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ASSESSMENT OF THE HYDRAULIC GEOMETRY OF THE UPPER MEGHNA RIVER IN BANGLADESH

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ABSTRACT

The Meghna is one of the major rivers in Bangladesh. Frequent changes in flow and water level is a regular phenomenon due to the high seasonal rainfall variation. Such variations are exaggerated with cliamte change induced effects. Hence, it is crucial to figure out how climate change will affect the Meghna river's hydraulic properties. This study assesses water surface profile of a specific 120 km long reach of the Meghna river. A model was set up to run unsteady flow analysis for the years 2018, 2019, and 2020. The result matches well with the actual observation after calibration and validation. The study finds maximum water level during August, which mostly correlates with the high rainfall during this month of the monsoon season. The model has also been used to run a steady flow analysis for the return period of 2.33 years, 5 years, and 20 years. The result is useful for the sustainable design of bridges and other hydraulic structures.

Keywords: *Water Surface profile, Meghna River, Steady and Unsteady Flow Analysis, HEC-RAS*

1. INTRODUCTION

Bangladesh is a low-lying flood plain country at the confluence of the Ganges, Brahmaputra and Meghna (GBM) River. The country annually drains an amount of water, which can form a lake of 10.3 meters depth and area equal to its own (Ahmed, 1989; Bingham, 1991). Water is vital to the national economy and people's livelihood in this area. River cross-sections and water surface fluctuate due to the impact of the hydraulic infrastructure over rivers, as well as the effects of climate changes. A study based on the last 50 years for Bangladesh identifies increasing trend of mean monthly temperature and mean rainfall for the monsoon season with significance level of $p > 0.10$ (Mullick et al., 2019). Excessive rain (flooding) during the monsoon season (June-September) and insufficient rain during the pre-monsoon (March-May) and winter (December-February) seasons both have negative consequences on agricultural and human life (Shahid & Khairulmaini, 2009). Floods, because of significant water level rise, are becoming increasingly dangerous for humans because of population increase, the need for water and settlements, Lack of comprehensive and systematic zoning plan, and uncontrolled engineering practices. As a low-lying country, at least 20% of the land is flooded every year, and in extreme floods, 68 percent of the land is flooded (DMB, 2020). A hydrological drought causes annual average damages of 2.32 million hectares of Aman rice and 2.2 million hectares of Rabi crops. Here, regulation is the first step in taking steps to reduce these damages (Shaw & Nguyen, 2011). As a result, the river flow process is required to determine the behaviour of hydrological variables.

Prediction of dynamic hydraulic geometry variables can assist in determining the future river flow and deformation of the river bed. The perennial river, Meghna is generally flat along with high floodplain width and low slope (USAID [United States Agency for International Development], 1988). Kumar et al. (2002) measured hydraulic characteristics (velocity and sediment concentration) in the Upper Meghna River using collected water level data. However, it is difficult to assess hydraulic geometry variables in this natural river with such dynamic structure of the river. Yuce et al. (2015) used river discharge and cross section data to assess hydraulic geometry of Seyhan River. Many software packages have been developed to make the analysis and calculation of water surface profiles more convenient. One of them is HEC-RAS. This program investigates water surface profiles that are caused by hydraulic structures or route alterations. Furthermore, this program is employed in the construction of hydraulic structures, taking into account issues such as flood level determination (Dash et al., 2022; Hasan, 2015; Ogras & Onen, 2020).

