SPATIAL ANALYSIS OF FLOODING ON BAITARNI RIVER BASIN USING MIKE HYDRO AND REMOTE SENSING

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ABSTRACT

India has a disadvantage of being in the path of depression of severe floods that occurs every frequent year. Floods are a regular phenomenon in Odisha happening almost every year. In Odisha, damages are caused due to floods mainly in the Mahanadi, the Brahmani, the Baitarani, Subernekha, Rushikulya, Nagavali, and Kalyani. This inundation flooding events at frequent intervals demand identification of flood hazard-prone areas in a scientific way for prioritizing appropriate flood preparedness and long-term planning. For the better management of floods, non-structural measures are practicing nowadays such as flood forecasting, flood hazard mapping, and flood risk zoning are more in trends. Remote sensing and GIS play a major role in mapping, monitoring and providing all flood-related studies with a spatial database. The present work focuses on the use of topography and imagery based on remote sensing in the GIS system for Baitarani River's integrated flood analysis, which is one of the most flood-prone rivers. The shuttle radar topography mission (SRTM) Digital Elevation Model (DEM) has been used to create a detailed sub-basin and river map of the entire Baitarani basin. The SRTM DEM, discharge time series, rating curve and ground-based river cross-section from Anandapur barrage to Jajpur stretch of Baitarani River were used to create 1-dimensional hydrodynamic (1-D HD) model for simulating flood water level, discharge and flood inundation of various gauge stations for the monsoon period. Validation of simulated flood flows was done using the observed water level of central water commission (CWC) from Anandapur barrage to Akhuapada stations, with a coefficient of correlation of 0.85. Finally, an integrated framework for flood modelling and management system is proposed.

KEY WORDS: *Floods, Hydro-Processing, SRTM DEM, Hydrodynamic model, MIKE HYDRO, Flood Inundation.*

1. INTRODUCTION

Natural disasters are always a significant threat to society. The most recurrent, widespread, calamitous and common natural hazards in the world are probably floods. Many people are affected by floods than by any other type of natural disaster. India is in the first position with 4.84millions among 15 countries accounting for 80% of the population exposed to river flood risk worldwide (World Resource Institute,2015). India is highly susceptible to floods, droughts, storms, storm surges, seismic events, urban floods, landslides, rockfalls, and heatwaves, mostly because of its geo-climate and socio-economic conditions. The magnitude of the problem can be imagined as flood, cyclone, drought and cyclonic rains have wreaked havoc in the State and every year, Odisha has faced one or the other natural calamity.

During the last 24 years, 17 floods, five severe cyclones, and 11 droughts occurred. On an average, Odisha is incurring Rs 3,000 crore of financial loss every year due to natural calamities, which is not only colossal but also resulting in weakening the economy of the State to a large extent (Pioneer report,2019). The normal rainfall of the state is 1451.2mm. About 75% to 80% of rainfall is received from June to September, which causes severe damages to crops as well as lives. Floodwaters of the Baitarani river submerged over 40 villages in Jajpur and MacArthur Blocks of Jajpur district affecting around 22,000 people. The water level in the Baitarani rose to 18.16 ft as against the danger mark of

17.83 ft at Akhuapada village. Two types of measures can be implemented for flood control, i.e. structural and non-structural measures. In the long run, the structural measures such as embankments, levees, spurs, etc. did not prove to be quite successful. For the preparation of flood risk maps using a hydrological-hydraulic method, flood depth, flood area, and flood duration are calculated using hydrological and hydraulic models for the peak level of a given return period. Several mathematical models have been developed for flood plain delineation, flood inundation and flood simulation which can be used as a method for delineating flood plain zones neighbouring the rivers and measuring the associated risk taking into account the potential floods of different return periods.

In the past few years, the hydrodynamic modelling approach has been used by various researchers to simulate flood inundation in the flood plains. Different mathematical models have been developed for floodplain delineation/flood inundation and flow modelling that can be used as tools to delineate floodplain areas surrounding the rivers and to quantify the associated risk taking into account simulated floods with different periods of return. The mathematical models of one-dimensional (1D) approximation are usually based on the method of finite difference and the method of finite elements(Nwaogazie & Tyagi, 1984; Sen & Garg, 1998). Nevertheless, due to comparatively less computational effort, the finite difference method is still popular. Some commercially available software packages such as DWOPER, FLDWAV, MIKE HYDRO which is the modified version of MIKE-11 developed by the Danish Hydraulic Institute, Denmark (DHI, 1997), ISIS, SOBEK-1D developed by Delft Hydraulics, Delft (Werner, 2001), etc., are widely used to model complex 1D flows in rivers. The 1D models are easy to use and provide data on the characteristics of bulk flow. In this paper, MIKE HYDRO is used to simulate the flood inundation for the delta region of the Baitarani River basin in India. Initially, the MIKE HYDRO model was calibrated and validated for the rivers of the delta region of the Baitarani River basin.

