ASSESSMENT OF EFFECTIVENESS OF STRUCTURAL INTERVENTIONS FOR RIVERBANK PROTECTION USING MATHEMATICAL MODELING

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ABSTRACT

Recent riverbank erosion at Naria Upazila of Shariatpur district is now a national concern due to its diverse impacts on the country's economy and insecure entity of bank dwellers. This study aims to assess the effectiveness of series of groynes and dredging through mathematical modeling using DELFT 3D software. A 12 km reach has been selected as the model domain to observe the hydrodynamic and morphological changes near Naria along the right bank of Padma River. The model has been simulated for a constant discharge of 90000 m^3/s at the upstream boundary and a constant water level of 5.45m PWD at downstream boundary. Then simulations have been done for six different scenarios consisting of series of groynes varying in numbers, dredging along the char or even a combination of both dredging and groynes. Model results indicate that at the upstream of structural intervention(s) water level rises up due to afflux. The depth averaged velocity and bed shear stress show decreasing tendency around the structures which indicates the attainment of siltation zone. Model results indicate that at the tip of groynes huge amount of erosion takes place due to scouring of bed material. However due to the insertion of groyne(s), the erosion decreases significantly at the upstream and downstream of the structure(s) and bed level rises up due to siltation. From the velocity vectors and cumulative erosion deposition contours, it can be decided that for the specific reach of the river option 3 (7 Groynes) and option 5 (15 m dredging with 5 Groynes) have proven to be more successful in reducing riverbank erosion near Naria. Thus, it can be concluded that this type of structures, when used in increasing numbers and at various spacing, effectively prevent bank erosion. In general, the outcomes of the model showcase its capacity to assess how rivers respond to options in terms of their hydro characteristics.

Keywords: *Riverbank erosion, groynes, dredging, Delft 3D, hydro-morphological response*

1. INTRODUCTION

Bangladesh is a country located in the basins of the Ganga, Brahmaputra and Meghna rivers, which're among the most powerful rivers worldwide. These rivers experience movement, due to their significant water discharge and high sediment load. Riverbank erosion is a disaster in Bangladesh that has wide ranging impacts, on society the economy, healthcare, education and politics. Each year severe erosion occurs along the banks and bed of the Padma River, which holds importance for Bangladesh. Although measures are occasionally taken to avoid problems of this nature, the Padma River's erratic behavior frequently causes projects to fail. These days, two-dimensional hydrodynamic and morphological models are employed as useful tools to address the issues. One such modeling program for analyzing river responses under various circumstances is Delft3D. This study compares the results of structural intervention, such as groynes, with the free flow condition by analyzing a chosen stretch of the Padma River that is prone to erosion. Thus, relationships between various hydrodynamic and morphological parameters have been established for various conditions, which may aid future Padma River work by planners, engineers, and implementing authorities.

The Padma River, one of Bangladesh's waterways is known for its nature in terms of architecture (Yeasmin, 2011). Originating from the Gangotri Glacier, in the Himalayas it flows through India before being called Padma in Bangladesh. The riverbed and banks of the Padma mainly consist of materials with the banks being composed of fine grained and compact sands (Azuma et al., 2007). Due to the presence of sand silt sediments and occasional clay the riverbanks are prone to instability (McLean et al., 2012) leading to a process of erosion and accretion (Kummu et al., 2008). The Padma River has a braided pattern with islands or chars forming between its channels. These chars often shift along with the flow of the river. Are highly sensitive to changes, in erosion and accretion patterns. Many of these chars are inhabited by people.

Numerous studies have been conducted worldwide to address the challenges posed by bank erosion. In addition, to laboratory experiments researchers have employed modeling techniques to investigate the mechanisms and impacts of bank erosion. Bangladesh has also seen a number of studies exploring planform changes, hydrodynamics and morphology, hydrology and bank erosion. One such study examined the erosion deposition processes of the Padma River from Goalunda to its confluence with the Padma Meghna near Chandpur (Rahman, 1978). The primary objective of this study was to establish a relationship between sinuosity and meandering patterns. Another assessment utilized multi Landsat data to detect changes in the northwestern part of Bangladesh, along the Padma River (Hassan & Akhtaruzzaman 2010). The study conducted by Yeasmin in 2011 examined the evolving channel patterns of the Ganges Padma River. The analysis involved compiling satellite images from 1973, to 2006. Various time series were used to calculate the sinuosity ratio and braiding index. The findings indicated that the sinuosity ratio increased over time while it was also observed that the braiding index changed at a rate than the sinuosity ratio. Laz (2012) focused on observing the changes of the Jamuna River using the Delft3D model. This study analyzed sediment transport rate, erosion and deposition bed level changes as the shifting process of the river. The findings indicated that the path of the river has shifted towards the west. Using the Delft3D modeling suite, a 2D coupled Wave-Hydrodynamic model of the larger bay area was created in order to estimate the major wave properties needed for coastal engineering purposes (Matin et al.,2020).

