Hydraulic and Civil Engineering Technology VI
M. Yang et al. (Eds.)

doi:10.3233/ATDE210203

Preliminary Study on Siltation in Pussur Navigation Channel with Regulating Structure

Weisheng ZHANG [a], Motiur Rahman [b], Huisheng LI [c], Aixing MA [a], Md Shahjahan ALI [d] and Jinshan ZHANG [a,1]

[a] *Nanjing Hydraulic Research Institute, State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, 223 Guanzhou Road, Gulou District, Nanjing City, 210029, China*

[b] *Mongla Port Authority, Bagerhat, Bangladesh*

[c] *China Civil Engineering Construction Corporation, No.4, Beifengwo Road, Haidian District, Beijing City, 100038, China*

[d] *Department of Civil Engineering, KhuIna University of Enginering and Technology, Khulna-9203, Bangladesh*

Abstract. In view of the serious problem of siltation rate in Waterway Engineering, feasibility of the scheme is studied from the perspective of sedimentation on Pussur River of Bangladesh in this paper. Based on the analysis of the tide, sediment and topography of the waterway and numerical simulation, the characteristics of the flow movement in the project reach, the influence of the dredging channel on the flow and the siltation were analyzed. With the excavation of channel, due to the influence of dynamic changes and elevation difference, the siltation of the channel is about 0.70-1.79m/a near Inner Bar area, and is more severely in the upper section near Chalna. The implementation of the preliminary regulating structure can increase the velocity and reduce the siltation of the local section. Yet the siltation of the upstream and downstream sections may be added due to changes of flow with the structure. The further scheme should be optimized from the angle of increasing the velocity in channel and reducing the influence to upstream and downstream. The feasibility results can provide scientific basis for the design and construction departments.

Keywords. Navigation channel, back siltation, sediment carrying capacity, mathematic model, Pussur River

1. Introduction

Pussur River, a distributary of the Ganges is situated in South Western part of Bangladesh. Mongla Port, the second gateway of Bangladesh situated at the confluence of Pussur River and Mongla Nulla, approximately 131 km upstream from the Fairway buoy of the Bay of Bengal (figure1). In recent years, with the completion of supporting projects such as Padma Bridge and Rampal power plant, the ship navigation business in

[1] Jinshan Zhang, Nanjing Hydraulic Research Institute, State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, 223 Guanzhou Road, Gulou District, Nanjing City, 210029, China; E-mail: jszhang@nhri.cn.

Mongla Port will be busier. The Pussur water depth of Mongla Port is planned to meet the requirements of 12 MCDM draft vessel. In November 2014, the dredging of the port area of Pussur channel of Bangladesh port was completed, and ships with a draft of 7.5m can directly reach jetties port. However, due to the serious siltation rate of the dredged channel, the water depth after dredging is only maintained for a short time [1]. Therefore, the water depth condition of Pussur channel is far from meeting the navigation requirements, which has become a constraint factor for the development of Mongla Port.

Being an important water course for Bangladesh, Pussur River has been drawn attention of different national and international researchers [1-8]. The empolderment schemes in the Pussur basin, harbor and jetty operation of Mongla port, dredging and disposal, fish farming, etc. affected the morphology and ecology of Pussur River significantly. The main cause of this siltation is empolderment schemes between the Sibsa and Pussur rivers carried out between 1966 and 1974, resulting in reduction in tidal storage and redistribution of flow, mostly between the Sibsa and the Pussur river, starting in 1959 [2-5]. Another is upland flow restricted due to less discharge of water from Padma ultimately to Pussur due to Farakka withdrawal of Ganges water. Less availability of fresh water in the system increased the salinity of water. This increased salinity, which in turn, is causing more siltation in the estuary by flocculation processes [1].

Although a series of studies were carried out in the past to understand the cause of the siltation problem at Mongla, and to suggest potential solutions to improve navigability in the Pussur River. However, practical and effective solutions and related research of Pussur River is very few. Therefore the overall objective of this study is to investigate changes of flow and siltation after dredging through mathematic model. Based on those, changes of flow and siltation with proposed regulating construction has identified. Advantages and disadvantages of the scheme are also discussed. Some potential optimization to improve efficiency for the regulating works are also suggested.

