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Flood Inundation Mapping of Floodplain of the Jamuna River Using HEC-RAS and HEC-GeoRAS

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ABSTRACT

Bangladesh lies at the confluence of world's three major rivers, namely the Ganges, the Jamuna and the Meghna. In Bangladesh, normally four types of flood, expressly river flood, flash flood, tidal flood and storm surge flood appear. The Jamuna River is the most vulnerable to river flood. As a low lying country, flood occurs repeatedly in Bangladesh and causes tremendous losses in terms of property and life. Therefore, a study is carried out to develop flood extend map and flood inundation depth map of the Jamuna River. One dimensional hydraulic model HEC-RAS with HEC-GeoRAS interface in co-ordination with ArcView-GIS is applied for the analysis. The Nash-Sutcliffe Coefficient (NSE) values have been found greater than 0.60 for both calibration and validation. The percentages of area inundated by 2, 5, 10, 25, 50 and 100-year return period's floods are 26, 46, 51, 55, 57 and 59% respectively. The classification of flood depth area showed that most of the flooding area had water depth between 1.2 m to 3.6 m. Thus, finding 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. The automated floodplain mapping and analysis using these tools provide more efficient, effective and standardized results and saves time and resources.

Keywords: Inundation Map, flood, Jamuna River, HEC-RAS, and HEC-GeoRAS

INTRODUCTION

The densely populated Bangladesh is located in the south Asian sub-continent. Specifically, Bangladesh lies at the confluence of worlds' three major rivers, namely the Ganges, the Jamuna and the Meghna. Bangladesh is one of the most natural disaster prone nations in the world where storm surges, cyclones, floods, river bank erosions, and droughts are frequently occurred (Nasreen, 2004). Among natural disasters in Bangladesh, flood is the dominant one. As a low lying country, at least 20 % areas are flooded every year and in case of severe flood 68 % areas are inundated (DBM, 2010). Bangladesh has experienced floods of a vast magnitude in 1974, 1984, 1987, 1988, 1998, 2000 and 2004 (FFWC, 2005). The Floods of 1988, 1998 and 2004 inundated about 61%, 68 % and 38% of the total area of the country, respectively (Rahman, 2007). The Brahmaputra-Jamuna River, draining the northern and eastern slopes of the Himalayas, is 2900 km long where in Bangladesh the reach length is 240 km (Bhuiyan, 2014).

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The Jamuna one of the dominant rivers of the country where river floods are a common phenomenon. Normally, 25-30% of the area is inundated during monsoon season along the river (Hossain, 2003). In case of extreme flood events 50-70% of the countries are inundated extending the areas far beyond the riverbanks (Hossain, 2003). The causes of Jamuna River floods are heavy rainfall in monsoon, snowmelt, enormous discharge coming from upstream, levee breaching, river siltation etc (FFWC, 2008).

Though flood inundation modeling requires a two dimensional model, however, study of flood inundation can be done using a one dimensional (1D) hydrodynamic model which includes flood plains as a part of its domain. For example, HEC-RAS and HEC-GeoRAS were being used widely to develop flood inundation map in many studies (Hazarika, 2007; Hicks and Peacock, 2005; Abera, 2011; Merwade et al., 2008; Yang et al., 2006; Heimann et al., 2015). Most of the studies have been done in abroad. Flood extends and inundation depth mapping studies using mathematical model in Bangladesh is limited. In Bangladesh, a few studies have been done using satellite images and GIS (Bhuiyan et al., 2010; Islam et al., 2010).

