MORPHOLOGICAL CHANGES AT THE ESTUARY OF PUSSUR-SIBSA RIVER SYSTEM AND ITS RESPONSE TO DREDGING.

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ABSTRACT

Estuaries are hydrological features formed at the interface between land and sea, characterized by open connections to the ocean due to sediment deposition from river systems and coastal processes. The Pussur Sibsa river system in Bangladesh is crucial for environmental, hydrodynamic, and commercial considerations. The Mongla Port (MP) is located on the left bank of the Pussur River, which has an entrance channel called the "Zulfiquar Channel" that crosses a shallow area called the "outer bar." This outer bar is the only obstacle for ships of 9 meters and above to enter the anchorage area. The Pussur-Sibsa river system carries a high sediment burden due to monsoon-time freshwater flow and tidal pumping during the dry season. Numerous shoals, bars, and islands have formed within and around the entrance of the Zulfiquar channel due to the abundant sediment supply. The study area covers around 45 km at the entrance of the Pussur-Sibsa Channel, also known as the Julfiquar Channel, between latitudes 21°35.29' and 21°40.691', exposed to the open sea.

Dredging locations in the study area include Section-1 and Section-2, with the angle between dominant current direction and dredging alignment minimized to prevent re-siltation. Bathymetry from 2006-2017 showed a narrower shoal between the east and west channels, with a significant scoured way point between the deep sea and outer bar area. The west channel improved significantly, while the east channel's depth deteriorated. A further east side channel is improving but not suitable for alternative channels. Hydrographic survey charts from 2006-2019 showed Section-1 was almost stable at 7.5m depth over 1.5 decades, while Section-2 had mild scoured patterns. In 2020, these areas were dredged up to 8.50m CD depth, with two-thirds disposed near fairway buoys and one-third near Dubla Island. The average depth of Section-1 and Section-2 was 7.2m and 6.74m before dredging, respectively. Section 2 had a higher dredging thickness. Surveys from 2020, 2021, 2022, and 2023 showed less backfilling/siltation in Section-1 due to less cutting thickness and favorable flow direction. Section-2 had a higher cutting depth and was not fully aligned with flow direction. In 2020, the depth was reduced to 7.0m, and in 2022, to over 8.0m. In 2023, it again reduced to near 7.0m, requiring dredging. The actual siltation rate was higher than section-1, indicating immediate maintenance dredging is needed.

Keywords: *Estuary, Pussur River, Dredging, Siltation, Navigation*

1. INTRODUCTION

Estuaries are hydrological features that form at the interface between land and sea, characterized by one or more open connections to the ocean. They arise as a result of sediment deposition from both river systems and coastal processes (Leuven et al., 2016; Nicholls et al., 2020; Cox et al., 2022). Naturally formed estuaries typically exhibit a convergent planform configuration, characterized by the presence of interweaving ebb and flood channels that give rise to a complex multi-channel network (Jeuken & Wang, 2010; van Dijk et al., 2021; Weisscher et al., 2022). According to Leuven et al. (2016), these regions contain several intertidal shoals and bars, which are most prominent at their maximum width. Additionally, van Veen et al. (2005) note the presence of significant floodplains in the area.