2. STUDY AREA

The Baitarani River basin has a total of 14,218 sq. km catchment area located in two states: Odisha and Jharkhand. The major portion of the Baitarani river basin with 13482sq. km catchment area lies within the state of Odisha and Jharkhand have the rest catchment area 736 sq. km constitutes the other minor portion of the river. It originates from the Gonasika/Guptaganga (Cow Nose Shaped) hills at 21° 32´20´´N- 85°30´48´´E and starts flowing over a stone looking like the nostril of a cow. The Baitarani River rises near Dumuria village in the hill ranges of Kendujhar district of Odisha at an elevation of 900 meters (3,000 ft) above sea level. Even the initial portion of the river acts as a boundary for Odisha and Jharkhand. The total length of the river is 360 km (India-WRIS) from its origin from Gonasika to its outfall 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.

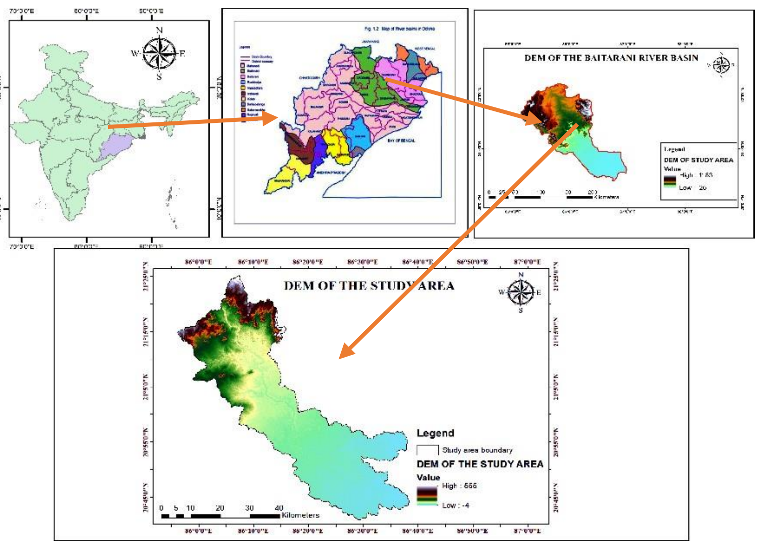

Fig. 1. DEM Map of the Baitarani river basin and study area from Anandapur to Jajpur with location map (Sources: DIVA-GIS and Maps of India)

The uppermost portion of the river passes from hilly terrain, about 80 kilometres in length, flows in a northerly direction; then it changes its path suddenly by 90 degrees and flows eastward and then it enters a plain at Anandapur and creates a deltaic zone at Akhuapada through which enters Jajpur and Bhadrak areas of relatively flat slopes which are the most flood-prone areas in this basin. 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 having frequent floods in last previous years. Total it is 74.3 km from Anandapur barrage to Jajpur. This total length is used for 1-D Hydrodynamic modelling and flood inundation mapping.

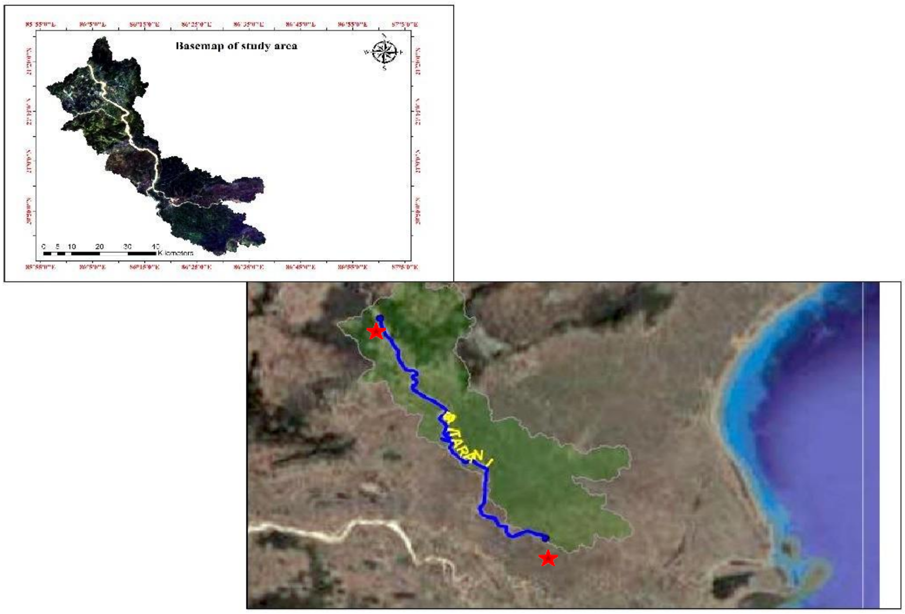

Fig.2. Base map and working area in Mike hydro setup of study area from Anandapur barrage to Jajpur

3. SIMULATION SETUP

3.1 One-dimensional MIKE-HYDRO hydrodynamic model

MIKE HYDRO is a flexible and customizable system for modelling 1D hydrodynamic conditions in streams, lakes/reservoirs, drainage channels, and other inland water systems. It is a fully adaptive modelling method for evaluating, planning, controlling and running the river and channel systems in detail. The hydrodynamic (HD) method is the nucleus of the modelling process MIKE HYDRO and forms the basis for stream flood simulation. The HD model can simulate 1D unstable flow within a river network. The result of HD simulation consists of a time series of water levels and discharges at various points along with the river system. MIKE HYDRO HD provides a choice among three different flow descriptions, namely kinematics, diffusive and dynamic wave approaches. MIKE HYDRO HD solves the Saint-Venant equations to obtain the hydrodynamic state of the river networks. The post-processor tool of MIKE HYDRO is the MIKE VIEW, which helps to view and analyse the results through graphical and animated interfaces.

