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FLOOD INUNDATION MAPPING ON TEESTA FLOODPLAIN USING HEC-RAS 1D/2D COUPLE MODEL

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ABSTRACT

Bangladesh is known as one of the highest flood prone countries in the world, being located at the convergence of the three major rivers named Ganges, the Jamuna and the Meghna. Bangladesh is a low-lying country which is situated on the lower elevation of Ganges Delta and the many distributaries which flow into the Bay of Bengal. Flood frequently takes place in Bangladesh, causing enormous losses in terms of property and life. A large amount of border monsoon runoff, together with its own runoff through a network of rivers, are drained out forcefully by Bangladesh. Most of the time the capacity of the drainage channels is exceeded by the volume of generated runoff, and this makes Bangladesh one of the most vulnerable countries in the world. Almost one fifth of our country is flooded every year. In case of severe flood, up to 68% of the total area remains inundated on average.

Teesta is one of the major rivers in the northern region of Bangladesh. From its entrance into Bangladesh to the Kamargani Moura of Gaibandha, it makes a total runoff of about 120 km where it meets the river Brahmaputra. In the months of June to September, the Teesta flow is greatest when there is massive monsoon rain and abundant meltwater supplied by the glaciers. The main objective of the study is to show the capacity of HEC-RAS 1D/2D coupled model to simulate the flood inundation of the Teesta river floodplain.

To create a HEC-RAS 1D/2D coupled model, GIS software and HEC-GeoRAS tool was used to produce an appropriate river geometry. The hydrological data were collected from the BWBD (Bangladesh Water Development Board). Discharge and water level data were defined for the boundary condition of upstream and downstream. After that, with the help of collected hydrological data, the channel calibration and validation were performed. Using RAS Mapper, the flood inundation map was generated after the model had been calibrated and validated for Manning's value n=0.031. A lateral structure was placed on a tentative mid-way of the river reach to connect with 2D mesh flow areas to the left and right. At the end of the study, the area which was inundated during the flood season was determined with respect to the total floodplain area.

Keywords: *Teesta, HEC-RAS, HEC-GeoRAS, Floodplain, Inundation.*

1.INTRODUCTION

Bangladesh is a low-lying country which is highly prone to cyclones, river erosions and floods. Among all, flood is the most prevalent one. Flood is one of the most subversive natural hazards in Bangladesh, and has a great impact on the society. The plate of Bangladesh is mostly flat, with an exception of some hilly regions located mostly to the south-east region of the country. As being located on the Ganges Delta and many tributaries flowing into the Bay of Bengal, flood occurs almost every year in Bangladesh. In summer from the month of June to October heavy monsoon rainfall occurs. The annual average rainfall varies from 1200 mm in the west to 5800 mm in the northeast. (Rahman,1996)

According to IPCC (2013), Bangladeshis are highly vulnerable to climate changes where both monsoon rainfall and sea level will be raised. Flood cataclysm will be invaded for increasing monsoon rainfall and raising sea level. Bangladesh has faced floods of an immense magnitude in 1974, 1984, 1987, 1988, 1998, 2000 and 2004 (FFWC 2005). In the year of 1988,1998 and 2004 the floods are inundated about 61%, 68% and 38% respectively of the total area of a country (Rahman et al. 2007). Recent disastrous flood took place in 1988, 1998, 2004, and 2007 which caused losses from one to over two million metric tons of rice, or 4–10 % of the annual rice production (Islam, et. al., 2009). Flood prone districts in Bangladesh serve to have consistently greater headcount ratios of poverty and that floods cause subsidence in poverty headcount ratio, especially in historically flood-prone areas (Dasgupta, 2007)

Teesta is the tributary river of Jamuna which is flowing through India and Bangladesh. It originates in Himalayas near Chungthang in Sikkims and flows to the South. The Teesta river flow initiates from Jalpaiguri (India) by the three channels, named the Karotoya, Punarbhaba and Atrai. The Teesta is one of the most significant rivers in Northern Region. Without provoking flood, the Teesta with huge amount of water left over, could not pass down the Atrai. The catchment areas of Teesta are the Sikkim, Darjeeling and northern part of Bangladesh. The Teesta subject area is the largest sub-regions of Bengal basin. It covers almost the entire Rangpur district.