The study was conducted in Naria Upazila, which is located alongside the Padma river, in Shariatpur district. This region has experienced damage over the years due to erosion, along the river banks. Naria Upazila covers a land area of 203.58 kilometers (78.60 miles). Shares its borders with Zajira Upazila to the west Munshiganj District to the north Bhedarganj Upazila to the east and south and Shariatpur Sadar Upazila to the west.

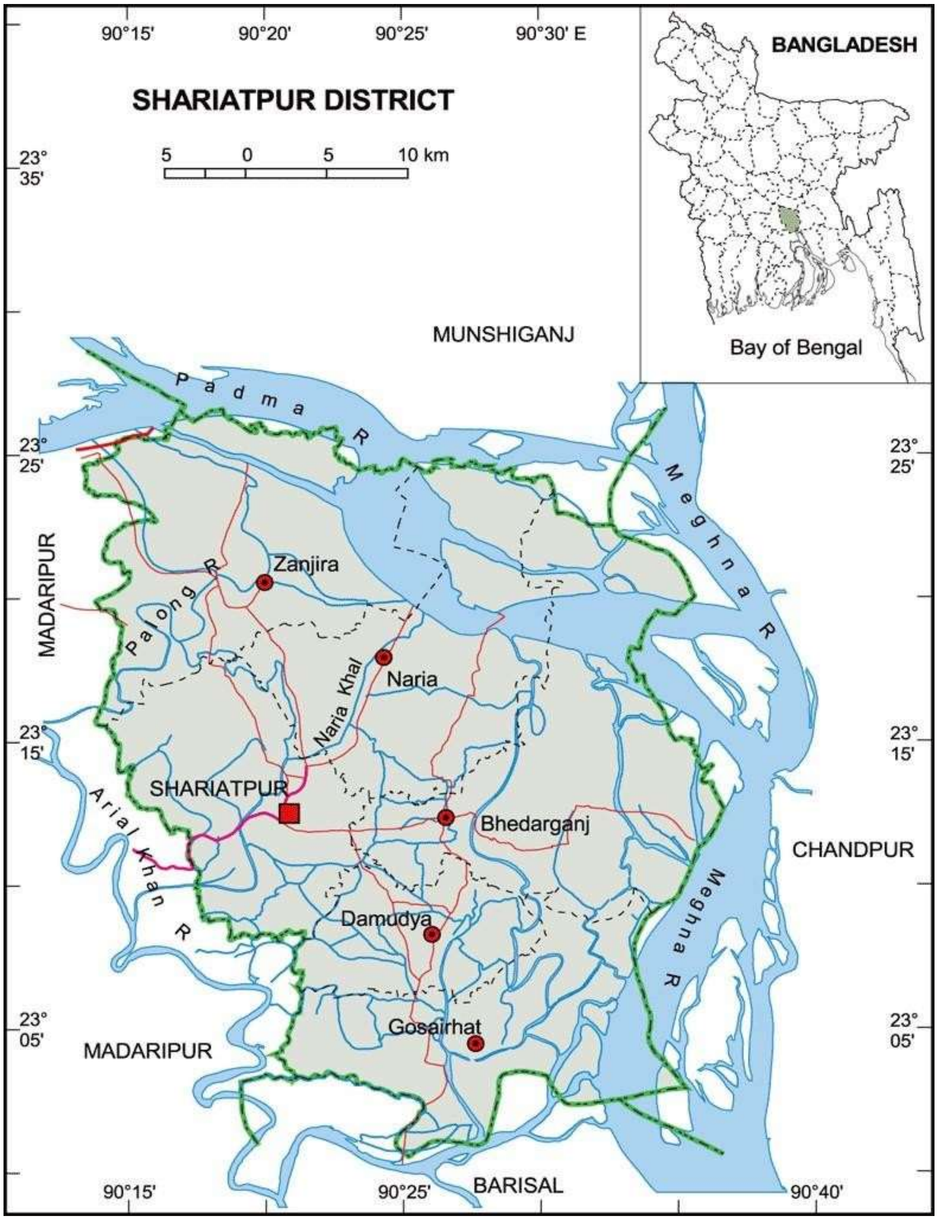

Figure 1: Study Area Map (Naria Upazila)

Using Delft3D, the study aims to:

- Establish a two-dimensional hydro-morphological model for a chosen reach of the Padma River;
- Evaluate the river's hydrodynamic response for conditions of constant inflow resulting from structural interventions on its right bank; and
- Examine the morphological response resulting from these structural interventions.

