Study on Morphological Change and Navigation Problems of Pussur River in Bangladesh

By

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A thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering in the department of Civil Engineering

Khulna University of Engineering & Technology
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May 2017

Declaration

This is to certify that the thesis work entitled *"Study on Morphological change and navigation Problems of Pussur River in Bangladesh"* has been carried out by *Motiur Rahman* in the *Department of Civil Engineering,* Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Acknowledgement

All praise and gratitude is to Almighty Allah, the most merciful. It is well known that for any accomplishment requires the sincere efforts of many people and this thesis is not out of this nature of the rule.

The author would like to express his profound respect, deepest gratitude and heartiest thanks to Prof. Dr. Md. Shahjahan Ali, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna, for his enthusiastic supervision, advice and guidance from the very early stage of this thesis as well as for guiding me to work on the honest way throughout the work. His encouragement, guidance, co-operation and constructive criticism in making this project a success. His helping with references and guidance in any type of difficulty that arose during the work helped me to complete the job successfully.

The author wish to express his heartiest thanks to the respective teachers of Department of Civil Engineering, KUET for their valuable suggestion and co-operation for making this thesis successful.

The author also convey special thanks to CPE division of IWM for helping me in my field survey and all of those who participate in the survey by spending their valuable time and helping to collect all the data on the various stages of the thesis. The author also likes to thank the Civil & Hydraulics Department and Hydrography section of MPA for providing a lot of secondary data and previous study reports.

Last but not least, the author solemnly acknowledges his parents and the family members, who gave him the utmost mental and financial supports throughout his whole student life and make a way to build up his career in the field of Civil Engineering.

May 2017 Motiur Rahman

Abstract

Pussur River is situated in the south western hydrological zone of Bangladesh. Mongla Port has established at the confluence of Pussur River and Mongla Nulla, approximately 71 nautical miles upstream from the Fairway buoy (approaches to the Pussur River) of the Bay of Bengal. It is the second gateway of Bangladesh was designed for an average 8.5m navigation draft. But after the construction of Jetties at Mongla Port, the depths in several areas of Pussur Channel reduced significantly and regular maintenance dredging is required to provide adequate depth alongside the berths, in the approaches to the berths and in the Southern Anchorage areas. The study investigates the temporal and spatial change of morphological behavior of Pussur River and to suggest some engineering interventions for sustainable navigation in the Pussur channel. The bathymetric charts of Pussur River surveyed for different years (2005 to 2016) from Chalna to Fairway buoy have been collected from Mongla Port Authority (MPA) and the siltation/scouring rate and pattern of morphological change has identified through the analysis. Some field studies are performed to collect some baseline primary data such as tidal variation of water level, suspended sediment concentration and bed material characteristics.

In the navigation route of Pussur River, the areal distance (straight) of Hiron Point to Chalna is 55 km where the channel length is 91 km. The ratio of channel length to straight length is found as 1:1.65, which implies that the channel is mildly meandering. From MPA Hydrographic charts, it is observed that the width of the Pussur River varies at different sections between 700 m to 3000 m and approach to Pussur is about 6000 m. The minimum depth is found to be varied from 1.4 m to 11.7 m below CD. It can be noted that the lowest depth is found at upstream (Chalna) that gradually increases towards downstream with the highest minimum depth at Mazhar Point to D'Suza Point and again decreases at further downstream near Outer bar. The maximum depth is found to be varied from 7.5m to 29.6 m below CD from upstream to downstream, respectively. At 0.8 depth from water surface, the concentration is found to be varied from 360 mg/l to 2096 mg/l in flood tide which changes inversely with water level and velocity. Sieve analysis of bed material shows that the Fineness Modulus (FM) of the collected 04 samples are 0.30, 0.60, 0.48 and 0.49 respectively i.e. the bed material is mostly sandy. From the average grain size distribution of bed material, d_{50} is found as 0.052 mm.

It is observed that the MPA jetty area and its approaches are mildly scoured where the upstream i.e Chalna to Digraj is being silted up. This upper segment is very shallow having depth about -1 to -5 m CD and have a siltation rate of 0.22 to 0.95 m/year. From 2008 to 2013, there was a natural deepening near jetty front and approaches (scour rate 0.20 m/yr) due to increasing of ship movement and increase of fresh water flow from upstream after Gorai river dredging. In 2014, jetty front of MPA was dredged upto 8.0 m CD which has silted up by 1.0 m within one year. But at upstream of jetty no.9 i.e at front of Kleenheat LPG jetty, the channel scoured naturally about 1.5 to 2.0 m between 2008 to 2015. MPA vessel berth and wreck pavlina area has not changed significantly after one year of dredging. The vessel berth area has found to be scoured about 0.5 m and the channel along wreck pavlina has silted about 0.25 m in west side and scoured about 0.75 m in east side in one year. The backfilling rate in mooring buoy dredging area has found very high. Near the danger khal the dredged area has filled up 1.5 m within one year. The main reason of siltation here is creating a deep pocket where the surrounding areas are shallower. The base creek area was dredged upto -5.2 m CD in the year 2014.