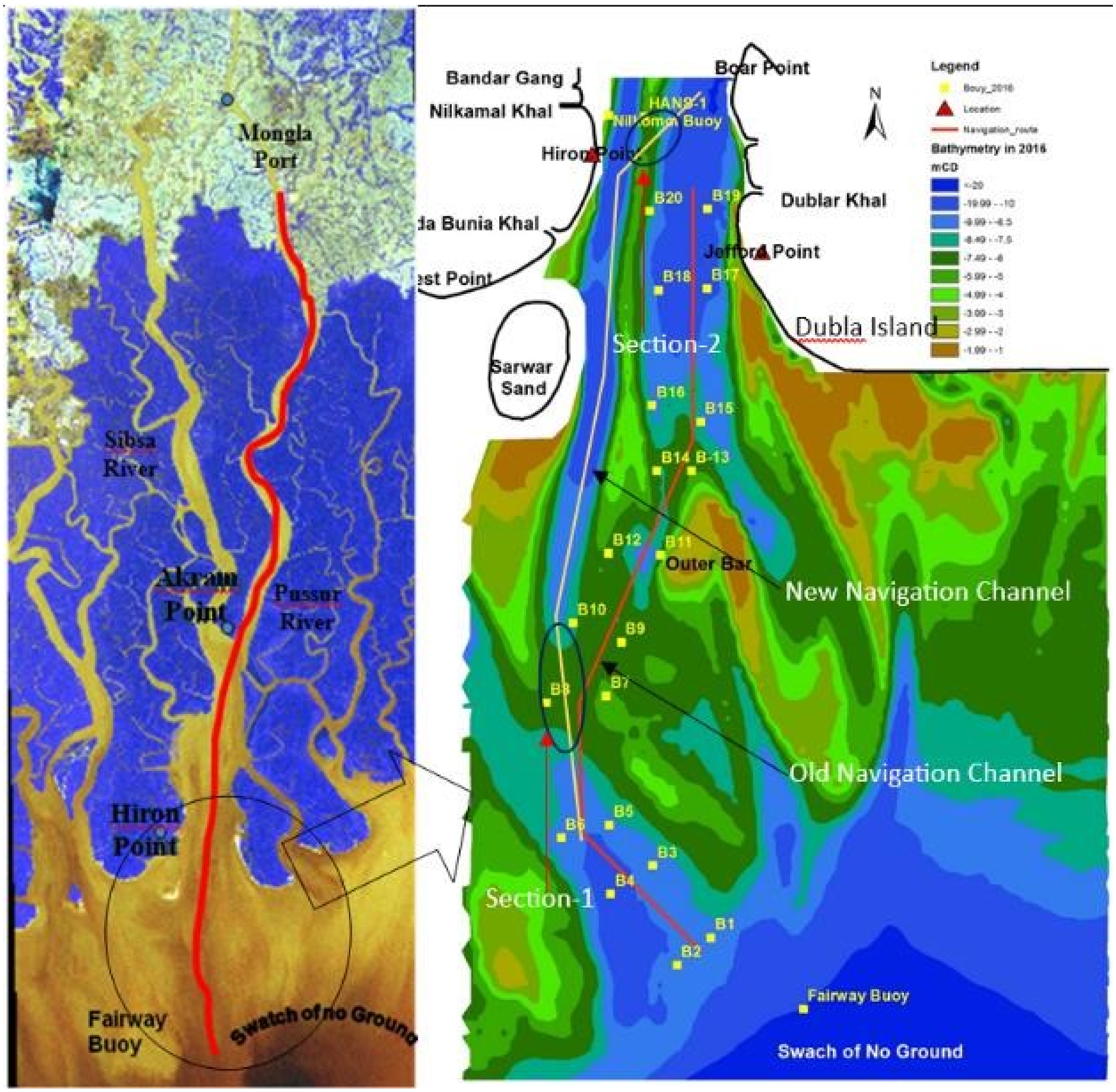

Figure 1: Location of Outer Bar (Source: IWM, 2004)

Pussur Sibsa river system in the southwest region of Bangladesh plays a vital role in terms of environmental, hydrodynamic and commercial consideration. The Mongla Port (MP), 2nd sea port of Bangladesh is located on the left bank of Pussur River. The entrance channel of Pussur-Sibsa river system is known as “Zulfiquar Channel” crosses a wide shallow area known as “outer bar”. Outer bar is the only obstacle for ships of 9 m and above to enter into anchorage area. Capital dredging followed by regular maintenance dredging is the only cost-effective option to keep the outer bar area navigable for deep draft vessel. Outer bar is comprised of a vast number of islands with interconnected tidal channels and backwaters. Significant monsoon-time freshwater flow in the Pussur-Sibsa river system carries a very high sediment burden. During the dry season, tidal pumping also brings massive amounts of sediment to the area (IWM, 2004). Numerous shoals, bars, and islands have formed within and around the entrance of the Zulfiquar channel as a consequence of the abundant sediment supply.

The northern point of the 'swatch of no ground', a very deep trough in the center of the seabed, is in close proximity to the Pussur entrance, and the bathymetry of the Bay of Bengal is connected to it. All channels' outlets appear to be directed towards this deep trough. Figure 1 depicts the configuration of the coastline, channels, and outer bar area as well as the bathymetry. The depth of the bar area varies between 0 and 4.5 meters (as measured by chart datum). Two deeper channels from the Pussur River enter the estuary, one to the east and one to the west. Upto 2016, the east channel was used for navigational purpose. However, the depth of that channel was declining due to enhancement on nearby shoals. IWM (2016) has studied the morphology and sedimentation pattern in both of the channels and suggested that dredging at two segments of west channel could give optimum result than dredging in east channel. Following that recommendation MPA has dredged outer bar area in 2020. After dredging few areas of dredged channel silted up quickly. This paper aims to study the historical morphological changes at outer bar area and its response to dredging.