2. METHODOLOGY

2.1 Workflow Diagram

The work plans structure and content can vary depending on your area of study and your institutions requirements. In this study we aimed to create an understandable work plan. The overall plan has been designed to achieve the stated objectives of the study. While following the plan we made adjustments, to our strategy. To kick start the project we devised a cut flowchart that encapsulates the stages of our analysis and work plan. This flowchart serves as an outline, for the steps entailed in the project.

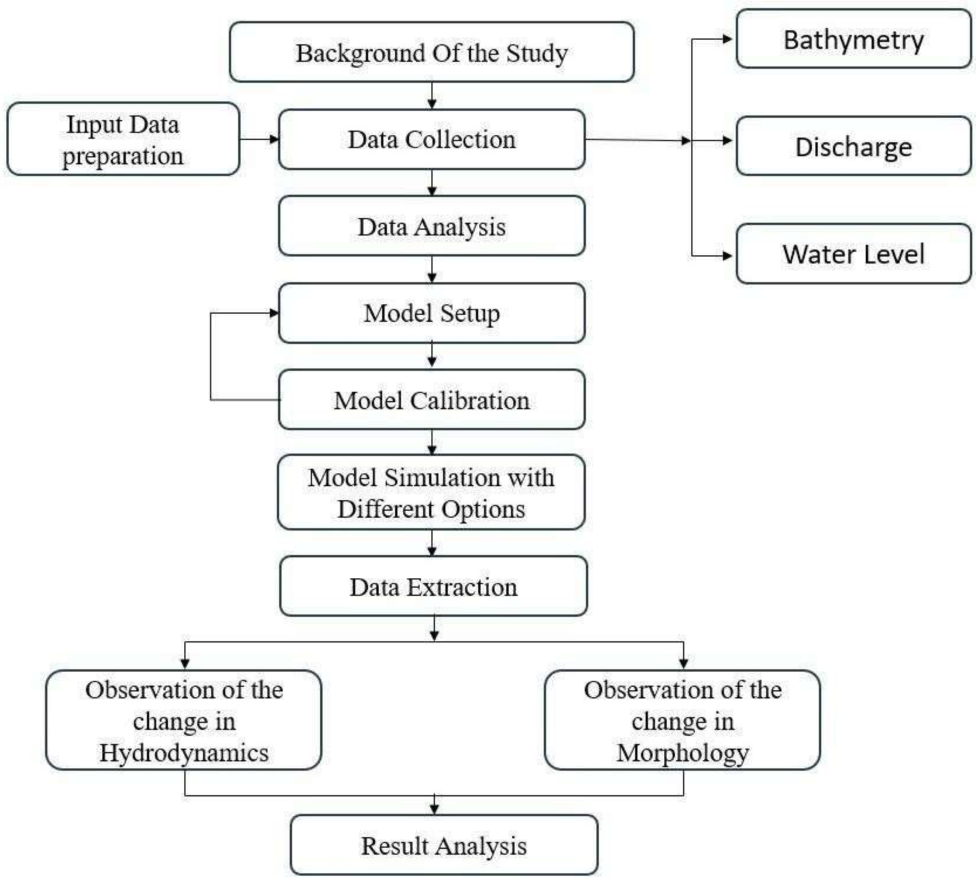

Figure 2: Flow chart showing the entire methodology

2.2 Model Setup

2.2.1 Grid Generation

The curvilinear regular grid has been created as illustrated by figure 3, consisting of 245 grid points along the river in the M-direction and 56 grid points across the river in the N-direction, for a total of 13720 grid points. Land borders are also included in the grid. Every computational grid point's hydrodynamic and morphological parameters are simulated by the model.

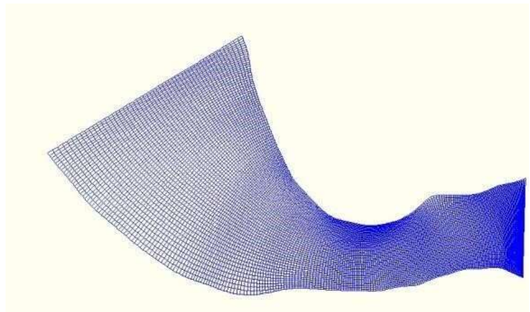

Figure 3: Computational Grid cell of Padma River in the study area.

2.2.2 Bathymetry Preparation

In order to simulate various scenarios for the hydro-morphological model, the bed level data has been superimposed onto the curvilinear grid as illustrated in figure 4. It indicates that river cross-section data are present in each grid cell.

