khasi hills, and over most of the Brahmaputra valley amounts to more than 2500 mm. Most of the floods occur during the monsoon period and are usually associated with tropical storms, depressions, and active monsoon conditions. Due to the mentioned conditions, floods occur in almost all river basins in India (Patel *et al*., 2018).

Floods which are occurred due to heavy runoff in the mainstream can be predicted using channel geometry data and water level of the upstream cross-section (Agrawal and Regulwar, 2016; Ullah *et al*., 2016). Flood risk maps can be prepared using the simulated results of water depth in the river and floodplain areas. Due to the entrance of pollutants in different branches of the river network, it is essential to study contaminant transport at the river confluences. (Chabokpour *et al*., 2020). The riverbank near low-lying areas can be affected by waterlogging due to drainage or runoff (Ingale and Shetkar, 2017). It is very easy to plan a mitigation strategy and evacuate the people from flood-affected areas using a flood risk zone indication (Khattak *et al*., 2016; Kumar *et al*., 2017).

In India mostly economic losses due to natural climate hazards, 79.6% approximate 378.62 crore rupees loss due to floods during in 65 years. Floods are occurring frequently in monsoons due to the river located near the region.

OBJECTIVES OF STUDY

The objective of the present study is to carry out steady flow analysis of 62 km stretch of river reach in Purna river basin to calculate the water level on the downstream side for different discharges.

Following are the objectives of the study:

- To delineate the Purna river watershed using DEM (Digital elevation model) and develop Terrain surface for cross-sections using ArcGIS software.
- To develop a steady flow model of Purna river of Navsari Region using one-dimensional hydrodynamic model in HEC-RAS.

STUDY AREA

Purna River lies in four districts in Gujarat. This river rises in the Saputara hills of the Western Ghats near the Chinchai village in Maharashtra. This river flow 180 km before emptying into the Arabian sea. The total drainage area of the river is 2431 km^2 among which 58 km^2 lies in the state of Maharashtra and 2373 km^2 lies in the state of Gujarat, India. The length of the river considered in the present study is approximately 62 km. Aqueduct (21°1'39.86" N,73°11'49.67" E) present in the upstream of the river and Arabian sea at end of the Purna river are considered as boundary conditions. The study reach consists of 246 cross-sections, the distance between river cross-section is approximately 250 meters at streamline.

The Navsari town is located on the bank of the Purna river. It is located in the southern part of Gujarat. Navsari town (20°56'48.01" N, 72°57'7.24" E) is a headquarters administration of the district. The average elevation of the city above sea level is 9 meters and the average annual precipitation in this region is 1220 mm. The catchment receives most of the precipitation from June to September (South West monsoon). Figure 1 and 2 show the Navsari district map and Purna River, respectively.