STUDY AREA

The Jamuna watershed lies in North-Central & North-West Zone of Bangladesh. The Jamuna's middle portion and its floodplain, about 25km in the left bank and 35 km in the right bank of the river, are the study areas in this study (Fig. 1). Its extends between 24°28'26" to 25°12'8" N latitude and 89°23'38"

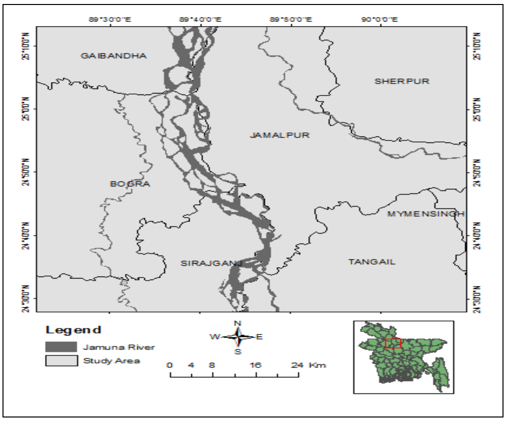


Fig. 1. Location of Jamuna river and its flood plain.

to 90°7'30" E longitude. The river reach length is about 100 km and the total area is 5858 square km. The study areas have been chosen based on the 1998 flood's inundation area, which are the maximum inundation areas for the study area. Only the Jamuna River's floodplain has been considered for this study which includes the following districts: Gaibandha, Bogra, Sirajganj, Sherpur, Jamalpur and Tangail.

|DATA COLLECTION AND METHODOLOGY

Data collection

Distinct sets of data were collected from different organizations for this study. Among the collected data, geometric data like bathymetry of the river, hydrologic data like discharge, water level, flood inundation map and digital elevation model as land topographic data were included. All collected data are summarized in table 1.

Table 1: Collected data list

Data Type	Source	Data location	Periods
Bathymetric data	IWM	Jamuna River	2011
Discharge data	BWDB	Bahadurabad station	1956-2012
Water level	BWDB	Sirajganj station	2001-2007
Water level	BWDB	Kazipur station	2004-2005
Water level	BWDB	Mathurapara station	2004-2005
DEM	NASA	Bangladesh	2014
Flood map	FFWC	Bangladesh	2004

Model Development

The bathymetric grid has been created from bathymetric data by using Arc GIS. The bathymetric grid has been merged with topographic DEM to produce the complete bathymetry. The geometric data for HEC-RAS model has been extracted from the complete bathymetry by using HEC-GeoRAS. The HEC-RAS model is calibrated and validated against the observed water level data. HEC-RAS has been used to simulate different known flood events. HEC-GeoRAS is used to generate flood inundation maps. Historical flood event 2004 of Bangladesh has been compared with the resulting maps from the HEC-GeoRAS model.

The future flood inundation maps of the Jamuna river is developed for different return periods using HEC-GeoRAS.

MODEL CALIBRATION AND VALIDATION

Model calibration

The model has been simulated using the daily hydrograph for four months from June to September in 2004. For this study, effort has been made to calibrate Manning's roughness coefficient for single value using aforesaid data and subsequently, different values have been used to justify their adequacy for simulation of flow in the Jamuna River. Finally, ‘n’ value as 0.022 for main channel and ‘n’ value as 0.037 for flood plain has been fixed as Manning's ‘n’. The comparison of model calibration observed and simulated stage hydrograph at Kazipur and Mathurapara gauging stations have been shown in fig. 2 and 3 respectively. Further, 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. Coefficient of determination (R^2) and Nash and Sutcliffe Efficiency (NSE) have been found 0.82 and 0.65 respectively for the unsteady flow calibration.