The Teesta flood plain is bound by latitudes 25.30 to 26.18 N' and longitudes 88.52 to 89.45 E'. The present districts of Lalmonirhat, Nilphamari, Gaibandha, Kurigram and Rangpur are included in that boundary. An area of about 3861.5 square kilometers is covered by the 14 thanas located in the floodplain region of Teesta river. We can know, with this study, the amount of area that will be flooded for the given discharge. We need to know the amount of flood plain areas that will be flooded due to the increasing and decreasing discharge at various rates. A two-dimensional model is required for flood inundation modeling. For this, hydrodynamic model of one dimensional (1D) and two dimensional (2D) is used in combined. It includes the river as 1D and flood plain as 2D. Using the HEC-RAS software 1D/2D coupled model has been done which has given some special features. An implicit finite volume algorithm is used for the 2D unsteady equation solving. The detailed flood mapping is utilized in this software. By this along with the simulation of flood stage, the amount of flooding that has increased or decreased over the year can be evaluated.

2.METHODOLOGY

2.1 Data Collection

For the study, data of recent and previous years have been collected to develop the hydrodynamic model. These data are required for analysis of the hydrodynamic model and for further interpretation of the condition of the study area. Various hydrologic data, namely water level and discharge data were used along with topographic data, which includes river cross-sections and Digital Elevation Model (DEM). Pre-processing of the data in GIS was a necessary step for further developing the mathematical model for inundation mapping. The collected DEM data for Bangladesh is of 30 m x 30 m resolution. The DEM elevation has been measured taking the mean sea level as datum. All the data used in pre-processing has projected to Bangladesh Transverse Mercator (BTM).

2.2 Data Analysis

After taking the DEM of Bangladesh, the shape file of the floodplain identified for Teesta River in the North West Zone of Bangladesh has been superimposed. The DEM of the study area has been clipped using the clipping tool in Arc-GIS ArcToolbox (Figure-1). After the required DEM has been clipped from the original DEM file, it is converted from Raster type to TIN file by using the Raster to TIN tool in the Arc Toolbox. The purpose of using the Raster to TIN tool is to create a Triangulated Irregular Network (TIN) whose surface does not differ from the input raster by more than a specified Z value. To create 1D geometry of the river, we used only the bathymetric grid and excluded the river floodplain. This was done for developing the spatial data required to generate a HEC-RAS import file with a 3-D river network and 3-D cross sections. This extraction follows several steps before being completed, which are, creation of a river centreline, cross-sections, river banks, and flow path lines as shape files, keeping certain rules in mind which must be followed for proper execution of the work. After completing the extraction, the 1D geometric data was imported into HEC-RAS, where further processing was done (Figure-2).

The floodplain was then divided into two parts of the river and 2D mesh were created on each side of the river. The cell size used for creating the 2D mesh was 400 x 400. After the analysis of mesh, the cells were created. 1D and 2D model were coupled using a lateral structure on the upstream of river. The bank elevation and the elevation of the lateral structure were kept approximately close in the model. Later, the lateral structure was made to breach to depict actual flooding condition and then ran the geometric pre-processor from RAS-Mapper. Finally, boundary condition lines were drawn at the upstream and downstream part of the river flood plain. For the calibration and validation of unsteady flow data, different boundary conditions were applied for different time series. In case of 2D connection, additional boundary condition needs to be applied. Hence, in order to allow entrance of water flow from outside, discharge data was provided at the upstream boundary condition Data of year 2013 have been used to calibrate and of year 2016 have been used to validate the hydrodynamic model for Teesta river. After iterating calibration graphs for Manning's n ranging from 0.015 to 0.035, 0.031 was fixed as calibrated value and the graph was then verified with n value as 0.031.