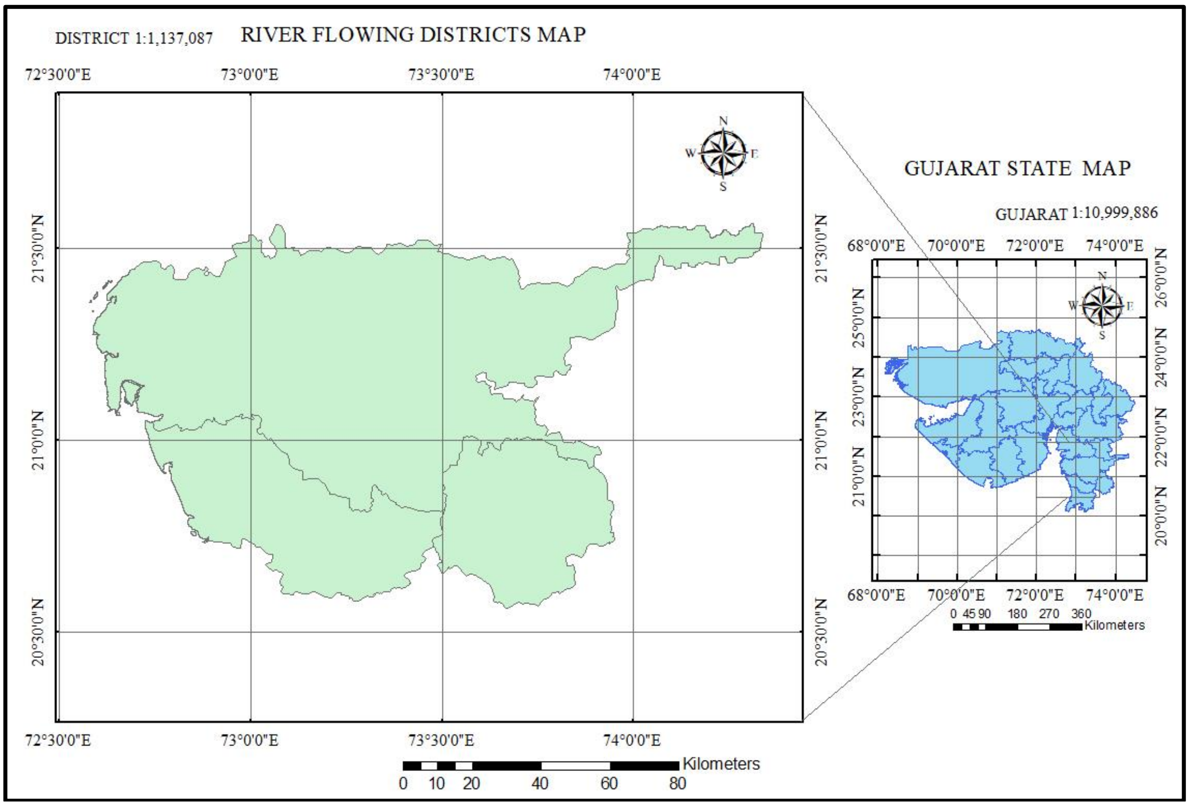

Fig. 1. Navsari district map

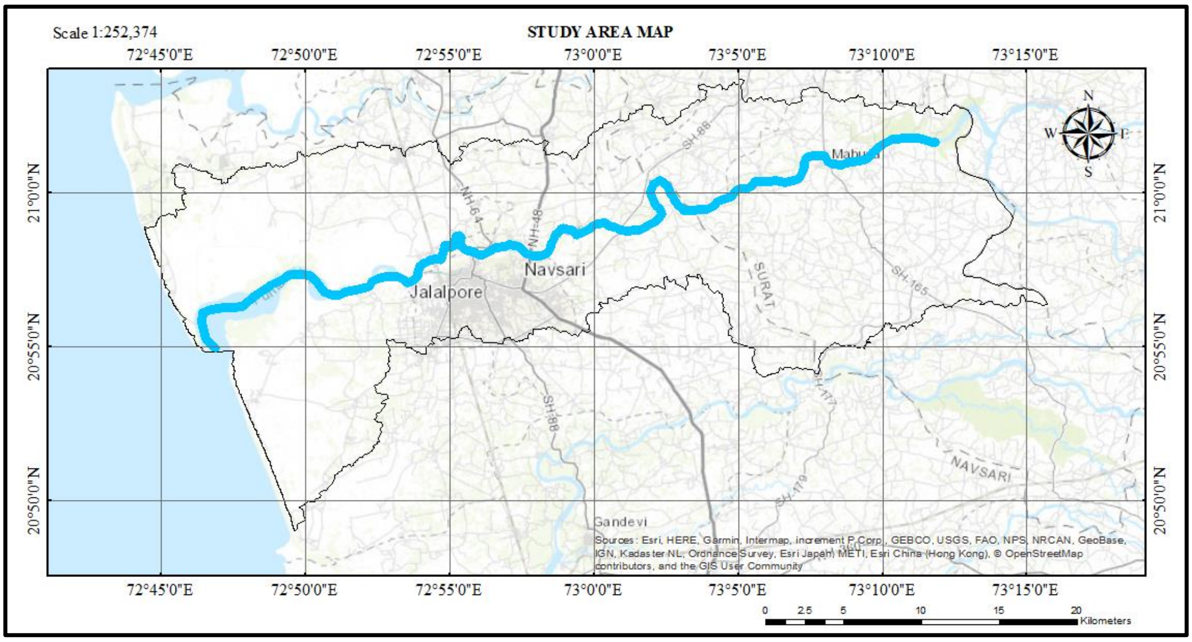

Fig. 2. Purna River basin map

DATA COLLECTION

The DEM of 30 m resolution was downloaded from the Bhuvan Indian geo platform of ISRO (Carto DEM Version-3 R1) and used to generate the cross-section. The discharge data of Mahuva gauging station were collected from Centre Water Commission office (CWC, Surat). Figure 3 shows the maximum discharge data of the Purna River.

