Flood Mapping for Dharla River in Bangladesh using HEC-RAS 1D/2D Coupled Model

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Abstract: ***The densely populated Bangladesh is located in the south Asian sub-continent and is prone to flooding as being situated on the deltaic floodplain of the Ganges–Brahmaputra–Meghna (GBM) River basin. Bangladesh has experienced periodic floods of severe magnitudes in 1974, 1984, 1987, 1988, 1998, 2000, 2004, 2007 and 2010. Dharla River, among one of the 57 trans-boundary rivers originated in the Himalayas, along with Brahmaputra River has a great influence on the recurring floods and erosion in north-western Bangladesh. Almost every year, excessive flooding caused by Dharla render thousands of people homeless with massive loss of crops and poultries. In this study, to identify the low lying areas prone to inundation and to reduce the uncertainty in flood mitigation measures, HEC-RAS based 1D/2D Coupled hydrodynamic model has been carried out for Dharla River. Boundary conditions for upstream and downstream have been defined by discharge of Taluk-Simulbari station and water level of Kurigram station respectively. Flow has been simulated under unsteady conditions, calibrated for the year 2013 and validated for the year 2014. Flood Inundation maps have been generated in the RAS mapper for the years 2010, 2013 and 2014 from the month June to October for highest water levels of each month. The validation of the generated flood map of 2010 has been performed using the Moderate Resolution Imaging Spectroradiometer (MODIS) flood map of 2010. A comparative analysis has been carried out between the maps generated by using HEC-RAS 1D/2D coupled model and using HEC-RAS 1D model and Arc-GIS reported in our previous work. Also, a correlation has been developed from the comparison. Proper floodplain management and the use of science and knowledge can reduce flood damages in a country like Bangladesh and hence this study could be important for proper planning and management of flood hazards caused by Dharla River.***

Keywords: 1D/2D Coupled Model, MODIS, Flood, Flood Maps

1. Introduction

Flood is one of the most devastating disasters in the present world which causes damage to economical, social, and human lives at about 43% of all natural disasters **[1]**. Bangladesh is located on the Tropic of Cancer at a longitude of 90E and has a land area of only 145000 km². It is located downstream of three major river basins name by the Ganges, Brahmaputra, and Meghna. As a consequence, 80% of the land area is considered as floodplains and thus frequently flooded with widespread damages around the year **[2]**.Annual average rainfall varies from 1200 mm in the west to up to 5800 mm in the northeast, making the flood damage even worse **[3]**.Bangladesh has experienced periodic floods of vast magnitudes in 1974, 1984, 1987, 1988, 1998, 2000, 2004, and 2007. Flood damage potential in Bangladesh is also on the rise due to possible causes including climate change, urban concentration in the three river basins and encroaching of settlements in the flood prone areas. Catastrophic floods in 1988, 1998, 2004, and 2007 caused losses of over two million metric tons of rice, or 4–10 % of the annual rice production in the country **[4]**.The floods of 1988, 1998, and 2004 inundated about 61%, 68 %, and 38% of the total area of the country, respectively **[5]**. In 2010, 49 out 64 districts of Bangladesh were flooded, affecting ten millions of people **[6]**. Dharla is one of Bangladesh's trans-boundary and flood prone rivers, which originates in the Himalayas and enters Bangladesh through the Lalmonirhat District and flows as the Dharla River until it empties into the Brahmaputra River near the Kurigram District. Dharla River along with Brahmaputra River has a great influence on the floods and erosion of different districts of Bangladesh**.** In Lalmonirhat, about 2 kilometers of a 7-kilometre long flood control embankment was devoured by the Dharla, after recession of flood water in 2007. The water level of Dharla flowed 5 centimeters above Danger level at Dharla Bridge point in Sadar upazila of the district. According to Annual Flood Report (2012) of Bangladesh Water Development Board (BWDB), the water Level of Dharla River at Kurigram registered two distinct peaks during the monsoon 2012, in June and July. The Water level at Kurigram attained peak of 26.74mPWD on 29th June which was 24cm above the Danger Level, then fell and again rose up to 26.68m (18cm above the Danger Level) in the 3rd week of July. According to Annual Flood Report (2014) of BWDB, the water level at Kurigram attained peak of 26.95 mPWD on 28 August which was 45 cm above the DL (26.50 m). The embankment of the Dharla near Mondolpara area of Kurigram was damaged resulting from floodwaters rushing into the villages on August 2017. According to BWDB, the water at Dharla Bridge Point in Kurigram is flowing 131 cm above the danger mark on August 2018. Unquestionably, flood mapping of Dharla is a matter of great importance. Accurate flood mapping can help indicating the vulnerable zones and taking proper measures that can reduce the flood damages.

