FLOOD INUNDATION MAPPING ON JAMUNA BASIN FLOODPLAIN USING HEC-RAS 1D/2D COUPLED MODEL

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ABSTRACT

Bangladesh lies at the confluence of worlds three major rivers, namely the Ganges, the Jamuna and the Meghna. Bangladesh is very much prone to flooding owing to its lower elevation. Flood causes tremendous losses in terms of property and life, particularly in the low land areas. At least 20 % areas are flooded every year and in case of severe flood, about three fourth part of the country is inundated. Therefore, the study is carried out to develop inundation maps of the Jamuna River. Therefore, an associative study was made upon the impact of breached levee on particular districts. The study made here is based upon a combined one and two dimensional model which needs cooperation of GIS and HEC-GeoRAS. The later twos help to form appropriate topographic data and channel cross sections. In HEC-RAS, boundary conditions for upstream and downstream are defined by discharge and water level for running the 1D river, while for 2D floodplain discharge data was used in upstream side and rating curve was used in downstream portion. After boundary condition setup, the channel calibration and validation are performed using known hydrological data collected from BWDB. For floodplain calibration we used about 1% discharge flowing through the channel and only when the channel discharge is more than bank full discharge. However calibration and validation showed result much closer to the actual scenario. After calibration and validation flood inundation map are generated using RAS Mapper and calculated in GIS by exporting data from HECRAS to GIS. The average levee height was about 2m which showed significant amount of resistance against flood. Later, the analysis of flood pattern helped to understand the seasonal growth of flood. Thus, ending of the study may help in planning and management of flood plain area of the Jamuna River to mitigate future probable disaster through technical approach. Findings of the study may also help to determine suitability of building flood control structure like embankment, detention ponds for prevention purposes.

Keywords: *HECRAS; GIS; Bathymetry*

INTRODUCTION

Bangladesh is a riverine country which lies at the confluence of world's three major rivers, namely the Ganges, the Meghna and the Jamuna. Owing to its lower elevation, Bangladesh is very much prone to flooding. Flood causes tremendous losses in terms of property and life, particularly in the low land areas. Every year at least 20% areas are flooded in case of severe flood which is about three fourth part of the country. Moreover, Bangladesh is prone to flooding due to being situated on Ganges delta and the many distributaries flowing into the Bay of Bengal. Including three of the world's largest rivers, the Ganges, the Brahmaputra (Jamuna) and the Meghna about 90% of total stream flows through Bangladesh originate from upstream catchment in India, Nepal, Bhutan and China.

For being a braided river, the characteristics of Jamuna is not fixed, rather changes with time. So it is essential to understand the characteristics of flood inundation for the Jamuna River. With this study, we can know how much area will be flooded due to a given discharge. In addition to that, we need to know how fast or at what rate the flood plain areas are flooded due to given discharge, to answer these key questions, this study has been taken. Flood inundation modeling requires a two dimensional model, however, study of flood inundation can be done using a combined one dimensional (1D) and two dimensional (2D) hydro dynamic model which includes flood plains as 2D part and river as 1D part .In that sense this is a very new study in the subcontinent and also new to the other part of world as coupled 1D and 2D modeling is new in HEC-RAS. In case of this 1D/2D coupled model HEC-RAS has given some special features. The 2D unsteady equations solver uses an implicit finite volume algorithm which allows larger time step in calculation and improved stability and robustness over traditional finite difference and finite element techniques. Moreover it provides detailed hydraulic property table for computational cells and cell faces. Finally in this study we could utilize the detailed flood mapping capability of HEC-RAS 5.0.0 which was not possible in the older versions.

Fig. 1: Study Area

The main objective is to study the capabilities of a 1D/2D coupled hydro dynamic model in simulating flood inundation of the Jamuna River, generate and compare flood inundation map and estimate the effect of construction embankment for particular location. The Jamuna's middle portion and its floodplain, about 25 km in the left bank and 35 km in the right bank of the river, are the study areas in this study (Figure 1). The river reach length is about 90 km and the total area is 6870 square km excluding the river. Only the Jamuna River's floodplains has been considered for this study which includes Gaibandha, Bogra, Sirajganj, Sherpur, Jamalpur and Tangail districts only.