METHODOLOGY

In this study, various software's were used for flood modeling and simulation.

Figure 4 shows the flowchart of the methodology used in the present study.

Preparation of the Channel Geometry

In this study, ArcGIS Desktop v10.5 software is used for pre-processing of the geometry data. First of all, the downloaded raster DEM tiles were incorporated into ArcGIS and pre-processed using 'Spatial Analyst' tool. This Digital Elevation model were then used to delineate the river basin and mainstream line. Figure 5 shows the delineated basin of Purna River.

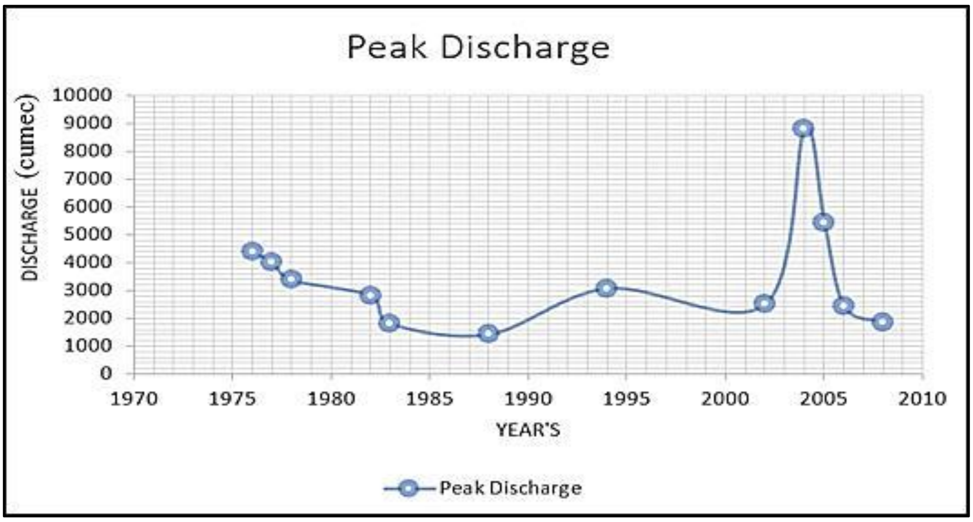

Fig. 3. Graphical representation Peak Discharge of various flood events

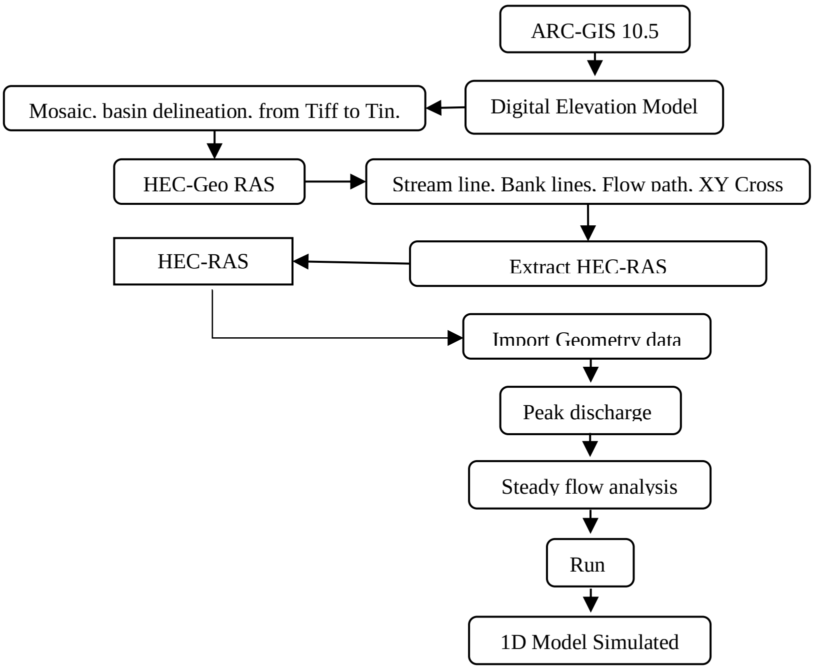

Fig. 4. Methodology flowchart

Extraction of the cross-sections

HEC-Geo RAS is an extension of ArcGIS. This extension is used for creating streamline, bank lines, and flow path lines. Cross-sectional data and spatial data were extracted from the terrain surface. Figure 6 shows the cross-sections, and river bank lines which are used in the present study.

