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ANALYSIS OF THE EFFECT OF WARMEST CLIMATE CHANGE SCENARIO IN JAMUNA RIVER FLOODPLAIN USING HEC-RAS 2D MODEL

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Abstract: Bangladesh is located in the lower part of the basins of the three mighty rivers – the Ganges, the Brahmaputra and the Meghna. Jamuna is the main distributary of Brahmaputra river which carries an enormous volume of water through the country. Therefore, the geographical position of Bangladesh made her more vulnerable to flood. Furthermore, due to global climate change, catastrophic floods in Bangladesh will appear more frequently and with increasing severity. Therefore, a synthetical approach has been made to understand the effect of the warmest climate change scenario (RCP 8.5) on the flood parameters, e.g., flood inundation depth, flood duration, flood arrival time, and flood recession time for the floodplain of Jamuna river. The analysis is done by using a HEC-RAS 2D model for year 2020s (2010-2039), 2050s (2040-2069), 2080s (2070-2099) and the base year flow (1981-2010). The study shows that flood arrives earlier by approximately 12 days, 26 days and 57 days in year 2020s, 2050s and 2080s respectively. Similarly, flood duration increases by 10 days, 23 days and 68 days in year 2020s, 2050s and 2080s respectively. The flood depth increases by 0.48m, 1.01m and 1.14m by 2020s, 2050s and 2080s than the Base Year Flow. Flood recession time has shifted by 2 days, 3 days and 11 days in year 2020s, 2050s and 2080s respectively. This analysis will be beneficial for local authorities, NGOs and communities to get a better idea about the characteristics of the flood in future for planning, agricultural production, and other important aspects.

1. Introduction

Bangladesh is located in a low-lying delta which is in between the Himalayas and the Bay of Bengal and has formed by the dense network of the distributaries of the Ganges, the Brahmaputra and the Meghna (GFDRR, 2011). Due to the geographic location, too much flow during monsoon and scarcity during the dry period has become highly sensitive to the contribution of flow from the major basins (Ahmed, 2006). The recent history of flooding in Bangladesh indicates that the interval between catastrophic floods is decreasing and the intensity and duration of such floods are both increasing (Rouf, 2015). Since independence in 1971, Bangladesh has experienced floods of a vast magnitude in 1974, 1984, 1987, 1988, 1998, 2000, 2004, 2007 and 2017. The most dangerous flood event occurred in 1998 which has the highest recorded flood in depth and duration (FFWC, 2005).

Bangladesh is familiar globally with the countries most disclosed to the influence of global warming and climate change (Pahlowan and Hossainl, 2015). According to IPCC 5th assessment report, it is predicted that temperature will be increased 1.6°C by 2050s while precipitation will be increased by 8% Moreover, the sea level rise in the Bay of Bengal by 2100 is projected within a range of 0.2 to 0.9 m (Ahmed, 2006). This assessment report had also adopted Representative Concentration Pathways (RCPs) which are the trajectories of four greenhouse gas concentration (not emissions). They are RCP8.5, RCP6, RCP4.5 and

RCP2.6 (Wayne, 2013). The Representative Concentration Pathway (RCP) 8.5 corresponds to a high greenhouse gas emissions pathway compared to the scenario literature (Riahi et al., 2007).

Few studies have previously been conducted on the floodplain of Jamuna river (e.g. Rahman, 2015; Khan and Mazid, 2017). In most cases, one-dimensional hydrodynamic model has been used to generate flood inundation mapping of the Jamuna river floodplain. However, very few studies have focused on the effect of climate change on the flood characteristics of Jamuna river. From the aforementioned background information, in this study an attempt has been made to identify the effect of warmest climate change scenario (RCP8.5) to the flood parameters (Flood arrival time, Flood duration, Flood depth and Flood recession) on the Jamuna river floodplain for year 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099) from Base Year Flow (1981-20010).