After one year of dredging the main navigation channel has not changed significantly. But the East side (Convex side) has deepened about 0.8 m naturally. The bed at Karamjol Forest Office (F.O) area is found to be naturally scoured more than 01 m in last 05 years. Similarly the Sultan khal area scoured more than 0.5 m in last 10 years. The food silo area has a mild siltation pattern with a rate of 0.2 m/year.

The river reach from Joymonirgoal to Harbaria is quite stable in last few decades. The navigation channel of this reach has sufficient draft for movement and anchoring upto 10.5 m draft vessel. This reach is the anchorage point of bulk cargo vessels. After Joymonirgol the river has found very much stable and have sufficient draft for 10.50 m draft vessel upto Hiron Point. After that, about 16 km river reach called outer bar between Hiron point to Fairway Buoy is very critical and don't have enough draft for more than 8.5 m draft vessel. After the cyclone in 1988, the outer bar has been raised up to 0 to 2 m and widening in the east-west direction and the trend is continuing until the recent year. At fairway buoy channel has sufficient depth for mother vessels (20-25 m draft). From fairway buoy to outer bar, this 16 km is quite stable in last few decades. At outer bar area presently shipping channel is on the eastern side of wreck ocean wave. But, this channel is being silted up and the shallow portion is extending towards east side day by day. In the downstream of buoy-14, the sedimentation rate at two points is found to be about 0.35 m/year. As a result the width of channel is also decreasing. However, in the west side of wreck ocean wave, the channel is quite stable is last ten years and in degrading type.

Capital dredging is required to get necessary draft for navigation from Sabour Beacon to Rampal Power Plant as well as for outer bar area to remove the sediment in the existing route or fix up a new route in the nearby area. The total volume dredged in Pussur River over the period 1979 to 2016 is about 12.872 Mm^3, which is equivalent to an average of 3,47,000 m^3 per year. Out of 37 years record, around 3.0 Mm^3 dredging was done in the Jetty Front to maintain the berthing pocket alongside the jetty. But, after every dredging the re-siltation rate becoming very high and it is becoming a very big challenge for the existence of Port. Therefore, only dredging could not sustain the channel effectively; Permanent measures such as structural interventions are essential for long term improvement of navigability. To improve the berthing pocket depth in front of the jetty, in addition to maintenance dredging, sheet piling could be proposed as a solution. The rapid siltation rate in front of the jetty is due to the sliding of the sediment from the jetty underneath. The main reason of siltation is low velocity of flood and ebb flow. If the velocity of flow could be increased in vulnerable sections such as MPA Jetty area and danger khal area, then the bed could be scoured naturally. Velocity could be increased by contracting the channel using structural interventions. For the canalization effect near the jetty area, spur dykes/groins/ guide bund opposite to jetty may propose as a structural intervention. The deflected flow due to the structural intervention in east bank may cause bank erosion at the upstream of the jetty area, a bank revetment may propose to prevent this. For the canalization of the Mooring Buoy area, structural measures can be proposed to close the western channel along the inner bar. For more effective result, a bank revetment at the eastern bank, opposite to inner bar may be required. However, these structural measures require in depth study to establish the effectiveness.

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Abbreviation

ADB	Asian Development Bank
ADP	Annual Development Programme
BIWTA	Bangladesh Inland Water Transport Authority
BMD	Bangladesh Metrological Department
BWDB	Bangladesh Water Development Board
BHP	Break Horse Power
CD	Chart Datum
CPA	Chittagong Port Authority
CSD	Cutter Suction Dredger
DHI	Danish Hydraulic Institute
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
FGD	Focused Group Discussion
FY	Fiscal Year
GMAPS	Global Maritime and Port Services Pte Ltd
HAT	Highest Astronomical Tide
GOB	Government of Bangladesh
HCF	Holcim Cement Factory
IND-BD	India-Bangladesh
IWT	Inland Water Transport
IWM	Institute of Water Modelling
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
ML	Mean Level
MLWS	Mean Low Water Spring
MLWN	Mean Low Water Neap
LOA	Length Over All
MP	Mongla Port
MPA	Mongla Port Authority
MTPA	Metric Ton Per Year
MW	Mega Watt
MT	Metric Ton
NE	North East
PP	Port Protected
RORO	Roll-On-Roll-Off
SOB	Survey Of Bangladesh
SW	South West
SE	South East
TBM	Tabulated Benchmark
TEUS	Twenty Equivalent Units
TG	Turning Ground
TSHD	Trailing Suction Hopper Dredger
WL	Water Level

Chapter 1

INTRODUCTION

1.1 General

Southwestern region of Bangladesh is bounded by the Ganges and the Lower Meghna in the east and by the Indian Border in the west and by the Bay of Bengal in the south. The coastal region of Bangladesh and the rivers in this region shows a continuing process of siltation progressing generally from northwest to southeast. The significant source of upstream freshwater at Mongla Port is flow through Ganges to Pussur. Pussur River is situated in South Western part of Bangladesh and Mongla Port is established on left bank of this river. Mongla Port, the second gateway of Bangladesh is the most eco-friendly seaport of the country, situated at the confluence of Pussur River and Mongla Nulla, approximately 71 nautical miles (about 131 km) upstream from the Fairway buoy (approaches to the Pussur River) of the Bay of Bengal. The Port is well protected by the largest mangrove forest known as the Sundarbans, part of which has been declared as "World Heritage" in 1997 by UNESCO. The Port provides facilities and services to the international Shipping lines and other concerned agencies providing shore based facilities like 5 (five) Jetty berths (total length 914 m), have a capacity of about 6.5 million tones general cargo/break bulk and 50,000 TEUS. The midstream berth (7 buoys & 14 anchorages) have a capacity of about 6.00 million tones. Total 33 ships can take berth in the Port (in the Jetties, buoys & anchorage) at a time. However, alike other modern port of the world Mongla Port is keen to provide highest port facilities, so that bigger draft ships can enter into the port channel safely.