METHODOLOGY

For the study we used different sets of data named bathymetric data, hydrologic data (discharge and water level) and topographic data as Digital Elevation Model (DEM) data. To set up the model preprocessing was necessary in GIS. The river bathymetric data collected from Institute of Water Modeling (IWM) has been used for the generation of the shape file. Data Management tool of ArcGIS has been used to process the data. To create a surface grid in ArcGIS, the 'Spatial Analyst' extension employs one of several interpolation tools. In this study, Kriging interpolation method has been used to create the surface grid of the river bathymetry. The size of the grids has been chosen as 10 meter. The created topographic grid contains some default topographic data that are not appropriate. Only river bathymetric grid is needed. Extraction of grid needs the 'Grid Analyst' extension. A polygon has been drawn in accordance with the river bathymetric size. Using this polygon the bathymetric grid file has been extracted from the topographic grid file. The bed level for bathymetry was referenced with respect to the Public Works

Datum (PWD) of Bangladesh, which is established by the Department of Public Works, Bangladesh. The complete bathymetric grid has been shown in figure 2.

Fig. 2: The River Bathymetric Grid

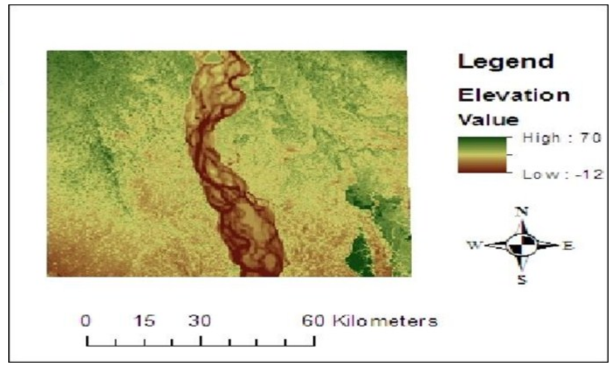


Fig. 3: Merged Bathymetry with DEM Data

After downloading the DEM, the study area DEM has been clipped from the entire DEM by using the data management tool. Finally, DEM has been resampled into 10*10m resolution. The elevation of the DEM has been measured relative to the mean sea level (MSL). DEM's value has been transferred to PWD datum by adding 0.46 m. All the data in the DEM have been projected on to the Bangladesh Transverse Mercator (BTM). Then the bathymetric grid has been merged with the topographic DEM to produce the complete DEM of the river bathymetry along with the topographic DEM (Figure 3). Hence, for the preparation of channel geometry, preprocessing was done in HEC-GeoRAS. To create 1D geometry we used the bathymetric grid only and excluded the nearby floodplain. The goal of this section was to develop the spatial data required to generate a HEC-RAS import file with a 3-D river network and defined 3-D cross sections. This extraction comprises several steps. These are development of a river centerline, cross-sections, river banks, and flow path lines as shape files.

1D geometric data was imported to HEC-RAS. After that we divided the floodplain into two parts of the river and created 2D mesh at both left and right side of the river. In case of creating 2D mesh, we took 300m*300m as cell size. Then the cells have been created after mesh analysis. We did coupling of 1D and 2D model by using lateral structure on the upstream of both sides of the river. In our model, bank elevation and levee height were kept approximately at the same elevation. Then we breached the levee for creating actual condition and ran the geometric preprocessor from RAS Mapper. Finally, boundary condition lines were drawn at the both upstream and downstream side of the floodplain.

We have applied different boundary condition for different time series data for calibration and validation respectively for unsteady flow simulations. For 2D connection, additional boundary condition is necessary to be applied. So we provided discharge data at the upstream boundary condition line in order to allow the entry of the inherent flow from the outside of the area into the floodplain. Rating curves were used at the downstream floodplain so that the flood water can pass away.

The data regarding to the flood year 2004 has been used for calibration and the parameter was Manning's roughness co-efficient 'n'. The model has been simulated using the daily hydrograph for four months from June to September. The 'n' value as 0.032 for main channel and `n' value as 0.035 for flood plain has been fixed as Manning's 'n'. The comparison of observed and simulated stage hydrograph at Kazipur and Mathurapara gauging station was noticed for different Manning's 'n'. After that the flood peak and time to peak for the flood year 2004 is computed and it is observed that there is a close agreement between the observed and computed values (Figure 4). In unsteady calibration, the co-efficient of regression R^2 has been found 0.9295, which indicates, the simulated value is closer to the observed value.

The calibrated HEC-RAS 5.0 based model has been also used to validate the flow for the year 2004 and the value of R^2 was found to be 0.8306.