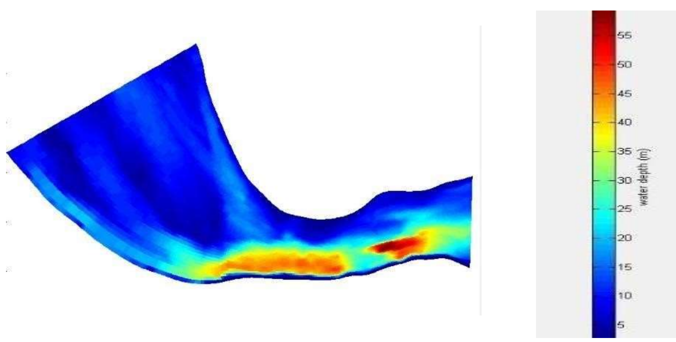

Figure 4: Bathymetry of study area

2.2.3 Boundary Definition

The model's upstream boundary has been set to a constant discharge of 90000 m^3/sec for different simulations, while the downstream boundary condition has been set to a water surface elevation of 5.45 m.

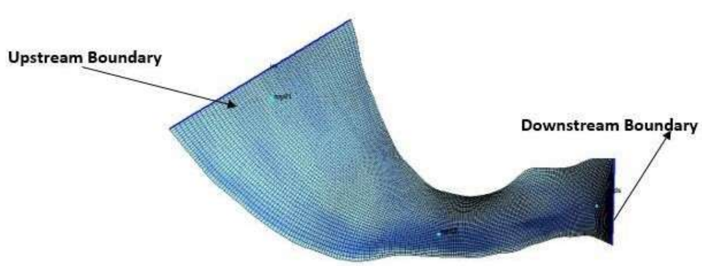

Figure 5: Boundaries of the model.

2.2.4 Model Simulation with Different Options

This study focuses primarily on structural interventions such as spurs or groynes in areas of the Padma River's right bank that are prone to erosion. Thus, a variety of groynes positioned in various directions will be incorporated into the river to monitor hydro-morphological changes. The table 1 gives an overview about different scenarios that has been considered for model simulation.

Table 01: Description of the simulation options

Name of the options	Description of the options
Base	Without any structure
Option 1	With 3 groynes
Option 2	With 4 groynes
Option 3	With 7 groynes
Option 4	15m dredging along the char
Option 5	15m dredging with 5 groynes

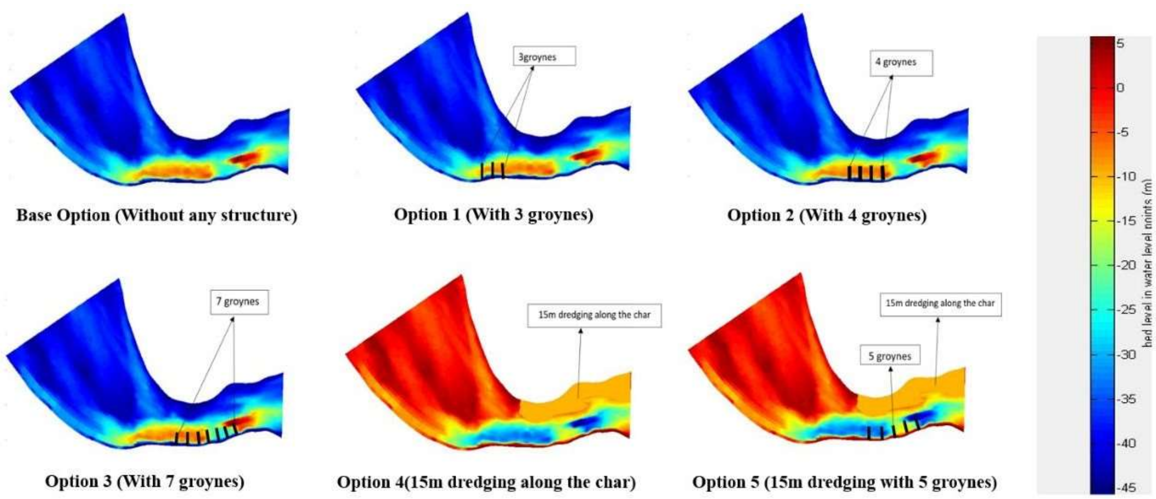

Figure 6: Simulation with different scenarios

3. RESULTS

3.1 Observation of Hydrodynamic Parameters

To observe the scenarios, some figures displaying the hydrodynamic parameters—such as water level, depth averaged velocity, bed shear stress, etc.—are sequentially displayed.

3.1.1 Depth Averaged Velocity

As the number of groynes increases, the depth averaged velocity at the upstream and downstream locations decreases. It is evident that any obstruction lowers a fluid's velocity. Because the groynes are ever-present obstructions, the velocity decreases upstream. Now, as figure 7 illustrates, the depth averaged velocity variation associated with each option will be shown. Option 5—which incorporates five groynes and 15 meters of dredging along the char—is the one that is advised. With this scenario, the river's flow is diverted and its vulnerability to erosion is decreased, leading to more efficient outcomes.

