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Application of Delft3D FM Suite for Simulating the Hydrodynamic Characteristics of Karnafuli River

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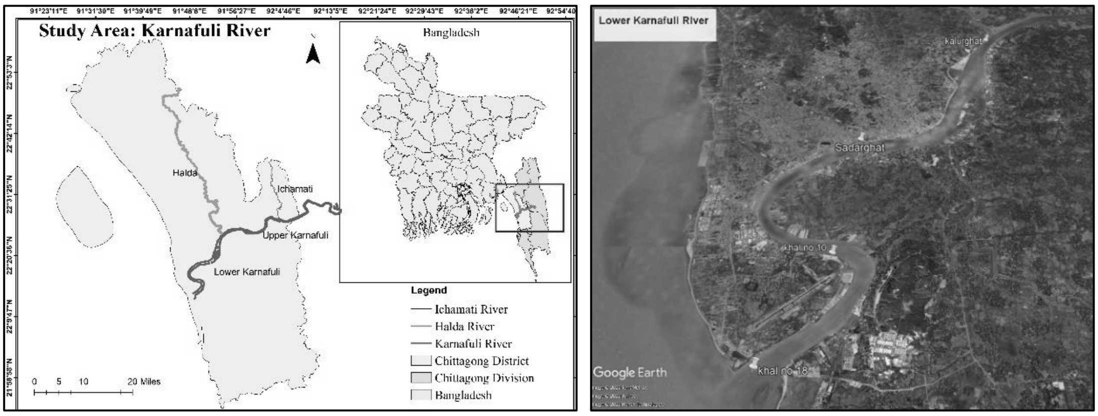
Abstract

Karnafuli River is the lifeline to the economic activities of Bangladesh since the main seaport is situated on the river. The hydrological, ecological, and hydrodynamic characteristics of the eastern hilly regions of Bangladesh are also dependent on this river. However, the river is also prone to erosion and sedimentation, which can have positive and negative impacts on the socio-ecological environment. To better understand the behavior of the river, a two-dimensional numerical model was developed using Delft3D FM suite. Delft3D FM software provides D-Flow Flexible Mesh engine for hydrodynamical simulations on unstructured grids. In this study, an approximate 30-kilometer section of the river spanning from Kalurghat to Khal 18 was selected as the model boundary. The model was calibrated and validated using available water level data collected from Chittagong Port Authority. The simulation results showed the spatial and temporal variation of water depth along the main channel, which is important for safe navigational movements of ocean-going vessels. In addition, the velocity and bed shear stress distribution were also estimated along the channel. The results could be useful to the port management authority for managing navigational draft and conservation efforts, including dredging, and future structural and non-structural developments along the river banks.

Keywords: *Karnafuli River; Chittagong Port; Hydrodynamic; Delft3D FM Suite; 2D Modeling*

1 Introduction

The Karnafuli River is the most significant river in the Chittagong region. It originates in the Mizoram state of India's Lushai Hills, flows over 180 km of rocky, untamed terrain, and makes loops at Kaptai. Then the river travels through several mountain ranges, makes a confluence with the Halda river, and reaches the Bay of Bengal.



(a) (b)

Figure 1: (a) Karnafuli River Network, and (b) Lower Karnafuli River

The hydrological regime of the river exhibited considerable fluctuations over the course of the previous century. The formation of some alluvial plains, such as Char Bakalia and Chandgaon, can be attributed to the change of the river's course from its original western and southwest paths to a new channel located on the left bank (Sarwar et al., 2010). The study area covers about 30 km stretching from Kalurghat as the upstream boundary to Khal 18 as the downstream boundary, representing the lowermost and most significant section of the river (Alam and Matin, 2013).

A two-dimensional mathematical model has been developed using Delft3D FM Suite to investigate the hydrodynamic characteristics of the river, including fluctuations in water level, velocity, and bed shear stress. Consequently, the incorporation of the river's dynamics and flow patterns into management strategies for navigation and flood protection is expected to improve in the future. Several research studies have been carried out on the Karnafuli River in the past (Alam and Matin, 2013; Kabir and Ali, 2017; CPA, Dept. of WRE and Institute of Flood Control and Drainage Research, BUET, 1987; Danish Hydraulic Institute, BUET, Nov. 1990). However, the use of unstructured mesh in Delft3D represents a recent development, and this study aims to enhance understanding of the hydrodynamic properties of the Karnafuli river with greater precision.