2. Study Area

Brahmaputra River Basin (BRB) is one of the major basins in the world draining an area of about 530,000 km^2 through China (50.5%), India (33.6%), Bangladesh (8.1%) and Bhutan (7.8%) (Alam, 2015). The catchment area of the mighty Brahmaputra-Jamuna river is about 5,83,000 km^2 of which only 47,000 km^2 is within Bangladesh. The maximum drainage area above Bahadurabad is 536,000 km^2 (Chowdhury, 2015). The study area has been selected based on the 1998 flood's inundation area, which is the maximum inundation areas of Bangladesh. The extent of this floodplain is in between 24˚27’34” to 25 ˚ 8’14” N latitude and 89 ˚ 22’50” to 90 ˚ 02’48” E longitude. Jamuna's middle portion and its floodplain, about 36.15 km in the left bank and 22.04 km in the right bank of the river, are the study areas in this study The river reach length is 78.78 km and the total area of the study area is 4990.27 km^2. The Bahadurabad station has been selected for the upstream boundary and the Shirajgong station has been selected for the downstream boundary. Figure 1 shows the extent of the study area used for this study.

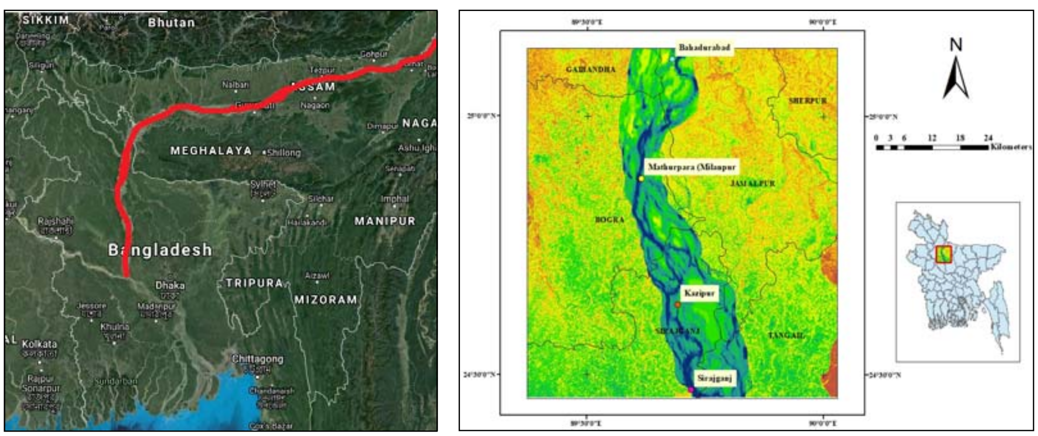


Figure 1: Google Earth View of Brahmaputra-Jamuna River (Left Side) and Study extent of Jamuna River Floodplain (Right Side)

3. Data Collection and Methodology

3.1 Data Collection

The bathymetry data of the year 2011 have been collected from Institute of Water Modeling. The discharge data for year 2004-2005 of Bahadurabad station and the water level data of the year 2004-2005 of Sirajganj station, Kazipur station and Mathurapara station have been collected from Bangladesh Water Development Board (BWDB). The discharge data of Base Year Flow (average data of year 1981-2010) and the discharge data of warmest climate scenario for year of 2020s, 2050s and 2080s have been collected from a previous study done by Alam (2015) which are shown in Figure 2.

The Digital Elevation Model (DEM) which were used in this study was collected from the US Geological Survey (https://earthexplorer.usgs.gov/). The originator of USGS is NASA (National Aeronautics and Space Administration. The data comprises of a resolution of 1 arc second (30.87 meter).

MODIS (or Moderate Resolution Imaging Spectroradiometer) images were used in this study. A quantitative analysis has been performed by comparing inundated area of MODIS Flood Map and the Simulated Flood Map. MODIS data set have also been collected for year (2004-2010) from USGS (https://earthexplorer.usgs.gov/).