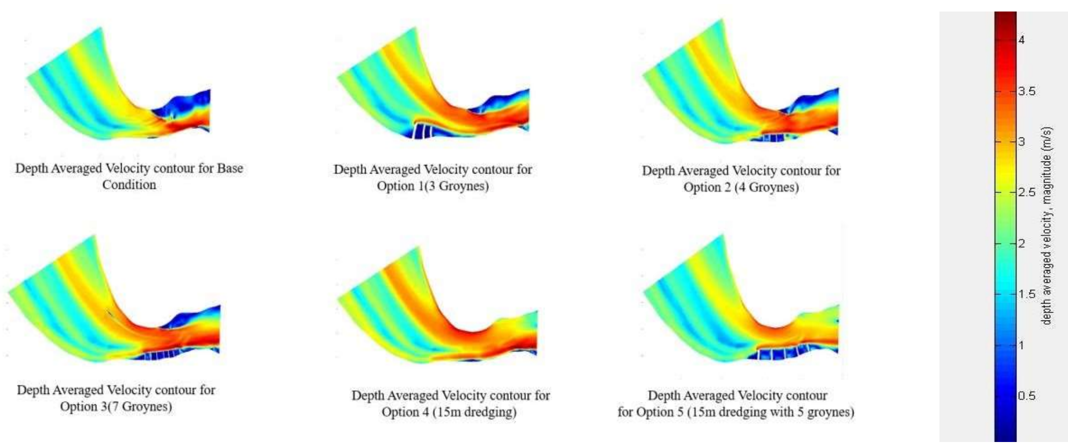

Figure 7: Depth Averaged Velocity contour for different conditions

3.1.2 Depth averaged velocity along the cross section

The following figure 8 will now display the depth averaged velocity variation at a given cross section for various options. In this case, the base condition and the velocities have been compared option by option. The insertion of groynes causes a significant drop in velocity in the vicinity of the structures as shown in figure 8.

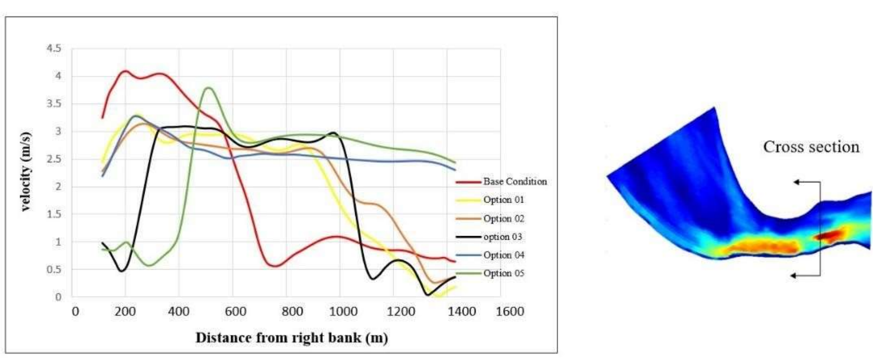

Figure 8 :Relative change along the cross section for all options

From figure 8, in case of both options 1 and 2 the average velocity, near the riverbank decreases from around 3.25 m/s to 2.4 m/s and 2.3 m/s respectively. However, option 3 shows a drop in velocity to 1 m/s. This sharp decrease is due to the implementation of a system of seven groynes in option 3. It's worth noting that in all cases as the flow moves away, from the bank the average velocity increases rapidly. It is clear, from this information that the water flow is being redirected away from the riverbank.As a result, we can conclude that the number of groynes has an impact on both the direction and strengthof the water velocity, in the areas surrounding these structures.

3.1.3 Bed Shear Stress

The presence of drag force leads to bed shear stress. Additionally, the strength of the drag force decreases as the velocity of the water decreases. As a result, changes in bed shear stress are closely linked to changes in velocity. The models findings suggest that when there are more groynes present there is a decrease in bed shear stress, near the structure.

Based on the observation from figure 9, the maximum bed shear stress at the base condition is approximately 50 N/m^2, and for options 1 and 2, this value decreases to 35 N/m^2. With option 3, however, the bed shear stress drops dramatically to 25 N/m^2. This option involves a series of 7 groynes. The flow still hits the riverbank, increasing stress development, even though the maximum bed shear stress has decreased from 50 N/m^2 of base condition to 20 N/m^2 as a result of the 15-meter dredging along the char, as shown in the figure below. Consequently, option 5, which incorporates five groynes into the model area and involves 15 meters of dredging along the char, is advised. This approach produces more effective results by rerouting the river's flow and lessening its vulnerability to erosion.