2. Study Area and Methodology

The study area covers around 45 km at the entrance of Pussur-Sibsa Channel, which is also known as Julfiquar Channel. It exists between latitudes 21°35.29’ and 21°40.691’ beginning from Hiron Point and exposed to the open sea. Figure 1 shows the layout of the coastline, channels, the bar area and the existing navigation way together with navigation buoys. The outer bar consists of several shoals and two deeper channels, one is in west side and another in east side. These two channels are divided by a shoal, which was mainly formed by a sunken wreck called “Wreck Ocean Wave”. The ship named “MV Ocean Wave” was sunk in 1999 and several efforts has been taken to remove it, but could not be removed the full portion successfully. The previous navigation route at the downstream east side of the wreck is narrowing and swallowing and causes threat to the existence of the route. The study is based on the combination of primary and secondary data analysis. The analysis of secondary data such as hydrographical characteristics has used to find out the navigational problems. The siltation rate and pattern of morphological change has identified through chart analysis.

3. RESULT AND DISCUSSION

3.1 Characteristics of Outer Bar

The survey charts of 2006 to 2019 was analyzed to assess the pattern of morphological changes. Since the dredging was carried out in 2019-20, the pre survey charts, post survey charts and chart of 2021-23 has been analyzed to find out the siltation rate and morphological response to dredging. The long profile of east and west channel before dredging has presented in Figure 2. The east channel is and west channel follows same alignment upto 9 km from fairway buoy. The shoaling effect in west channel starts 3 km earlier than east channel. However, along the full west channel (upto Hiron Point) two segments of 7.2 km and 3.8 km i.e total 11 km is less than 8.5m CD. But along the east channel around 18 km is less than 8.5m CD. Considering the length and volume of dredging as well as the stability of Channel, the west channel was selected for dredging.