Development of the one-dimensional hydrodynamic model

HEC-RAS is an open-source software, which is developed by the United States Army Corps of Engineers for modeling the hydraulics and hydrodynamic water flow through artificial channels and natural rivers (Wang, 2014). In the present study, HEC-RAS software is used to carry out the steady flow analysis and also to find out the water surface level as well as carrying capacity of the study reach.

HEC-RAS has the ability to calculate the water surface profiles for steady and gradually varied flow as well as for subcritical, supercritical, and mixed flow regime. In addition to this, HEC-RAS is capable to do modeling for sediment transport, which is notoriously difficult. Therefore, modeling sediment transport is based on assumptions and empirical theory that is sensitive to several physical variables.

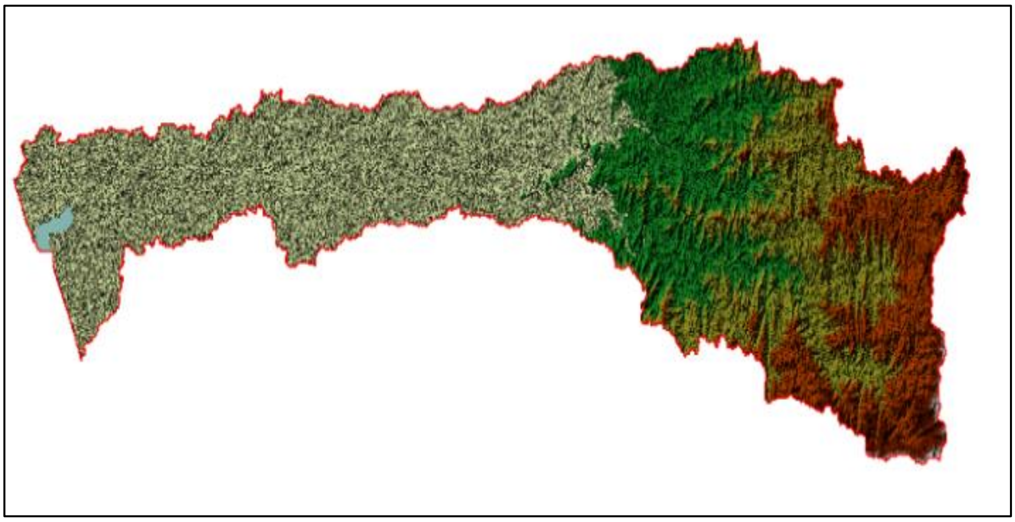

Fig. 5. Delineated Purna river basin

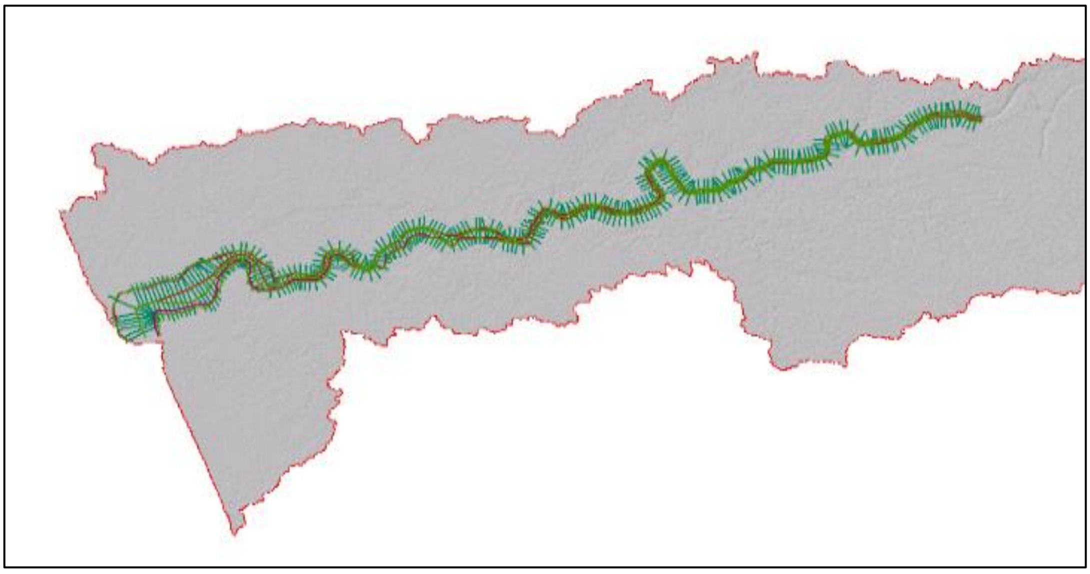

Fig. 6. Cross-sections and river bank lines

For making such calculations, HEC-RAS requires boundary conditions for each type of data. These boundary conditions are important to determine the mathematical solutions to the problems. Boundary conditions are required to obtain the solution to the set of differential equations describing the problem over the domain of interest. In HEC-RAS, there are several boundary conditions available for steady flow and sediments analysis computations. Boundary conditions can be either externally specified at the ends of the network system (upstream or downstream) or internally used for connections to junctions.