This study provides an easy, simple, and short technique to obtain flood maps for Dharla River by developing a hydrodynamic model of the river in HEC-RAS 5.0.1. HEC-RAS 5.0.1 (1D/2D coupled model) directly gives the maps by calculating the water levels using the built-in equations and hence the flood maps obtained are more accurate, the validation of which has been performed using MODIS flood map.

2. Data and Methodology

2.1 Study Area

The Dharla River and its flood plain (approximately of 850 km^2), about 20 km from the left bank and 27 km from the right bank of the river (excluding the effect of Teesta River) are the study areas **(Figure 1)**. The river reach length is about 56 km. The flood plain of Dharla River which is taken into consideration mostly is in Kurigram district and some of it includes Lalmonirhat district.

2.2. Data

The DEM of the study area has been downloaded from the Shuttle Radar Topography Mission (SRTM). SRTM data has emerged as a global elevation data in the past one decade because of its free availability, homogeneity, and consistent accuracy compared to other global elevation dataset **[7].** The resolution of the DEM is 90m x 90m. All the data in the DEM have been projected on to the Bangladesh Transverse Mercator (BTM). In this study the cross-section data of RMDLA-1 to RMDLA-10for 2013 have been used, which have been collected from BWDB. Water level and discharge data of the Dharla River at Taluk-Simulbari (25.9646 N and 89.505 E) and Kurigram (25.8199 N and 89.6704 E) stations have been collected from BWDB. For validation of maps generated in HEC-RAS 2D, the images of MODIS have been used.

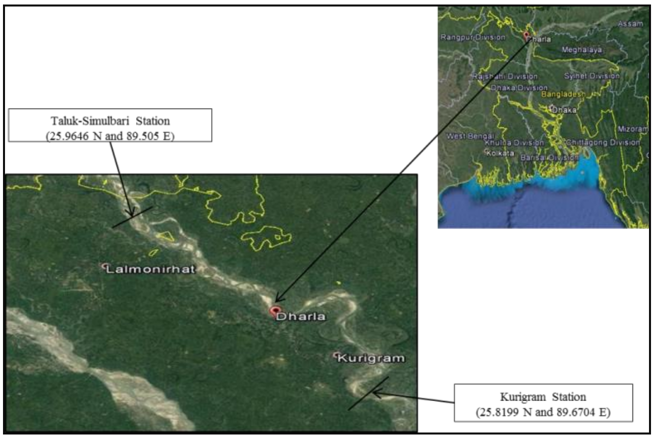


Figure 1: Study Area (Source: Google Earth)

2.3 Model Details

HEC-RAS 5.0.1 calculates one-dimensional steady and unsteady flow. HEC-RAS 5.0.1 has also added the ability to perform two-dimensional (2D) hydrodynamic routing within the unsteady flow analysis portion of HEC-RAS, which has the ability to simulate detailed 2D channel and floodplain modeling. A complete bathymetry grid has been generated in Arc-GIS and used in HEC-RAS 5.0.1 for the preparation of terrain to set up the model. BTM projection was used which has a datum of Everest Bangladesh. After defining 2D flow area and adding break lines inside the 2D flow area, 2D computational mesh has been generated with a value of 300 m for both Dx and Dy. Initially the mesh was generated for n=0.029. For unsteady flow simulation, flow hydrograph has been provided at Taluk-Simulbari as upstream boundary condition and stage hydrograph has been provided at Kurigram as downstream boundary condition. After entering geometry data and unsteady flow data, the 1D model has been run for the period of 01 June -31 December 2010, 01 June -31 December 2013, and 01 June -31 December 2014.In Ras Mapper, floodplain delineation is done itself as a map view.