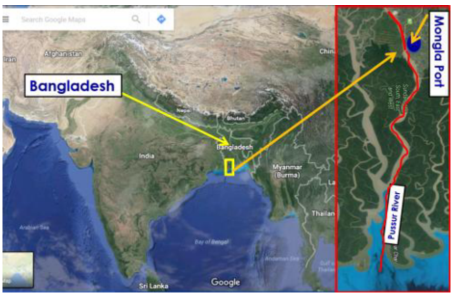

Figure 1. Study reach of Pussur River.

2. Data

2.1. Tide

According to the analysis of water level data [6], the maximum tidal range of upstream at Chalna in dry season of Bangladesh in 2015 is about 3.75m, and the maximum tidal range in flood season is about 3.4m. For neap tide, the maximum tidal range is 2.0m in dry season and 1.9m in flood season. The seasonal variation of Bangladesh port from March to September is about 0.85m.

2.2. Sediment

According to MP feasibility study report [1], at 0.8d layer, the suspended sediment concentration (SSC) at high tide is 359.65mg/l ~ 2096.06mg/l. At 0.2d layer, SSC varies from 153.6 mg/l to 1478.0 mg /L. The SSC in time averaged, is about 790 mg/l at 0.2d layer and 1270 mg /l at 0.8d layer and the averaged in depth is estimated to be about 1000 mg/l.

2.3. Properties of Bank and Bed Material

14 soil samples (7 in river beds, 7 river in banks) were collected from the site between quay 5 and quay 9 [6]. The representative particle size (D_{50}) of bed material and shore material is 0.014-0.022 and 0.010-0.050 mm respectively, which is composed of cohesive fine sediment.

2.4. Bathymetry

According to MPA Hydrographic chart, the width of the Pussur River varies from 700 m to 3000 m and is about 6000 m near the estuary. The minimum depth of the channel varies from 1.4m to 11.7m below the base level of the chart (CD), as seen in figure 2. The minimum water depth is near the upstream (Chalna), the minimum depth increases gradually in the downstream, the maximum and minimum depth increases gradually from Mazhar point to D'suza point, and further decreases in the downstream near fairway buoy. The maximum depth varies from 7.5m to 29.6m below CD from upstream to downstream.

Figure 2. Elevation about CD (m) of channel axis.

3. Methods

3.1. Descriptions of the Model

The hydrodynamic module (FM module) of Mike 21-hd series software is used for flow calculation. The software can be applied to the hydrodynamic simulation of coastal and estuarine areas. FM module (flexible mesh) adopts unstructured triangular mesh, which has powerful functions in dealing with the dynamic boundary of tidal current and the boundary of complex engineering buildings, and has fine calculation stability [9].

The model domain is shown in figure 3. The offshore boundary is located near Hiron point. The upstream boundary of Pussur River is located near Jalma, about 15km away from Mongla plant, and the downstream includes Jhapjhapia, Chunkuri Nulla, Mongla Nulla and Sibsa River. The mesh is about 10 m-200m in length, and the number of elements and nodes are 251473, 128359 respectively.

The observed tidal level of Hiron Point station is used to control the south boundary of the model, and the discharge provide by the Southwest Region Model (SWRM) [10] is used to control the runoff boundary of the upstream river.

3.2. Model Validations

There are three tidal gauges and four survey section for discharge (see figure 3), which can be used for verification for the model. Figure 4 shows the tide level verification for Joymoni station during March 2011 to July 2011. It can be seen that the tide level process calculated by the model is in good agreement with the measured tide level.

The model is validated by the observed discharge processes in March 2011 and July 2011. According to the verification process of spring and neap tide (figure 5), the calculation is in good agreement with the observation on the whole, the peak of the discharge and turning time are consistent.