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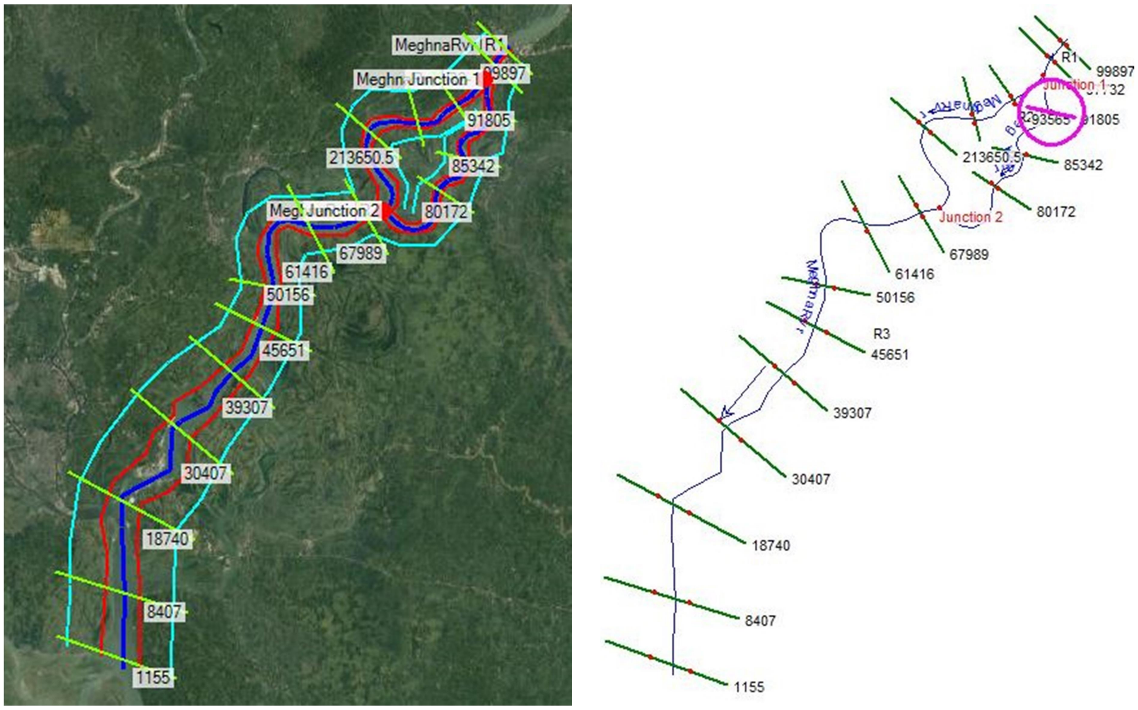

Figure 1: Study Area (Upper Meghna River along with its reaches and junctions).

The study mainly focuses on the Upper Meghna river basin within the six districts (Brahmanbaria, Comilla, Chandpur, Munshiganj, Narsingdi, Narayanganj) for a 120-kilometer river reach (Figure 1). Chowdhury & Ward (2004) identifies a strong correlation between the streamflow of the GBM River and rainfall in the upper catchment. However, this study refers to the requirement of rainfall data from other countries on a real-time and continuous basis for streamflow analysis. The objective of this study is to set up a model in HEC-RAS, and assess the hydraulic geometry (water surface profile) by modelling the impacts of climate changes (rainfall variation) within the study area. Moreover, analysis of a steady flow profile for the return period of 2.33 years, 5 years, and 20 years will be done to observe the highest water surface elevation during extreme impacts, which will assist in regulatory measures taken in that extreme period.

1.1 Study Area

Bangladesh is situated inside the Bengal Basin, which is one of the world's biggest geosynclinals. Because of its lower elevation and frequent floods, the basin absorbs a major percentage of the sediment load from GBM River, and their numerous tributaries and distributaries. Hence, the grain size of the sediments is quite similar to that of the neighbouring floodplain sediments (Datta & Subramanian, 1997; USAID [United States Agency for International Development], 1988). Bhuyan & Islam (2018) assessed different soil quality variables of the Meghna River during the period from September, 2015 to March, 2016, which is presented in Table 1. The concentration of sand, silt, clay, bulk density, pH, and electrical conductivity (EC) showed no significant spatiotemporal variation except soil organic matter, which showed significant spatial variation.

Table 1: Soil Quality Variables and its range within the Meghna River.

Soil Quality Variable	Range
Silt	13.33-58.33%
Sand	29.25-88.42%
Clay	4.92-17.42%
Bulk Density	1.43-1.71g/cm3
pH	6.86-8.06
EC	43-942.67µs/cm
Soil Organic Matter	0.24-3.1%

The Meghna River originates from Assam in India, named as the Barak River and divides into two streams (Surma and Kushiara). The two rivers rejoin at Bajitpur in Kishoreganj district in Bangladesh, named as the Meghna River. The Meghna River has two distinct parts (Upper Meghna and Lower Meghna). The Upper Meghna River receives the flow of Old Brahmaputra River at Bhairab Bazar, a number of small channels and hilly streams. The Upper Meghna River flows on the abandoned bed of the old Brahmaputra and Meghna rivers, and discharges the overall flow of the north central, northeast and southeast regions to the Padma near Chandpur. The River is known as Lower Meghna, as it meets the confluence of Ganges-Padma and the Brahmaputra-Jamuna. The Lower Meghna River discharges the flows of the Ganges-Padma, the Brahmaputra-Jamuna and the Meghna itself into the Bay of Bengal in Bhola district in Bangladesh (Banglapedia, 2021; Datta & Subramanian, 1997).