For the present study area, Manning's roughness coefficient n is taken as 0.012 for each cross-section according to the gauge station data of CWC, Surat.

Following are the steps for developing 1-D hydrodynamic model using HEC-RAS:

Step 1: Create a new HEC-RAS project.

Step 2: Create a new river and reach in the geometry editor window with steady flow analysis

Step 3: Enter Geometric Data

Step 4: After adding all the data in the geometric data window we get cross-section in HEC-RAS.

Step 5: Enter the Manning's roughness coefficient (n) for the upstream reach of Purna River. Here the value of "n" is taken as 0.012 for Banks and channels (bed).

Step 6: Enter steady flow data for different peak flood discharge. Once the geometric data is entered, the necessary flow data can be entered subsequently. Steady flow data consists of the number of profiles, the flow data, and the river system boundary conditions.

Finally, the simulation of 1-D steady flow analyses was carried out for the peak flood discharge of the year 2004 and 2005.

RESULTS AND DISCUSSIONS

Steady flow analysis is an important tool in understanding the behavior of the river cross-sections under the effect of various flood events. After collecting all the relevant data of the study reach, data was entered in software for developing 1-D hydrodynamic model of a river reach segment, and simulation was carried out using HEC-RAS v5.0.7 for the past flood events. In this study, carrying capability of the existing cross-sections of the river reach were accessed.

Steady Flow Analysis

In the present study, a steady flow analysis simulation was carried out using peak discharge for the years 2004 and 2005. Figures 7 and 8 show the results of the water surface level for the peak discharge 8835 m^3/s in 2004, and 5436 m^3/s in 2005, respectively. The simulated water surface elevation from the steady flow analysis is then compared with the observed flood depth of Purna river reach as shown in Table 1. If the flood discharge overtops from a particular cross-section then such condition is considered as a flooded zone and if the flood discharge remains in a particular cross-section with sufficient carrying capacity of riverbank, then such condition is considered as non-flooded. For any year, the flow condition will be different which depends upon the flood discharge of that particular year. The water surface elevation and energy gradient line were also computed. From the steady flow analysis of the 2004 flood event, it was found that 135 cross-sections on the right bank side and 129 cross-sections on the left bank side, whereas in the 2005 flood event it was found that 106 cross-sections on the right bank side and 107 cross-sections on the left bank side are of less carrying capacity as compared to other cross-sections out of 246.