3.2 Governing equations in MIKE -HYDRO

The governing equations in MIKE HYDRO are 1D shallow water type, which are the modifications of basic Saint-Venant equations. The Saint-Venant equations representing conservation of mass and momentum are Equations (1) and (2), respectively, as given below.

$$\frac{\partial Q}{\partial X} + \frac{\partial A}{\partial t} = q \quad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial [\gamma \frac{Q^2}{A}]}{\partial X} + gA\frac{\partial H_1}{\partial X} + \frac{gQ|Q|}{c^2 AR} = 0 \quad (2)$$

where Q=discharge (m^3/s); A=flow area (m^2); q=lateral inflow (m^2/s); H_1=stage above datum; c= Chey's resistance coefficient ($m^{1/2}/s$); R=hydraulic radius (m); γ =momentum distribution coefficient; g=acceleration due to gravity ($9.81m^2/s$); X=longitudinal distance in the direction of flow (m); and t=elapsed time (s).

Equations (1) and (2) are transformed to a set of implicit finite difference equations and solved using double sweep algorithm (Abbot and Ionescu, 1967). The computational grid comprises alternating Q and H_1 points automatically generated by the model, on the basis of user requirements. Q points are always placed midway between neighbouring H_1 points. H_1 points are located at cross sections or at equidistant intervals in between if the distance between cross-sections is greater than the maximum space interval, dx, specified by the users.

3.3 MIKE HYDRO model setup

The river network configuration, cross sections, boundary conditions, hydrodynamic parameters, and simulation parameters are the five basic input parameters to be defined for the MIKE HYDRO HD setup.

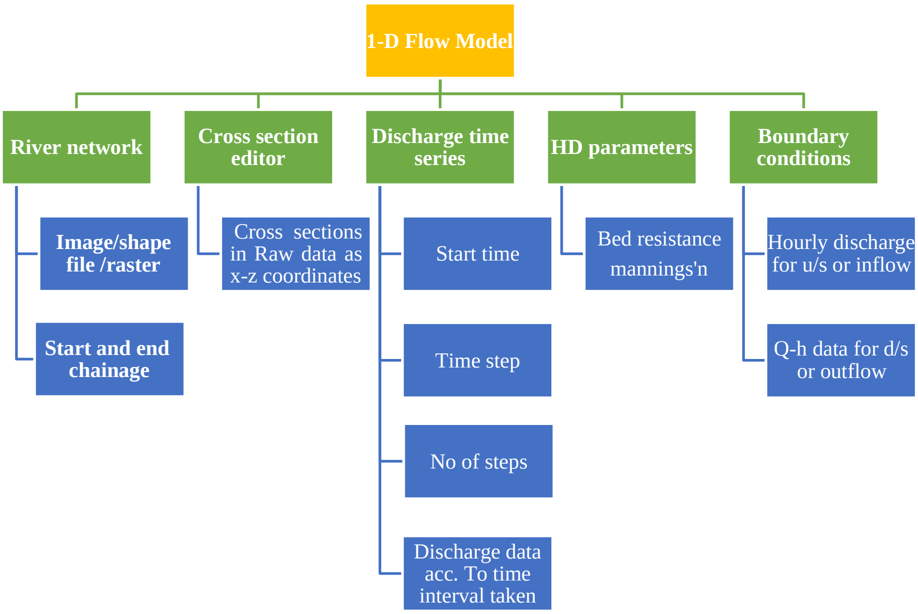

Fig. 3. Flowchart of 1-D modelling setup in MIKE HYDRO

3.4 River network

The MIKE HYDRO river network design was prepared in the present work by digitizing the scanned and geo-referenced topographic map of the study area in the MIKE HYDRO network editor tool**.**

3.5 Cross-sections

The cross-sections were provided for river reach at an average interval of 3km. The x-z co-ordinates were entered as raw data in the cross-section editor. The cross-sections were taken from CWC Bhubaneshwar. The cross-sectional data for the stretch is inserted by giving the branch name, Topo-Id, and chainage. Then after updating all the markers in the raw data the cross-sections were automatically processed in the form used in the hydrodynamic calculations, i.e. the hydraulic parameters, the cross-sectional area, the hydraulic radius, and the storage width were calculated for different water levels between minimum and maximum, either automatically determined or defined by the user.

3.6 Boundary conditions

MIKE HYDRO requires discharge at all upstream open boundaries and the water level or Discharge–Water Level relationship i.e. Q-h rating curve from CWC at the downstream open boundaries. In this study, the two open boundaries were provided with upstream inflow and downstream a constant water level. The point at Anandapur barrage (Anandapur at 0.0km) was the upstream inflow-type open boundary and Jajpur (Jajpur at 74.3km, chainage measured from Anandapur barrage) was downstream constant water level open boundary.