3. Results

3.1. Calibration and Validation of the Model

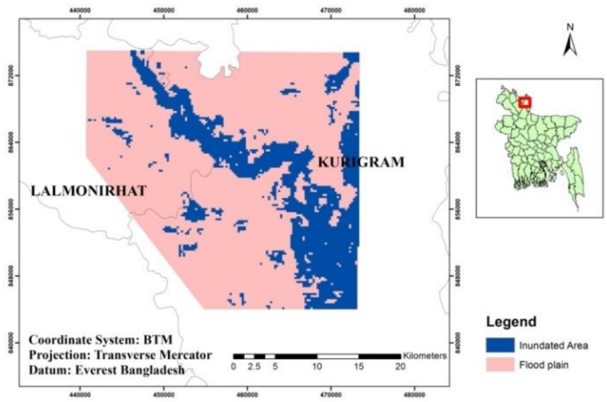
For calibration of the model, 2013 dataset has been used. As upstream boundary condition, the rating curve generated from the water levels at Taluk-Simulbari station has been used. Mean daily water level data at observed station is compared with model simulated output for calibration and validation. From analysis the roughness coefficient was found to be 0.032. The correlation co-efficient (R^2) value for the year 2013 is 0.9865. For validation of the model 2014 dataset has been used. The correlation co-efficient (R^2) value for the year 2014 is 0.9697.The detail analysis was described in our previous study **[8].**

3.2. Validation of the simulated flood maps

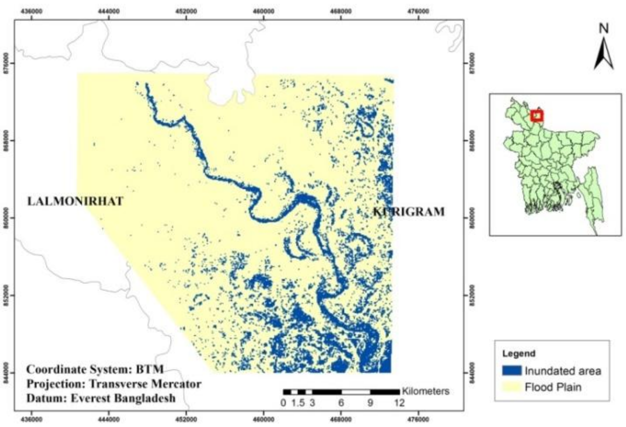
MODIS flood map has been used to validate the model result. The MODIS maps that have been used in this study were generated in a previous study **[9].**The qualitative analysis has been performed by comparing inundated area of MODIS flood map and the simulated flood map. Validation for the year 2010 has been shown in **Figure 2**.

3.3 Generation of Flood Maps

The required map has been exported to Arc-GIS from RAS Mapper as a shape file. By classifying the inundation depth in various ranges the flood maps are finally obtained. The dataset is taken from June to October because the flood event or high discharge normally occurs in this time period only. The resulting flood maps for the peak water level of the year developed with the simulation of HEC-RAS model are shown in **Figure 3**.



(a)

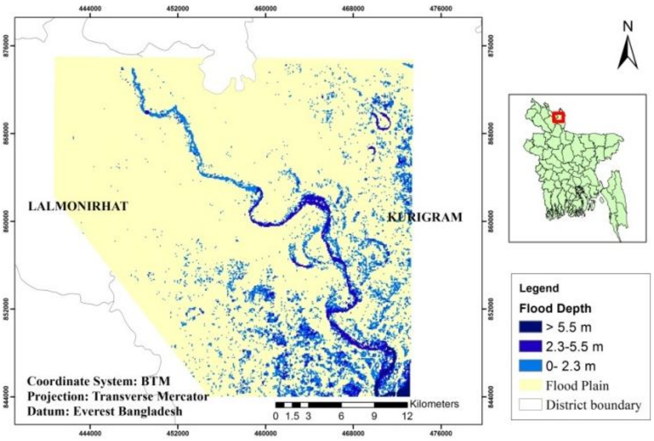


(b)

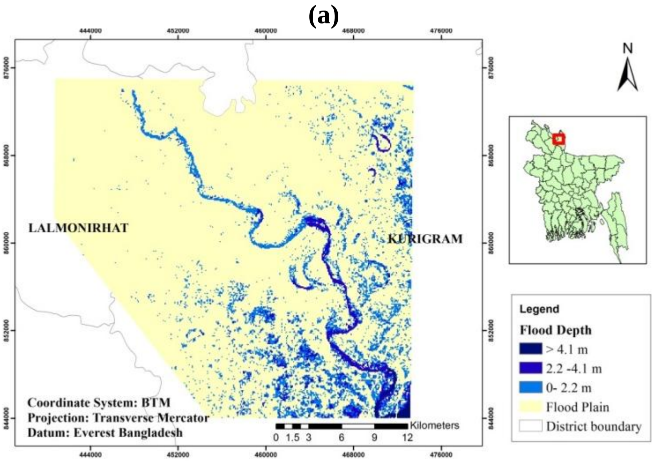
Figure 2: Validation of simulated flood map of 2010 (a) MODIS Flood Map (b) Simulated Flood Map