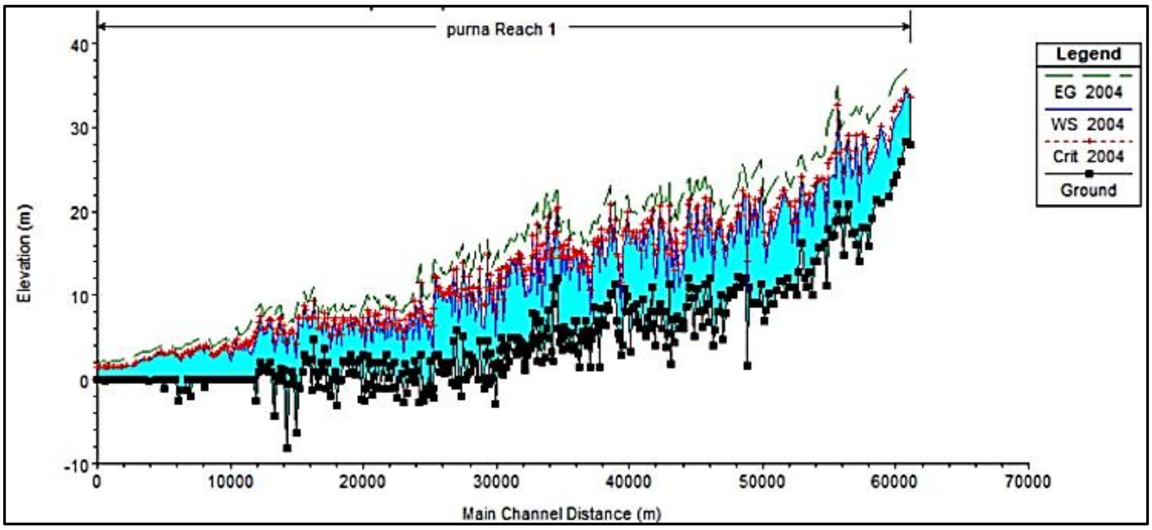

Fig. 7. Simulated results for the 2004 flood event

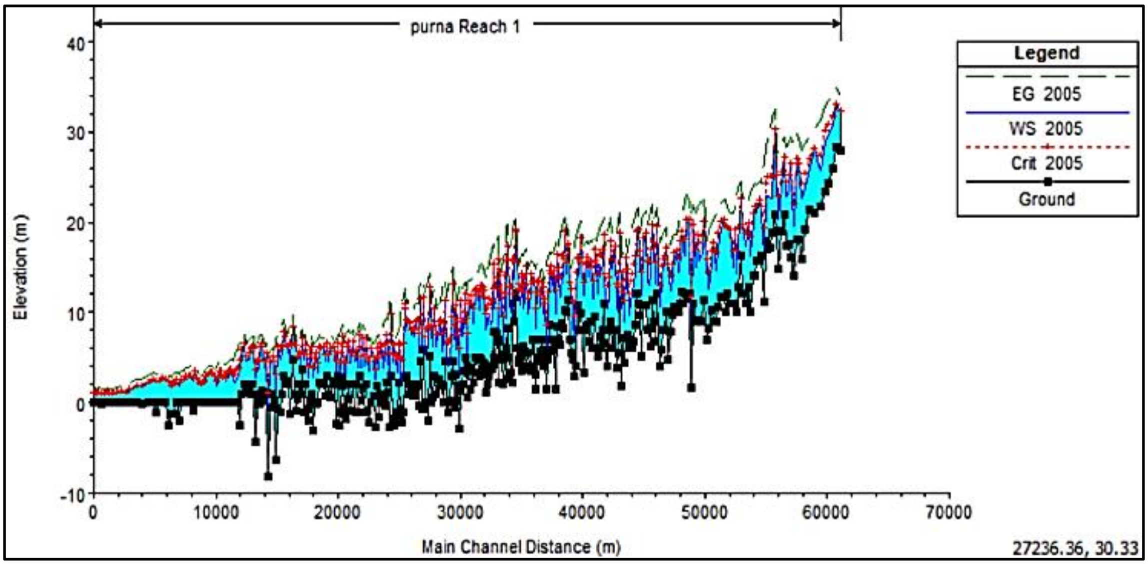

Fig. 8. Simulated results for the 2005 flood event

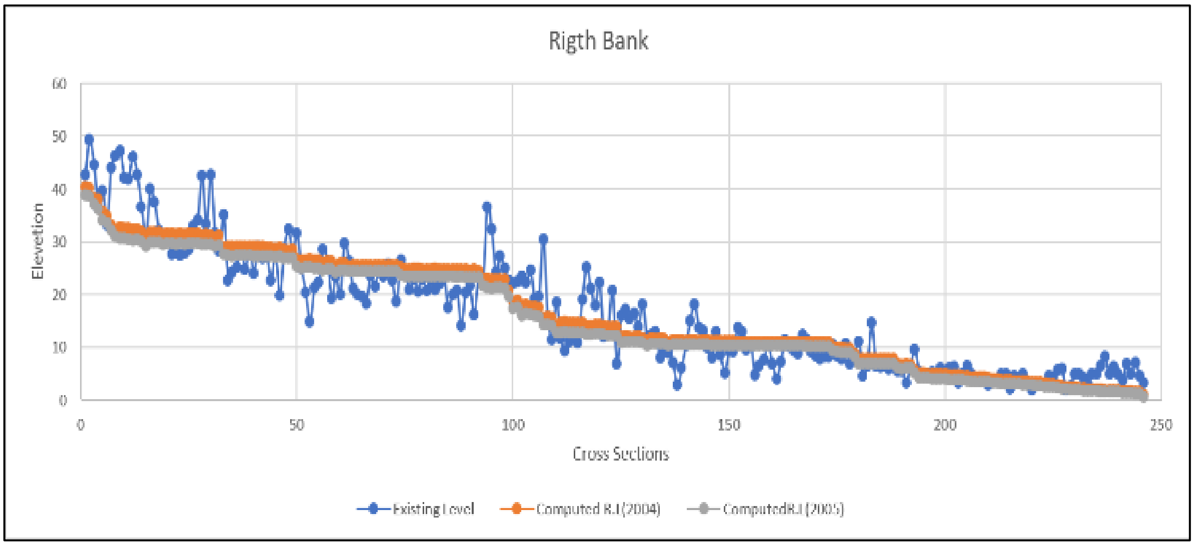