The study area focuses on the Upper Meghna River, comprising six districts, from the Bhairab Bazar to the UttorMatlab in Chandpur. The River width is 5 km at the downstream part. Figure 2 shows the land-based classification of the study area with a resolution of 100 m and Table 2 shows each land type area and percentage of each land type to the study area. The several small channels and the hilly streams, connected to the Upper Meghna River causes flash floods through the siltation in the river bed, and causes substantial damage to the lives, agriculture and overall economy despite of taking precautions (embankments, levees).

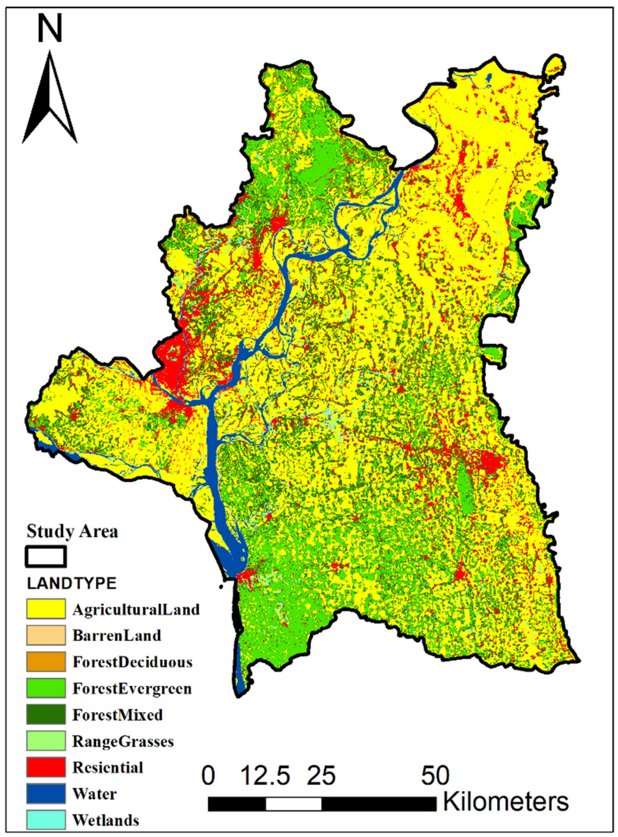

Figure 2: Land based classification of the study area for the year 2019.

Table 2: Land type, area of each land type and percentage of each land type to the study area.

Land type	Area (Square Km)	Percentage of Area (%)
AgriculturalLand	5169.75	54.5790
BarrenLand	2.48	0.0262
ForestDeciduous	0.03	0.0003
ForestEvergreen	1356.07	14.3166
ForestMixed	1497.30	15.8076
RangeGrasses	22.86	0.2413
Resiential	875.24	9.2402
Water	390.74	4.1252
Wetlands	157.58	1.6636

2. METHODOLOGY

To assess the hydraulic geometry, both steady and unsteady flow water surface profiles of HEC-RAS can be utilized. HEC-RAS requires two data sets for hydraulic modelling and river channel characteristic simulation, namely, (i) Geometry data and (ii) Steady/Unsteady Flow data