2 Methodology

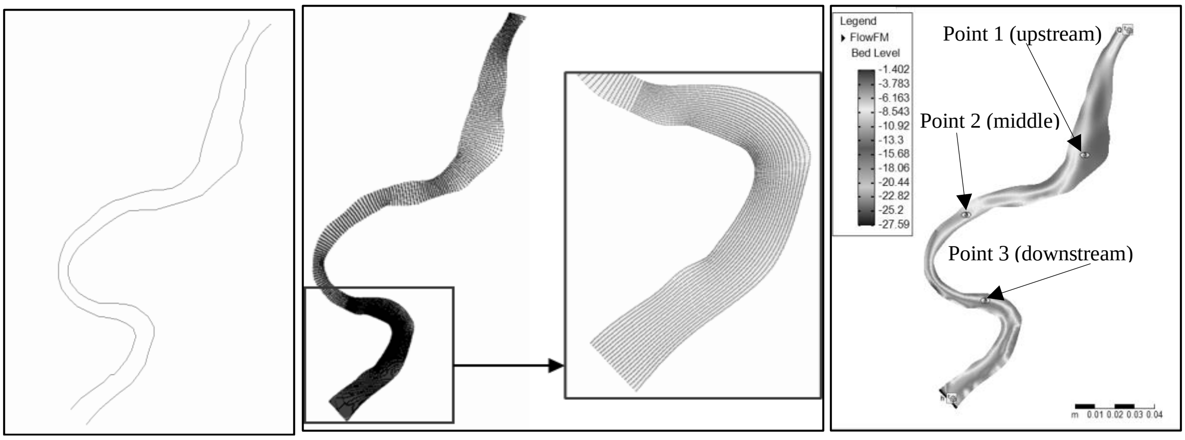
The hydrodynamic simulation is conducted using the Delft3D FM Suite software. However, the establishment of this model necessitates a substantial amount of data preprocessing. In the case of a tidal river such as Karnafuli, the use of discharge data at the upstream boundary creates major challenges since discharge data is not available for tidal rivers. Consequently, a one-dimensional hydrodynamic model was developed using HEC-RAS for the Karnafuli and Halda River network to generate discharge at Kalurghat Point, considering flow coming from Kaptai Dam and the Halda River (Alam and Matin, 2013). For the Flow Flexible Mesh model setup, an unstructured grid was generated using Delft3D-RGFGRID. This grid was then imported into Delft3D FM Suite, and all other required forcings, including bathymetry, roughness, and boundary conditions, were incorporated into it.

2.1 Data Collection

All the data required for the study, including bathymetry and water level data, was collected from the Chittagong Port Authority for the year 2020. The bathymetry data covers the major portion of the reach, and water level data was collected for the stations of Khal-10 and Khal-18.

2.2 Grid Generation and Bathymetry Setup

In order to operate within the Delft3D FM suite, it was necessary to create a land boundary file of the lower Karnafuli river using Delft3D QUICKPLOT. The significance of this land boundary file is to simplify the creation of unstructured grids within RGFGRID in a spherical coordinate system. Local refinement was carried out between Khal-10 and Khal-18, as this was the targeted areas of the research. An estimated 8100 grid cells were generated along the reach. Then, in Flexible Mesh Suite, after creating a new Flow Flexible Mesh Model, this generated grid was imported, and the collected bathymetry data of the lower Karnafuli River was incorporated into it. Along the reach, some monitoring points are taken.