3.4. Comparison of Flood maps generated from HEC-RAS 1D/2D coupled model and our previous study

Apart from this study, another procedure of obtaining flood maps is to export the flood water levels obtained from HEC-RAS output and to use in HEC-GeoRAS for raster interpolation technique and then the raster is overlain onto the land surface elevation of the study area. Difference between water level interpolation and land elevation surfaces is considered as depth of inundation. By classifying the inundation depth in various ranges the flood maps are finally obtained. This procedure was conducted in our previous study **[8].** A comparison has been carried out between the maps of the previous study and this study. From the comparison, it is found that the maps generated in HEC-RAS 5.0.1, provide inundation areas which are greater than the values obtained in our previous study but the peak values are obtained for the same months in both cases. This happens because the maps generated in HEC-RAS 5.0.1 are more accurate than the maps generated using Arc-GIS. In Arc-GIS the raster interpolation technique is used for generating the water surface. Hence the values of the water levels are less precise. As in HEC-RAS 5.0.1 (1D/2D coupled model), the model directly gives the maps by calculating the water levels using the built-in equations, the flood maps obtained are more accurate. This accuracy has been verified using MODIS image, which is shown in **Figure 2.**A correlation has been developed between the inundation areas (from June to October) obtained from these two methods and shown in **Figure 4**. The value of R^2 has been found 0.9592, which indicates good correlation. As it indicates good correlation, if equation for one method (1D model) is known, it is possible to get the inundation areas that could be obtained using another procedure (1D/2D coupled model). In both the methods the peak value of inundation is larger in the year 2010, as a devastating flood occurred in that year. From the visual observation the maps look quite similar (**Figure 5).** The comparison of the peak values are shown in **Table 1**.



(a)



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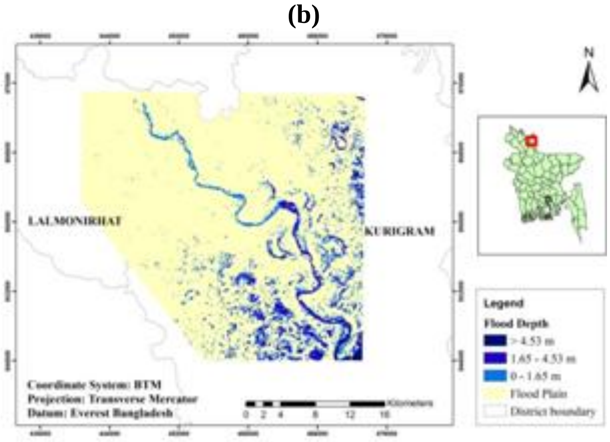

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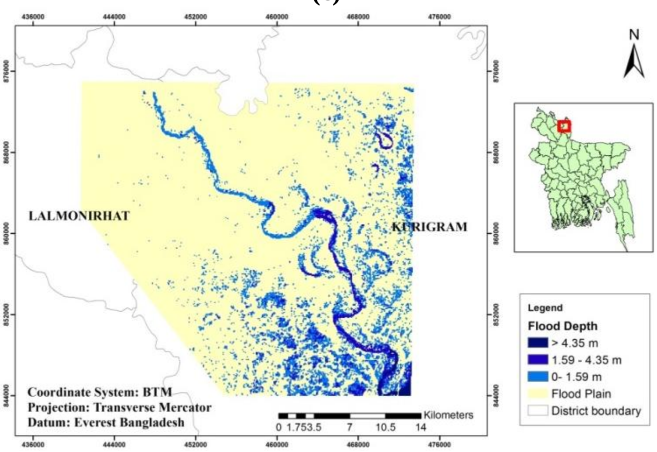


(d)

Figure 3: Flood Maps for Dharla River for (a) July 2010, (b) July 2013, (c) September 2013, (d) August 2014

Table 1: Comparison of Peak Values

	Peak Inundated Area obtained from previous study (km²) [8]	*Peak Inundated Area obtained from this study (km²)*
July, 2010	87.45	105.58
July, 2013	78.76	93.21
Sept, 2013	74	94.73
Aug, 2014	75.1	91.02

