Flood Hazard Assessment of Baitarani River Basin using One-Dimensional Hydrodynamic Model

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September 14, 2020

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Abstract. The present work focuses on the use of topography and imagery, based on remote sensing in a GIS splat form for Baitarani River's integrated flood analysis, which is one of the most flood-prone zones in India. Flood frequency analysis is carried out for the flood data from 2001 to 2018. The work has been carried out using the maximum flood for the year 2015 with value of 7688 m^3/s discharge.

The current work uses a methodology that combines the HEC-RAS and Arc-GIS application tools for better vision of flood monitoring analysis, which is a non-structural measure of flood management system. The work is sorted in three phases; in the first preparation phase TIN generation has been done from the DEM with other initial modifications, while in the second execution phase pre-processing on HEC-GeoRAS Tool is carried out and data is exported to the HEC-RAS for computing the water surface profiles for the unsteady flow. In the third phase, flood depth and its extent for the flood hazard analysis is done. The recommendations from this study are; either to increase height of banks or construct a retaining wall at certain sections in the downstream part of Jajpur town in Odisha state.

Keywords: HEC-RAS, HEC-GEORAS, Arc-GIS, Flood Hazard Analysis.

1. Introduction

Natural disasters, as we know are the outcomes of events caused by natural hazards that exceed the capability of local intervention and adversely affect a Nation's socio-economic development (Target study n.d.). The most recurrent, widespread, calamitous and common natural hazards in the world are probably the floods affecting people at large. There have been 17 floods, 5 severe cyclones and 11 droughts in the last 24 years in Odisha state. On an average, Odisha suffers Rs. 3000 crores of financial loss in each year due to natural calamities, which is not only massive but also severely stresses the state’s economy. The average State rainfall is 1451.2 mm. Approximately 75-80 percent of the rainfall is received in the months of June to September, which causes remarkable damage to both crops and lives. Baitarani River floodwaters submerge over 40 villages in Jajpur Blocks of Jajpur district affecting some 22,000 residents. The water level in the Baitarani rises to 5.5m as against the danger mark of 5.4m at Akhuapada gauging station, very frequently.

After reviewing these flood effects, two types of flood management measures are proposed by the river authorities i.e. Structural and Non-structural methods. The structural method, construction of embankments, levees, spurs and others have not proved to be completely successful in the long runs. In the non-structural approach, flood risk maps are prepared using a hydrological-hydraulic method, where in the flood-depth, flood duration and flood area are computed with peak discharge of a specific return period. Various numerical models have been developed for flood plain delineation, flood inundation and simulation that could be used as a means to delineate flood plain zones adjacent to rivers and quantify the associated danger by taking into account the potential floods of different return periods.

In the past, the hydrodynamic modelling approach were adopted by various researchers to simulate flood inundation in the flood plain zones. Different arithmetical models have been proposed for floodplain delineation/flood inundation and flow modelling that can be instrumental to delineate floodplain areas adjoining the rivers and to quantify the associated risk or possibility, by taking into account the simulated floods with different periods of return.

Flood analysis helps in administering the prevention and prediction of flood occurrences. Modelling performed through computer techniques have supported the engineers and researchers with regulating more accurately by precisely defining the location and time of the flooding. Computer models for the assessment of impact of floods uses the following four steps:

1. Hydrological modeling in which, from the past flow records, determination of the rainfall-run off relationship are developed.
2. Hydraulic modeling, which assist the runoff propagation through river/channel and generation of water surface profiles in a tabular and graphical form at a particular location across the cross-section.
3. Floodplain mapping and monitoring devices.
4. Extraction of Geospatial data.

Many of the techniques in hydraulic modelling use one-dimension tools of steady state flow measured at a particular time. Since flows in streambeds are naturally random and unsteady, steady-state methods do not often show water surface profiles precisely (Snead 2000).

(Agrawal 2016) had successfully studied steady and unsteady flow for Dudhuna river and prepared a 3D view of perceptive plot for single discharges for the given study area. The performance of calibrated model has been verified from the observed discharges from dam.
(Patel, Mehta, and Yadav 2018) developed a model that can be used to predict water levels along the river reach from Ichhapur to Dhamdachha village for different water flows conditions. Flood inundation area for the years 1984, 1994 and 2004 has been assessed and investigated that dykes breaching was the major causes of the flood events. Hence, it was recommended to improve the carrying capacity of Ambica River which could help to minimize the flood in surrounding of Navsari city.

HEC-RAS is a tool used by hydraulic engineers which are used to analyze water flow through channel and river and floodplain control (US Army Corps of Engineers 2016). HEC-RAS is a one-dimensional steady flow hydraulic modelling approach that is used by many government agencies. With the help of HEC-RAS, simulating water surface profile for steady flow is simple that quantify the effect of any obstructions such as over bank region, weir, bridges and culverts. HEC-RAS is used to predict the flood inundation maps for a given flood (Manandhar 2010). A combination of Arc-GIS and HEC-RAS tools are used to create flood plain maps using river geometry, historical flood records, river discharge records and channel roughness.

The objective of the study is to implement a one-dimensional hydrodynamic model for the Baitarani river basin between Anandpur Barrage to Jajpur using HEC-RAS (5.0.5) modelling software for the flood hazard analysis.