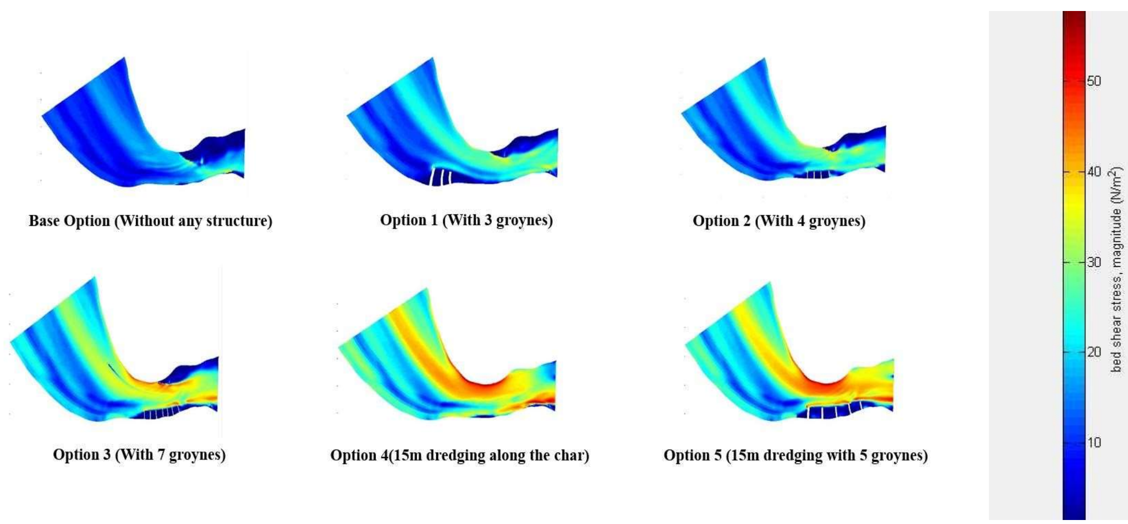

Figure 9: Bed Shear Stress contour for different conditions

3.1.4 Bed Shear Stress along the cross section

The following figure 10 will display the variation in bed shear stress with various options at a given cross section. In this case, the base condition and the bed shear stresses have been compared option by option. The Figure 10 demonstrates how the bed shear stress considerably reduces in the vicinity of the structures as a result of the insertion of groynes.

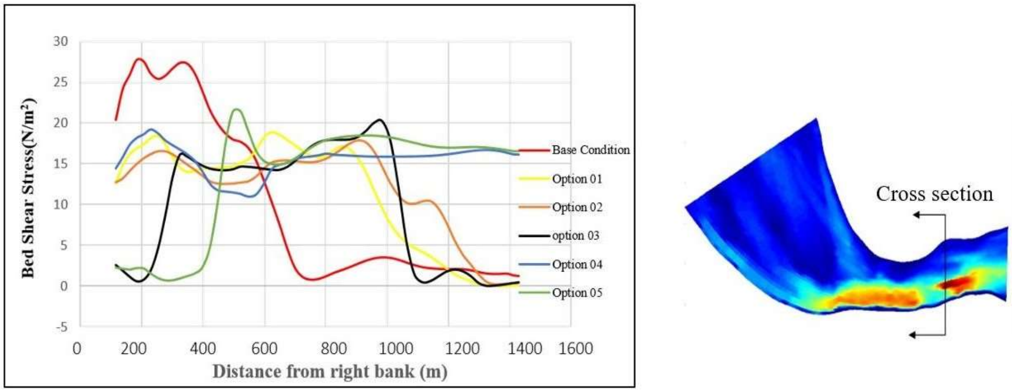

Figure 10 :Relative change along the cross section for all options

From the figure 10, in the case of options 1 and 2, the bed shear stress near the riverbank decreases from a value of approximately 21 N/m^2 to 12.5 N/m^2. However, when considering option 3 involving a sequence of seven groynes the shear stress, on the riverbed significantly decreases to 2.5 N/m^2. It is worth mentioning that as the bed distance from the riverbank increases in all scenarios the shear stress also increases. This clearly indicates that the flow is being diverted away, from the riverbank.

3.2 Observation of Morphologic Parameters

To observe the scenarios, a series of sample figures displaying morphologic parameters such as total transport, cumulative erosion or sedimentation, bed level variation, etc., are displayed sequentially.

3.2.1 Bed Level

The relative change of cumulative erosion or sedimentation has been noted from the previous section. The actual bed level variation with respect to the base condition has now been displayed for various options in this section.