(a) (b) (c)

Figure 2: (a) Land boundary and (b) Unstructured Mesh (c) Generated Bathymetry with Monitoring Points

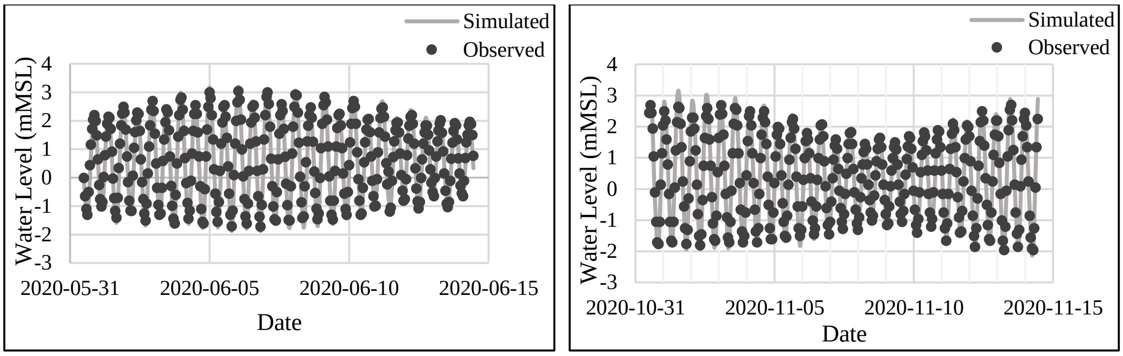
2.3 Boundary Condition

Boundaries are significant because they establish the input conditions for the grid-based modelling method. For a tidal river like Karnafuli, it is important to have discharge data as an upstream boundary condition and water level data as a downstream boundary condition. The earlier generated discharge data at Kalurghat point was used as the upstream boundary. The water level at Khal-18 was collected from CPA and used as a downstream boundary condition. Both of the data were in hourly intervals.

3 Results and Discussion

3.1 Model Calibration and Validation

Calibration and validation are critical steps in ensuring that a numerical model accurately represents the physical system being modelled. In this model, after adjusting different values of Manning's roughness coefficient, the output results were compared to the observed data. For this research, Khal-10 was taken as a calibration and validation point. The model was calibrated for the monsoon season and validated for the post-monsoon season. During this process, the simulated result demonstrated a good agreement with the observed data. As a result, the model seemed ready for simulation and other studies.

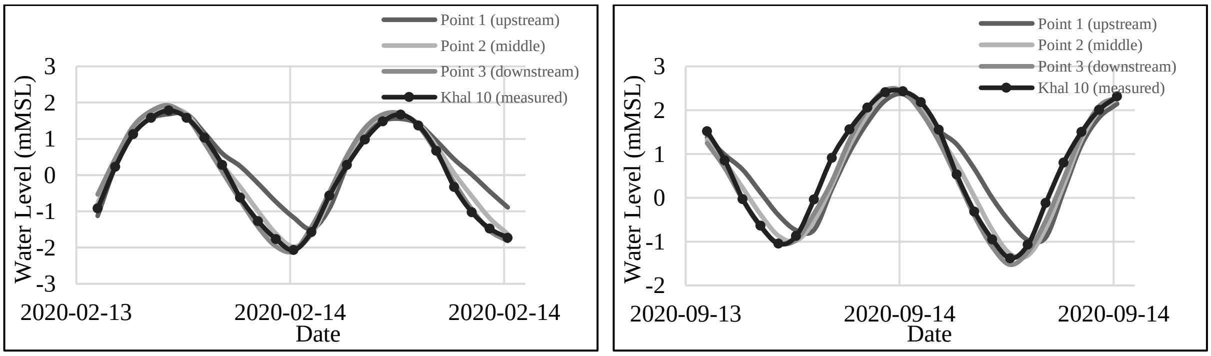


(a) (b)

Figure 3: (a) Calibration, and (b) Validation of Flow Flexible Mesh Model at Khal-10

3.2 Tidal Effects on Water Level

The Karnafuli River has substantial tidal effects on both its upstream and downstream sides. The model outputs are used to determine tidal effects at three sites along the river shown in Figure 2(c). Figure 4 shows that the tidal cycle is highly sinuous, lasting 12 hours and 25 minutes. Two high and two low tides in one tidal period suggest a considerable effect. In downstream, the river has a relatively higher tidal range of 2 meters to -2.10 meters and 2.5 meters to -1.5 meters during the dry and wet periods, respectively. The measured water level data of a nearby station, Khal 10, was also plotted, and it coincides with the simulated water level result of point 3 (downstream). The figures also show that during the dry period, it exhibits lower tides than during the wet period.