2.1 Geometry Data

Geometry data consists of a background map layer (Optional), connectivity information for the stream system (River System Schematic), cross-section data, storage areas, two-dimensional (2D) flow areas, and hydraulic structure data. Meghna is one of the large river basins that is mostly ungauged and lacks the necessary and routine in situ measurements of river bed depth/slope, bathymetry (river cross section), flood plain mapping, and boundary condition flows for setting up of a river model. Hence, remote-sensing data from space platforms is one of the alternatives to compensate that lack of in situ data. An SRTM (Shuttle Radar Topographic Mission) digital elevation model (DEM) with a spatial resolution of 30 m was taken from USGS Earth Explorer (https://earthexplorer. usgs.gov/). Ali et al. (2016) and Maswood & Hossain (2016) also used SRTM data for Upper Meghna River basin and GBM River respectively to get the DEM data of the river bed. The DEM dataset was merged using the MOSAIC feature to accommodate the full study area. The Mosaic Data was projected to universal transverse Mercator system. RAS Mapper, a spatial data and mapping tools in HEC-RAS can be used to create river hydraulic models from this dataset. Hence, the dataset was incorporated in RAS Mapper after subsequent processing to obtain cross-sections in the HEC-RAS software. A river geometry data (river, reach, bank and flow path) was created.

2.2 Steady/Unsteady Flow Data

2.2.1 Unsteady Flow Data

Unsteady flow data includes flow hydrographs at the upstream boundaries; starting flow conditions; and downstream boundary conditions. The boundary conditions are given in Table 3. One day was considered for the computation time interval and one month was considered for the mapping output interval in the unsteady flow analysis.

Table 3: The boundary condition for upstream and downstream portions of the Upper Meghna River.

U/S Boundary Condition	Flow Hydrograph	Weekly Flow data of Bhairab bazar station for the year 2018, 2019 and 2020 (Latitude = 24.05), (Longitude = 91) (BWDB, 2021)
D/S Boundary Condition	Normal Depth	Friction slope = 0.001

2.2.2 Steady Flow Data

The steady flow water surface profile is used to calculate water surface profiles for the calculated discharge of different return period, which can assist in flood plain management and flood protection studies. Steady flow data comprises the number of profiles to be computed, flow data and boundary conditions for each reach. The profiles are based on the calculated flood discharge of different periods, shown in Table 4.

Table 4: Calculated Flood Discharge of Different periods from Gumbel's extreme value distribution method for Bhairab Bazar Station (Hasan, 2015).

Profile	Return Period (Year)	Discharge (m^3/s)
1	2.33	13700
2	5	15800
3	20	19200

All profiles Boundary condition: Normal Depth, S = 0.002

3. RESULTS

3.1 Assessment of Water Surface Profile Based on Rainfall

More often, total areal rainfall data has been used to calculate the link between precipitation and flow. This study used rainfall data from six rainfall gauge stations, shown in Table 5. Rainfall gauge stations were collected from NASA Langley Research Center (LaRC) POWER Project. The inverse distance weighted interpolation approach to visualize the spatial variation of rainfall for the study period was done using Arc-GIS 10.5 (ESRI, 2014).

Table 5: Rainfall gauge stations.

Station	Latitude	Longitude
Bancharampur	23.78	90.79
Munshiganj	23.57	90.53
Narayanganj	23.68	90.54
Narsindi	23.94	90.75
Shibpur	24.03	90.75
Shimrail	23.64	90.62

Figure 3 represents monthly spatial variation in rainfall for the six districts. In 2018, rainfall was much higher in the lower region compared to the upper region. The least amount of rainfall for a year was mainly observed in October. Moreover, the spatial variation of rainfall in October was between 0.5 to 1 mm. However, high spatial variation along with a large amount of rainfall was mainly detected in July and August.

Figure 4 shows the water level elevation from a constant existing ground surface (EG) of 2 m for the Bhairav Bazar Station. Water surface elevation data is given in Table 6. The water surface elevation result mostly correlates with the rainfall observation. As the Table 6 presents simulated water surface elevation data for the dates specified, and Figure 3 represents monthly spatial rainfall data, there exists a slight deviation. For the monsoon months of July to October, the maximum water surface elevation was mainly observed in August. The minimum water surface elevation within a month is mainly found in October, where the range is between 5.12 m and 5.94 m. As, the simulation is run for only the Upper Meghna River within Bangladesh, the inward flow from the upper part of the watershed has been identified as a key factor for simulating water surface profile.

Table 6: Simulated Water Surface Elevation Data at Bhairav Bazar Station for the Specific date of the year 2018, 2019 and 2020.