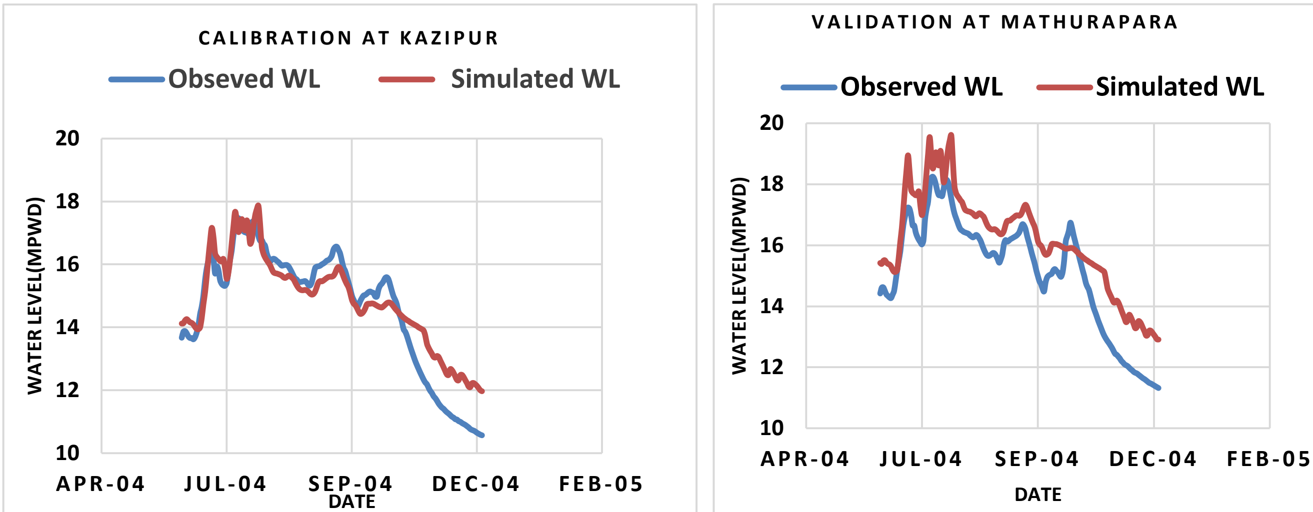
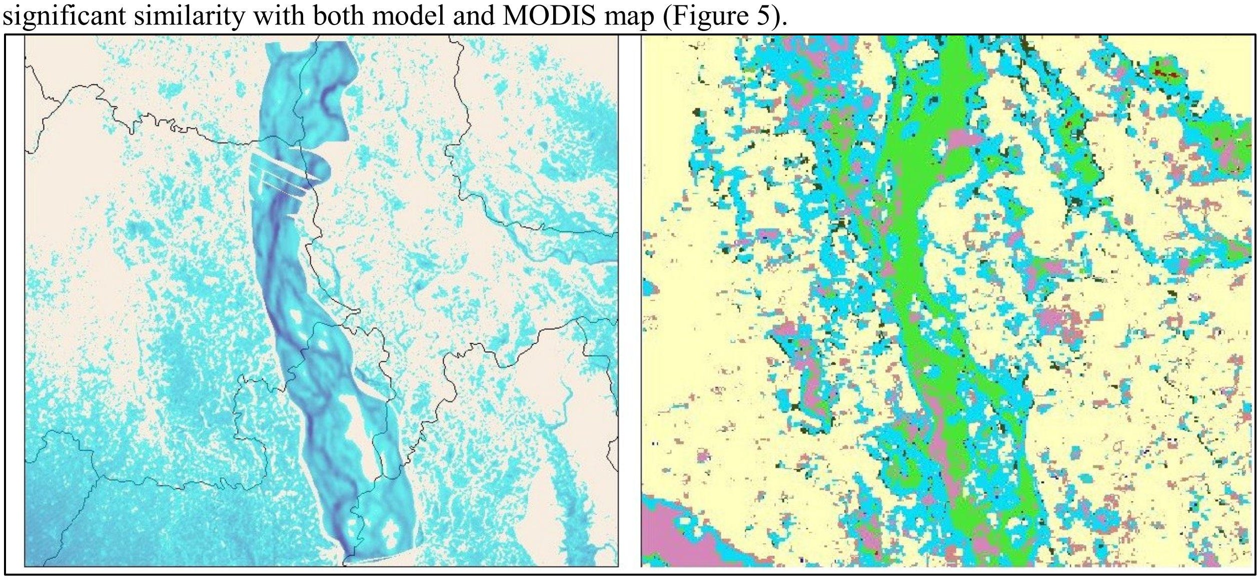


Fig. 4: Plotting of Calibration at Kazipur and Validation at Mathurapara

The calibrated and validated model has been used to generate water surface profiles for different flow conditions. At first, 2004 flood discharge water profile has been generated. Water surface profiles of one-day-interval from June to December have been generated for five years from 2004 to 2008. The generated water surface profile data have been exported in GIS format data to develop flow inundation map. Besides, floodplain delineation is done by HEC RAS 5.0 software itself and shown in RAS Mapper. No GIS help is needed here. Shape file of different flood extend can be produced for different time. Then we exported the shape file into GIS and calculated the area of inundation. Our model simulation map and MODIS data map also shows the approximate result. In fact, flood in 2005, 2006,2007 also shows a significant similarity with both model and MODIS map (Figure 5).