Mongla Port was designed for an average 8.5 m draft ship. But after the construction of Jetties at Mongla Port, the depths in several areas of Pussur Channel reduced significantly and regular maintenance dredging is required to provide adequate depth alongside the berths, in the approaches to the berths and in the Southern Anchorage areas (IWM, 2004). 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 (Farleigh, 1981). Since 1979, several dredging efforts had been made to restore the navigability of the Pussur River. However, because of continued high siltation rates, none of the dredging efforts could sustain a navigable channel and requirement of maintenance dredging has been significant (Malek and Ashraf, 2004). Entrance to the Pussur River is about 6 miles wide at the mouth and has a bar over about 5 miles known as Outer bar where depth is about -6.4 m CD. Ships having draft up to 8.5 m can cross the bar in all seasons. The bar is relatively stable with sea bed elevation of -6.4 m CD. With the existing depth in the outer bar, maximum 8.5 m draft vessel can cross the outer bar and enter the port at normal high tide (IWM, 2013). But the depths over the anchorage area of the channel permit anchoring of 11 m draft vessels. Outer bar area is only obstacle for the ships of more than 10.5 m draft to enter into the anchorage area of Mongla Port.

Moreover Government of the Republic of Bangladesh has undertaken a project to set up a 1320 MW (2 x 660 MW) Coal based Thermal Power Project at Rampal in Bagerhat district of Khulna division, Bangladesh. The power plant is located at approximately at 13 km upstream of Mongla port on the left bank of Pussur River. The power plant is envisaged to be based on super critical technology and fuel envisaged for power generation is imported coal.

Around 5.00 MTPA of imported coal shall be required for the project which amounts to approximately 15,000 tons of coal movement per day through Pussur river channel. The Power plant authority plans to procure coal from Indonesia or Australia or South Africa or elsewhere. The coal will brought to Bangladesh in partly loaded mother vessels of approximately upto 55,000 DWT which will berth at Harbaria Anchorage/ Hiron Point Anchorage. But due to non availability of sufficient depth, coal from Harbaria Anchorage/Hiron point will be transshipped to feeder ship having draft approximately 7.50 m. Presently the water depth in upstream area of Mongla Port is about -4.5 m CD. After establishment of power plant, the navigation channel of Mongla Port will be extended another 13 Km.

Measures for effective and efficient management of the rivers in an active delta should be based on the morphodynamics of those rivers (Akter et al. 2013). Methods and tools used in the geomorphic assessment include analysis of channel geometry data, stage and discharge data, dredging records, sediment data, and natural events and anthropogenic influences (Little, 2010). Mongla Port Authority (MPA) has implemented three capital dredging project in the Pussur river between 1990 to 2014. But, after every capital dredging the back filling rate is very high and it is becoming a very big challenge for the existence of Port. Therefore, it is a very important task to understand the morphological characteristics of Pussur River along with navigational study.

1.2 Objectives

The overall objective of the study is to investigate the temporal and spatial change of morphological behavior of Pussur River and to suggest some engineering interventions for sustainable navigation in the Pussur channel. The specific objectives of this study are :

a) To study the previous bathymetric survey data and available hydrographic charts to characterize the change in morphological behavior of Pussur River.
b) To identify the venerable sections for navigation in Pussur Channel at Harbour and Outer bar area.
c) To study the effect of capital dredging for navigability of the river route.
d) To suggest potential engineering interventions as mitigation measures to reduce the effect of siltation for sustainable navigation in the Pussur channel.

1.3 Scope of Work

Scope of works of the study is given below:

- Primary and secondary data collection, i.e. river bathymetry & riverbank line, water level, water flow and satellite images;
- Review of available data and reports;
- Detailed analysis of hydrometric and river bathymetry data;
- Prepare bed profile (long & cross section) of Pussur River;
- Find out the most venerable sections of Pussur River;
- Analysis on shipping characteristics in Pussur river;
- Study on dredging history of Mongla Port;
- Analysis of siltation rate in dredging area;
- Assessment of effectiveness of dredging;
- Assessment of available navigation depth in the navigation channels;
- Propose some structural interventions to reduce navigation problem;

1.4 Organization of Thesis

The study comprises of Seven chapters including **Introduction**. A review of related previous studies is presented in **Chapter Two**. Brief description on existing conditions of the Study area and Methodology has explained in **Chapter Three**. In **Chapter Four** the behavior and Characteristics of Pussur River has presented. **Chapter Five** presents the Geomorphology of Pussur River where bathymetry of Pussur River, siltation rate and navigation condition of MPA has described. In **Chapter Six,** the causes of navigation problem, previous intervention and future plan of MPA to improve navigability, dredging history of the river and effectiveness of dredging are discussed based on the results obtained in previous chapters and information collected from MPA. Some potential measures to enhance navigability are also suggested in this chapter. **Chapter Seven** summarizes the findings of the study and suggests some recommendations for future research.