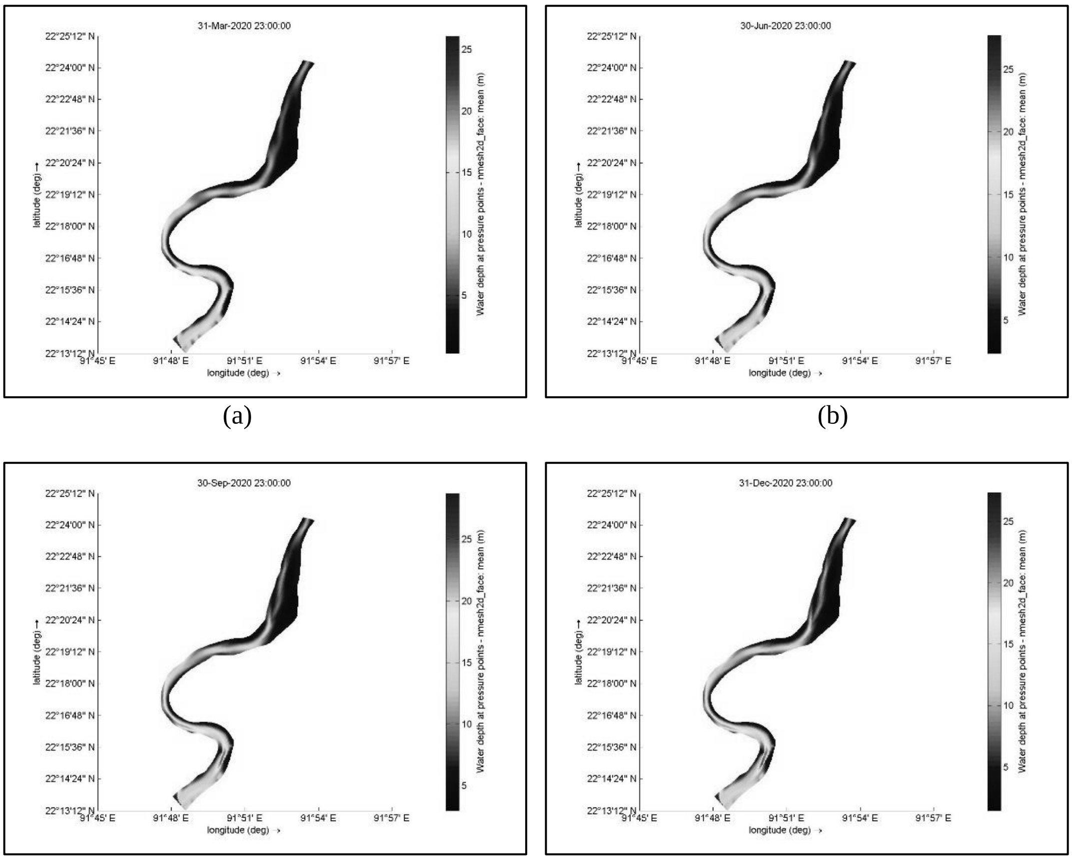


(a) (b)

Figure 4: Daily Tidal Effect on Three Locations of the River (a) Dry Period (February), and (b) Wet Period (September)

3.3 Variation in Water Depth

The depth of water plays a crucial role in determining the navigability of a river. For this research, the variation of water depth along the river is shown in Figure 5 over a three-month interval. The overall variation does not change over time, seemingly. But during the monsoon and post-monsoon periods, at some points, water depth increases. On average, the water depth ranges from 8 meters to 15 meters along the lower portion of the river.