2.3 Mapping and Visualization

The floodplain for Teesta river was delineated based on year 2004, as one the most recent devastating flood in Bangladesh occurred in 2004. The calibrated and validated model was used for generating water surface profiles for different flow conditions. Flood discharge water profile for 2004 was firstly generated, followed by water surface profiles with an interval of one-day for the duration June to October. The water surface profile which was generated, have been exported in GIS format for development of flood inundation map. Apart from this, the floodplain delineation which was done by HEC-RAS 5.0.3 software itself was shown in RAS Mapper. The inundation map was exported from HEC-RAS to ArcGIS, where the area inundated was re-drawn as a shapefile for evaluating the area which were flooded during the year 2004 during June to October.

3.RESULTS AND DISCUSSIONS

3.1 Digital Elevation Model, Study Area and River Reach

The DEM was clipped with respect to the extents of the floodplain region. As a part of post-processing, the river reach, bank stations, cross sections, flow lines and bank lines were drawn in Arc-GIS and then exported to HEC-RAS for further processing.

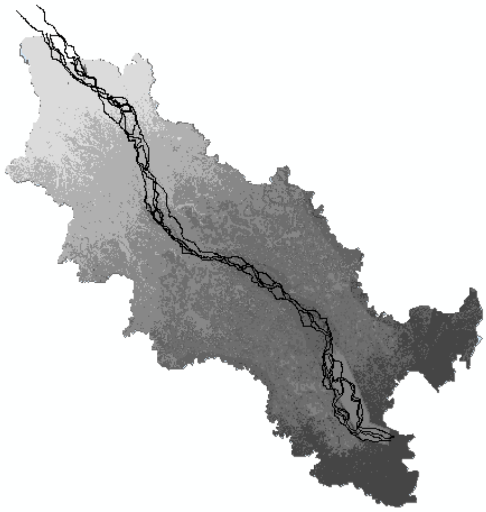

Figure 1: Study Area DEM and Teesta River

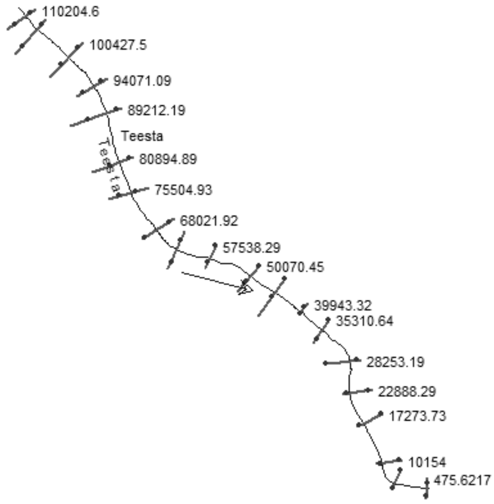

Figure 2: River Reach and Cross Sections

3.2 Calibration and Validation Graphs

The hydrodynamic model was calibrated for the year of 2013 and validated for 2016. For the purpose of calibration, the model was undergone 1-D simulation for various values of Manning's roughness coefficient (n) ranging from 0.015-0.035. A comparison two-line graph was generated for the duration of 1-D simulation against the observed water level and hydrodynamically simulated water level. After quite a number of trials, the graphs were calibrated and validated for n=0.31 as shown in the figure 3(a) and figure 3(b).