3.2 Methodology

In this study a 2D hydrodynamic model has been developed for the study area using HEC-RAS 5.0.3. The pre-processing of the data have been done by using ArcGIS 10.2.2. Once the 2D hydrodynamic model is calibrated and validated against water surface elevation and flood inundations map, the model is used to simulate flood inundation for the years of base year (average of 1981-2010), 2020s, 2050s and 2080s. From the simulations, selected flood characteristics, e.g., flood arrival time, flood duration, flood recession time and flood depth, have been estimated compared to the base flow year. The following sections describe the model setup and results of this study.

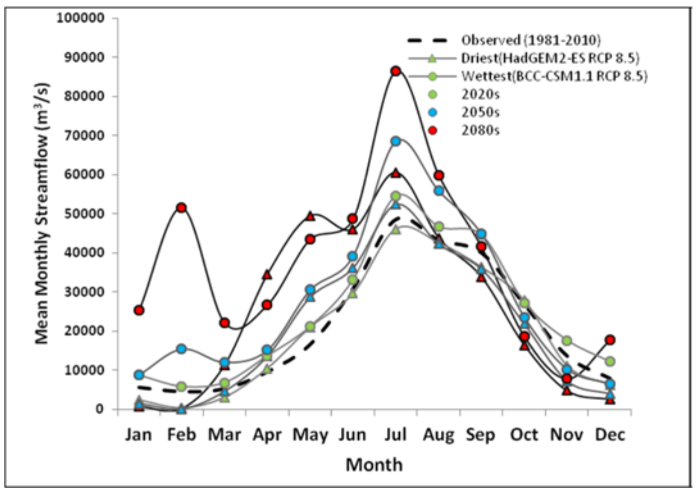
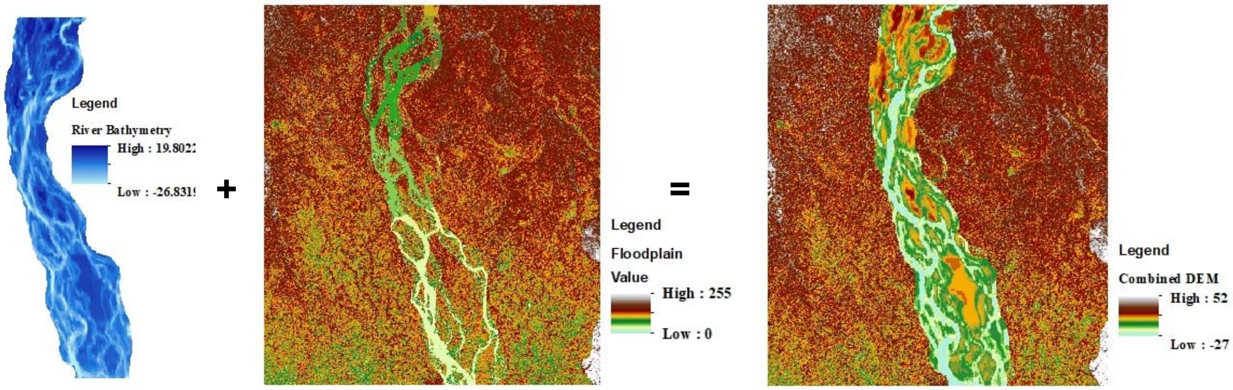


Figure 2: Monthly averaged hydrograph of BRB for Base Year Flow (1981-2010), 2020s, 2050s and 2080s (Alam, 2015)

4. Model Setup

Pre-processing of the bathymetry data as well as DEM of the floodplain are done in ArcGIS 10.2.2. For the pre-processing, the bathymetry grid has been created from river bathymetry data by using kriging interpolation. After completion of interpolation, resampling of river bathymetry has been done by grid size 30m×30m which is as same as the Digital Elevation Model (DEM) of the floodplain. Then the resampled bathymetry grid was clipped according to the study extent. For the floodplain, 6 individual DEMs has been collected and mosaicked to get an individual DEM. The elevation of the floodplain DEM has been measured with respect to the mean sea level. Therefore, DEM has been transferred to PWD datum by adding 0.46 m. Similarly, the DEM of the floodplain was also clipped as per the study extent. Finally, the bathymetry grid of the river and the DEM of the floodplain has been merged to get the possible combined bathymetry grid as shown in Figure 3.