Chapter 2

LITERATURE REVIEW

2.1 General

Several studies in the past have been carried out where accessibility to Mongla port through the improvement of navigability in Pussur channel including options for dredging and other engineering measures in connection with sustainability were addressed.

2.2 Previous Studies on Hydrodynamic & Morphological Modelling

To improve the navigability as well as the efficiency of Mongla Port a lot of study has been carried out by local and international consultants. Farleigh (1984) carried out first detailed study on Pussur River in 1981-1984 along with mathematical modeling. The Danish Hydraulic Institute (DHI) also carried out another detailed study to establish the morphological behavior along with mathematical modeling in the year 1990-1993. The other international consultants carried studies on Pussur River are MacDonald (1998), Japan Overseas Consultants Co. Ltd. (1998), Wallingford (1984) , and NEDECO (1967) etc. National consultants are IWM (2004), IWM (2013), CEGIS (2013), WARPO (2001) etc. Some of these studies on navigability improvement part have been reviewed and are summarized in the following:

DHI (1993): Mathematical Model Study of Pussur-Sibsa River System and Karnafuli River Entrance

A comprehensive study on navigational constraints in Pussur River entrance and the river leading up to Mongla Port has been carried out through extensive field investigations and establishing MIKE 11 Mathematical Model (Hydrodynamic and Sediment Transport Model). The study has established that the significant increase in tidal range in Pussur River in Chalna and Mongla is the result of polder development in the region since the 1960's. It further concludes that the river system has adjusted to the changed conditions - hydrodynamically and indirectly morphologically. Thy system has not fully stabilized in a new equilibrium.

The study investigated 12 schemes to improve the water depth in the Pussur River. One group of schemes would affect the water depth in the whole Pussur River System; the other group comprises local measures, to improve the water depth at Mongla Port. With regard to the first group, DHI recommended in their Final Report, 1991, on the Pussur-Sibsa River System to carry out further detailed studies on closing one or more of the rivers connecting the Sibsa river and the Pussur river. Closing these connections is expected to increase the net sediment transport out of Pussur River which - in the long term - will be favorable for the navigation to Mongla Port. However, as noted in the DHI report,

"In the slow process of reaching these more favorable conditions large amounts of sediment have to be shifted around and may thereby for some time create serious deterioration of the navigability". Hence, eventually the whole Pussur River should have improved depth, but the process might take decades.

IWM (2004): Feasibility Study for Improvement of Navigability of Mongla Port

The study has formulated different engineering options for short and long term solutions for the improvement of navigability of Mongla Port by applying latest technology of numerical models associated with sophisticated field survey. Combination of several engineering interventions like dredging, constricting the channel and at places entraining the flooding and ebbing channels into a single channel by guide bundhs and tidal basins at suitable locations were studied together with the environmental and social impacts.

The study identifies that the required navigation depth in the channel from Maidara to Joymonirgoal does not exist. On the other hand, the river maintains a good navigable channel from Joymonirgoal to Hiron Point with minimum dredging at a few locations. The channel from Hiron Point to Fairway Buoy does not have the required navigable depth for 9m draft vessel. The study also identifies that Pussur River maintains two distinct channels, flood and ebb channel suggests the divergence of ebb and flood axes should be minimized as far as possible to get the full benefit of ebb and flood tidal energies without reducing tidal flux.

Finally, out of three studied options, option for Dredging (between Mongla port and Southern Anchorage) together with Canalization through Structural Interventions (Sheet pile along jetty, river training works between Mongla port and Chilla Bazar) and tidal river Management (tidal basins at right bank of Mongla Nullah and left bank of Pussur river) has been recommended at it was the most sustainable solution, technically feasible, environment friendly, economically viable and socially acceptable.

IWM (2013a): "Environmental Impact Assessment (EIA) of the Proposed Dredging Project at the Outer Bar area of Pussur Channel"

The study was carried out by Institute of Water Modelling (IWM) to assess the environmental impacts of the Proposed dredging Project "Dredging at the Outer Bar area in the Pussur Channel of Mongla Port".

The main objective of this study was to identify the likely potential impacts, both positive and negative, of the proposed interventions to quantify and where possible, value these so that they can be used in a multi-criteria analysis for rational decision making by the project authority and policy makers. The overall aim is to ensure that the recommended intervention is carried out in environmentally sound and sustainable manner and that the EMP recommendations are abide by the project proponent during all the phases of the project cycle.

The Pussur River forms part of a very big and complex river system. Numerous tributaries and channels connect the Pussur River with other rivers like Sibsa, the Ganges and Jamuna Rivers. Flow conditions in all these rivers determined the current and morphological condition in the Pussur River. The navigation channel at the Pussur River entrance crosses a wide bar known as outer bar. The bar is relatively stable with sea bed elevation of -6.4 m CD. With the existing depth in the outer bar, maximum 8.5 m draft vessel can cross the outer bar and enter the port at normal high tide. But the depths over the anchorage area of the channel permit anchoring of more than 9 m draft vessels. Outer bar area is only obstacle for the ships of 9 m and above to enter into the anchorage area. If the depth of the outer bar would be increased to make safe passage of 9 m draft vessels in normal high tide, Mongla port could handle more ships means handling of more cargoes. Before implementation of Outer Bar dredging it was mandatory to assess the potential impacts on the environment.