3.7 Hydrodynamic parameters

The completely dynamic flow equations of Saint Venant include a number of variables, some of which are determined automatically during the simulation and some are described as users. The dialog on hydrodynamic parameters allows the user to identify specific values for specific parameters unique to the hydrodynamic model. For the entire river network, parameter values can be entered as a single Global value or as a range of spatially varying local values.

The hydrodynamic parameters include the initial water depth and discharge conditions, the choices for the friction coefficient and the parameter performance. This study includes the description of the riverbed's global and local roughness coefficient values (Manning's n), which was the key and only calibration parameter. Other parameters were kept at their default values.

3.8 Simulation parameters

Before running the model simulation, control parameters such as simulation period, simulation time step, data to be stored and storage time were specified. There exists a versatile relationship between the time step and the computational distance to define the Courant number given below in Equation (3), which is widely considered to choose the time step for the model simulation.

$$\text{Courant number } (C_R) = \frac{\Delta t(V+\sqrt{gy})}{\Delta x} \qquad (3)$$

where Δt =time step, V=mean flow velocity (m/s), y=water level (m) and Δx = dx = max. The time step and computational distance were kept as 60seconds and 5000m, respectively, for this study.

4. DATA COLLECTION AND METHODOLOGY

4.1 Data Collection

In addition to RS data, hydrographic and hydrological data from Odisha water resources department (WRD) and CWC was also used. The data used in this study area are the time series of daily discharge and water level of different gauging stations for the years 2017. At Anandapur which forms the upstream boundary of the model setup, a daily discharge data was used and at the same time, the data of the stage and discharge is taken for the downstream boundary. In this study, 14 field surveyed river cross-sections in between Anandapur barrage and Jajpur is used for HD simulations (Source: CWC, Bhubaneshwar).

The software used in this analysis is: ERDAS IMAGINE 8.7 for geometric correction, satellite image identification & digitization, ILWIS 3.3 for DEM hydro processing, ARC GIS 9 for DEM visualization, MIKE HYDRO for river database formation and hydrodynamic modelling. Universal transverse Mercator (UTM) with WGS 84 datum and spheroid and 45 North UTM zone is the projection system used in the present work.

4.2 Methodology

The integrated work in this area is done in three parts as shown in figures 2.1 and 2.2. In first part hydro processing of watershed in Baitarani river basin is done along with its delineation and its physical characteristics in terms of catchment area, shape, slope, stream length, longitudinal slope, stream order, fill, sinks, flow direction, flow accumulation etc. using SRTM 90m DEM downloaded from USGS. In the next part the flood modelling is done by the numerical model i.e. MIKE HYDRO for the simulating water level and flood flow by showing its trends in MIKE view.

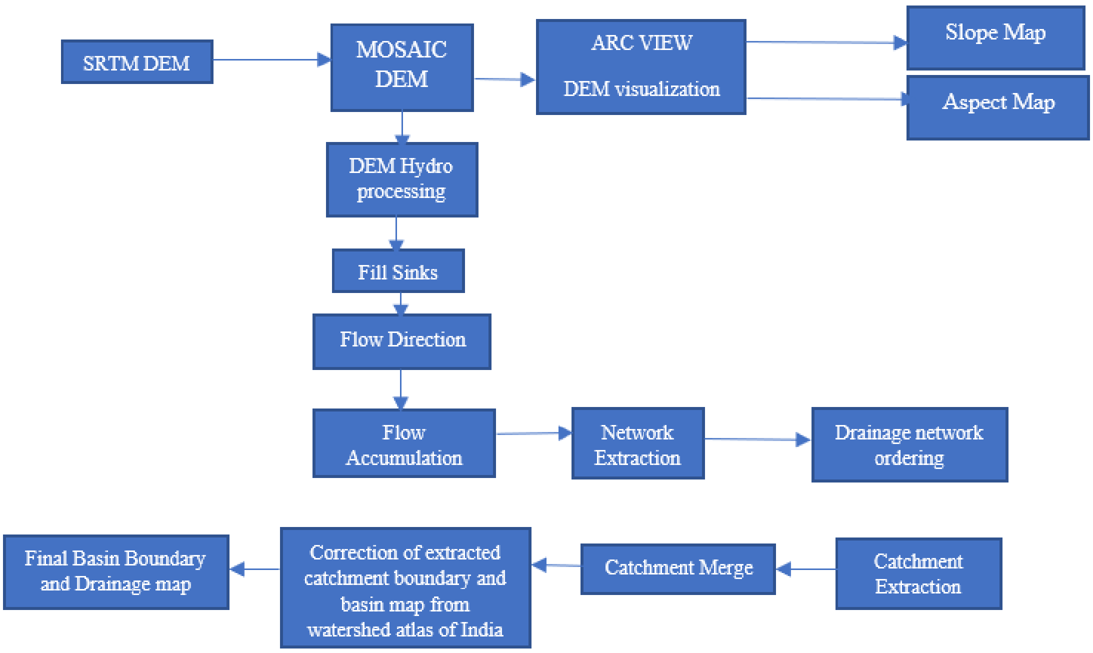

Fig. 4. Flowchart for basin hydro-processing

The HD simulation were done from Anandapur barrage to Jajpur stretch of Baitarani River (shown in 1.2). The input river data for Mike-HYDRO was created from LISS-III image, flood plain elevation was taken from SRTM DEM and river cross sections were taken from Central Water Commission Bhubaneshwar.