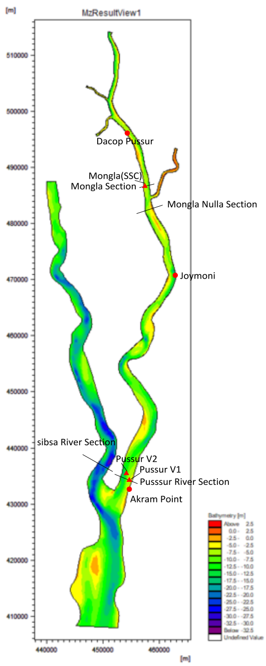

Figure 3. Domain of the 2D model and location of tidal gauges and survey section for discharge.

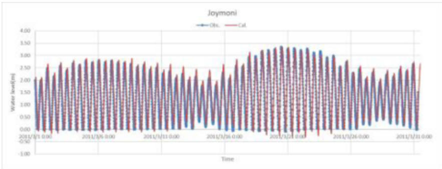

Figure 4. Verification of tide level.

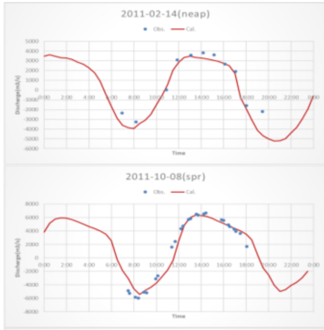

Figure 5. Discharge verification Mongla.

4. Results

4.1. Schemes

According to the layout of the planned channel, the total length of the channel from Chalna to base Creek is 28.3km, and the bottom width of channel is between 200m to 400m. Two schemes are considered in the calculation, namely:

Dredging scheme: the dredging depth is -8.5m and the tide level is 1.5m. The dredging area of the channel is about 5.712 million m^2. The average dredging depth is about 3.40 m, and the maximum dredging depth is 6.33 m.

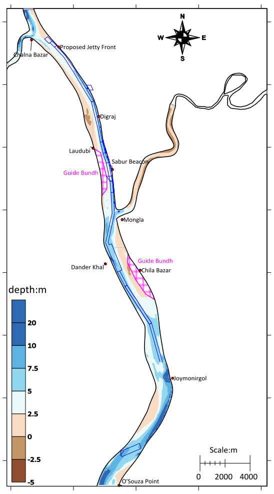

Figure 6. Layout of channel dredging + construction scheme.

Dredging + Construction scheme: According to the regulating scheme proposed by IWM [1], two guide bundhs are set on the opposite side of Mongla port and at Inner Bar to narrow the width of channel and increase the flow velocity. The length of the regulating scheme is 3km, with the top elevation + 3.3m. The guide bundh at Inner Bar is 450m in width, and the bundh opposite the Mongla port is 400m in width (see figure 6).

4.2. Flow Field and Its Change

In the dry season, the time ratio of rising tide to ebb tide is about 1:1.4 in spring and neap tide, and that of flood season is about 1:1.5 and 1:2.1 in spring and neap tide. During the spring tide in the dry season, the maximum rising or falling velocity of the main channel is between 1.20-1.60m/s, and 0.80-1.20m/s in neap tide.

For dredging scheme, the average velocity of rising tide and falling tide in the channel area in the upstream near Chalna changes -0.30m/s to +0.08m/s during spring tide, and that in the west side beach decreases from 0.02m/s to 0.25m/s (figure 7). In the downstream of Digraj, the tidal current velocity increases by 0.05-0.12m/s in the channel area, while the tidal current velocity decreases by 0.05-0.15m/s in the side beach. During neap tide, the average velocity in the channel excavation area near Chalna decreases by 0.01-0.22m/s, and the velocity in the west side beach decreases by 0.02-0.15m/s. The velocity in the main channel of the downstream channel varies from -0.05 m/s to +0.02 m/s.