At the most U/S Station (Bhairav Bazar)	Water Surface Elevation (m)		
	2018	2019	2020
Max WS	6.13	6.73	6.93
01-July	6.13	5.92	6.56
01-August	5.75	6.38	6.77
01-September	5.49	5.71	6.12
01-October	5.43	5.3	6.08
17-October	5.12	5.05	5.94

3.2 Calibration and Validation of the Simulated Data

Figure 5 represents the results after calibration of the water surface elevation profile for the year of 2018. Roughness of the riverbed, floodplains and expansion/contraction loss coefficients can be used as calibration parameters in widening or constricting rivers. Equation (1) presents the calculation of Water level. In this study, the simulated water level data fits well with the observed water level data of BWDB (2021) after adjusting the calibration parameter, which is taken as roughness coefficient, n=0.01 for the whole geometry. Maswood & Hossain (2016) used in value ranged from 0.018 to 0.035 for HEC-RAS modelling of GBM River. After calibration, the model has been validated with the observed data for the same station for the years 2019 and 2020.

$$\text{Water Level} = \text{Water Surface Elevation Data} - \text{Existing Ground Data} \quad (1)$$

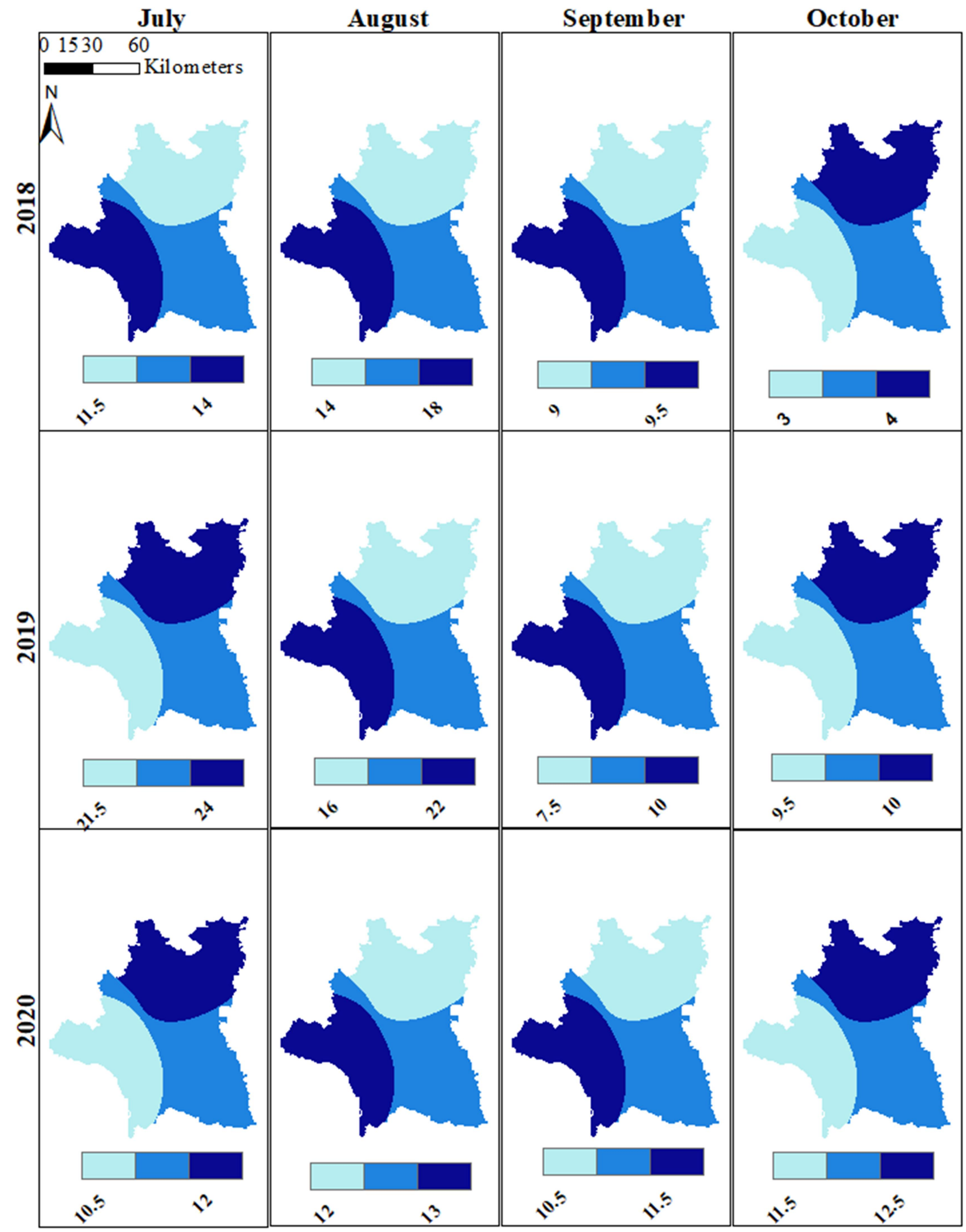

Figure 3: Monthly Spatial Rainfall Variation (in mm) for the years 2018, 2019 and 2020 during monsoon season (July to October).

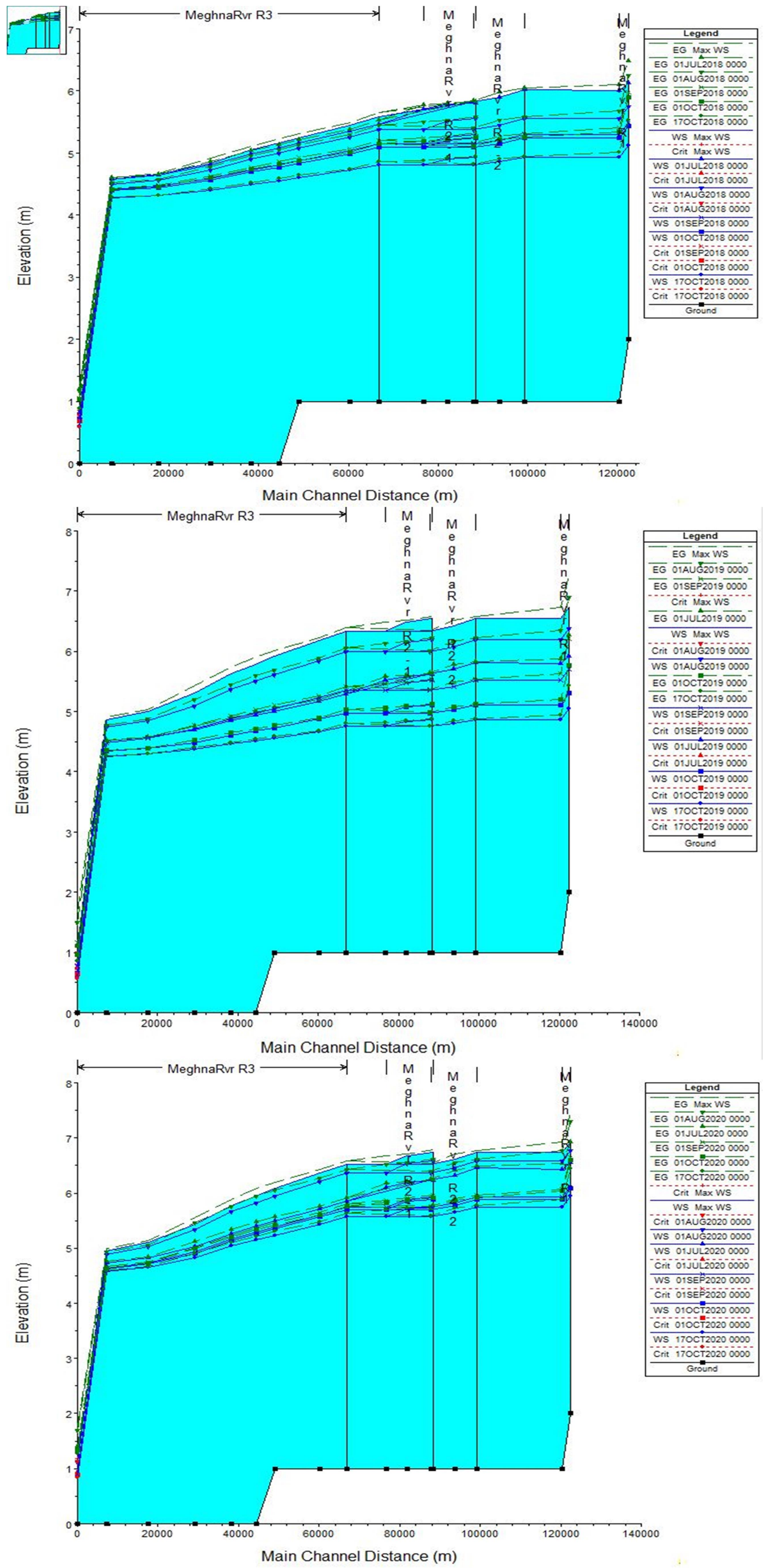

Figure 4: Water surface elevation profile for the longitudinal cross section of the Upper Meghna River for the unsteady flow data of the years 2018, 2019 and 2020 (Top to bottom).