2. Study Area and Data Collection

2.1 Study Area

Baitarani River basin has a total catchment area of 14,218 sq. km spreading over the two states of Odisha and Jharkhand in India. A major portion of the river basin with 13482 sq. km of catchment lies in the state of Odisha while Jharkhand have the rest of 736 sq. km. The rive originates at the Gonasika/Guptaganga hills at 21° 32´20´´N- 85°30´48´´E and starts flowing over a stone which looks like the cow’s nostril. The river at its origin has the elevation of 900 meters (3,000 ft) above sea level. The river traverses a total length of 360 km. from its origin at Gonasika until it flows into the Bay of Bengal after joining the Brahmani river at Dhamra mouth near Chandabali. This river has a total of 65 tributaries, of which Deo, Kanjhari, Kusei, Salandi are some of the main tributaries of the Baitarani river (INDIA-WRIS 2012).

The stretch of Baitarani River, considered in the study is from Anandapur barrage (21°13´35´´ N-86°07´00´´E) to the Jajpur (2°51´19´´ N-86°25´13´´ E) which is witnessing frequent floods over the years. Its total length is 64.3 km from Anandapur barrage to Jajpur and is considered for 1-D Hydraulic modelling and mapping for flood inundation. Nearly 90% of the basin receives average annual rainfall between 1400 to 1600 mm. The analysis of rainfall indicates that the average annual rainfall in the basin is 1442.53 mm (Kset, Biterrois, and France 2002).

The basin is also rich in forest which constitutes around 34.36% of the total area. The forest class includes evergreen, deciduous and scrub forest. The State Government of Odisha classifies forests based on the criteria of density. About 538 km^2 of land are classified as very dense forest with a canopy density of over 70%, 27,656 km^2 of forests falls under the category of moderately dense cover with a canopy density between 40 to 70% and 20,180 km^2 is classified as open forest with a canopy density between 10 to 40%. Major cropping pattern found in the region are Kharif [paddy (77%), vegetables (9%), oil seeds (5%), pulses (6%), fibres (2%) and species (1%)] while the Rabi crops include pulses (44), oil seeds (19%), vegetables (23%), spices (5%), sugarcane (1%) and paddy (8%). The location map of the study area is shown in Fig. 1.

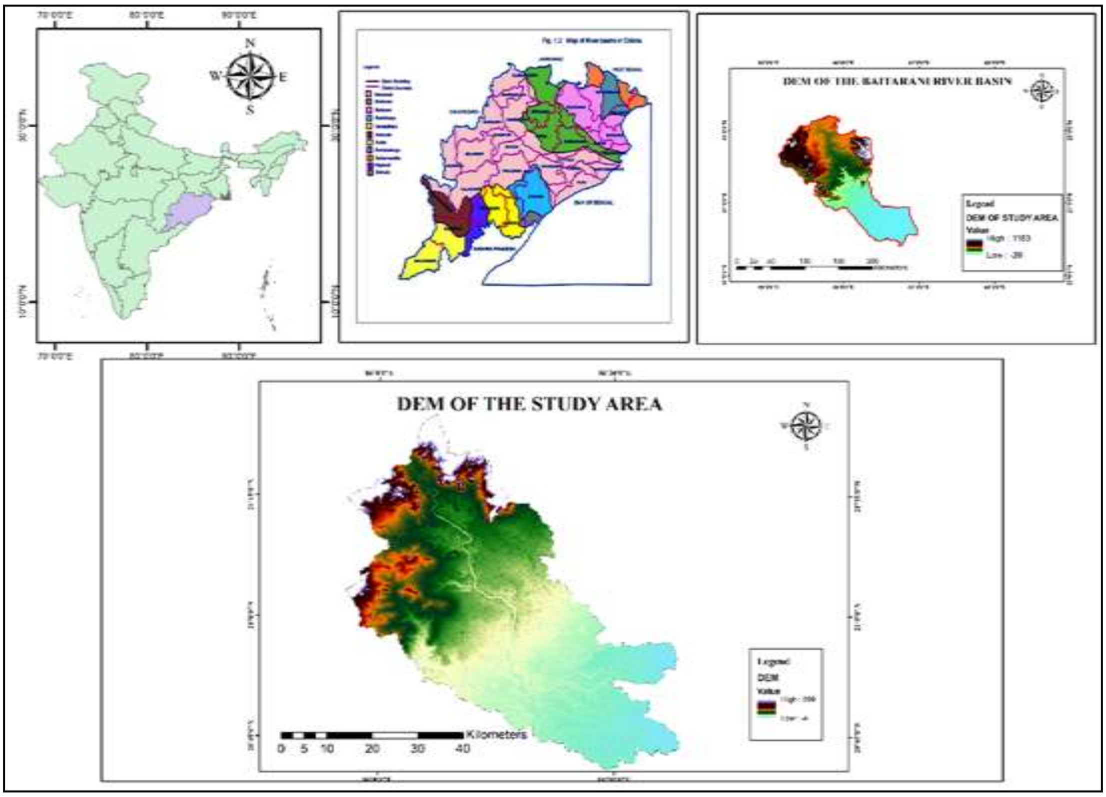


Fig. 1: Location Map of the Study Area.

2.2 Flood Frequency of Study Area in Baitarani River

Rainfall data are collected from the Central Water Commission (CWC), Bubneshwar, Odisha. From the last 18 years of data, it is observed that in the years 2009, 2012 and 2015 major flood events have occurred which lead to immense damage of properties and lives in the catchment. Fig. 2 shows the year-wise discharge in the study area. On 5th August, 2015 the Baitarani river basin had very heavy rainfall in its catchment with 7688.5m^3/sec discharge which is maximum among all the discharges from the year 2001-2018. The Fig. 3 representing inflow hydrograph which is used as an upstream boundary condition in the hydrodynamic model.