Disposal of dredged spoil has been one of the major challenges in this EIA study and is addressed involving technical, social and environmental considerations. Three potential alternative sites i) Dublarchar, ii) Sarwar sand Island and iii) Deep sea were selected and conducted comparative analyses against pertinent technical and socio-environmental parameters to choose the most preferred site for dumping of the dredged spoil. The analyses assessed deep sea as the most suitable site for disposal. In order to ensure safe disposal of the dredged spoil it is to be released during the low tide condition. The disposal of dredged spoil if released during low tide at the designated location will be guided to the deep sea. Trailer Hopper dredger has been preferred to be used in the dredging operation which will carry dredged spoil to facilitate dumping of the materials at the designated location.

The environmental study revealed that the proposed dredging in the Outer Bar area of Pussur Channel will not result any long-term significant adverse environmental impacts. Simultaneously the Social survey findings from FGDs, KIIs, public consultations and observations concluded that the dredging intervention has no direct negative impact to the local community. It was reported that the proposed dredging area is within fishing ground and dredging will ultimately enhance the capacity of catching fish, which would be a kind of livelihood augmentation. However, the likely negative impacts can be avoided through implementation of EMP to an acceptable level. Environmental and social benefits of the Project outweigh the negative impacts.

GMAPS Consortium (2011): Port and Logistics Efficiency Improvement

The main objective of this study was to identify critical areas for future project funding by ADB to further improve the efficiency of port operations and inter modal transport logistics so to enable these gateways to handle the project traffic volumes. Among other studies, Feasibility study on Mongla port for navigability improvement was also carried out. The feasibility study identifies the problems of navigability in 131 km navigation route in Pussur Channel from Fairway Buoy in the sea to Mongla port. It identifies the current status of navigation route and states that the harbor area of the port approximately 13 km from jetty to Base creek has been seriously affected by siltation. Presently 6 m draft vessel has the accessibility to Mongla Port as the harbor area gets silted up. However, Joymonirgol to Hiron point the channel has sufficient depth for more than 8 m draft vessel. From Hiron point to Fairway Buoy, the approach channel to Pussur River has accessibility to 7.5 m draft vessel.

During the study a comprehensive data collection programme on March 2011 has been made to collect bathymetry, sediment concentration, and water level, and discharge data at and around the Project areas. These data have been utilized to establish the baseline hydrodynamic and morphological conditions, for updating the existing and also developing two dimensional morphological models. The model simulates the impacts of the navigation channel with project condition and provided information on resiltation rate after proposed dredging including the changes in tidal volume. It also provides information on yearly maintenance volume.

Through various studies on navigability of Pussur river in the past, morphological changes in Pussur river between 2005 and 2010, present navigation problem and improvement in navigability, it recommends the following engineering interventions considering sustainability, social, environmental and economic view point.

- Capital dredging from Sabur Beacon to base creek and at two locations in the approach channel of Outer bar including maintenance dredging;
- Sheet piling at Jetty front to protect bank sliding;
- River training works (inner guide bundh at inner bar and opposite to Mongla Port Jetty, bank revetment at upstream of jetty, opposite to inner bar guide bundh and on western bank opposite to Mongla nullah confluence.);
- Two tidal basins - one at right bank of Mongla Nullah 7 km *u/s* of the confluence and the other at the left bank of Pussur River 10 km *u/s* of the port jetty.

IWM (2015): Feasibility Study of Capital Dredging in Pussur River from Mongla Port to Rampal Power Plant.

The main objective of this study was to identify definite alignments for dredging in Pussur River to achieve adequate depth for smooth and safe movement of vessel between Mongla Port and proposed Rampal coal terminal on the basis of hydrological, morphological, navigational and environmental considerations. The necessary coal for proposed power plant will be transported to the plant site at Rampal through Pussur river route from the sea coast at outer bar. Every day three coal borne vessels having draft of 7.5 m will be run along the route. In December 2014, MPA has accomplished dredging in the harbour area of Pussur channel and has ensured safe movement of 7.5 m draft vessels along Pussur River from Outer Bar up to Mongla port. However, at upstream of Mongla port, the river does not have sufficient depth for the vessels of 7.5 m draft. So, safe movement of coal borne vessels between Mongla Port and power plant site at Rampal was requires detailed hydrological, morphological, social and environmental studies.

During the study data collection programme has been made to collect bathymetry, sediment concentration, and water level, and discharge data at and around the Project areas. These data have been utilized to establish the baseline hydrodynamic and morphological conditions, for updating the existing and also developing two dimensional morphological models. The model simulates the impacts of the navigation channel with project condition and provided information on resiltation rate after proposed dredging including the changes in tidal volume. It also provides information on yearly maintenance volume.