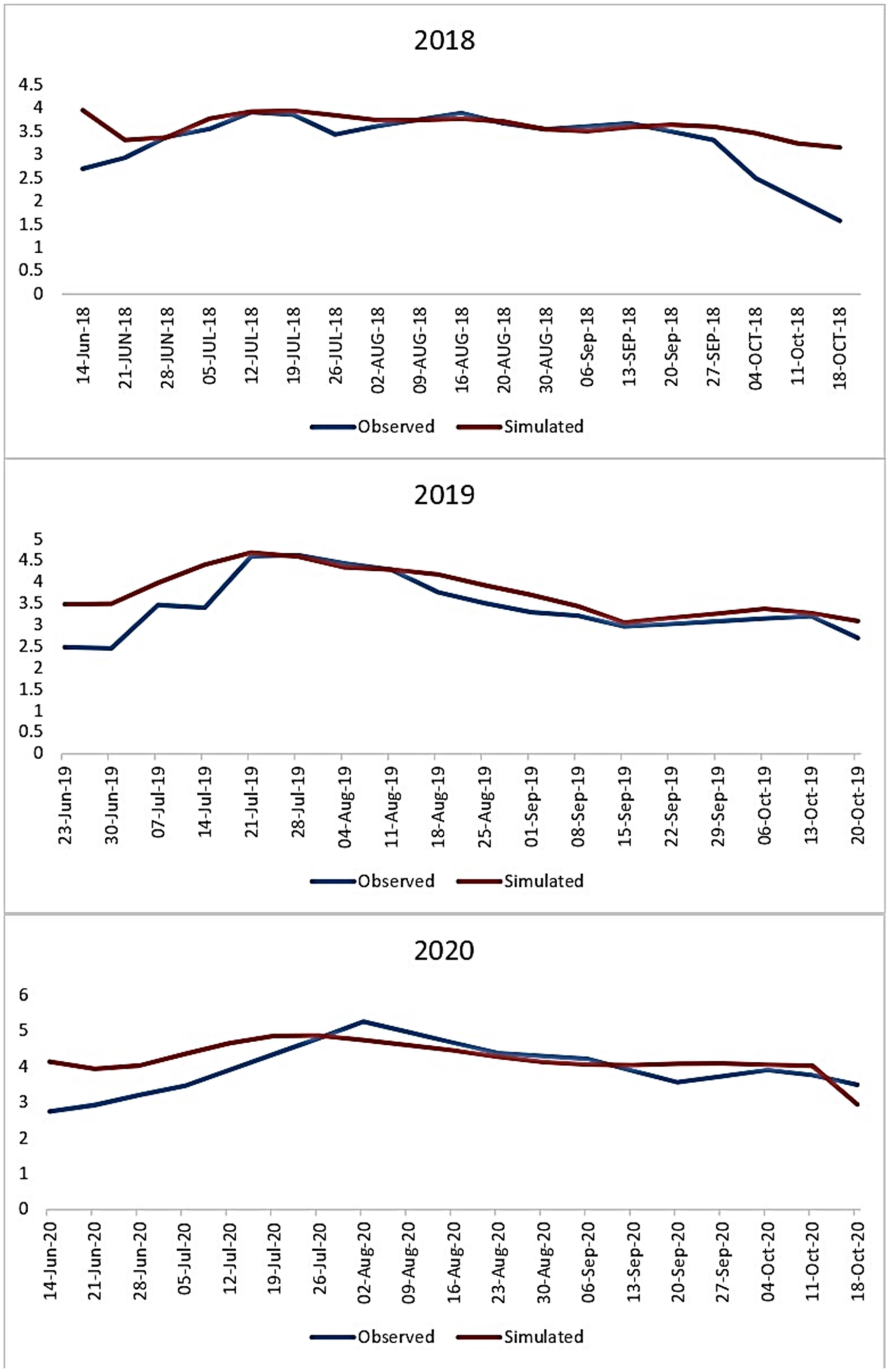

Figure 5: Calibration of the water level data at Bhairavbazar Station for the year 2018 and Validation at the Same Station for the years 2019 and 2020 (Top to bottom).