MODEL FLOOD MAP MODIS FLOOD MAP

Fig. 5: Qualitative comparison between simulated and observed flood map of 02 October, 2004

RESULT AND DISCUSSION

After the model calibration and validation, flood extent and inundation maps have been prepared for different time series. Unsteady simulation has been performed for analysis of the changing flood pattern with time. Finally, we estimated the levee impact on the flood inundation area. We completed unsteady simulations for the year of 2004 to 2008. Summary of the observed result is shown in table1.

Table1: Inundation area, maximum discharge and percent inundation in different years

Year	Maximum discharge (cumec)	Inundated area (sq.km)	Percent inundation
2004	83945	3593	52.29
2005	55340	1848	26.9
2006	46791	707	10.3
2007	94236	5001	72.79
2008	64354	2234	32.53

Then we have made analysis upon the flood pattern for the year of 2004, 2007 and 2008. The flood of 2004 shows a massive inundation. The analysis is briefly represented in the figure 6. As per our model result, it is seen that flood starts from third quarter of June and peak occurs at late July. Sirajgonj, Tangail and Bogra were mostly affected by that flood. 2007 flood seems to be more extensive than the flood of 2004. Here the peak occurs lately nearly at mid-August. The flood sustained for a long period compared to the other ones. According to the flood map generated from model simulation it is seen that peak occurs at the end of September and its duration was much short compared to 2004 and 2007. Now, the levee elevation plays important role in controlling the floodplain area. For analysis of its effect, we set up two levees at left and right side of the river which are about 14 km long. The levees were meant to resist the flooding of Tangail district on the right side and Sirajgonj on the left of the river. Analysis on simulation

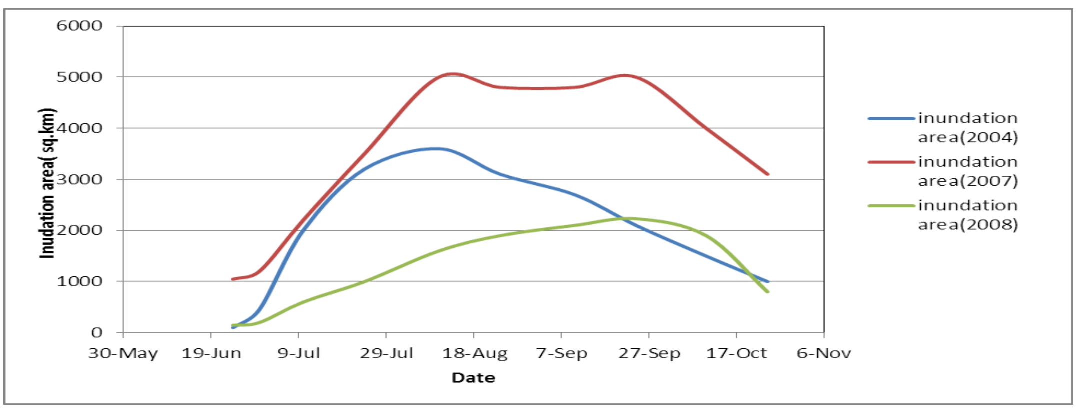


Fig. 6: Analysis of the flood patterns for different years

shows that flood extent decreases significantly due to the levee set up (70-80% in our case). We tried with a levee on an average of 16.25mPWD elevation all through the span.

CONCLUSION

This study presents a systematic approach in the preparation of flood inundation and flood hazard maps with the application of combined hydrodynamic 1D and 2D model, HEC-RAS and GIS. The change of flooding with time is also shown in this study by performing unsteady flow analysis and flood mapping. The major tools used in this method are a combination of 1D/2D numerical model HEC-RAS 5.0 and ArcGIS for spatial data processing and HEC-GeoRAS for interfacing between HEC-RAS and ArcGIS.

Here, establishment of Hydrodynamic model through coupling of 1D river and 2D floodplain was made for the Jamuna River. Calibration and validation of the model show good correlation between the observed and simulated data. The value of correlation coefficient, R is 0.93 and 0.83 for calibration and validation respectively. Comparison between observed flood from MODIS image and model result were satisfactory. Application of levee can be computed by the model. Establishment of a levee of about 2m height reduces flood extent about 85%.

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