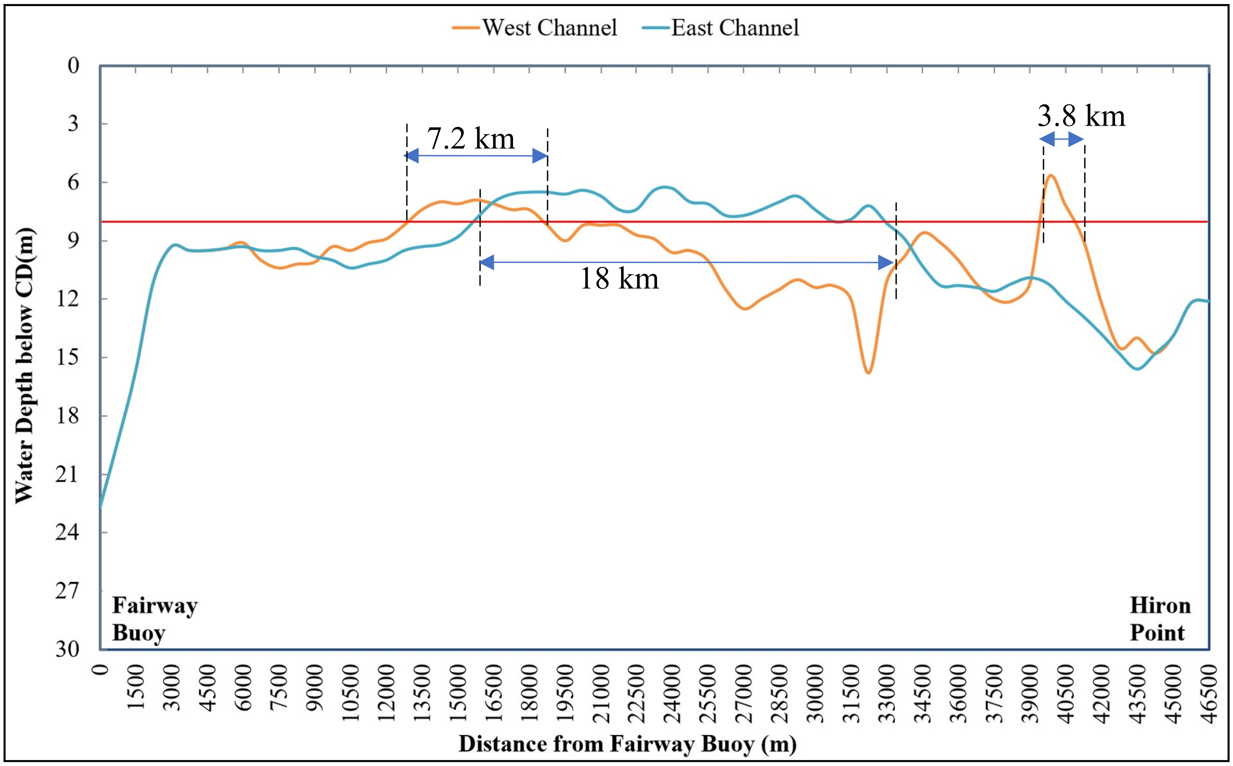

Figure 2: Long profile of east and west channel at Outer bar area.

3.2 Dredging Locations

The 1st part of west section is named as Section-1 (In the estuary) and 2nd part is Section-2 (Inside of Channel). Section-1 dredging length is straight and parallel to the dominant current direction, width of the navigational channel is less compared to the curved portion.

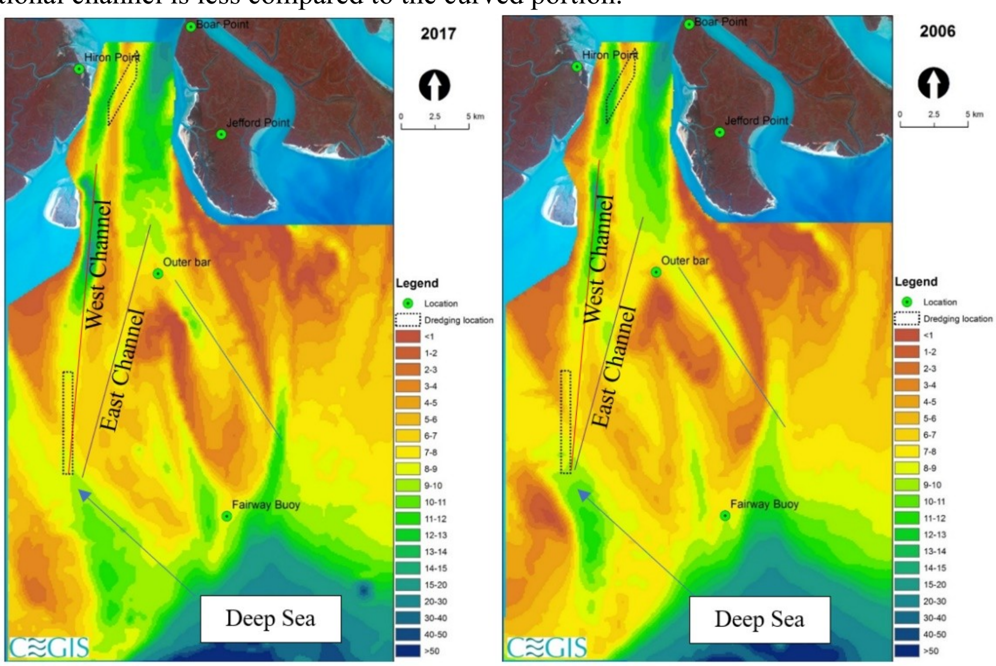

Figure 3: Morphological Changes at Outer Bar Area for the period 2006-2017 (CEGIS, 2020)
Section-2 dredging alignment is curved and not parallel to the current direction. Angle between dominant current direction and dredging alignment was minimized as much as possible to ascertain minimum re-siltation in the dredged channel.

3.3 Siltation pattern before and after dredging

The bathymetry of 2006 and 2017 of the study area has analyzed to observe the siltation pattern before dredging (Figure 3). In 2006, the shoal between the east channel and west channel was narrower than 2017. The way point between the deep sea to outer bar area has also scoured significantly in this period. The west channel has been improved significantly whereas depth of the east channel has deteriorated. In this period another channel is improving in further east side, however till now not suitable for considering as an alternative channel.