After the implementation of dredging + construction scheme, the river width of the project section is narrowed and the water flow is concentrated, as shown in figure 8. The average velocity of rising tide and falling tide in the channel near the Inner Bar construction increased by 0.05-0.30m/s and 0.05-0.20m/s respectively in spring tide. While the velocity of rising tide and falling tide in the downstream of the building decreased by 0.05-0.34m/s and 0.05-0.54m/s respectively, and those in the upstream decreased by 0.05-0.73m/s and 0.05-0.48m/s respectively. The average velocity of rising and falling tides in the river section opposite to Mongla port changes in the same scale, as shown in figure 9.

The change of spring tide velocity in flood season is similar to that in dry season, and the change of neap tide velocity in flood season is slightly larger than that in dry season.

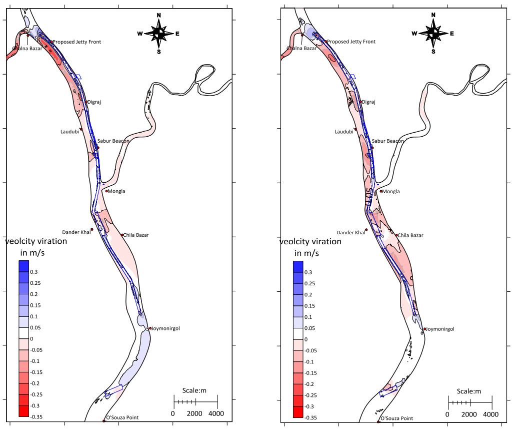

Figure 7. Change of average velocity of spring tide during rising (left) and falling (right) tide in dry season for dreding scheme.

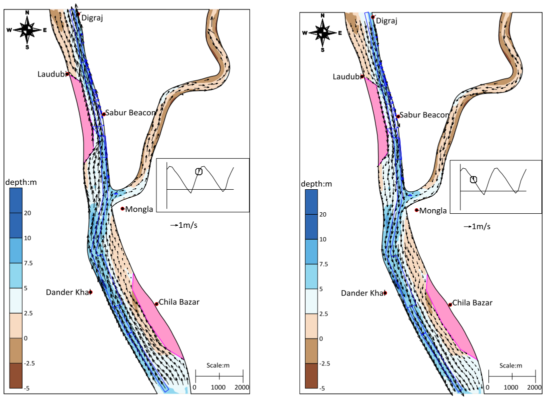

Figure 8. Flow field in rising (left) and falling tide (right) in spring tide in dry season for dredging + construction scheme**.**

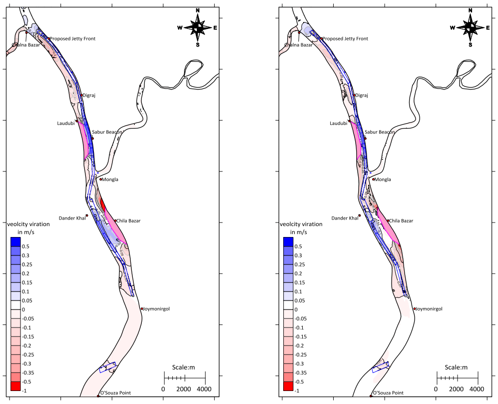

Figure 9. Change of average velocity of rising (left) and falling (right) tide of spring tide in dry season for dredging + construction scheme.

4.3. Siltation in the Channel

For the approach channel excavated in the shoal water area in balance of erosion and deposition, the expression of annual deposition intensity is as follows [11]:

$$P=\frac{\omega S_1 t}{\gamma_0}\left\{K_1\left[1-\left(\frac{V_2}{V_1}\right)^2\left(\frac{d_1}{d_2}\right)\right]\sin\theta+K_2\left[1-\frac{1}{2}\frac{V_2}{V_1}\left(1+\frac{d_1}{d_2}\right)\right]\cos\theta\right\} \tag{1}$$

In which P is siltation intensity of the channel (m); ω is flocculation settling velocity of suspended sediment (m/s); S_1 is average suspended sediment concentration (kg/m3); t is siltation duration (s) and γ_0 is dry density of sediment (kg/m^3). K_1 and K_2 are coefficients, can be taken as 0.35 and 0.13; d_1 and d_2 represent the average water depth before and after dredging respectively (m). θ is angle between channel direction and flow direction. V_1, V_2 are the flow velocity before and after the dredging and construction.