IWM (2010a): Hydrodynamic & Morphological Modelling to Investigate Land Accretion & Erosion in the Estuary Development Program (EDP) Area

Based on the findings of previous studies, Bangladesh Water Development Board (BWDB) emphasized on sustainable development and land reclamation by engineering interventions for accelerating the natural land accretion processes in the coastal zone of Bangladesh. The understanding of the hydromorphologic behaviour of the region is crucial before undertaking any action in connection with a land reclamation proposal. In this context, BWDB engaged Institute of Water Modelling (IWM) to carry out 2D hydrodynamic and morphological modelling in the Meghna Estuary. Based on the general Bay of Bengal model updated with recent data, two additional models have been developed; one is dedicated to the Sandwip-Urirchar-Noakhali area and the other one is dedicated to the Char Maink-Montaz at south of the Bhola Island. Utilizing these three models, the baseline condition and the impacts of the potential cross-dams have been ascertained. The design parameters for the proposed cross-dams have also been provided on the basis of the model simulations.

IWM (2010b): Feasibility Study for Dredging (by dredger) of Khaprabhanga Chapalir Don River (Mohipur Channel) in the Kalapara Upazila under Patuakhali district for Improvement of Navigability

The main objective of the study for dredging Khaprabhanga Chapalir Don River is improvement in navigability, drainage condition, communication facility, safety for sea going launch and engine boats an local community.

The Khaprabhanga Chapalir Don River (Mohipur channel) is an important navigation route, which is situated in Patuakhali district under Kalapara Upazilla. The river is the main drainage channel of the polders 47/4 and 48. The total study area is about 15000 ha and falls in the Kalapara Upazilla under the administrative district of Patukhali. The Khaprabhanga Chapalir Don river connects the Andarmanik in the west and Rabnabad channel in the east. Both Andarmanik and Ramnabad channel are fall into sea. Tides come in the Mohipur channel from Andarmanik and Ramnabad channel. The river used to be the harbor for sea going engine boats and during cyclone engine boats used to take shelter in this river .At present the river has been experiencing huge siltation over the years and navigability of the river is almost lost. No boat can be entering from Ramnabad and Andarmanik Channel to the Mohipur channel during the ebb tide. For siltation in the riverbed causes the following acute problems:

- Normal navigability system has been hampering.
- Drainage system on the both side of the river has been deteriorated due to huge siltation in the river.
- Fisheries boats has been facing problem during cyclone & storm surge at low tide.
- The communication of Alipur- Mohipur port has been hampering for low navigable depth.

It recommends the following engineering interventions considering sustainability, social, environmental and economic view point.

- The whole 24 km of the Khaprabhanga Chapalir Don river is suggested to dredge at -5m, PWD (Option -2) to improve navigability for enhancing river borne trade, development of harbour, improvement of drainage of the polder 47 and 48 and socio-economic activities. The option-2 is technically feasible, economically viable and environment friendly

It is recommended for monitoring and quality control of dredging to ensure dredging as per planned location and desired section and to assess the maintenance dredging to maintain the navigation route for operation in round the clock. Monitoring will generate timely information and knowledge, which subsequently will enable decision makers to take corrective measures. The maintenance dredging may be required after 6 months for movement of 3.66 m draft ship during dry season.

CEGIS (2013): Optimizing the dredging in the Jamuna, Padma, Meghna and Arial Khan rivers and monitoring the activity including dredging volume calculation

Every year, the Bangladesh Inland water Transport Authority (BIWTA) requires dredging of about thirty to forty lac cumec of riverbed to maintain the Paturia-Daulatdia, Mawa-Charjanajat and Harinaghat-Alubazar ferry routes and the Paturia-Baghabari navigation route in the Padma, Jamuna, Meghna and Arial Kha rivers. The Rapid changes of the rivers in channel alignment or riverbed during the recession of flood often create problems in conducting smooth dredging works. The main objectives of this study were to maintain navigability with less interruption and to optimize the dredging quantity so that huge cost and time can be saved.

The study findings reveals that morphological changes takes place very rapidly in the rivers at the recession of floods during monsoon. Development and movement of bars along banks often occurs at the study ferry route sections. Attached bars develop at the riverbank due to bed or bar erosion at the upstream. These bars generally move downstream at a rate of 2 to 5 km/year. The presence of bars in front of the ferry ghats determines the dredging requirements at different ferry ghat areas.

It has been concluded that the quantities of dredging at Paturia and Daulatdia will vary with the position of the confluence of the Ganges and the Jamuna and with the movement sand bar. The formation and movement of the bars at the above two places can possibly be predicted and thus qualitative prediction on dredging requirement can be made. It is also concluded that the nature of bank materials along the right bank of the Padma Rivers makes the Char Janajat vicinity unstable. Formation and propagation of the sand bars are the controlling factors to smoothly navigating this ferry route. As a result, dredging quantity varies from year to year. The morphological changes in different rivers are not similar to each year. It has been found that understanding of morphological process is a pre-requisite to effective and efficient dredging works in morphologically active rives.

Based on the findings of the study, it is recommended:

- Close and intensive monitoring of riverbed movement through hydrographical surveys, float tracking of flow velocity and direction in all dredging areas of the Padma and the Jamuna rivers should be carried out;
- Higher Scale charts are very much essential for the quantification of the dredged quantity;
- Pre and Post hydroghaphic charts should be of similar scale;

- Digital hydrographic charts are very much essential to avoid erroneous activity in connection to the volume calculation. Hydrographic charts play a vital role in dredging activity;
- Computerization of hydrographic surveys to enable BIWTA to process data in the field and make necessary calculations very quickly.