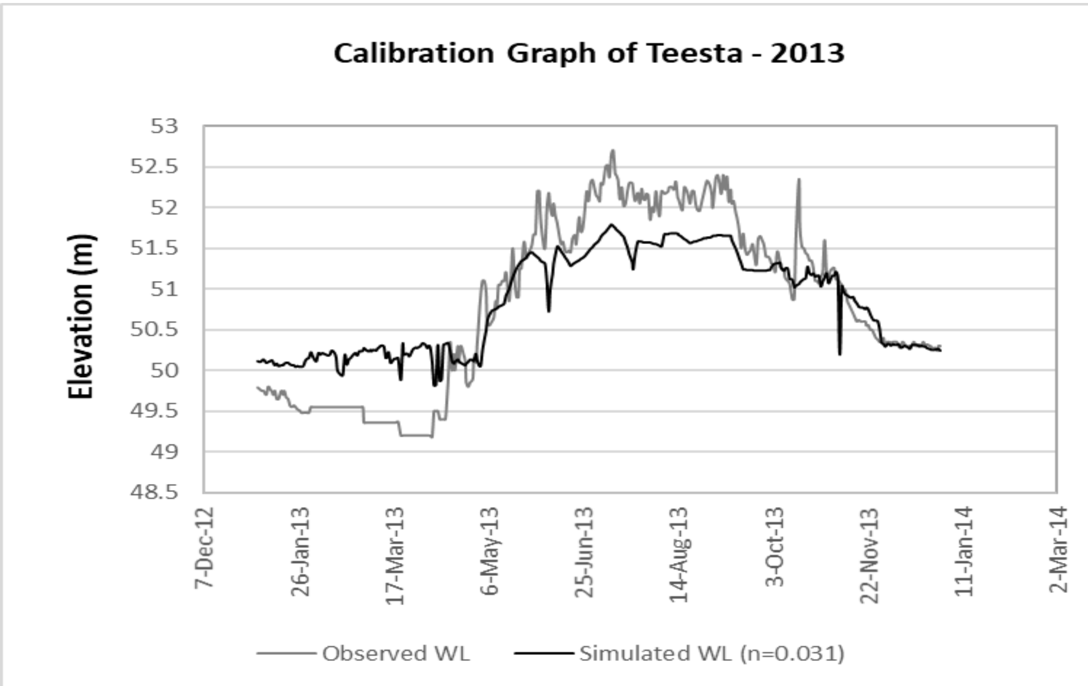

Figure 3(a): Calibration Graph for Teesta River - 2013

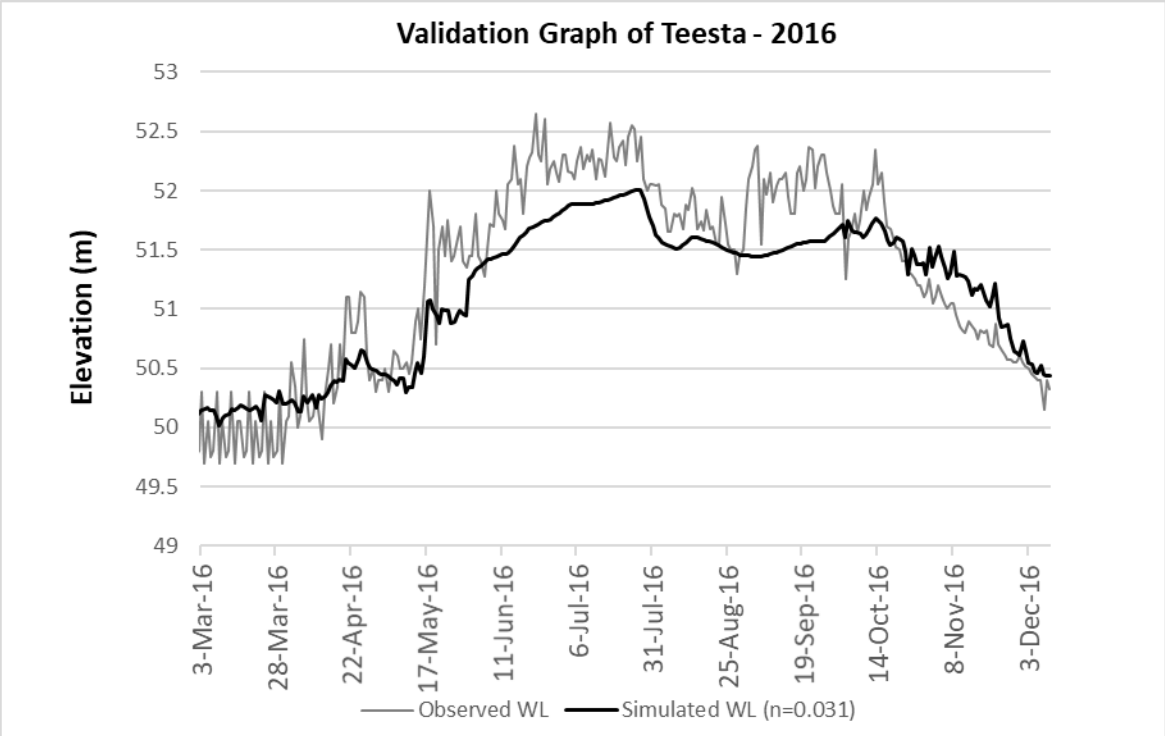

Figure 3(b): Validation Graph for Teesta River - 2016

3.3 Flood Inundation Map and Comparison with MODIS Satellite Imagery

MODIS Satellite Imagery was available for the day o 13th October 2004. For the sake of comparison, the inundation map of 13th October 2004 was compared to the available MODIS Satellite Image as shown in Figure 4. The places which shown similar inundation characteristics have been marked in circles.