(a) (b) (c)

Figure 3: (a) River bathymetry (b) DEM of the floodplain (c) Combined DEM after merging of River bathymetry and DEM of the floodplain

The combined DEM which has been prepared in ArcGIS, then has been used in HEC-RAS. Firstly, combined DEM has been used in Ras Mapper to create Terrain. Using this Terrain model in Geometric Data 2D computational mesh have been generated. The size of the mesh were 300m by 300m. The flow area has been selected and the boundary lines have been identified in this Geometric Data. Figure 4 shows the 2D mesh of the study area.

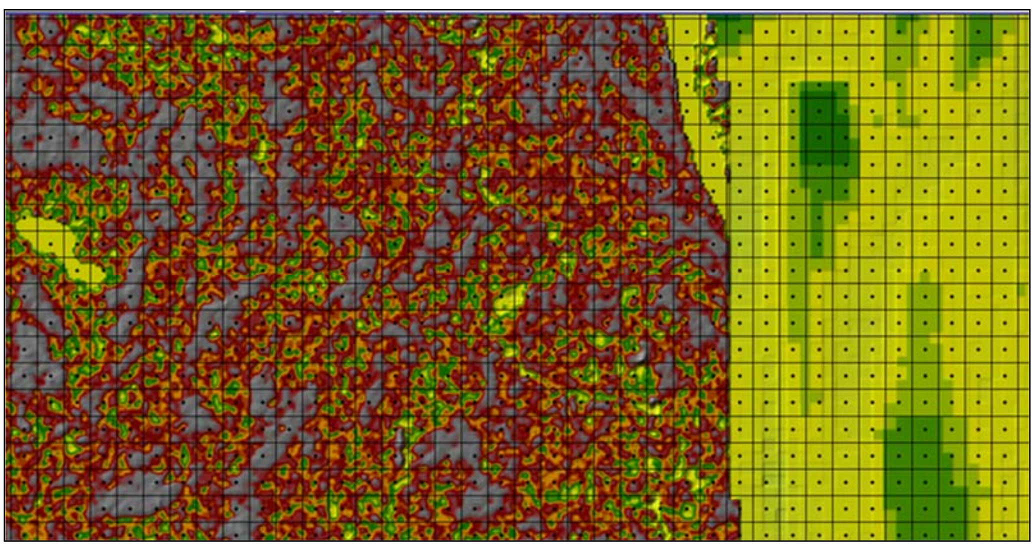


Figure 4: 2D Computation Mesh inside the 2D Flow Area

After defining 2D flow area, boundary lines and computational mesh; boundary condition has been provided. In the upstream boundary, in Bahadurabad Station, discharge data and in the downstream station, Sirajgonj Station water level has been provided.

Calibration has been done in Mathurapara station in year 2004 for Manning's roughness co-efficient, n=0.031. The model has been simulated using the daily hydrograph for six months from May to October. And for validation the data regarding to the flood year 2005 has been used in Kazipur station for the same criteria. Model performance has also been evaluated by using co-efficient of determination (R^2). For calibration R^2= 0.94 and for validation R^2= 0.97. Figure 5 and 6 show the discharge data and water level comparisons at boundary and calibration points for the year of 2004 and 2005.