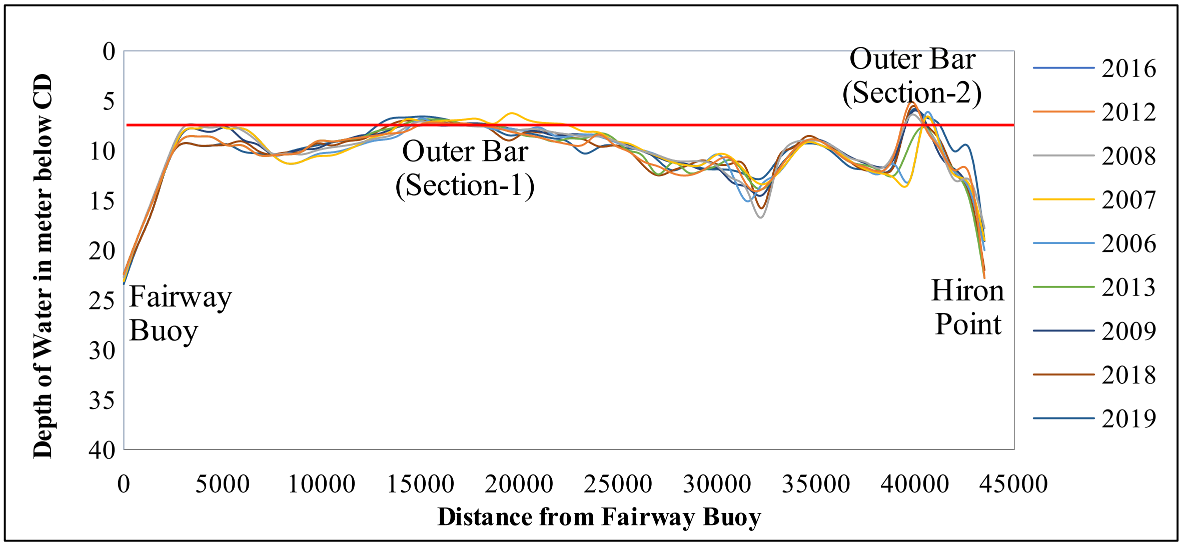

Figure 4: Long profile of West Channel for the year 2006-2019.

The hydrographic survey charts of 2006-2019 along the west channel has been analyzed (Figure-4). From the analysis, it's found that Section-1 is almost stable at a depth of 7.5m over the one and half decade. However, in Section-2, around has been scoured in mild pattern naturally. The average depth in this section is around 6.5m. These areas were dredged in 2020 upto 8.50 m CD depth. Two third of dredged material was disposed near fairway buoy where the water depth is more than 20 m. The remaining one third of dredged material was disposed near Dubla Island. The alignment, depth and dredged quantity of these two sections is described in Table-1.

Table 1: Dredging alignment, depth and Quantity of Outer Bar Area

Dredging Area	Length (m)	Width (m)	Average depth before dredging (m)	Dredging depth (m)	Dredged Quantity (Million cu.m)
Section-1	7260	520	7.2	8.8	6.28
Section-2	3820	740	6.8	8.8	5.63

Before dredging the average depth of Section - 1&2 was 7.2 m and 6.74 m respectively. The dredging thickness at section 2 was higher than section. The survey chart of 2020, 2021, 2022 and 2023 of outer bar area has analyzed to assess the effectiveness of dredging in that area.

Due to less cutting thickness and favorable flow direction, the rate of backfilling/ siltation at section-1 area is very less. The changes of bed level at section-1 area are presented in figure 5. After four years of dredging, that section is still navigable and ships having more than 9 m draft can cross in high tide. Depth at the middle of section-1 (Chainage 6000 m) has analyzed to assess the siltation rate. In 1st two year of dredging the siltation thickness was 0.2m and 0.3m. In 3rd year i.e in 2023 the siltation thickness was 0.5m. The average siltation rate was 0.33m/year. The north part of this section is more siltation prone than the south part.