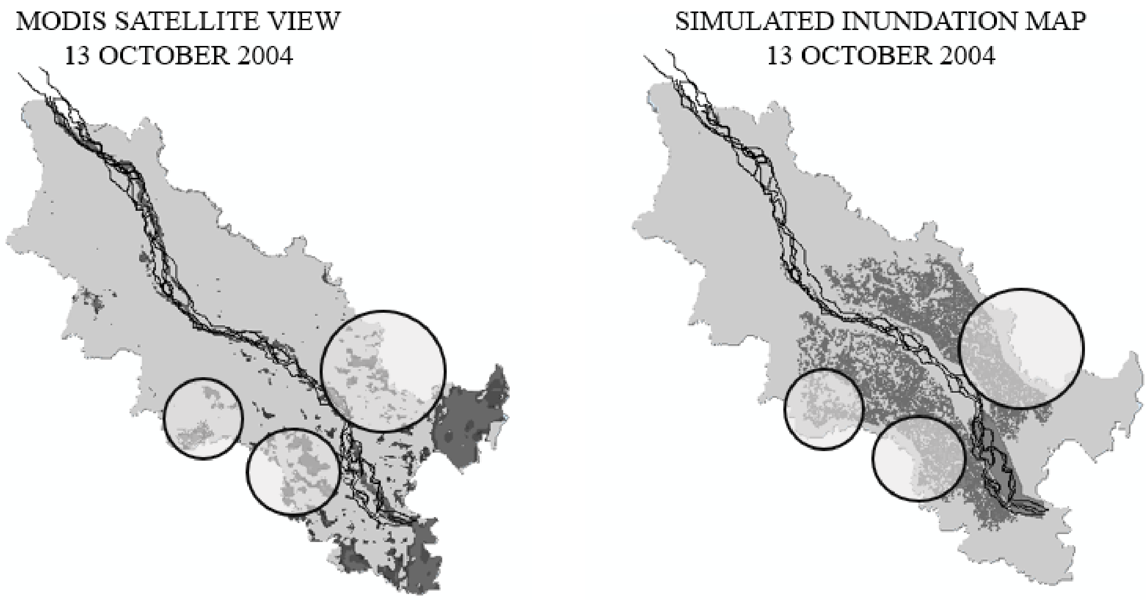

Figure 4: Comparison of Simulated Inundation Map and Modis Satellite Image

3.4 Flood Inundation Area

After the model was simulated for the months of June to October, a study was done based on how much land area of the total floodplain (3861.5 sq km) was inundated during the flood season. A summary has been done every 1st and 15th day of each month, through the months of June to October. Also, to get a better picture of the overall river flow, the flow hydrograph was generated for the year 2004 for Teesta River (Figure 5).