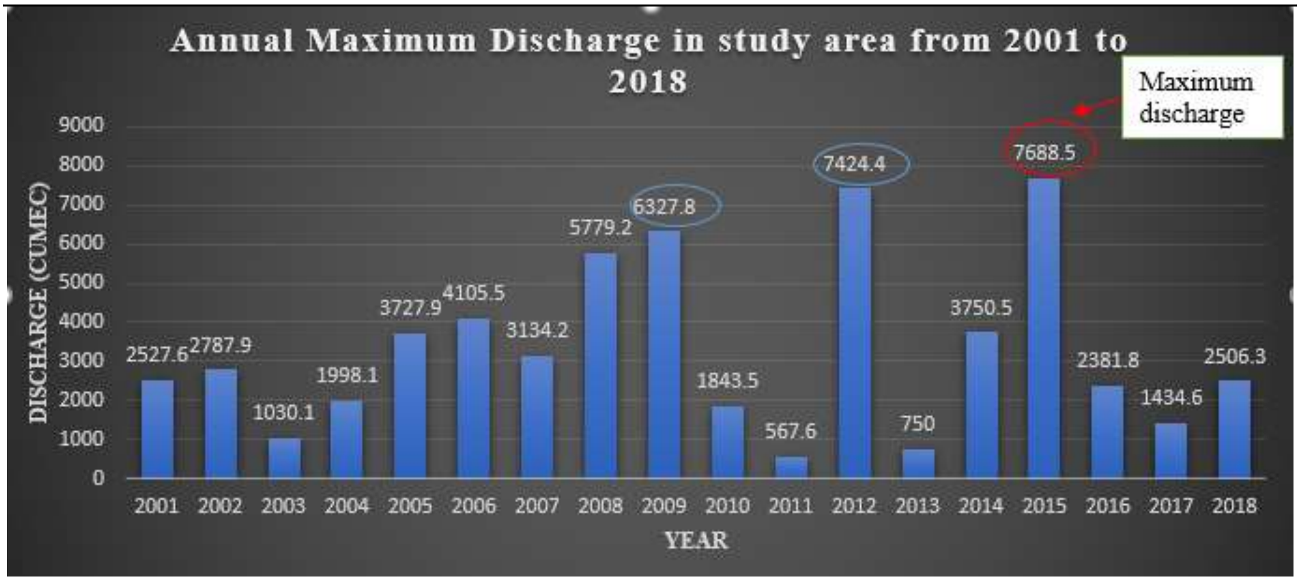


Fig. 2: Year-wise maximum discharge in Baitarani river at Anandpur barrage (upstream)

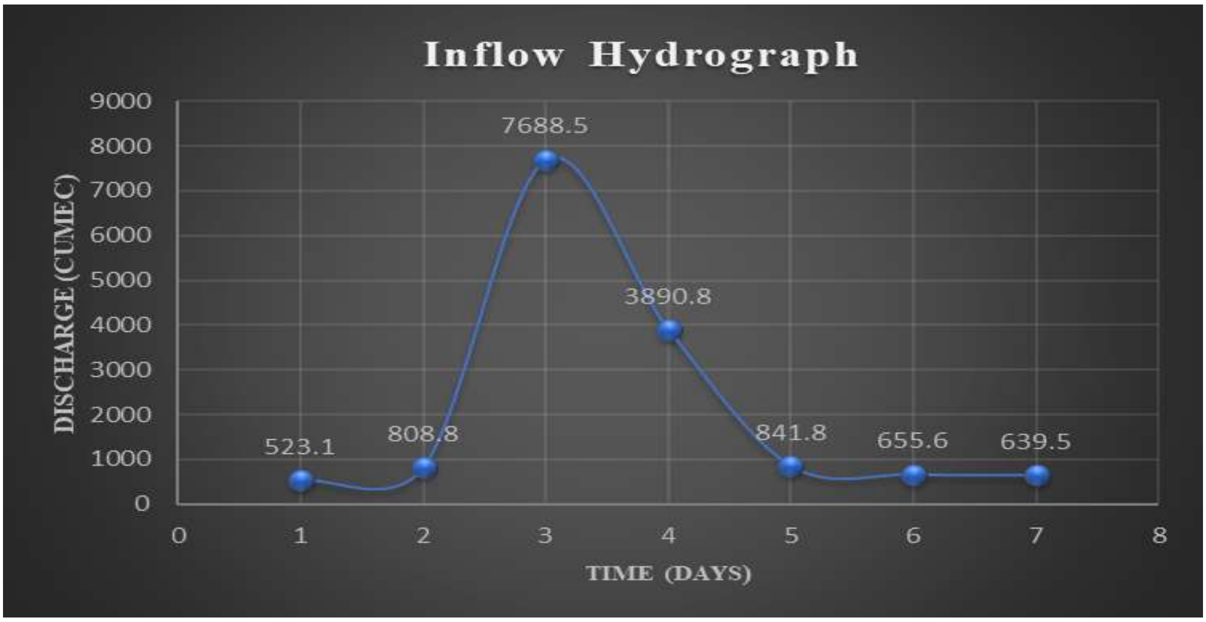


Fig. 3: Inflow hydrograph used as an upstream boundary condition in hydrodynamic model

2.3 Data Collection

- DEM is downloaded from the Bhuvan- Indian Geo Platform of ISRO from the satellite under the sub category of Cartosat-1 with all its version of CartoDEM. After collecting the DEM tiles, data is modified in Arc-GIS for further use in HEC-GeoRAS and HEC-RAS. Different operation such as mosaic, shape-file and watershed delineation has been carried out.

- Rainfall data from two meteorological stations and stream flow data at two gauging stations are used for the study. Discharges at two gauging stations from 2001 to 2018 and daily Rainfall data of two rainfall gauging stations for the same period are obtained from Central Water Commission, Bubaneshwar. Those are the input data for the HEC-RAS model that provides inundation areas.