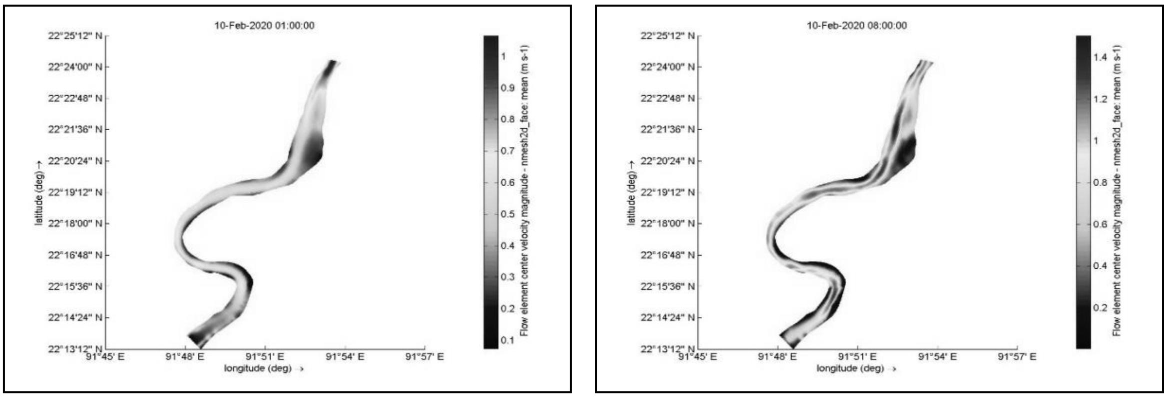
(a) (b)

(c) (d)

Figure 5: Water Depth at the (a) end of March, (b) end of June, (c) end of September, and (d) end of December

3.4 Variation in Velocity

As mentioned earlier, the river is tidal-dominant, which greatly influences the velocity of its flow. Several diagrams (Figure 6 and Figure 7) illustrate that the maximum velocity conditions occur during the dry and wet seasons, with higher velocities occurring in deeper areas. Velocity fluctuations have been depicted for four conditions during both the dry and wet seasons, which are spring flood, spring ebb, neap flood, and neap ebb. Typically, the magnitude of the velocity is greater during the wet season compared to the dry season. During the dry period, the results indicate that the peak velocity attains a value of 1.4 m/s, while the mean velocity ranges from 0.4 m/s to 1 m/s. In wet periods, the peak velocity has been observed to exceed 1.6 m/s, while the mean velocity falls within the range of 0.3 m/s to 1.4 m/s.