IWM (2013b): Morphological Mathematical Modelling for Planning, Design, Monitoring and Quality Control of Dredging for Gorai River Restoration Project, Phase-II

The overall objective of this study is to support the Gorai River Restoration Project Phase-II (GRRP-II) during the capital and maintenance dredging operations through application of the state-of-the-art mathematical modelling tool and to evaluate the benefits of dredging on the south west region in terms of flow augmentation and reduction of salinity in the south west region of Bangladesh.

The Gorai River is an important source of fresh water supply to SWR that emerges from the Ganges, and is the only remaining major spill channel of the Ganges River flowing through this region. For the last 20 years or so, the dry season flow (November - May) in the Gorai River has been decreasing, and ceased to flow in one period of time (1988-98). After implementation of dredging during 1998, 1999 and 2000 (in Phase-I), the dredging increased the water flow in the Gorai River, restoring the fish population and allowing year-round navigation. Considering the morphological changes that already took place during the period of long gap, BWDB took up dredging of the Gorai (Phase-II) in 2010. The present study was formulated that is being conducted by IWM, due to its past working experience and involvement in the Phase-I, in order to support the project implementation office of BWDB.

It is recommended every year there should be maintenance dredging in the Gorai River. For the last four years, it has been observed that the silt is mostly deposited from G-K Ghat to Gorai Railway Bridge. In some places between Gorai Railway Bridge and Janipur, humps are developed near the Groynes every year. The dredging in first 12 km of Gorai River can be done on priority basis to increase the dry season flow volume. For the remaining length of 30 km, clearing of hump could be effective. The alignment could be fixed through bathymetric survey preferably following the thalweg of the river and later could be authenticated with the aid of mathematical modelling as done in the past. The same design section used in the maintenance dredging could be followed. The dredging should start during falling flood in October when the river sediment decreases significantly. Increase in river discharge by dredging during falling flood will increase the flow through the river and will help in carrying bed sediment to downstream areas. Monitoring on river cross-section, sediment concentration and flow need to be carried out for three years in Gorai downstream part and Pussur river system and for two years in Nabaganga, Atai, Rupsa and Kazibacha river system.

IWM (2013c): Detailed feasibility study for drainage and navigation improvement and sustainable water management of Bhairab River basin

The main objective of the study is to find the most feasible option for drainage and navigation improvement and overall water resources development and management in an integrated manner, which should take all possible technical, socio-economic and environmental aspects into consideration.

Sedimentation and encroachments are the main problems of the Buri Bhairab river that restricts the propagation of tide causing reduction of navigability and water availability eventually the water related facilities during dry season. The entire river stretch from Taherpur to Bashundia is silted up and encroached by local people at various locations. Other major causes of non- functioning of the river system are placement of fish trap, nets, construction of narrow bridge/culverts and putting cross dams. Dredging requirement needs to meet the criteria of draining the design flood flow of the basin, water availability and navigation requirements of cargo vessels. The required depth of the navigational channel for 2m draft cargo vessels is 2.2m. In the existing condition the navigation depth in the channel varies from 0.63m to 0.86m at the upstream stretches of the river, which implies dredging is required to improve the navigability of the channel and enhancement of water availability. Drainage problem prevails along the Dakatia khal under extreme flood event. Drainage problem is not significant in this study area. However, dredging would improve the drainage condition of the river and khals significantly.

In order to find the solution of the prevailing problems 3 options have been devised. The Option-1 includes mainly dredging/excavation of 68km of the Buri Bhairab river and dismantling of the narrow encroachment. A regulator and navigation lock is considered in Option-2 in addition to the dredging/excavation as included in Option-1. In option-3 a large pump house is considered at Afraghat to pump water from Bhairab river in addition to the interventions in Option-2.

Option-1 is suggested for implementation for enhancing navigability, water availability and improving drainage conditions of the Bhairab river since it is technically feasible, economically viable, environmental friendly and socially acceptable.

IWM (2014): Techno-Economic Feasibility and Environmental Study for the Development of Sea Port at Rabnabad Channel in the Patuakhali District

The main objective of the study is to carry out Techno- Economic Feasibility Study and Environmental Impact Assessment of the sea port at Rabnabad Channel in the perspectives of technical, economic and environmental conditions.

The coast line of Bangladesh is about 710 km and there is no port in the central coastal zone. Economic and social development would be enhanced rapidly in this zone if a sea pot is established. International sea borne trade of Bangladesh has been using two existing sea ports, with about 92% passing through Chittagong Port. The Main port installations of the Chittagong Port are situated along the banks of the river Karnafuli about 16 km from its outfall into the Bay of Bengal. The Mongla Port is located at the confluence of Pussur River and Mongla Nulla about 131 km inland from the Bay of Bengal. There is no opportunity or place to build new port either along Karnafuli river or Pussur river. The coast line of Bangladesh is about 710km and coastal area is characterized by many tidal rivers, which can be utilized in development work for enhancement of economic growth of the country and creating employment opportunity of growing population of Bangladesh. The following key benefits are envisaged through the development of the Sea Port and at Rabnabad Channel:

- generation of opportunities of industrial development
- export of agricultural goods will be faster and easier
- easy fish processing and export will enhance employment opportunity
- enhance economic network in the country
- enhance international trade facilities

In order to select the best suited site for port development, two candidate sites; one at the right bank of Rabnabad Channel and the other at Baleswar river estuary have been selected and investigated considering hydraulic and morphological characteristics, available water depth, potential for industrial and regional development, conceptual design, cost etc. These two (2) candidate sites have been evaluated by the weighted scoring system based on literature review and in consultation with professionals of different disciplines as required for the study. According to site evaluation results Rabnabad Channel scored the highest point of 80.90 and selected as the final site. The main advantages of the site are land availability, favorable inland road and river transport access, navigability and shorter length of approach channel. The disadvantages are the area is prone to cyclone and the approach channel is within the accretion area.