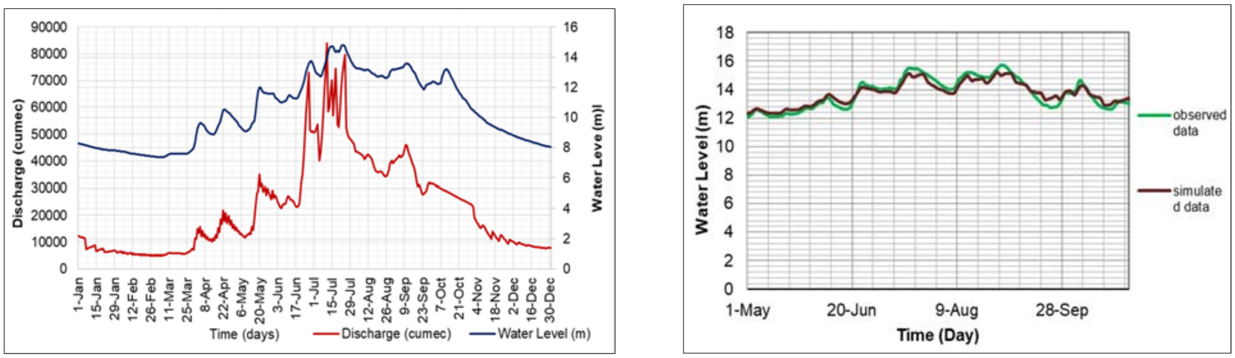


Figure 5: Boundary condition for calibration (left side) and calibration graph (right side)

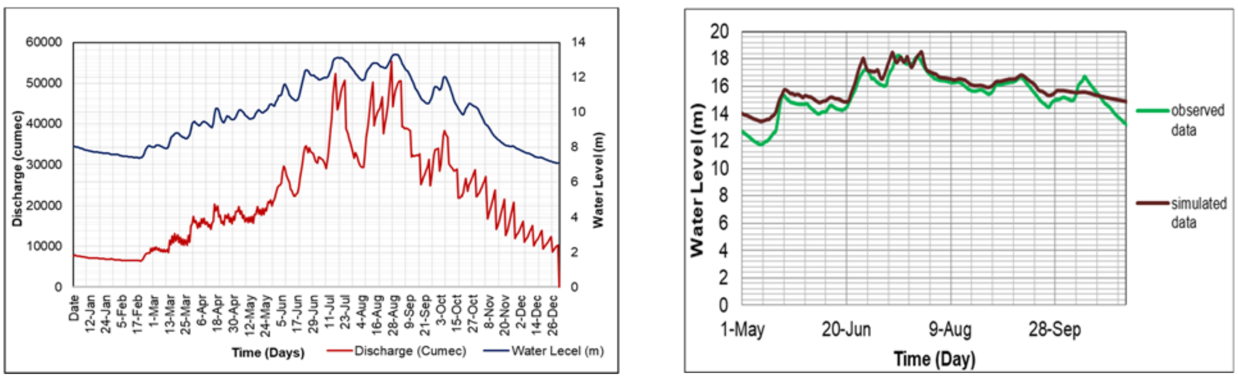


Figure 6: Boundary condition for validation (left side) and validation graph (right side)

A qualitative comparison is done by analysis flood inundation area of year 2004 and year 2005 with the MODIS image. In this, flooded area of different random days is calculated from 2D hydrodynamic model and then compared with the flooded area of MODIS Flood Map. The correlation between these two maps has found as $R^2 = 0.829$ for year 2004 and $R^2 = 0.8745$ for year 2005 as shown in Figure 7.