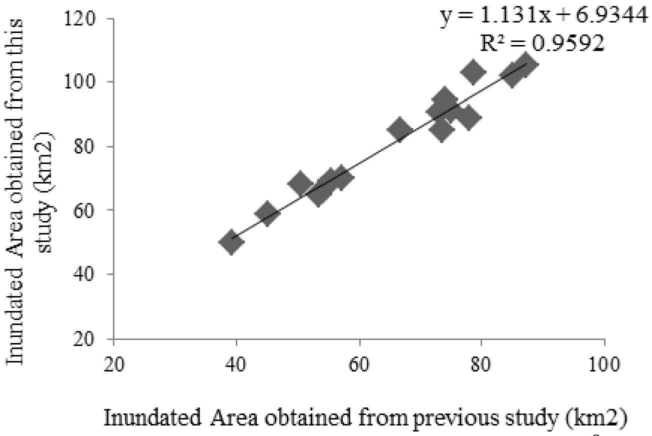
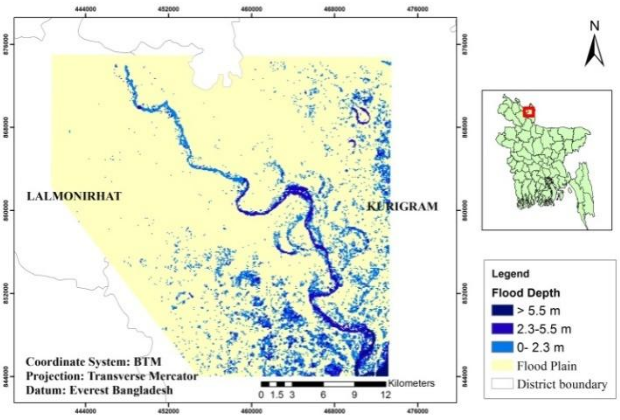
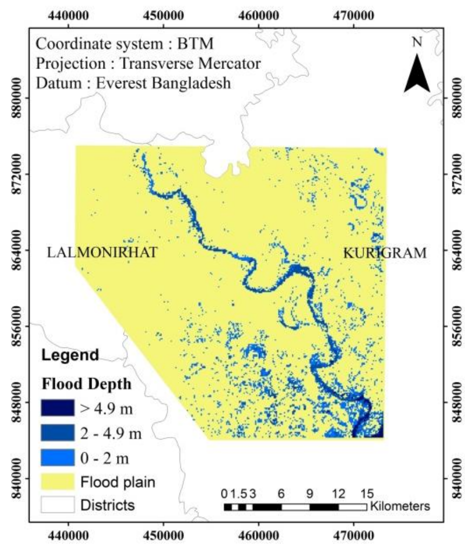


Figure 4: Correlation between inundation areas (km^2) obtained from this study and our previous study [8]



(a)



(b)

Figure 5: Visual Comparison of flood maps of 2010 (a) obtained from this study, and (b) previous study [8]

4. Conclusions

In this study, HEC-RAS 5.0.1 has been used to develop the hydrodynamic model of Dharla River and for flood mapping. As per our knowledge the study of Dharla River flood map has not been conducted yet using HEC-RAS 1D/2D coupled model. In our previous report, flood maps of Dharla River using Arc-GIS have been developed **[8]**. So this study could be helpful for more detailed and precise study in future. HEC-RAS 1D/2D coupled model directly gives the maps by calculating the water levels using the built-in equations hence the flood maps obtained are more accurate than those maps obtained using Arc-GIS which has been validated using MODIS image. For preliminary flood protection measures this method could be very effective as it is not so time consuming if the water level data are available. Determination of current status of flood map is very limited in Bangladesh, Compared to the wide range of research conducted in other flood prone countries. More complicated studies of flood mapping have been conducted using GIS tools. A study carried out by Seenirajan et al. (2017) on analysis of Chennai flood 2015 using GIS involved much complicated procedure as GIS was integrated with Multi-criteria Decision Analysis **[10]**. But development of flood inundation maps using HEC-RAS 1D/2D coupled model is less complicated. In this study flood maps have been generated for the years 2010, 2013, and 2014 for highest water level of each year. The peak is much greater in the year 2010, than 2013 and 2014. The floodplain of Dharla River which mainly covers the kurigram District, has suffered high inundation, the qualitative comparison using MODIS image also indicates that. The inundation areas were found to be greater in case of maps obtained in this study than the maps developed in the previous study. **[8]** As flood maps are obtained directly from RAS mapper in HEC-RAS 5.0.1, the maps could be considered more precise. So, from this study it can be concluded that flood maps are generated more easily and accurately in HEC-RAS 1D/2D coupled model. These findings can be useful for taking necessary steps to mitigate flooding in those high inundation areas and also prediction of erosion could be possible by identifying vulnerable banks.

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