Fig. 9. Graph between existing and computed levels of two flood events Right Bank of Purna river

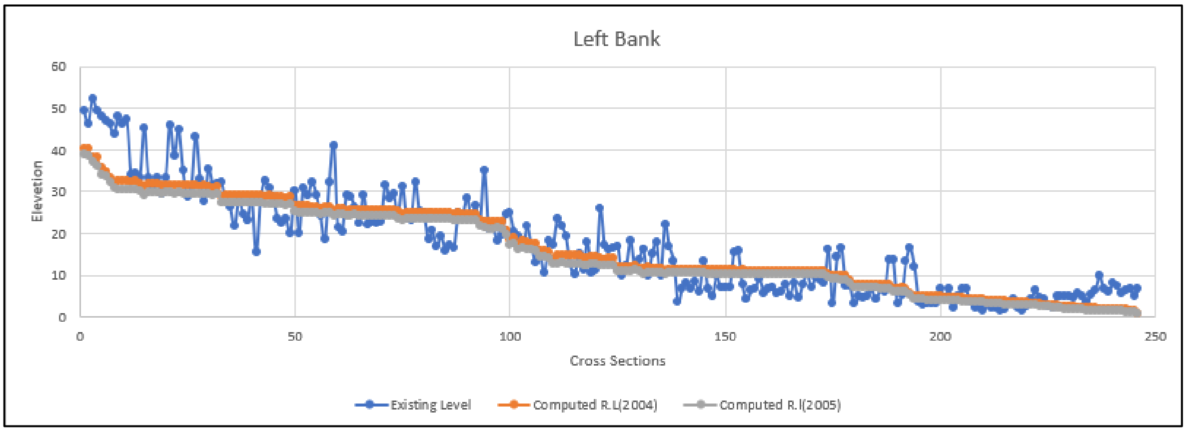

Fig.. 10. Graph between existing and computed levels of two flood events Left Bank of Purna river