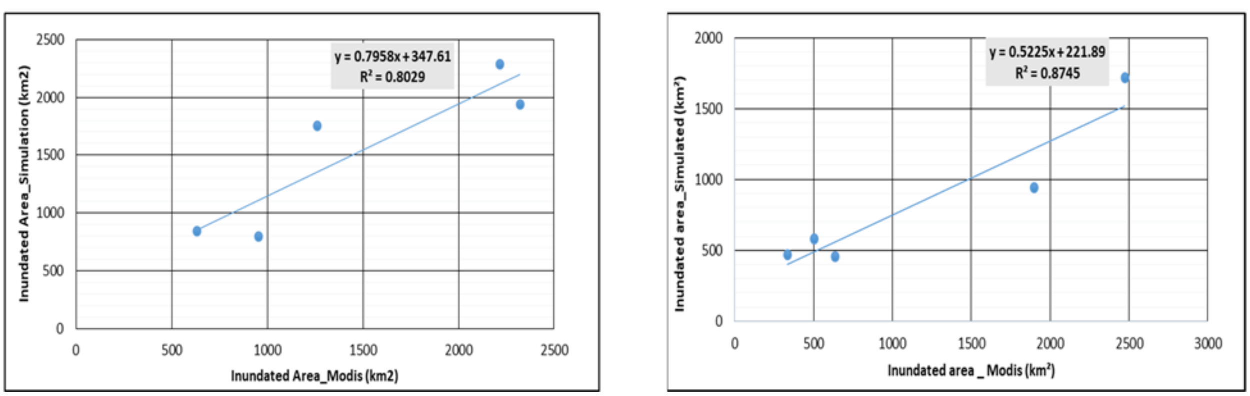


Figure 7: Comparison between MODIS flood images and Simulated flood maps

5. Result and Discussions

The study involves the synthetic analysis of the future flood inundated area for year 2020s, 2050s and 2080s compared to the base flow (average flow of 1981-2010). In this study, only the flow of the warmest climate change scenario as found by Alam (2015) is used. Based on the simulation, selected flood characteristics, e.g., flood depth, arrival time, recession time and duration, have been estimated compared the base flow flood map.

I. Flood Inundated Area Analysis:

The total area of the floodplain is 4990.27 km^2. An analysis has been done by comparing the monthly flood inundated area. Their graphical representation is shown in Figure 8.

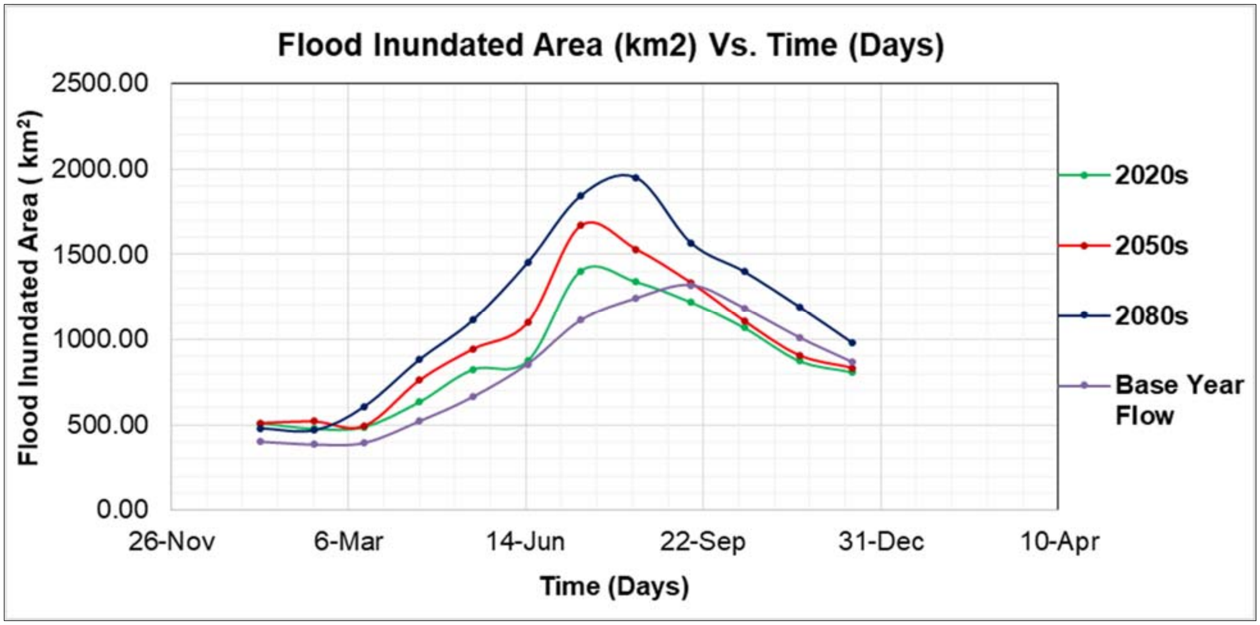


Figure 8: A Graphical Comparison of Flood Inundated Area for 2020s, 2050s and 2080s due to the Change of Warmest Climate (RCP 8.5) Scenario

Another analysis is done based on the maximum flood inundated area. The flood inundated area has been calculated for 2020s, 2050s and 2080s and summarized in Table 1.