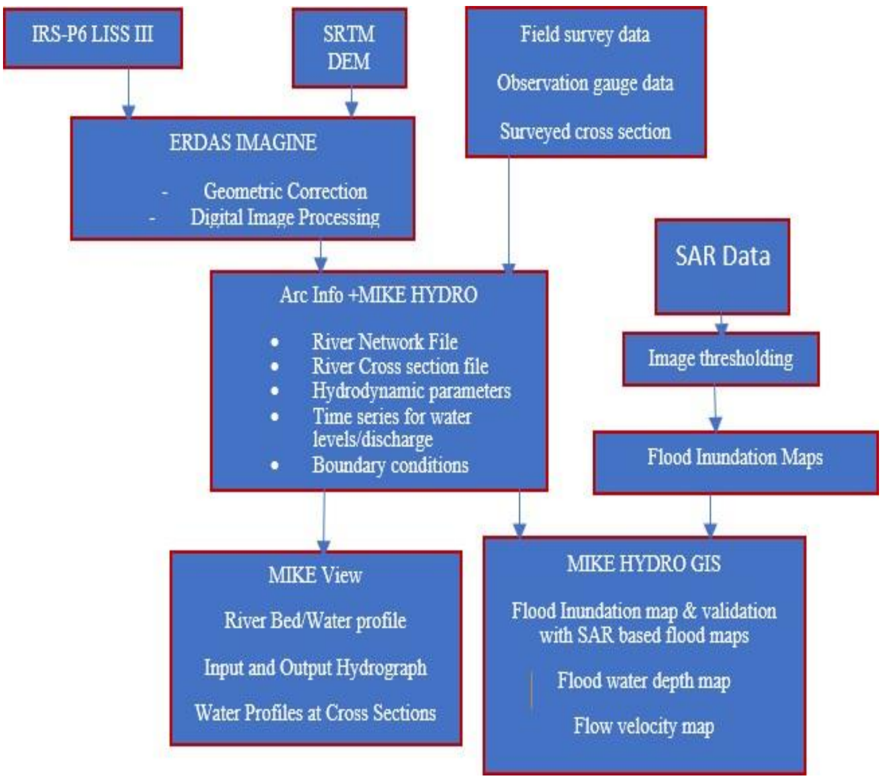

Fig. 5. Flowchart for flood inundation mapping and 1-HD modelling and visualization

The flood inundation map derived from Arc-GIS 10.1 data was also used to validate the flood simulation of HD model.

5. RESULTS AND DISCUSSIONS

5.1 Hydro processing

The main hydro processing operations to extract drainage network and sub-basin physical parameters for the Baitarani basin are done in Arc-GIS 10.1 platform. This process is consisting of following major steps, i.e., fill sinks, flow directions, flow accumulations, drainage threshold, sub-basin delineation, and finally the watershed/river morphometric parameter estimation. The flow chart shown in figure 2.1 gives the sequence of each operations. In the case of Baitarani River basin, the SRTM DEM used for hydro-processing has horizontal and vertical resolution of 90m and 16 m respectively. This area and drainage basin can further be improved if we use better resolution DEMs.

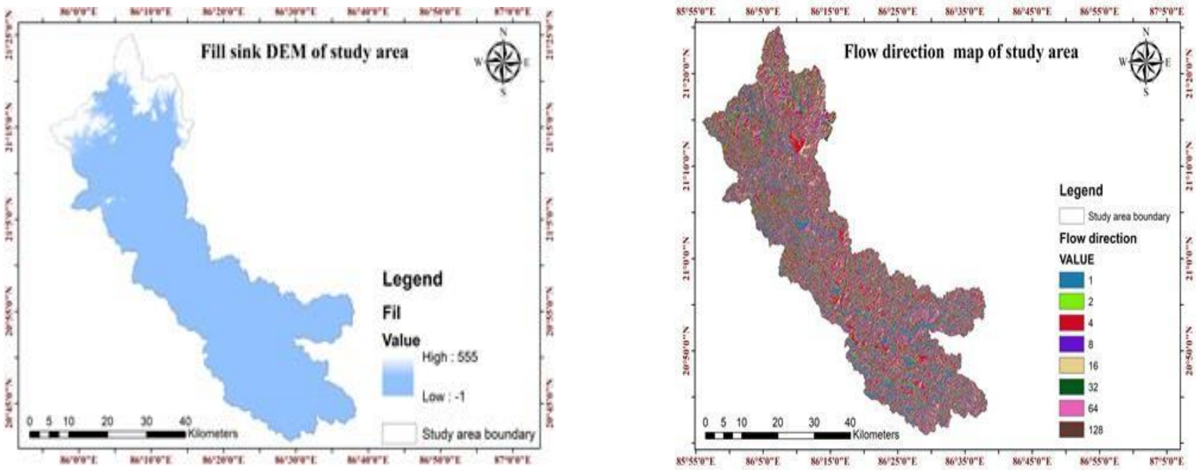

Fig. 6. Fill Sink and Flow Direction map of the study area.