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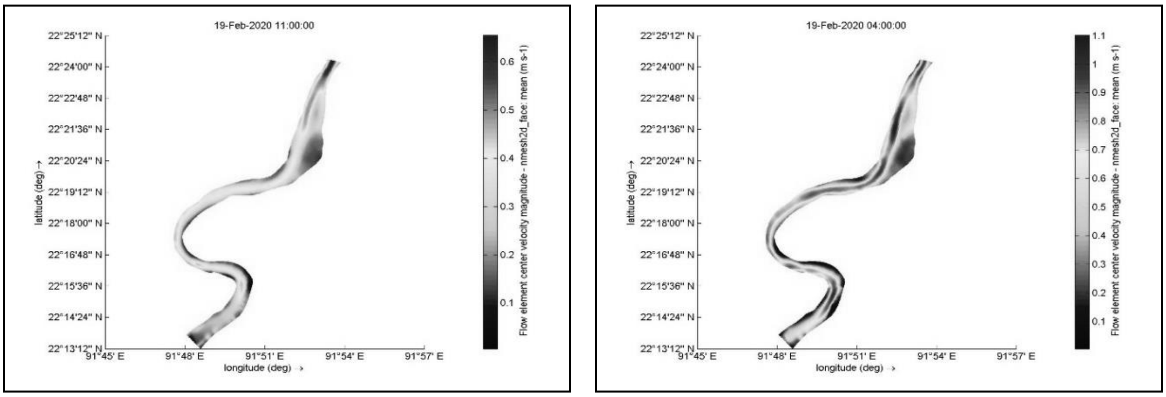
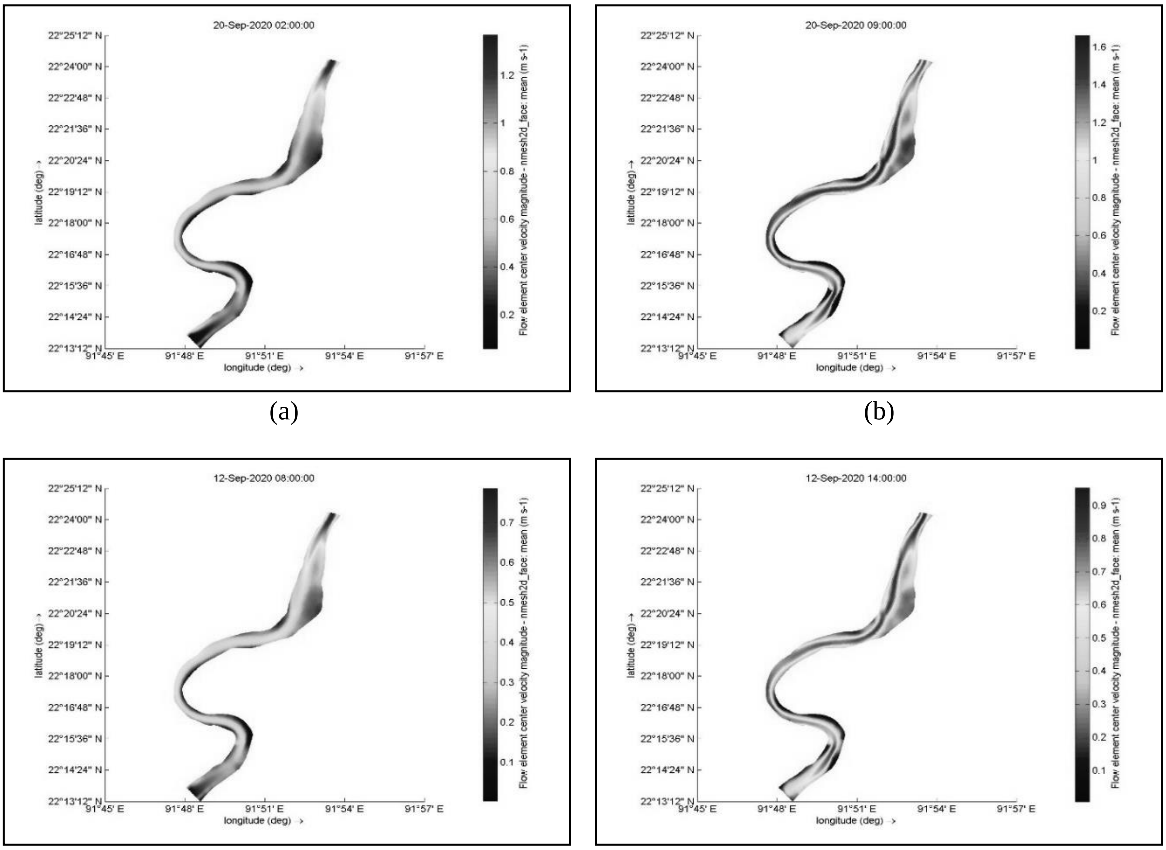


(c) (d)

Figure 6: Dry Period Velocity during (a) Spring Flood, (b) Spring Ebb, (c) Neap Flood, and (d) Neap Ebb