Table 1: Analysis of the Maximum Flood Inundated Area for 2020s, 2050s and 2080s due to the changes of Warmest Climate (RCP 8.5) Scenario

Year	Maximum Discharge	Maximum Flood Inundated Area	Percentage of Inundated Area to Total Area
	(m^3)	**(km^2)**	**(km^2)**
Base	48707.46	1411.91	28.29
2020s	60058.99	1505.03	30.15
2050s	72777.85	1846.49	37.00
2080s	73801.55	1915.18	38.37

II. Effect of Warmest Climate Change Scenario on Different Flood Characteristics:

Flood Depth (m): From figure 9 it can be seen that flood depth will be increased by 0.48 m, 1.01 m, and 1.14 m for the year of 2020s, 2050s and 2080s compared to the base flow flood depth.

Flood Arrival Time (Days): From figure 10 it can be seen that flood will be arrived earlier by approximately 12 days, 26 days, and 57 days in the year of 2020s, 2050s and 2080s compared to the base flow flood arrival time.

Flood Recession Time (Days): From figure 11 it can be seen that flood will be receded earlier by approximately 2 days and 3 days in the year of 2020s and 2050s. However, the flood will be receded later by 11 days in the year 2080s compared to the base flow flood recession time.

Flood Duration (Days): From figure 12 it can be seen that flood duration will be increased by approximately 10 days, 23 days, and 68 days in the year of 2020s, 2050s and 2080s compared to the base flow flood duration.

Changes of different flood parameters with respect to the base year flow are summarized in Table 2.

Table 2: Analysis of Different Flood Parameters with respect to Base Year Flow for the Warmest Climate Change Scenario (RCP 8.5)

	Flood Depth (m)	Flood Arrival Time (Days)	Flood Recession Time (Days)	Flood Duration (Days)
2020s	0.48	12	-2	10
2050s	1.01	26	-3	23
2080s	1.14	57	+11	68

6. Conclusion

The study has been conducted in a 2D hydrodynamic model named HEC-RAS with the pre-processing and post-processing which have been done in ArcGIS 10.2.2. In this study, the effect of warmest climate change scenario as suggested by Alam (2015) has been simulated to see their effects on the selected flood parameters of the floodplain of Jamuna river. This study shows that flood inundated area has been increased by the increase of time. Therefore, flood inundated area is maximum for year 2080s which is 1915.18 $km^{2.}$. It is also found that flood may come earlier and duration may increase in future years. So, for the increase of the emission of greenhouse gas results in the extremities of the flood parameters in future days which is extremely warning to the mankind. This study of flood parameters would be usable for the future planning of the floodplain of Jamuna river.

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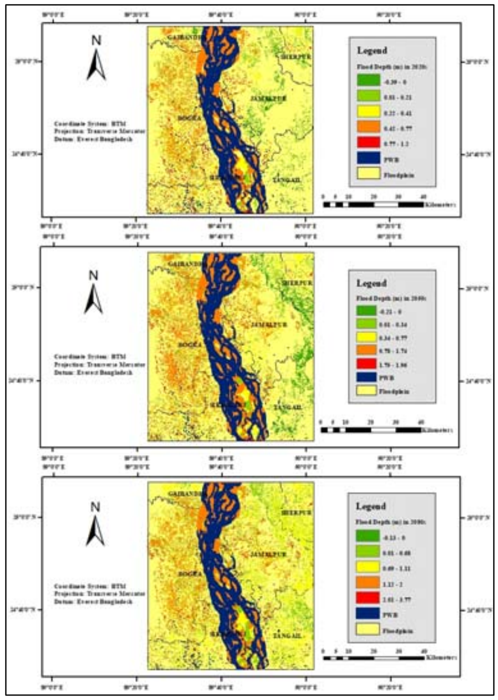