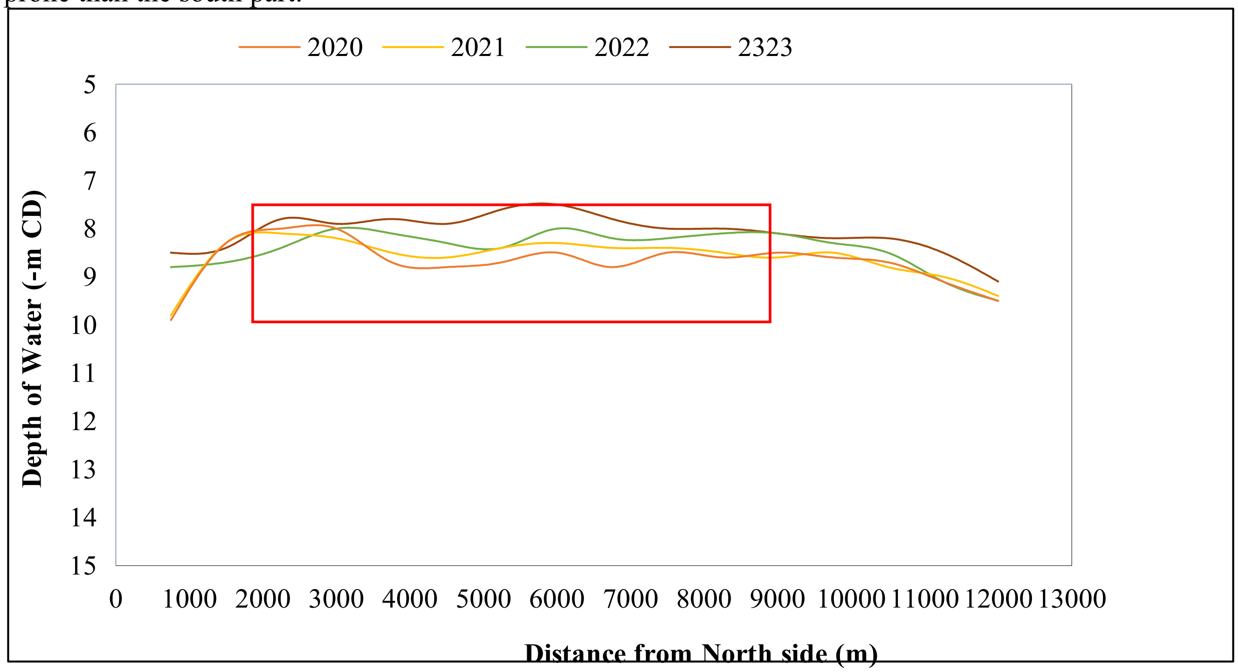

Figure 5: Long Profile of Outer Bar (Section-1)

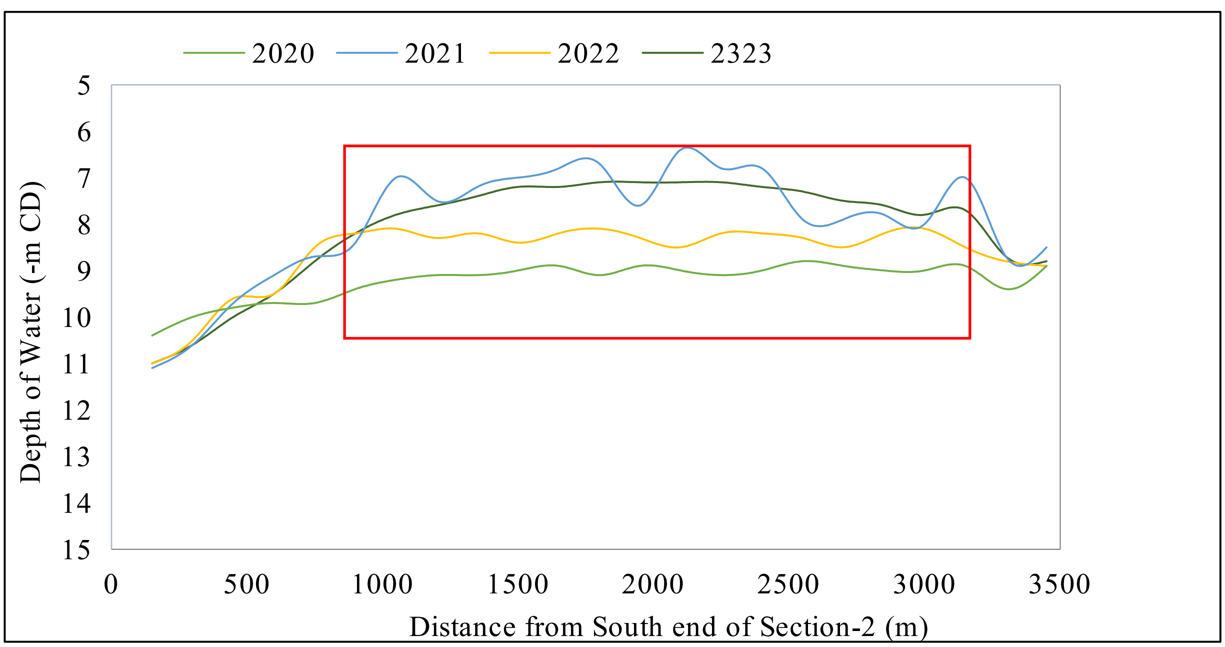

Figure 6: Long Profile of Outer Bar (Section-2)