A. Arc-GIS Software

ArcGIS is a geographic information system (GIS) for map and geographic information operations. It is used to build and maps; compile geographical data; analyse mapped information; exchange and discover geographical information; use the maps and geographical information in a variety of applications; and manage geographical information in a database(ESRI 1996).

B. HEC-Geo RAS

HEC-GeoRAS is an ArcView GIS extension specifically designed to process geo-spatial data for use with the Hydrologic Engineering Center River's Analysis System (HECRAS). The extension allows users to create an HEC-RAS import file containing geometric attribute data form an existing digital terrain model (DTM) and complementary data sets(Cameron and Ackerman 2011).

C. HEC-RAS

HEC-RAS is an integrated system of software, designed for interactive use in a multitasking, multi-user network environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities(Brunner 2016). The HEC-RAS system contains four one- dimensional river analysis components for (1) steady flow water surface profile computations, (2) unsteady flow computations, (3) movable boundary sediment transport computations, and (4) water quality analysis(US Army Corps of Engineers 2016). The user interface prepares the data for operating the steady and unsteady model which further results in numerical computations.

Theoretical Basis for One-Dimensional Flow Calculations (HEC-RAS)

The flows are defined by the user in steady-state modelling and the process measures water levels at specific cross sections. Two variables are determined in unstable modelling (stage and flow), therefore two equations are required. The partial differential equations, hereafter referred to as continuity and momentum equations that are used in the simulations are given in equation 1 and 2.

$$\frac{\partial A_T}{\partial x} + \frac{\partial Q}{\partial x} - q_1 = 0 \tag{1}$$

in which q_1 is the lateral inflow per unit length and the distance x is measured along the river. The flow and total flow area are denoted $Q(x, t)$ and A_T, respectively.

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA\left(\frac{\partial z}{\partial x} + Sf\right) = 0 \tag{2}$$

Where S_f indicates the friction slope in equation 2, which is positive for flow in the positive x-direction. The friction slope must be related to flow and stage.

3. Methodology

The methodology consists of the following steps a. Pre-processing of Data (Arc-GIS and HEC-Geo RAS), b. Model Execution (HEC-RAS) and c. Post-processing in HEC-Geo RAS. The conceptual diagram of 1-D hydrodynamic flood methodology is shown in Fig.4.

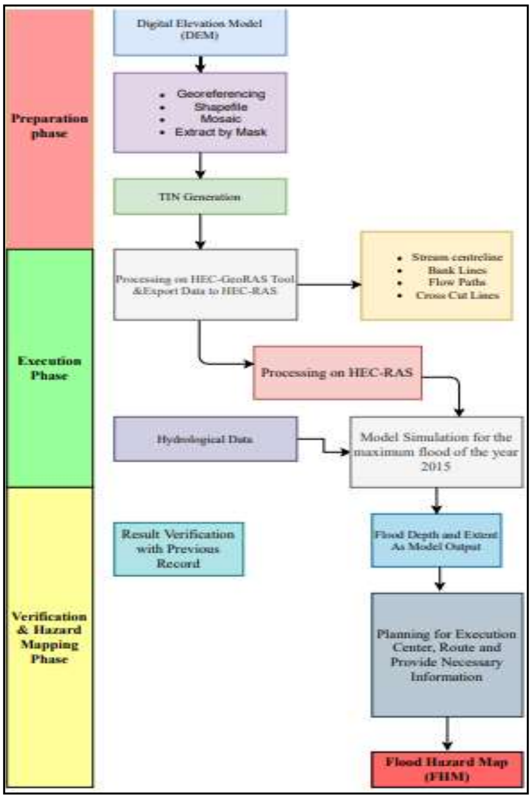


Fig.4: Outline frame of methodology work

3.1. Pre-processing Application

RAS Geometry is an informative file setup in the HEC-GeoRAS condition, which is used to develop geometric information and extract the waterway catchment from the floodplain. This pre-processing option is provided for preparing required input for the HEC-RAS. The geometrical information mainly main channel banks, stream centreline, flow path along with its centreline, and cross section cut lines are constructed in HEC-GeoRAS.