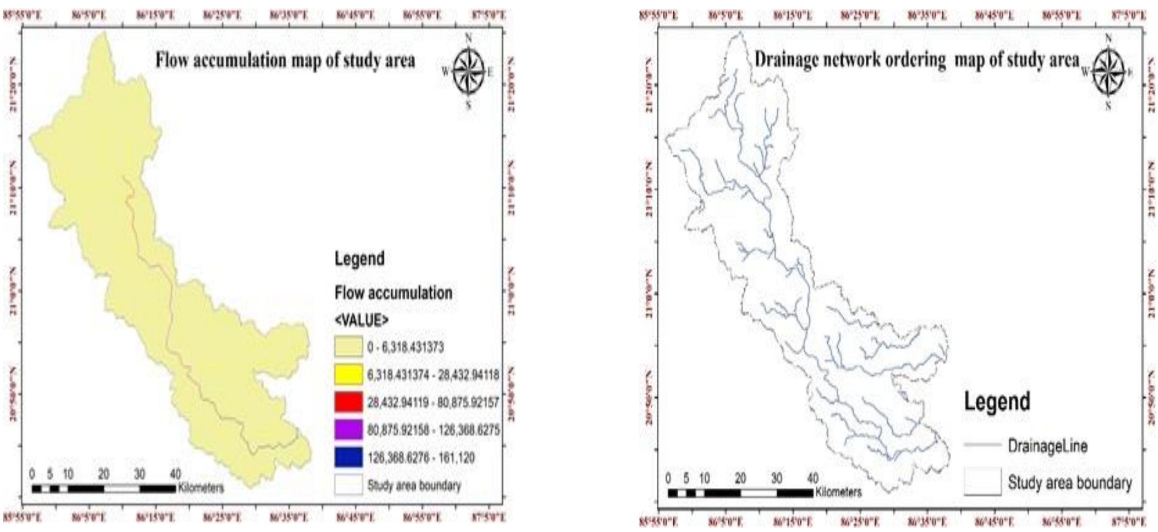

Fig. 7. Flow accumulation and drainage network ordering map of the study area.

The final basin boundary and stream network with other group of Rivers of entire Baitarani basin is shown in figure 7.

5.2 Flood inundation mapping

The flood inundation mapping was done using Arc-GIS 10.1 images dated 23 July 2017, 05 August 2017 and 09 August 2017 which were geo referenced using. These images are smoothened using Lee – Sigma filter for further water pixels' extraction using histogram-based threshold method.

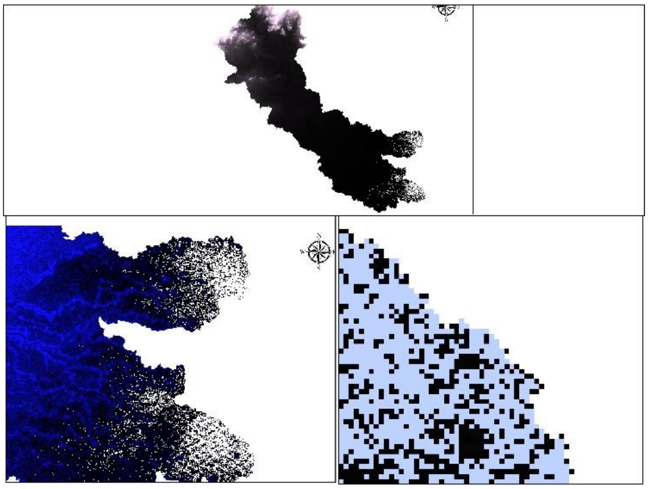

Fig.8. Flood inundation area as derived from LISS III images from 2017 data

Total inundation area on 23 July 2017, 05 august 2017 & 09 August 2017 during flood comes as 114.47 km^2, 230.42 km^2 & 563.24 km^2 respectively. The estimated flooded area (shown in figure 8) in based on threshold of digital number (DN) of geo referenced LISS III images, as calibrated Radarsat-1 data was available for 09 Aug. 2002 only. The multiple classes of flooded area are derived using by multiple spatial data threshold, i.e., less than 35-pixel value is taken as water pixels and density slicing is done on this data to various get water depths-based water sub-classes, lesser the DN, deeper and calmer is the water body or flood water. The flooded area can further be improved by using calibrated and fully polarimetric SAR data for study area.

5.3 1-D hydrodynamic flood modelling

Since the HEC-RAS HD model was unable to deliver satisfactory results on this river, MIKE HYDRO HD model was used to model the HD Time series data was provided at the starting point in the MIKE HYDRO model, i.e. Anandapur, river network file, cross-section in river and cross-section editor, and boundary conditions, HD model setting is provided in simulation editor. For Anandapur, inflow, and Jajpur, the water level is used as a boundary type. The time period of the simulation was taken from 1st August 2017 to 30 August 2017, with 15 minutes' time step. Bed resistance is taken as Manning's "n", with the value of 0.025 for river bed and flood plain resistance is kept as 0.20. After completion of HD simulations, the Mike view device is used to simulate the water level and discharge effects at various river cross-sections.