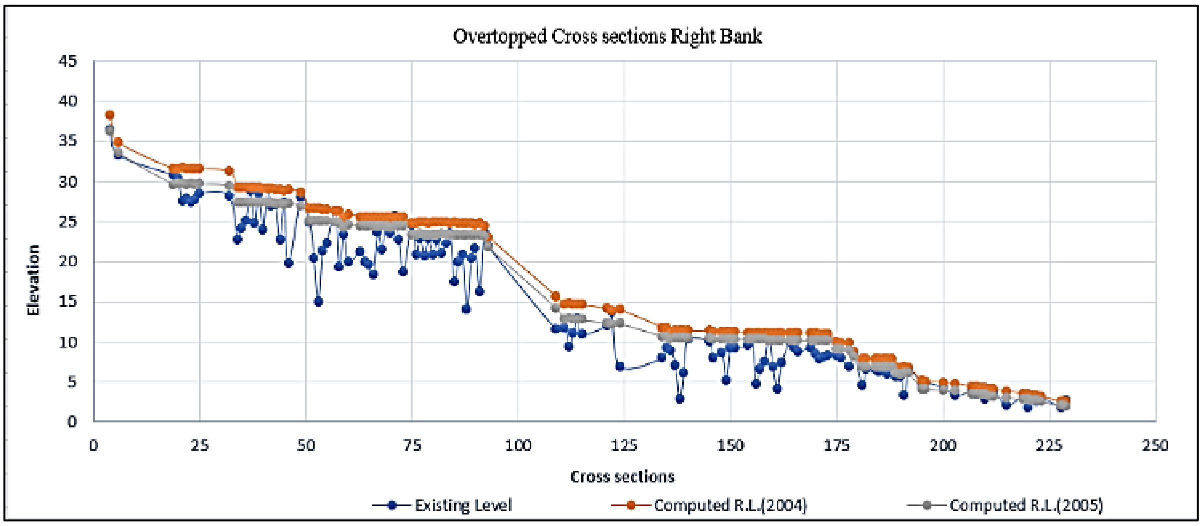

Fig. 11. Flooded Cross Section at Right Bank of Purna river

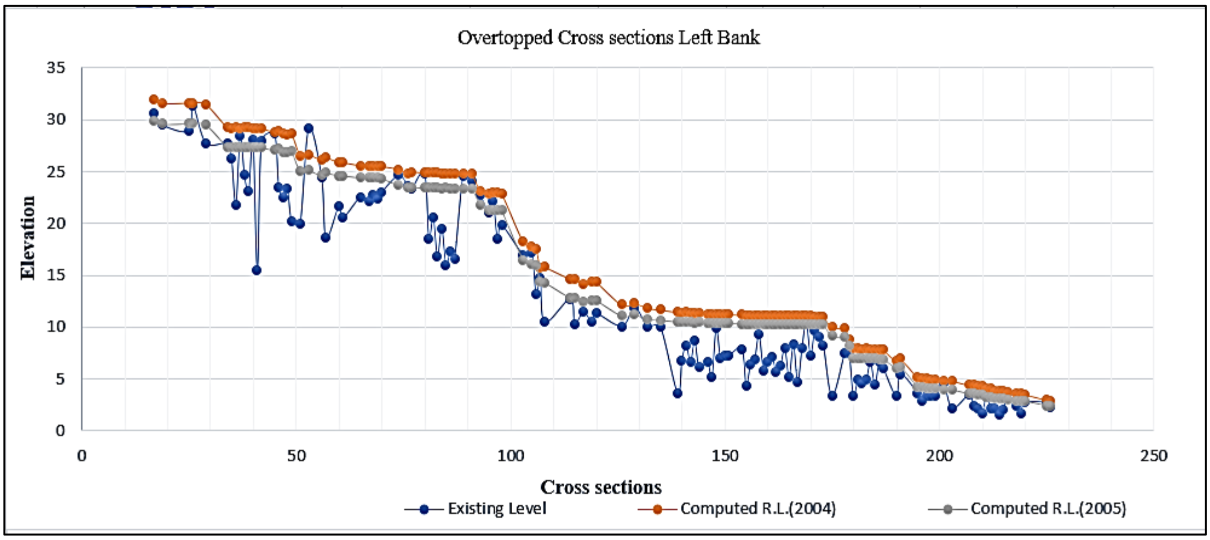

Fig. 12. Flooded Cross Sections at Left Bank of Purna river

Table 1. Validation of Computed RL with observed RL

Cross Sections	Computed Rl	observed RL
CS-132 (NH No.8)	13.62M	13.58M
CS-179 (Railway Bridge)	10.13M	9M

Figures 9 to 12 shows the graphical representation of existing and computed R.L. with Manning's coefficient, n = 0.012 at Mahuva gauging station for 2004 and 2005 flood. It can be observed from the graphs that the computed R.L. values are higher than the existing R.L. which may be due to the presence of main canal which is not considered in the present study. From the calibrated and validated 1D hydrodynamic model, the critical (most overflowing) cross-sections have been identified. Table 1 shows the reduced level (R.L.) with chainage for critical cross sections.

CONCLUSIONS

In the present study, ArcGIS, HEC-Geo RAS, and HEC-RAS v5.0.7 software was used for developing one-dimensional hydrodynamic model. Steady flow analysis is carried out using HEC-RAS software. As per the methodology, 246 cross-sections were analyzed by using peak flood discharge of the year 2004 and 2005. The simulated results show that 135 cross-sections on the right bank side and 129 cross-sections on the left bank side for the year 2005 and 106 cross-sections on the right bank side and 107 cross-sections on the left bank side were overtopped. The results from the present study can be used to suggest flood mitigation measures for the flood-prone villages around the Purna River reach. In the present analysis, embankment or retaining wall on either bank of the river has been considered as one of the flood mitigations measures. This solution may not be economical hence it is proposed to take advantage of parallel natural streams and ponds to conserve flood water. This solution seems to be more practical and economical. Further research lies to prepare zone wise floodplain mapping of the Purna basin using RAS-mapper tools in HEC-RAS.

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CONFLICTS OF INTEREST: The authors declare no conflict of interest

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