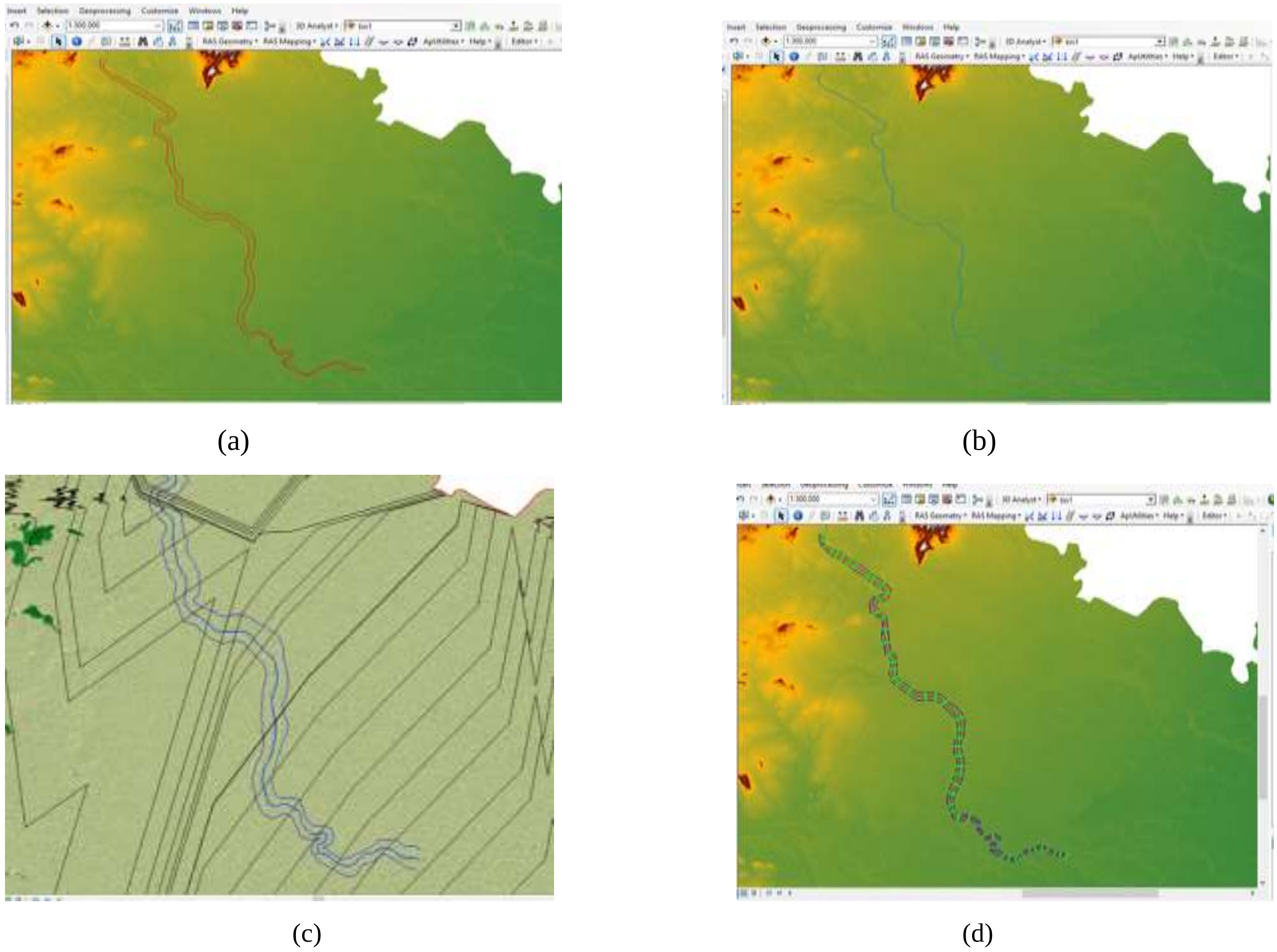
Main Channel Bank: Main channel bank are used to distinguish the main stream from the left bank or the right bank of the floodplain. The main channel bank is created by discretising it from the google maps.

Stream Centreline: Centreline of the stream is created from the stream centreline option.

Flow path along with its centreline: Paths of the flows has been created from upside to the downside of the stream along with its centreline.

Cross section cutline: The cross cut lines are drawn perpendicular to the direction of the flow. While creating cross section cut lines, the average distance between two cross section were at 1500 metres interval and average width of cross section were given width of 2000 metres.

The Fig.5 representing the processes done in HEC-GeoRAS which is an extension of Arc-GIS.



(a) (b) (c) (d)

Fig. 5: Processes (a) Main channel bank, (b) Stream centre line, (c) Flow path and its centre line and (d) Cross section cut lines respectively in Pre-GeoRAS application performed in the Arc-GIS

3.2. Model Execution in HEC-RAS

Model execution is the foremost operation in the work. The file made in HEC-GeoRAS is imported in HEC RAS under the Geometric data window. The section elevation data provided by HEC-RAS require some modification in bank stations and editing in the geometry. As by adding geometry data it gives only the section elevation data, additional Manning's value is assigned which is taken from the table of Chow's roughness coefficients based on its land use and surface material. The values considered are: for the left bank as 0.035, right bank as 0.035, and main channel as 0.030 as per observation. The Fig.6 representing the elevation and horizontal cross-sectional data at river station (RS) 68703.07 and 228.07 along with the manning's n value.

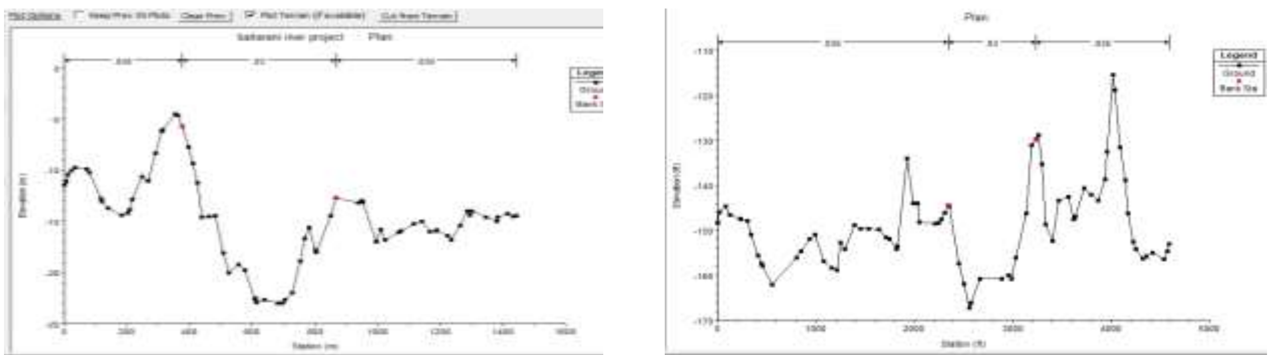


Fig.6: Elevation and horizontal cross section at different river stations entered in Cross Section Data (a) RS 68703.07, (b) RS 228.07

Boundary condition is given in unsteady flow data window. Flow hydrograph is selected for the upstream boundary condition at River station 68703.07. Normal depth = 0.00042 derived from the manning's equation is selected for the downstream boundary condition at River station 228.07.