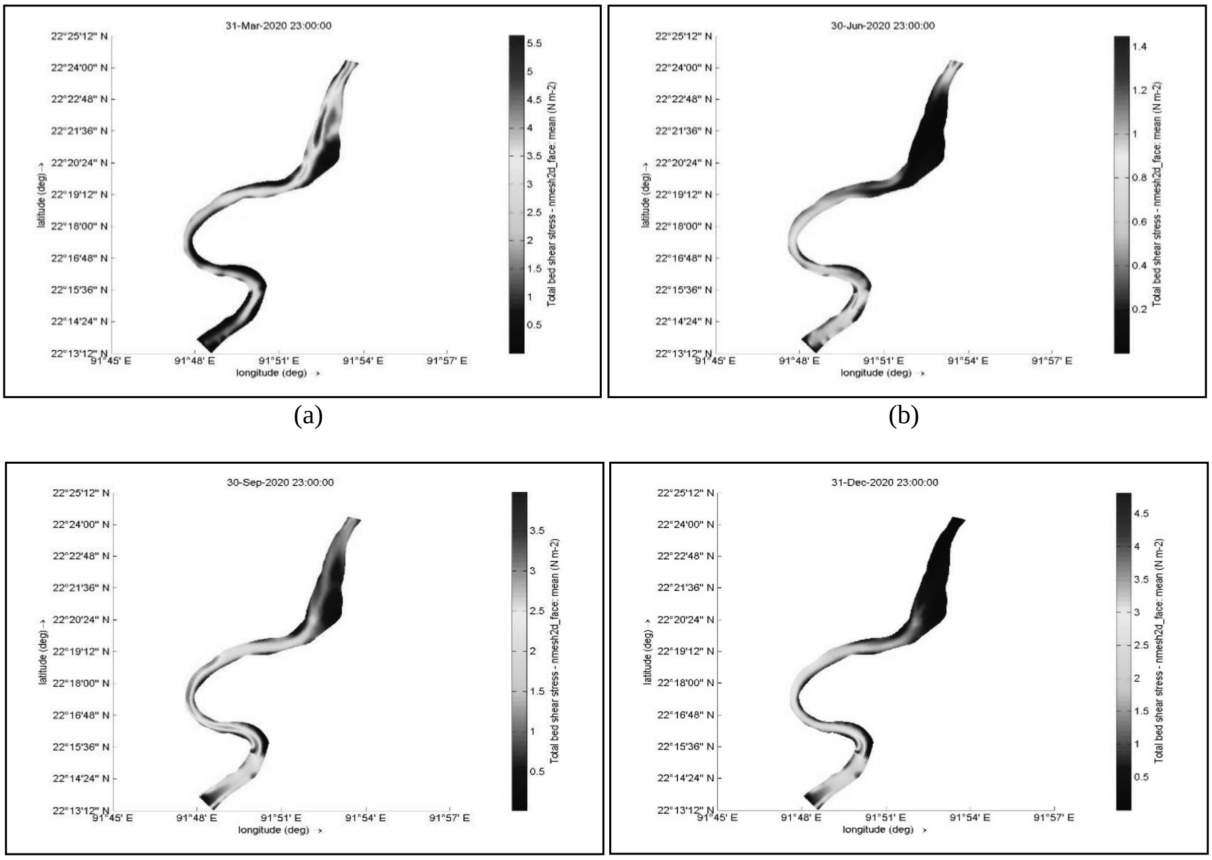
(a) (b)

(c) (d)

Figure 7: Wet Period Velocity during (a) Spring Flood, (b) Spring Ebb, (c) Neap Flood, and (d) Neap Ebb

3.5 Variation in Bed Shear Stress

Bed shear stress is an important factor that influences sediment transport and erosion/depositional patterns in rivers. Using a three-month interval, the variation in bed shear stress of the whole river is shown in Figure 8. During the pre-monsoon period (Figure 8 (a)), there is a higher range of bed shear stress, which can vary from 0.5 N/m^2 to 5.5 N/m^2. The shear stress in the majority of the river's sections ranges from 2 N/m^2 to 2.5 N/m^2. During the monsoon season, particularly towards the end of June, the average shear stress is recorded at 0.6 N/m^2. Following the monsoon season, there is a notable increase in shear stress, with an average value of 2.5 N/m^2 observed by the end of December. The bed shear stress is observed to be higher in the lower portion of the reach, particularly in deeper areas. Conversely, it can be observed that the shallower areas have lower bed shear stress.



(a) (b)

(c) (d)

Figure 8: Bed Shear Stress at the (a) end of March, (b) end of June, (c) end of September, and (d) end of December

4 Conclusion

The Karnafuli River is a tidal-dominant river where the water level fluctuation influences vessel movements. The downstream section of the river experiences a comparatively greater tidal impact than its upstream counterpart. The research shows a distinct pattern between the occurrence of spring tides and neap tides. The variation in water depth along the channel will be helpful for a safe navigational draft of Chittagong port. The velocity is higher during the wet season, with peak values of 1.6 m/s compared to 1.4 m/s during the dry season. On average, the river shows a velocity range of 0.4 m/s to 1.2 m/s. The bed shear stress in the river fluctuates throughout the year, with higher values during the pre-monsoon and post-monsoon periods (0.5 N/m^2 to 5.5 N/m^2) and lower values during the monsoon season (0.2 N/m^2 to 1.4 N/m^2). This hydrodynamic analysis has potential applications in both morphological analysis and future river development projects.

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