Figure 9: A Map of Changes of Flood Depth (m) of 2020s, 2050s and 2080s than Base Year Flow for the Warmest Climate Scenario (RCP 8.5)

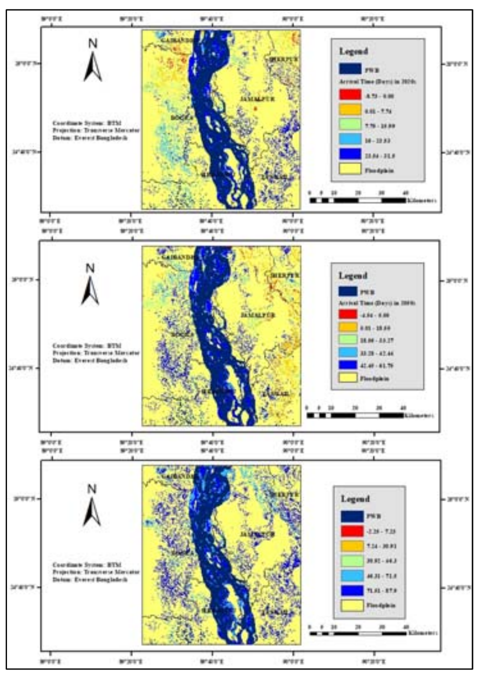

Figure 10: A Map of Changes of Flood Arrival Time (Days) of Year 2020s, 2050s and 2080s than Base Year Flow for the Warmest Climate Scenario (RCP 8.5)

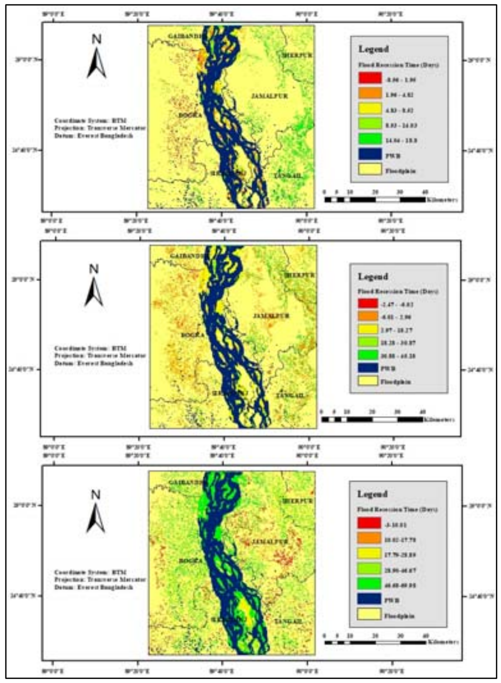

Figure 11: A Map of Changes of Flood Recession Time (Days) of 2020s, 2050s and 2080s than Base Year Flow for the Warmest Climate Scenario (RCP 8.5)

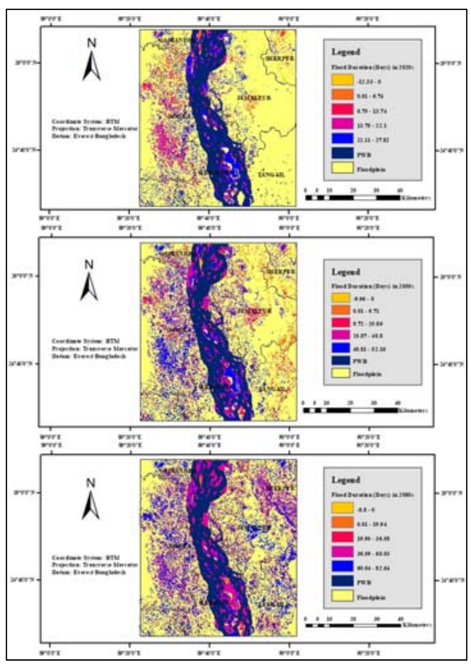

Figure 12: A Map of Changes of Flood Duration Time (Days) of Year 2020s, 2050s and 2080s than Base Year Flow for the Warmest Climate Scenario (RCP 8.5)

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