The figure 11 make it abundantly evident that scouring of the bed material causes a significant amount of erosion at the tip of Groynes. But because of the groynes, there is much less erosion upstream and downstream of the structures, and siltation causes the bed level to rise.

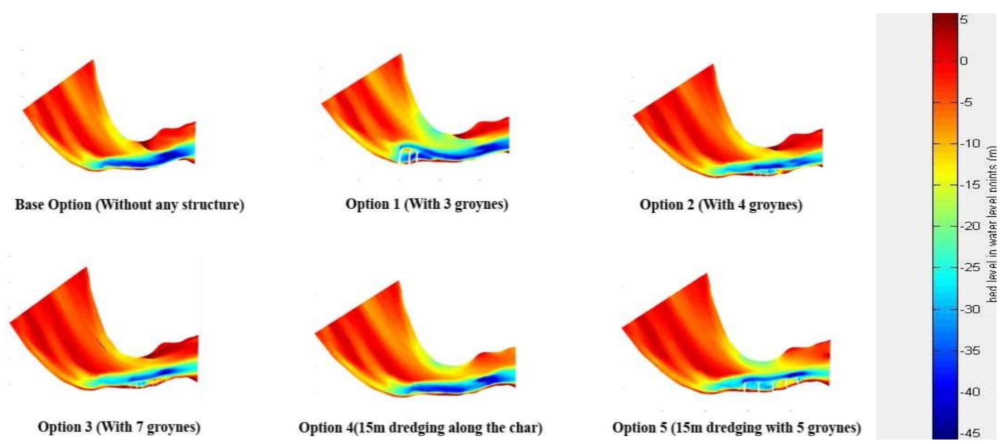

Figure 11: Bed Level contour for different scenarios

3.2.2 Bed level along the cross section

Now, the bed level at a particular cross section with various options will be displayed in figure 12. Here, the base condition and the curves have been compared option by option. The figure 12 illustrates how the insertion of groynes causes siltation to raise bed level and greatly reduce erosion in the area surrounding the structure or structures.

It is clearly visible from figure 12, Option 1 causes the bed level next to the riverbank to increase from approximately -28 meters to -18 meters, and from Option 2 and Option 3 to approximately -10 meters. On the side option 3 demonstrates an upward trend as evidenced by a sequence of seven groynes, near the riverbank that indicate significant sediment accumulation. By capturing these sediments along the edges of the structures we can determine the impact of each groyne on the bed level.

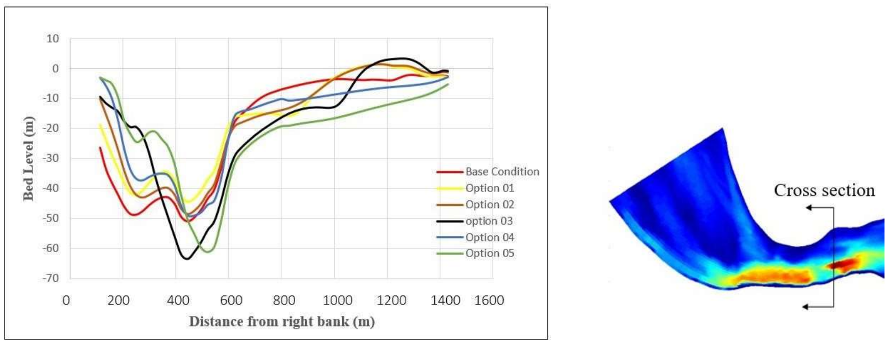

Figure 12 :Relative change along the cross section for all options

In contrast option 4 (15 m dredging) causes a rise in the bed level to the riverbank from -28 m to -10 m. However, when considering option 5 (15 m dredging with 5 groynes) there is a drastic increase in the bed level, to -2 m, suggesting a substantial sediment deposition. Consequently, it can be concluded that groynes in addition to dredging have been found to be more effective in reducing erosion close to the riverbank.

3.2.3 Cumulative Erosion or Deposition

From figure 13, the cumulative erosion or deposition contour at base condition shows up to 20 meters of deposition and about 35 meters of erosion.