After running the unsteady flow analysis, water surface profiles are calculated. Once the simulation is finished, export file from HEC-RAS to HEC-GeoRAS is prepared for the post processing.

3.3. Post-processing in HEC-Geo RAS

After exporting results from HEC-RAS, a GIS import file is developed and post-processing steps start. The steps involved in the post-processing are:

- Generation of stream network, cross cut lines and the bounding polygon: After finishing the theme setup and convert it into an appropriate extension, it will read RAS GIS export file and create primary data files. Automatically the steam network, cross cut lines, bank station points and the bounding polygon themes are generated.
- Water Surface TIN Generation: For every water surface profile, water surface TIN is created which depends on the water surface elevations of these cross section cut lines and the created theme of bounding polygons,
- Delineation of the floodplains: The next step is delineation of the floodplain after generating the Water surface TIN. The delineation of the floodplain forms a polyline theme which identifies the floodplain and a grid of depth. After deducting the water surface TIN raster values from the Terrain TIN values, a water depth grid is produced.

3.4 Flood Hazard Analysis

Flood hazard is categorized based on the level of difficulties in daily life and/or damage to properties. Flood hazard assessment is the estimation of overall adverse effects of flooding. It depends on many parameters such as depth of flooding, duration of flooding, flood wave velocity and rate of rise of water level. One or more parameters can be considered in the hazard assessment. In the present study, depth of flooding is considered for hazard assessment. The intensity of flood hazard is always given by a relative scale, which represents the degree of hazard and is called a hazard rank. Table 1 showing the Hazard Rank based on the depth of flooding. A smaller hazard rank is assigned for a lower depth or low hazard while larger hazard rank is used to indicate a higher hazard.

Table 1. Hazard rank provided for depth of flooding

Depth(D) of flooding (m)	*Hazard category*	*Hazard rank*
Hazard free	No hazard	0
$0<D\leq1$	Low	1
$1<D\leq3$	Medium	2
$3<D$	High	3

The areas bounded by the flood polygons were calculated to make an assessment of the flood hazard level for the peak discharge having 10-year return period

4. Results Outcomes and Discussion

4.1. Results of Unsteady Flow Analysis

After importing the files from pre-process in HEC-GeoRAS to HEC-RAS with all the modifications in the river geometry, the water surface profiles in the graphical plan has been interpreted as the results of the computations of the model. Results from HEC-RAS gives a 3-D perspective view of the stretch of the river taken as the study area which is shown in Fig. 7 and 8 for the river discharge 7688.5m^3/sec and 523.1 m^3/sec respectively. According to the data of the Central Water Commission, at the high flows of the river many of the cross- cross sections are at risk especially the downstream cross-section no. 13, 16, 20, 25 to 33 as water coming out from its banks. These cross sections are safe at low or normal flows which is 25-40 m^3/sec.

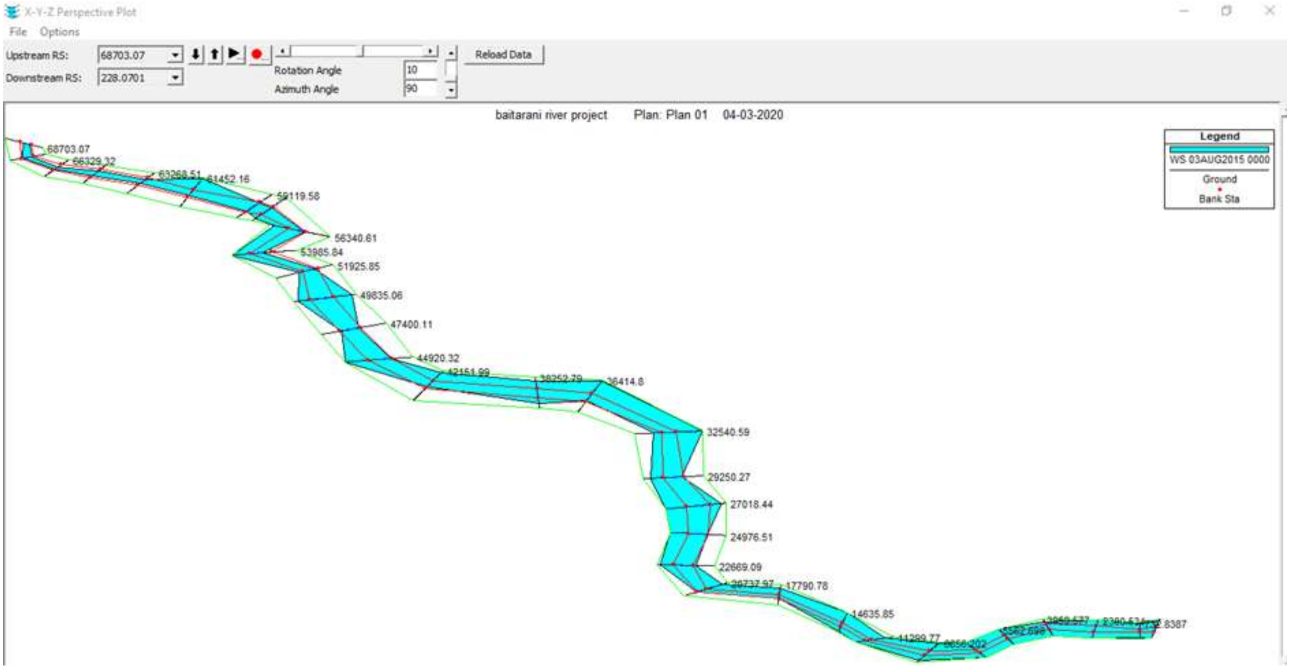


Fig.7: 3-D perspective view of river at discharge -523.1 m3/s

The Fig. 8 representing the X-Y-Z perspective plot for the maximum river discharge 7688.5 m^3/sec.