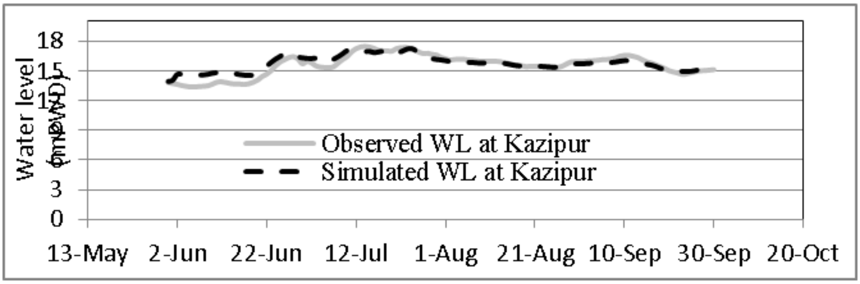


Fig. 2. Model calibration observed and simulation hydrograph at Kazipur

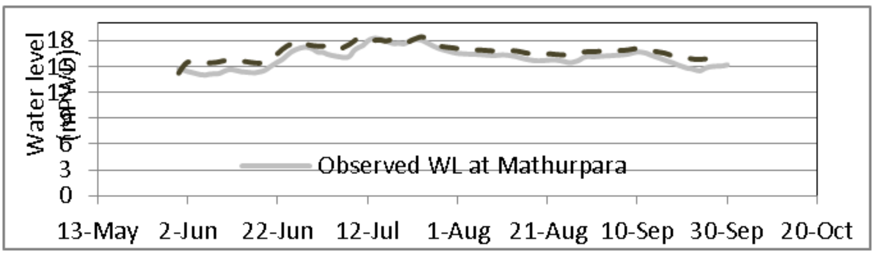


Fig. 3. Model calibration observed and simulation hydrograph at Mathurapara

Model validation

The model has been validated using the daily hydrograph for four months from June to September in 2005.The comparison of model validation observed and simulated flow hydrograph at Kazipur and Mathurapara gauging stations are shown in figs. 4 and 5 respectively. The figs. show the simulated flood hydrograph is in close agreement with observed hydrograph. Coefficient of determination (R^2) and Nash and Sutcliffe Efficiency (NSE) have been found 0.81 and 0.63 respectively for the unsteady flow calibration.

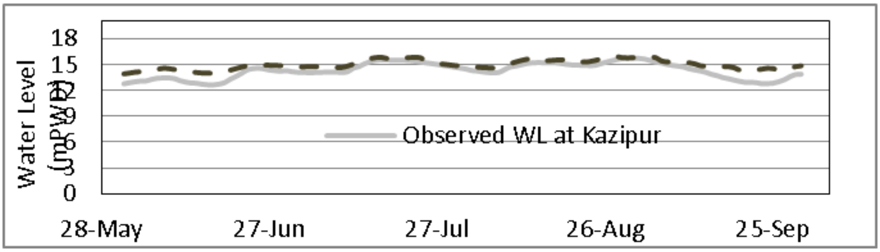


Fig. 4. Model validation observed and simulation hydrograph at Kazipur

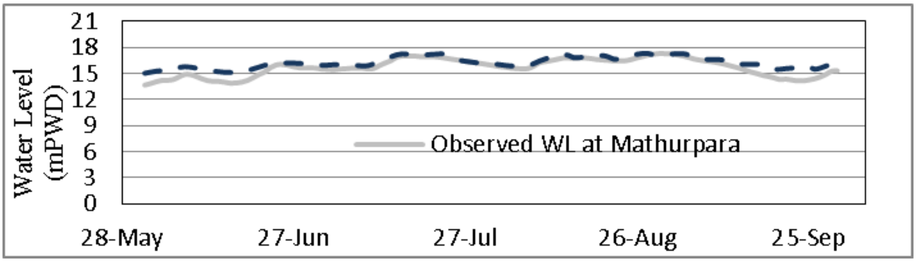


Fig. 5. Model validation observed and simulation hydrograph at Mathurapara

Qualitative comparison between model and observed 2004 flood map

The calibrated and validated model has been used to generate water surface profiles for 2004 flood flow condition. Finally, this water surface has been used to generate 2004 flood map. Qualitative