When the parameters are brought into equation (1), the sediment deposition after the implementation of dredging and regulating works can be obtained. The results are shown in table 1 and the location of calculation point is shown in figure 10.

It can be seen that after the implementation of the dredging project, the siltation rate is between 30% - 60% and the siltation intensity is between 0.70-1.79m/a near Inner Bar. Yet it is very severe at the end of the upstream channel, with the siltation intensity more than 2.0 m/a, and the siltation rate about 90%.

After the implementation of the regulating scheme, the siltation intensity of the narrowed section decreases, while it increases in the upstream and downstream sections.

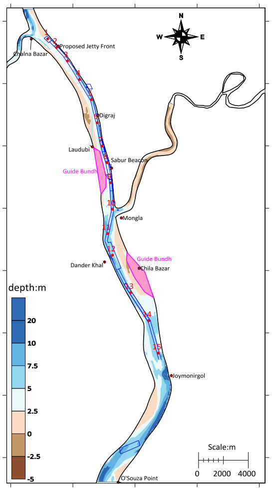

Figure 10. Location of calculation point.

Table 1. Siltation in channel of calculation point.

Point	**Natural depth(m)**	**Excavation (m)**	**Dredging**		**Dredging + construction**	
			Siltation intensity(m/a)	Siltation rate	Siltation intensity(m/a)	Siltation rate
1#	-3.19	5.31	4.84	91%	4.97	94%
2#	-3.58	4.92	2.99	61%	3.42	70%
3#	-3.57	4.93	2.88	58%	3.34	68%
4#	-5.45	3.05	1.49	49%	2.24	74%
5#	-5.57	2.93	1.36	47%	2.13	73%
6#	-6.08	2.42	1.06	44%	1.75	73%
7#	-6.43	2.07	0.26	12%	-0.03	/
8#	-4.83	3.67	1.79	49%	-0.85	/
9#	-5.96	2.54	0.73	29%	-2.75	/
10#	-5.53	2.97	1.07	36%	1.42	48%
11#	-5.75	2.75	1.18	43%	1.96	71%
12#	-5.86	2.64	1.69	64%	1.62	61%
13#	-5.1	3.4	1.62	48%	0.63	19%
14#	-5.99	2.51	0.78	31%	1.64	65%
15#	-5.78	2.72	0.13	5%	1.26	46%

5. Discussion

Sedimentation process is controlled by sediment factors (such as sediment source, sediment composition etc.), hydrodynamics and environmental condition [11]. The latter refers to the environmental changes caused by the implementation of hydraulic structures.

The observed data shows that the main component of the sediment in Pussur River is silt and clay which is suitable for long distance transportation. The measured suspended sediment concentration in Mongla section is as high as 1000-1500mg/l in spring tide. That means the supply of the sediment is very abundant in the river alluvial plain.

Hydrodynamic is the dynamic force for the exchange of suspended sediment and bed sediment. The flow velocity here includes effect of tides and runoff. Although, runoff has reduced result from less discharge from the upper mainstream after 1970s. Also tidal prism has decreased because of the empolderment schemes and settlement of the banks between the Sibsa and Pussur rivers. Yet, after decades of river channel evolution, the riverbed, flow and sediment are in a mutually adaptive relationship, and the river channel as a whole has been in a relatively stable state. The comparison of topographic data in recent ten years also shows that the main waterway of Pussur River changes little in erosion and deposition, maintaining a basically stable state, which provides basic conditions for channel development. That indicates that those historical reason is not the key factor to solve the problem of channel back siltation.