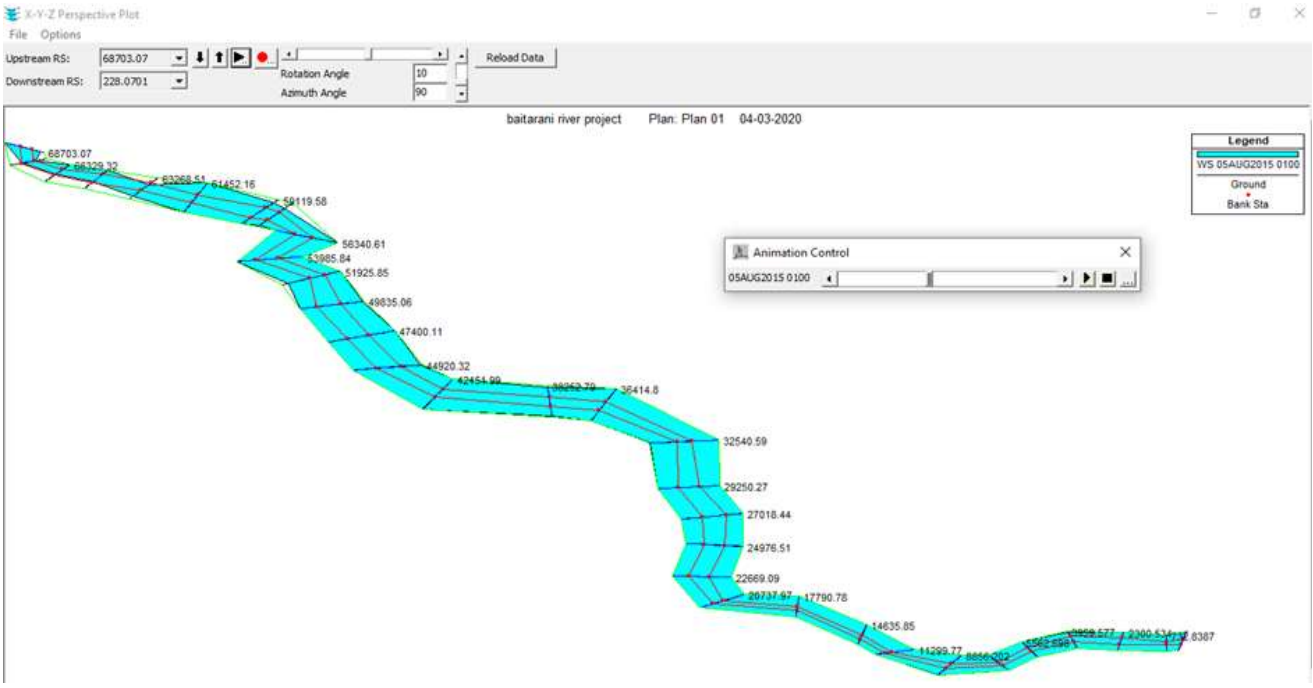


Fig.8: 3-D perspective view of river at peak discharge -7688.565 m3/s

The water surface profiles in Figure 9 representing the flooding in the right and left banks at cross-section 7 and 27.

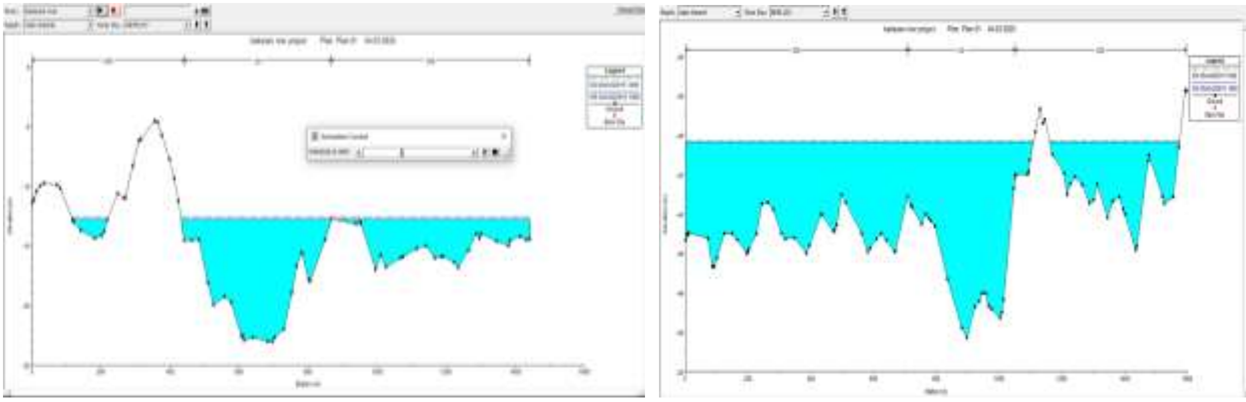


Fig. 9: Water surface profile at cross section 7 and 27 at 7688.565m3/s peak discharge

Table 2. shows the classifications of cross-sections which are experiencing flooding during high discharge.

Less Affected during High Discharge	Moderate Affected during High Discharge	High Affected during High Discharge
CS-1,2,3,4,5,	CS-6,8,9,10. CS-12,	CS-13, CS-16,
CS-7, CS-11,	CS-14,15, CS-17,	CS-20, CS-25,26,27,
CS-18	CS-19,	28,29,30,31
	CS-21,22,23,24,	32,33

After the execution phase in HEC-RAS model, the results are used for the further processing through HEC-GeoRAS for post processing. Delineation of the floodplain in the GIS platform results the mean water depth as 7.45 m for the flood hazard analysis.