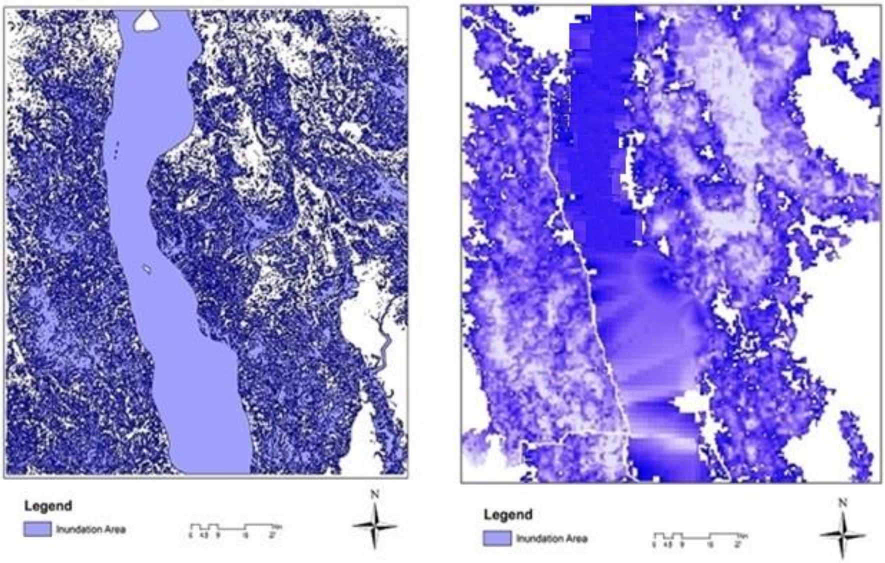


Fig 6. (a) 2004 simulated flood map **(b)**. 2004 observed flood map

comparison between simulated and observed 2004 flood map is shown in fig. 6(a) and 6(b). Figs. show that the inundation areas between simulated and observed are adequately alike

Results and discussion

Results of flood frequency analysis

Flood frequency analysis are done based on maximum flow recorded at Bahadurabad (Station ID 46.9L) from year 1956 to 2012 excluding 1971 using Normal Distribution (N), Log Normal (LN), Pearson Type - III Distribution (P3), Log Pearson Type - III Distribution (LP3), and Gumbel Distribution (EV1) method. For selecting best fitted distribution, goodness-of-fit test has been conducted. From the chi square test it is found that Log Normal is the best distribution among the five distributions for this station discharge data. Discharges for 2, 5, 10, 25, 50 and 100 year return periods using Log Normal distributions are 65772, 76871, 83519, 91299, 96703 and 101790 cumec respectively. The discharges from Log Normal (LN) distribution method have been used for future flood modeling.

Flood inundation extent analysis

Maps of flood extended of different return periods have been developed, among these maps only 100