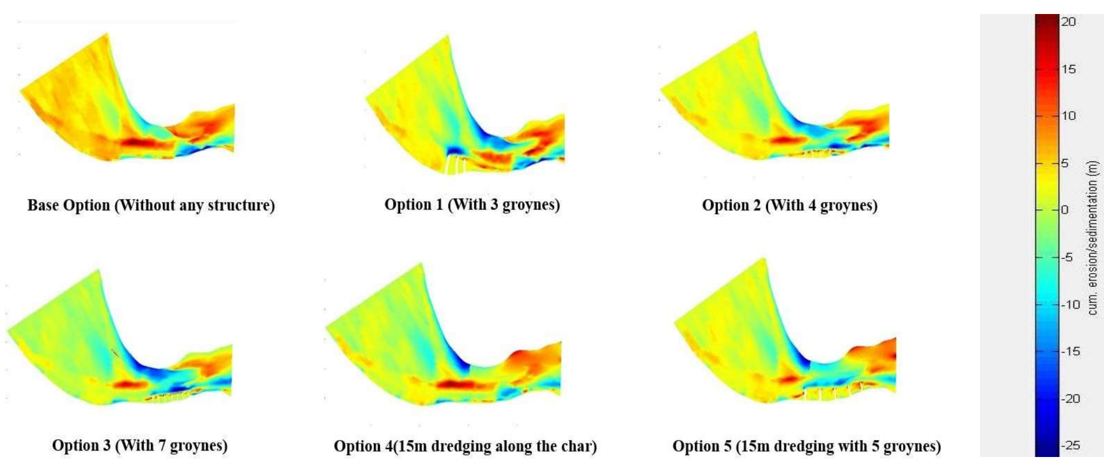

Figure 13: Cumulative Erosion or Deposition for all options

The remaining options of figure 13 make it abundantly evident that massive amounts of erosion occur at the tip of groynes as a result of bed material scouring. However, because of the groyne(s) insertion, there is a significant reduction in erosion both upstream and downstream of the structure(s), and siltation causes the bed level to rise.

3.2.4 Cumulative Erosion/Deposition along cross section

From the figure 14, the erosion along the riverbank decreases from about -28 m to -21 m when Option 1 is selected, and then to about -12 m for Options 2 and 3. However, option 3 shows a sharply rising trend, and there are seven groynes near the riverbank that indicate significant sediment deposition. Hence it is possible to determine the impact of groynes, on the bed level by capturing sediment at the edges.

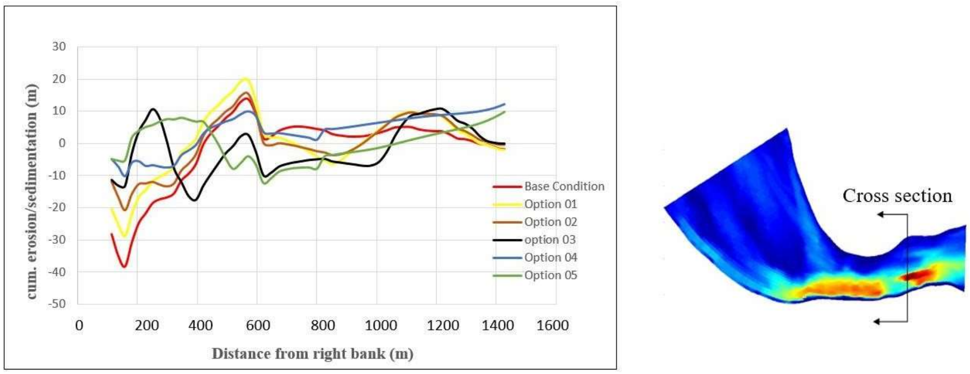

Figure 14 :Relative change along the cross section for all options

In the scenario of Option 4 (15 meters of dredging) erosion next to the riverbank decreases from around -28 meters to -6 meters as illustrated by figure 14. However, when implementing Option 5 (15 meters of dredging with five groynes) erosion reduces dramatically to -5 meters. Conversely, Option 05 exhibits an increase, near the riverbank indicating a deposition of sediment. Therefore, options 3 (7 Groynes) and option 5 (15 m dredging with 5 Groynes) have shown to be more effective than the otherfour in reducing riverbank erosion near Naria.

4. CONCLUSION

The following concluding remarks can be drawn from the present study-

- Six different scenarios have been tested in an effort to lessen riverbank erosion close to Naria. Dredging along the char, installing a series of groynes, or even combining dredging and groynes are examples of structural interventions included in these scenarios.
- The depth averaged velocity at the upstream and downstream locations decreases as the number of groynes increases, according to model results, and the water level rises upstream of groynes due to afflux. It is evident that any obstruction lowers a fluid's velocity. Because the groynes are ever-present obstructions, the velocity decreases upstream. Model results indicate that at the tip of groynes huge amount of erosion takes place due to scouring of bed material. Howeverdue to the insertion of groyne(s), the erosion decreases significantly at the upstream and downstream of the structure(s) and bed level rises up due to siltation.
- In the case of the chosen Padma River reach, structural intervention has a significant impact on the variables related to selected hydrodynamic and morphologic scenarios that are extracted from the model and interpreted
- Ultimately, it can be concluded that, out of the five options, options 3 (7 Groynes) and 5 (15 m dredging with 5 Groynes) have proven to be more successful in reducing riverbank erosion near Naria.

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