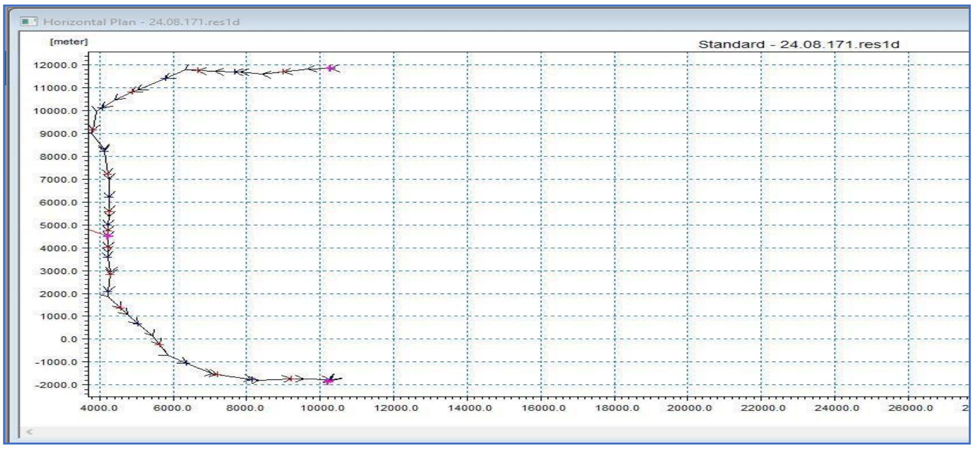

Fig. 9. Horizontal plan of the river in MIKE View.

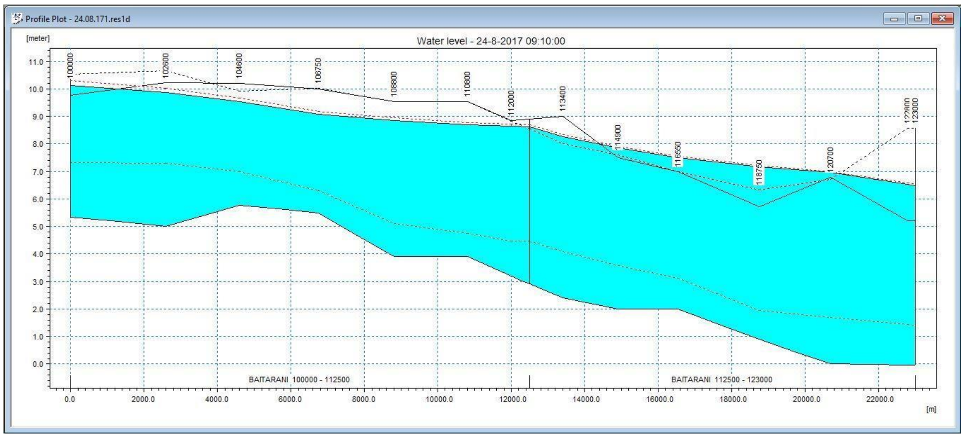

Fig. 10. Longitudinal Water Profile with maximum level near Jajpur on 24.8.17 at 9.10 am

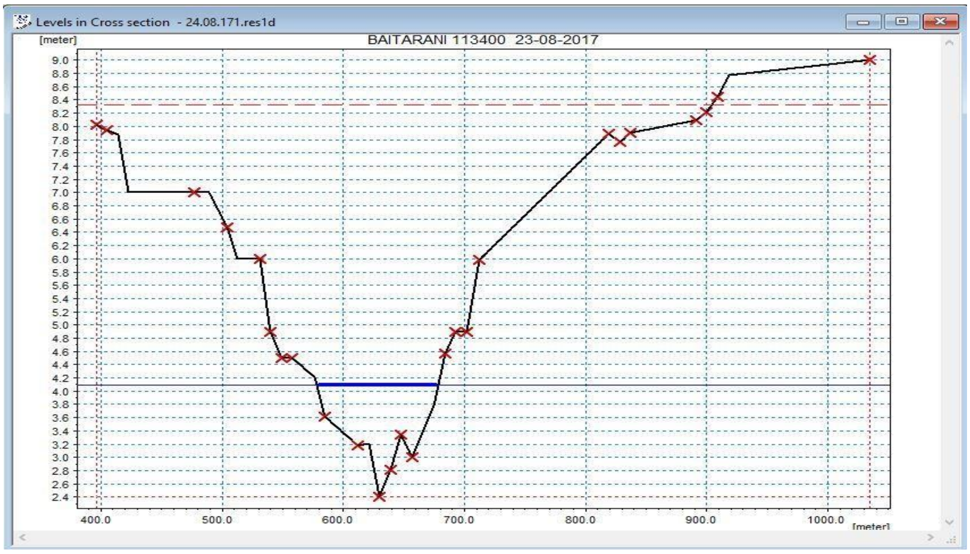

Fig. 11. Cross sectional levels at chainage 113400 near Akhuapada.