3.3 Water Surface Profile for the Return Period of 2.33, 5, and 20 Years

Figure 6 shows the water surface elevation profile for the longitudinal cross-section of the 120 km long river reaches for the return period of 2.33, 5, and 20 years. It identifies that the highest water surface elevation is for the return period of 20 years. At the most upstream station, the elevation was up to 12.71 m. For the return period of 2.33 years, it was 11.61 m (Table 7).

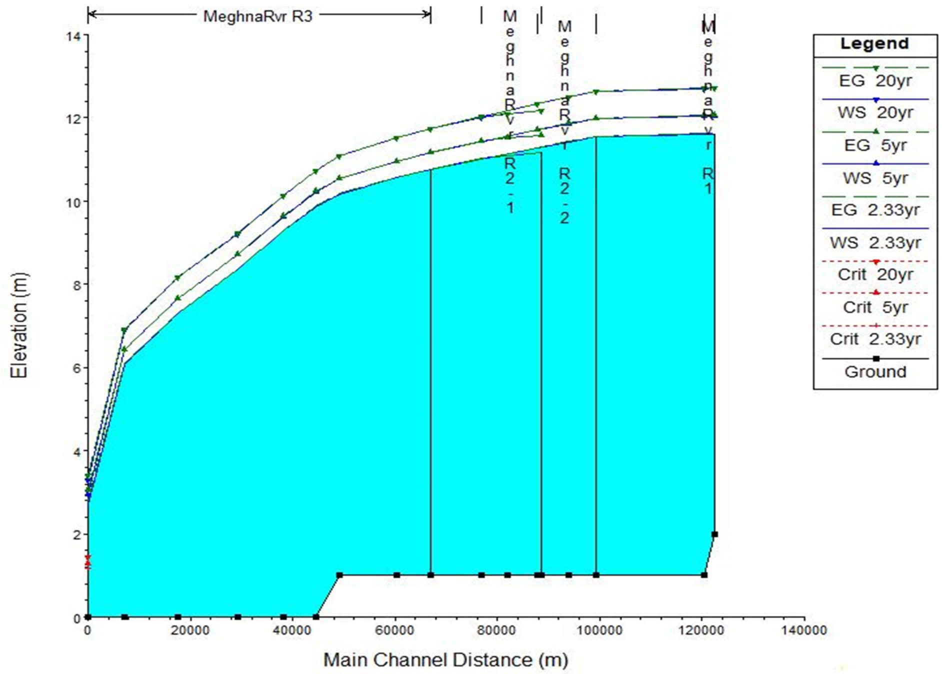

Figure 6: Water surface elevation profile for the longitudinal cross-section of the Upper Meghna River for the return period of the years 2.33, 5, and 20 (Top to bottom).

Table 7: Simulated Water Surface Elevation Data for the return period of 2.33, 5 and 20 years

Return Period (Year)	Water Surface Elevation (m)
2.33	11.61
5	12.05
20	12.71

4. CONCLUSIONS

Significant changes in water surface elevation were observed for the monsoon months of July, August, and September. The maximum water surface elevation was observed in the month of August with values of 5.75 m, 6.38 m and 6.77 m for the years 2018, 2019 and 2020 respectively. It is mostly correlated with the rainfall data with a proportional relationship. For the return period of 2.33, 5 and 20 years, the water surface elevation rises up to 11.61 m, 12.05 m and 12.71 m. However, the incorporation of other climate-changing variables (temperature data) can be incorporated to figure out the relationship in a more accurate manner. Again, the incorporation of existing three bridges of the 120 km long reach, and soil and land use data in the model will enhance the accuracy of the data retrieval. The results of the water surface elevation profile for the three different return periods can be used as a decisive tool for suitable and sustainable hydraulic structures design in the future.

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