Depth of cutting at section- 2 was higher than section-1 and was not fully aligned with the flow direction. In 2020, this section was dredged to around 9.0 m and after one year of dredging the depth was reduced to 7.0m. To keep the channel navigational, it was dredged to more than 8.0m in 2022. But in 2023 it has again reduced to near 7.0 m and need to dredge again. The siltation rate in this section is about 1-2m/ year. The comparative bed profile of this section is presented in figure 6. Based on the above analysis, the actual siltation rate in dredged channel was analyzed, which has been presented in Table 2.

Table-2: Siltation rate in the dredged channel of outer bar.

Dredged Section	Dredging Thickness (m)	Siltation in 1st year		Siltation in 2nd year		Siltation in 3rd year		Average Siltation Rate
		Thickness (m)	Percent	Thickness (m)	Percent	Thickness (m)	Percent	
Section-1	1.6	0.2	12.5%	0.3	19%	0.5	31%	21%
Section-2	2.2	2	90%	1	50%	1	50%	63%

The siltation rate at section-2 is much higher than section-1. However, the rate of siltation at section-1 is in increasing trend, which indicates that immediate maintenance dredging in that section is required to maintain the desired navigational depth.

3.4 Comparison of Predicted and actual siltation rate

Institute of Water modelling had carried the feasibility study of this dredging in 2016. Based on the morphological model results, time series hydrographic chart analysis, previous monitoring result, prevailing suspended sediment concentration, morphological history of the rivers and outer bar area the expected quantity of maintenance dredging and the frequency was assessed. According to that report the predicted siltation rate was 30-40% in each year.

The Center for Environmental and Geographic Information Services (CEGIS) was appointed by MPA as monitoring consultant of outer bar capital dredging. In the final report, CEGIS predicted 0.1m (6.25%) and 0.2m (12.5%) siltation in section-1 and section-2 respectively. However, the actual siltation is higher than this prediction. The comparison of predicted and actual siltation rate is presented in Table-3.

Table-3: Comparison of predicted and actual siltation rate

Dredged Section	Predicted siltation in IWM, 2016	Predicted siltation in CEGIS, 2020	Actual Siltation
Section-1	30%	6.25%	21%
Section-2	40%	12.50%	63%
Average of two section	35%	9.4%	42%

The comparison results show that, the siltation rate predicted in IWM (2016) was more realistic than CEGIS (2021) in long term. Sedimentation mainly depends on the sediment load, flow condition, etc. In monsoon, the flow is higher, and the bank erosion causes the increase of sediment load in the river flow. Based only on the modelling report its difficult to predict the siltation rate in a complex estuary system like Pussur-Sibsa estuary. Continuous monitoring survey could predict actual trend of siltation.

4. CONCLUSIONS

The study analyzed the siltation pattern before and after dredging in the Pussur-Sibsa estuary. The bathymetry of 2006 and 2017 showed a narrower shoal between the east and west channels, with the west channel improving significantly and the east channel deteriorating. Hydrographic survey charts from 2006-2019 along the west channel showed that Section-1 was almost stable at a depth of 7.5m over a 1.5-decade period. Section-2 had scoured in a mild pattern, with an average depth of 6.5m. The dredging thickness at Section 2 was higher than Section-1.

The survey chart of 2020, 2021, 2022, and 2023 assessed the effectiveness of dredging in the outer bar area. The rate of backfilling/siltation at Section-1 area was very less due to less cutting thickness and favorable flow direction. The depth of cutting at Section-2 was higher than Section-1 and was not fully aligned with the flow direction. The actual siltation rate in the dredged channel was much higher than Section-1, but the rate of siltation at Section-1 is increasing, indicating that immediate maintenance dredging is required to maintain the desired navigational depth.

The actual siltation rate was higher than the predicted rate of CEGIS but closer to IWM, indicating that sedimentation depends on sediment load and flow conditions. Continuous monitoring surveys could predict the actual trend of siltation in complex estuary systems like Pussur-Sibsa estuary.

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