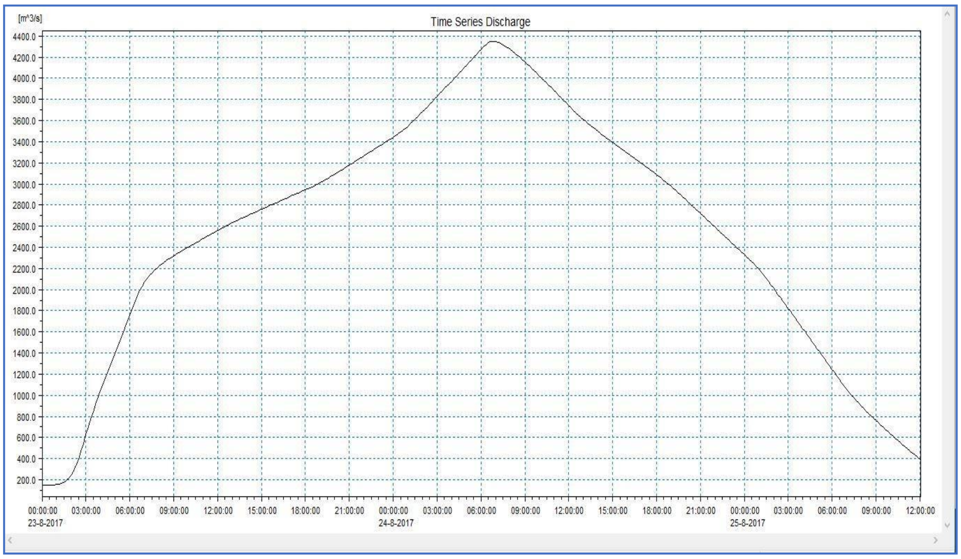

Fig. 12. Time Series Discharge of Baitarani river in study area at 113400 river stretch.

Table 1: Water levels comparison from current and CWC Hydrodynamic simulation

Distance (m)	Water Level (m) (Simulation 2 Results)	Water Level (m) (CWC Report)
0.0 (Anandapur barrage)	70.88	74.003
3490.80	70.371	69.796
10256.8	69.939	69.004
18526.46	67.979	67.811
25327.31	65.772	65.393
39376.61	61.378	62.811
51252.92(Akhuapada)	61.042	59.009
113	61.026	-
70236.38	61.023	-
73428.34	60.971	-
78421.44	60.885	-
87120.60	60.043	-
98678.78	56.137	-
103128.67	53.917	-
107223.80	49.755	-
115278.77	70.88	-

Table 1 displays the simulated effects from CWC measurements with real observed water levels. Comparison was made between Anandapur to Akhuapada river stretch, as observations were only possible for that section. For this data, the R^2 of 0.85 has been estimated. It is observed in the study that the maximum discharge calculated by the rating curve at Anandapur in 2017 is 4319.27 m^3/s (at Water Level 71.75 m), which is more than a flood peak of 3983 m^3/s for the 25-year return period.

Based on the results of HD simulation, it is observed that for cross sections between Anandapur and Akhuapada we have the same results, but at Anandapur and Akhuapada we have slightly different results. Due to the extent of the simulation reach in two studies, it can be explained. The longitudinal water profile derived from HD simulations clearly shows that there is a peak threat of reaching 22 km to 39 km from Anandapur. The river cross section has much less conveyance area after Akhuapada, and the river flows nearly across flood plains.

The Baitarani's right embankment started breaking at about 31 km in 2017. IRS–P6, photo LISS III of 03.10.12 clearly shows this breach of contract. Texture and colour show sandy areas at breach locations at that site. Similarly, the LISS –III image also shows a breach at the left afflux bund near Anandapur.

This work can be further enhanced by combining the MIKE HYDRO model with the mike-21 model to simulate flood inundation for this region, given that the HD model has accurate floodplain DEM and better boundary conditions.

6 CONCLUSIONS

The 2017 Baitarani River delineated basin, extracted drainage network and 1D-HD simulation using Remote Sensing and GIS demonstrated the high applicability and usefulness of these methods for the management of river basin floods. The drainage and basin maps along with basin DEM can also be used to locate the Baitarani sub-basin region in upstream hilly areas of Champua and downstream flood plain of India. Together with rainfall (rain gauge / satellite), temperature, other meteorological parameters, basin scale soil map and land use -land cover (LULC) map these georeferenced databases can be used to carry out hydrological simulations for the entire Baitarani basin. The resulting hydrograph of such hydrological models can be used as input to Anandapur barrage hydraulic models in almost real time. Then this discharge can be routed by combining 1D/2D hydrodynamic models in the GIS environment to see the downstream reaches of water levels, discharge and flood areas.
Thus, a complete near-real-time flood management information system can be created based on current and additional data sets and proper hydrological / hydraulic model selection for the Baitarani basin. With the digital image processing of Arc-GIS 10.1 images during real flood events, the predicted flood inundation region can be confirmed.

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