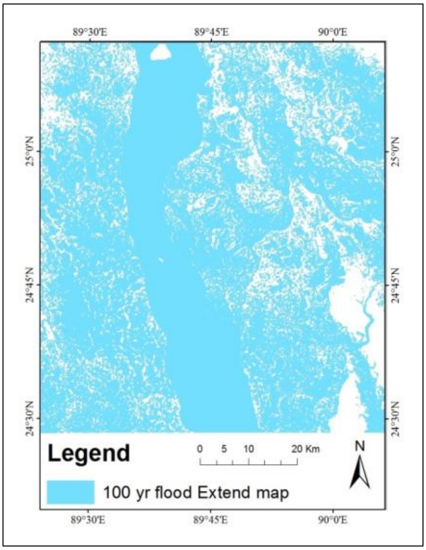


Fig. 7. Map of extent of flood for 100-year return period

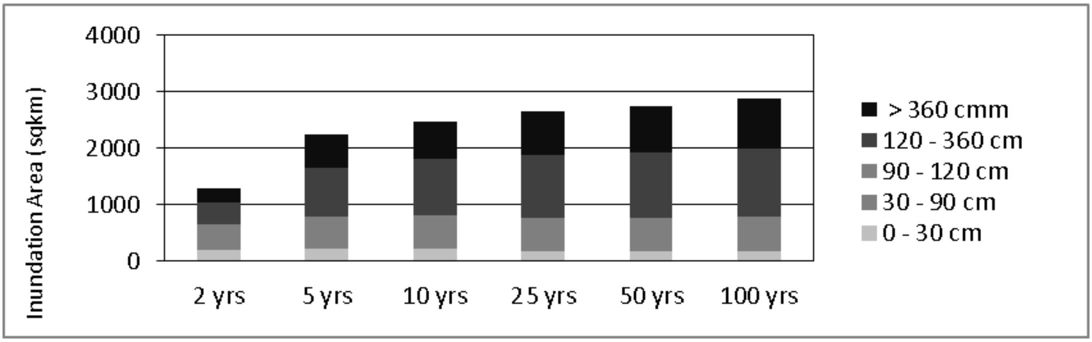
year return period flood map is shown in fig. 7. Inundation area and the percentage of inundation area with return periods are shown in table 2. Maximum and minimum inundation areas are 59% for 100-year return period and 26% for the 2-year return period respectively. For other return periods i.e., 5, 10, 25, and 50-year % of inundation area are 46, 51, 55, and 57% respectively.

Table 2: Return periods and corresponding inundation area

Return Period (year)	2	5	10	25	50	100
Inundation area (sqkm)	1264	2231	2474	2643	2753	2864
% Inundation area	26	46	51	55	57	59

Flood inundation depth analysis

In the study, inundated areas are defined into five qualitative inundation depth classes viz. F0 (very high land (0m - 0.3m)), F1 (high land (0.3m - 0.9m)), F2 (medium land (0.9m - 1.2 m)),



F3 (low land (1.2m - 3.6m)) and F4 (very low land (> 3.0m)) based on the inundation depth. The results of this assessment are summarized in fig. 8. The classification of flood depth areas indicates that 33 to 42% of the total flooded area has been inundated by water depth between 1.2 to 3.6 m and 28 to 31% of the total flooded area has been inundated by water depth greater than 3 m. The total area under the water depth 0.3 m is 6 to 15%.

Fig. 8. Return period-flood depth relationship

Relation between water level and inundation area

The relation between water level and inundation area is shown in fig. 9. Water level at Kazipur gauge station corresponding to discharge is considered to determine the relationship between inundation areas with water level. Up to 15.12 m water level the area is not inundated. The inundation area increases with the increase of water level after 15.12 m river water level. The increasing inundation area with respect to water level is followed by two degree polynomial equation. This equation is $Y = 4.77x^2 - 138.76x + 1008$. This equation is developed from five years unsteady simulation water level and its corresponding inundation area. About 49% area is inundated for the 17.77 m water level at Kazipur.

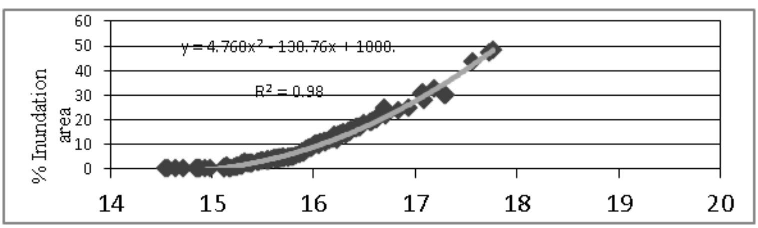


Fig. 9. Water level vs % inundation area relationship at Kazipur station

CONCLUSION

The major tools used in this study are a one-dimensional numerical model HEC-RAS, ArcView GIS for spatial data processing and HEC-GeoRAS for interfacing between HEC-RAS and ArcView GIS. Flood frequency analysis is considered to assess different return periods future maximum discharge for flood extend and inundation depth maps. Among the five distributions, the Log Normal Distribution (LN) is the best distribution for flood frequency analysis in this station. For 2, 5, 10, 25, 50 and 100 year return periods 26, 46, 51, 55, 57 and 59 % of the area were found to be inundated, respectively. The F0, F1, F2, F3 and F4 types land inundated area are 6, 13, 8, 42 and 31 % of 59 % respectively of total inundated land for 100 year return period flood. This method of floodplain mapping can be used as a useful tool for floodplain management and for decision making as well for future development within the floodplain of the Jamuna river basin.

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