The mechanism of back siltation in the channel excavated can be explained by the following physical process. When the flow passes through the navigation channel, its velocity decreases with the increase of the water depth. And the transport capacity of the bed load and suspended load thus reduced in next. As a result, the bed-load particles and a certain amount of the suspended sediment particles are deposited in the channel [12]. Sediment, the velocity (sediment-carrying capacity) and geometric parameters of channel are the main factors of deposition, which are included in Equation (1). Therefore, for the channel with large excavation, the flow should be enhanced through hydraulic structures, so that the suspended sediment is not easy to settle in the channel.

From the forgoing, the regulating scheme studied can increase the velocity of the local sections, yet the velocity of the upstream and downstream of the structure decreases instead. In this way, the siltation of the upstream and downstream would increase in the opposite. Therefore, this scheme may not be the optimal one, and further optimization research is needed, which may be the key research object in the next stage.

6. Conclusions

Based on the analysis of the tide, sediment and topography of the waterway, the two-dimensional tidal current mathematical model is used to calculate and analyze the flow changes after the excavation of the waterway and the implementation of the regulating structure, and the sediment siltation of the waterway is estimated through the empirical formula.

The analysis shows that the river bed of Pussur is mainly composed of cohesive fine sediment; Due to the combined effect of runoff and tide, the velocity is as large as 1.20-1.60m/s in the main channel and SSC is as high as 1000 mg/l or so.

Although, runoff has reduced result from less discharge from the upper mainstream and tidal prism has decreased because of the empolderment schemes and settlement in downstream, the river channel as a whole has been in a relatively stable state, after decades of river channel evolution.

After the channel is excavated, due to the influence of dynamic changes and elevation gap between channel and nearby seabed, the siltation of the channel is about 0.70-1.79m/a near Inner Bar area and it is more severely in the upper section near Chalna. The implementation of the preliminary regulating structure can increase the velocity and reduces the siltation of the local section. Yet the siltation of the upstream and downstream sections may be added due to changes of flow with the structure. The further scheme should be optimized from the angle of increasing the velocity in channel and reducing the influence to upstream and downstream.

Acknowledgment

This paper is supported by the Basal Research Fund for Central Public-Interest Scientific Institution (No. Y220010) and National Key Research and Development Program of China (2018YFC0407502).

References

[1] Institute Water Modelling (IWM). Feasibility study for the improvement of navigability of the Mongla Port. 2004.

[2] Farleigh DRP. Pussur River study phase I, Final report prepared for Port of Chalna Authority, Mongla, Bangladesh. 1981.

[3] Farleigh DRP. Pussur River study phase II, Final report prepared for port of Chalna Authority, Mongla, Bangladesh. 1984.

[4] Farleigh DRP. Report on mathematical model studies, prepared for port of chalna authority, Mongla, Bangladesh. 1984.

[5] DHI. Mathematical model study of Pussur-Sibsa River system and Karnafuli River entrance, Final Report, Annex 1 & 2. Bangladesh Water Development Board, Ministry of water resources, Government of Bangladesh. 1993.

[6] Khulna University of Engineering & Technology. Feasibility study for dredging and river training in Pussur Channel of Mongla Port, Report prepared for Mongla Port Authority, Ministry of Shipping, and Government of Bangladesh. 2018.

[7] Md Motiur Rahman and Md Shahjahan Ali. Potential Causes of Navigation Problem in Pussur River and Enhancement. Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD-2018), 2018 Feb 9-11; KUET, Khulna, Bangladesh. 2018.

[8] Md Motiur Rahman and Md Shahjahan Ali. Hydrological characteristics of Pussur River and its navigability. Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD-2018), 2018 Feb 9-11; KUET, Khulna, Bangladesh. 2018.

[9] DHI. MIKE 21 & MIKE 3 flow model FM mud transport module scientific documentation. 2012.

[10] Institute Water Modelling (IWM). Updating and validation of general model and six regional models. 2002.

[11] Liu JJ. Research of coastal sediment transport and its application. Beijing: China Ocean Press (In Chinese); 91-96p. 2009 Apr.

[12] Van RLC. Estuarine and coastal sedimentation problems. International Journal of Sediment Research. 2005, May; 20(1): 39-51.