4.2. Results of the Flood Hazard Analysis

Hazard aspect of the flood events is associated to the hydrological and hydraulic units of the study area. The flood depth area classification indicates that 77 % of the total flooded areas have water depths of more than 3 m. A very small area is flooded below the depth of 1-1.5 m. Results of flood hazard analysis are summarized in Table 3 and Fig. 11

Table 3. Flood depth area classification

Water depth (m)	Total inundated area	
	10-year return period Flood	
	Area	Area
<1	15.65	6.168
1-1.5	9.70	3.634
1.5-2	7.75	3.315

2-2.5	6.72	2.814
2.5-3	17.34	6.353
>3	192.23	77.716
Total	249.23	100

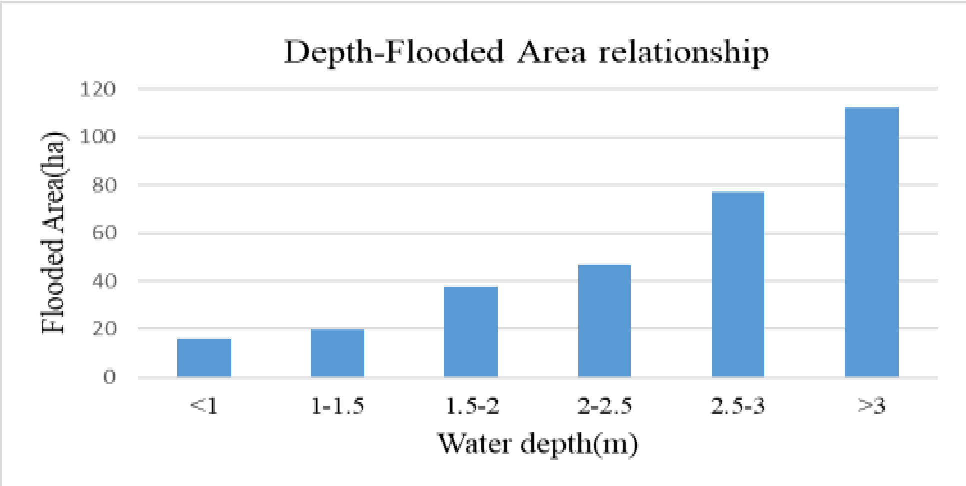


Fig. 10: Flood Hazard Map of 10-year flood

From the graph of figure 10 of depth flooded area relationship, it can be seen that with the rise in flood intensity, the flooded area increased significantly under the water level more than 3 m. For 10-year flooding, the flooded area which is 192, 17, 6, 7, 9, 15 ha corresponding to the water depth >3, 2.5-3, 2-2.5, 1.5-2, 1-1.5, <1 m respectively, indicate that with the increase in flooding intensity the water depth exceeds beyond 3 m. Fig.11 showing the flood hazard map pf the study area.

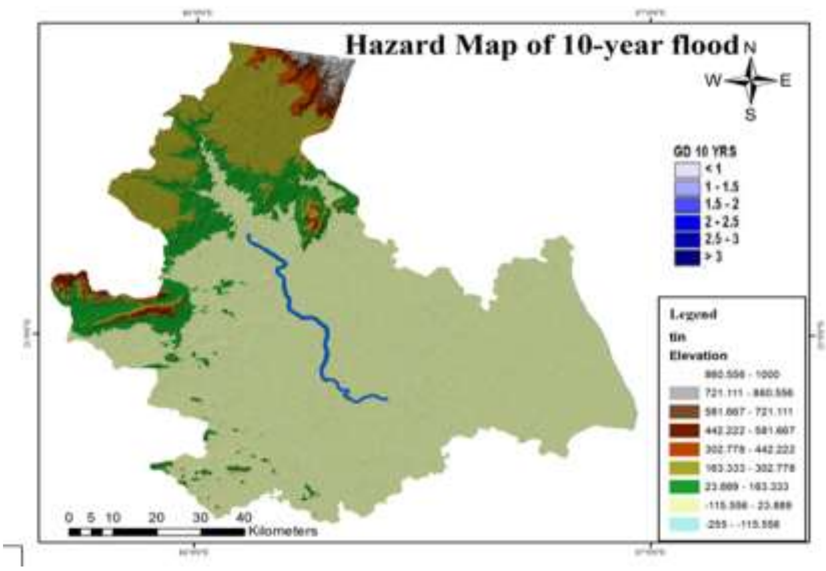


Fig. 11: Flood Hazard Map of 10-year flood

5. Conclusions

The study aims to look at how useful the combination of software Arc-GIS and HEC-RAS for the estimation of flooding at various cross-sections which are likely to be submerged. A special flood study of the August 2015 flood has been done to the assessment of flood hazard of the area downstream of the Jajpur with the help of the one-dimensional hydrodynamic model HEC-RAS. It has been observed from the results of the post-processing part of HEC-Geo RAS that at high flows most of the cross-sections at downstream of the river are at high risk and need to implement river training and riverbank protection works at Jajpur, as it is affected more at high flood discharge. The study also assessed flood hazards with the relation to the return periods of flood and their water depth. The relationship between the flood area and discharge indicates that there is a medium rate of increase of the floodwater depth, shows that most of the areas under flooding have water depth greater than 3.0m.

6. Scope of work

The Flood Vulnerability and Flood Risk maps cam be prepared in Arc-GIS environment of the study area with the help of census data of population and building material. With the help of vulnerability analysis and hazard analysis, risk analysis can be carried out. River cross section should ne measured from topographic survey.

Acknowledgement

I am grateful to all the Central Water Commission, Bubneshwar for providing necessary data for this research work.

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