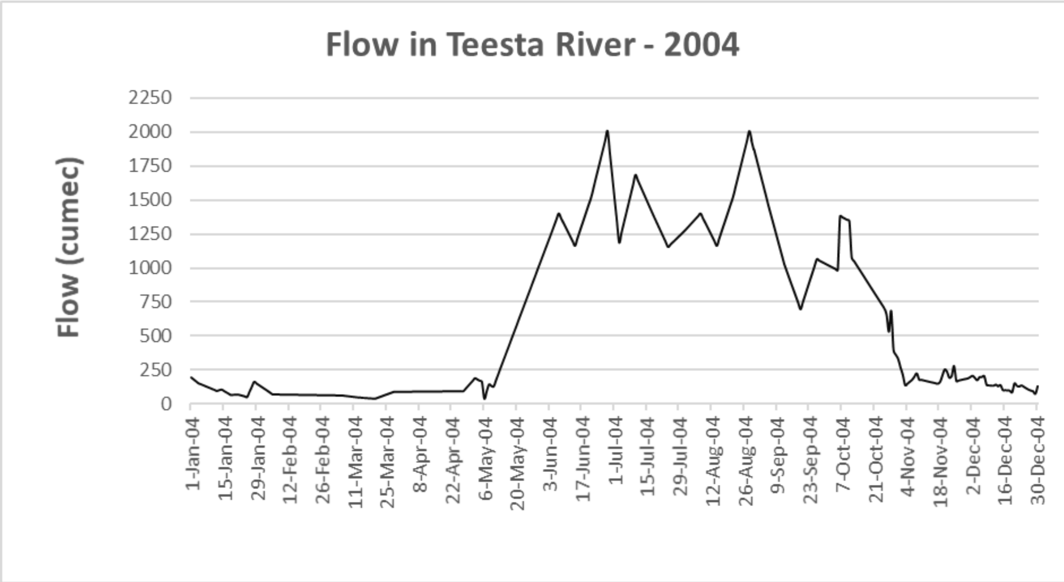

Figure 5: Flow Hydrograph for Teesta River (year 2004)

From the hydrograph it can be clearly stated that, the peak flow occurred during the months of June and September mainly. In accordance to this, our observation of the percentage inundation seems viable.

Table 1: Percentage of Area Inundated (Teesta, 2004)

Month	Date	% Area Inundated
June	1/Jun/2004	21.14
	15/Jun/2004	43.90
July	1/Jul/2004	20.09
	15/Jul/2004	12.19
August	1/Aug/2004	4.29
	15/Aug/2004	7.64
September	1/Sep/2004	14.21
	15/Sep/2004	45.26
October	1/Oct/2004	11.37
	15/Oct/2004	26.16

4. CONCLUSIONS

Hydrodynamic model for Teesta river was established through coupling of 1D and 2D flood plain. Calibration model for Teesta river was done for 2013 based on available sets of data. The model established was calibrated using Manning's n of value 0.028. The floodplain was delineated for the year 2004. From the inundated flood maps which have been developed, area inundated during the flood season was determined with respect to the total floodplain area.

Some of the prospective outcome from this study can be pointed out as follows:

a. Help in planning and management of floodplain area
b. Determining suitability structures like embankment, detention ponds, watershed etc.
c. Automated hydrologic analysis and floodplain mapping provides a better and more effective result.
d. Comparison of the result of this model with studies relating to 2D models can yield possibilities of overall process simplification and improvement through more trial and error.
e. Flood risk and hazard maps, impact of structures like flood control dam, reservoir etc. can also be studied with updated versions of the software and additional modeling tools.

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