Best suitable alignment for approach channel has been selected considering dominant current direction, available navigation depth, capital and maintenance dredging. The estimated length of approach channel is about 59 km and the amount of capital dredging is 58 Mm^3. Capital dredging has been determined considering 3-hr tidal window and the approach channel design was conducted according to PIANC guideline. Allowable draft and length of the ship are 10 m and 250 m respectively. Maximum carrying capacity of the vessel is 30,000 - 40,000MT. The design depth of the navigational channel is 11m and top width is 500 m and bottom width is 284m. Current and wave conditions are favorable for vessel operation but the approach channel is in accretion zone and needs regular maintenance dredging.

2.3 Summary

Most of the studies stated above are directly related with dredging and concluded with requirements of large quantity of maintenance dredging. In most cases the observation period after dredging is not enough to understand the actual morphology of River. Moreover all studies are based on mathematical modelling which need to reflect with physical modelling.

Chapter 3

APPROACH AND METHODOLOGY

3.1 General

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.

3.2 Study Area

The study area covers about 149 km navigation route of Pussur River from Fairway Buoy (Bay of Bengal) to Chalna. The Rampal power station is a proposed 1320 megawatt coal-fired power station located at Rampal Upazila of Bagerhat District and 13 km upstream of Mongla Port. Mongla Port is situated on the east bank of Pussur River about 131 km upstream from the fairway buoy. Figure 3.1 shows the study reach of Pussur River.

3.2.1 Climate

In this study, the relevant climatic data is collected from the meteorological station at Mongla, maintained by the Bangladesh Meteorological Department (BMD). Different meteorological data, such as: temperature, humidity, rainfall and wind speed are summarized in the following paragraphs.

3.2.2 Temperature and Humidity

To assess the climatic condition of the study area climate data of Mongla, the nearest meteorological station maintained by the Bangladesh Meteorological Department (BMD), have been investigated. For this purpose temperature, humidity, rainfall and wind speed data have been analyzed (Table 3.1)

The climate of the area is characterized by a pronounced tropical monsoon climate with wet, hot, and humid summer months from March to October followed by a cooler, drier winter period. Temperature rises to its peak in April and drops during winter, generally reaching the lowest in January in Bangladesh. Analyzing the climate data in the study area it has been found that temperature varies between 13.5°C and 34.9°C, with an annual average of 26.8°C, which is slightly higher than the national average of 26°C. The relative humidity is the lowest (73.1% - 67.5%) during December to March, and from April there is a steady increase till July. The annual total rainfall of the study area (Mongla data averaged over 25 years) is approximately 1908 mm, about 88% of the yearly rainfall occurs during May to October and 36% of the total rainfall during June-July. The predominant wind directions in the study area are from south during March to October with minimum speed (0.94 m/s) in October and maximum speed (1.91m/s) in May.

Table 3.1: Climate Data of Study Area

Station		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Avg.
Temperature (^{0}C)														
Mongla	Max	24.8	28.7	33.5	35.8	34.9	33.1	32.2	32.1	32.6	31.7	29.9	26.2	31.3
	Min	13.5	16.5	21.1	24.9	26.4	26.8	26.8	26.5	26.3	24.3	19.1	15.5	22.3
	Mean	19.1	22.6	27.3	30.3	30.7	29.9	29.5	29.3	29.5	28	24.5	20.8	26.8
Relative Humidity (%)														
Mongla	Mean	70.9	67.5	70	75.7	78.2	85	86.5	86.4	85.6	82.6	76.1	73.1	78.1

3.2.3 Rainfall

Rainfall varies significantly between the wet summer monsoon months and the dry winter months. The average annual rainfall of the study area (Mongla) is approximately 158.9 mm, with about 88% of the mean annual rainfall occurring during the period from May to October, and 36% during June – July (Table 3.2).

Table 3.2: Mean Monthly and Annual Rainfall (mm) (1991-2015)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual average
Mongla	11	24	38	58	178	342	378	330	331	178	37	3	159.0

3.2.4 Wind Speed

The predominant wind directions in the study area is from south during March to October with minimum magnitude of 0.94 m/s in October and maximum of 1.91 m/s in May are shown in Table 3.3.

Table 3.3: Mean Monthly and Annual Average Wind Speed and Direction (1991-2015)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Wind Speed (m/s) and Prevailing Wind Direction												
Wind Speed (m/s)	0.86	0.97	1.12	1.68	1.91	1.61	1.77	1.58	1.32	0.94	0.74	0.81
Wind Direction	NW	NW	S	S	S	S	S	S	S	S	N	N

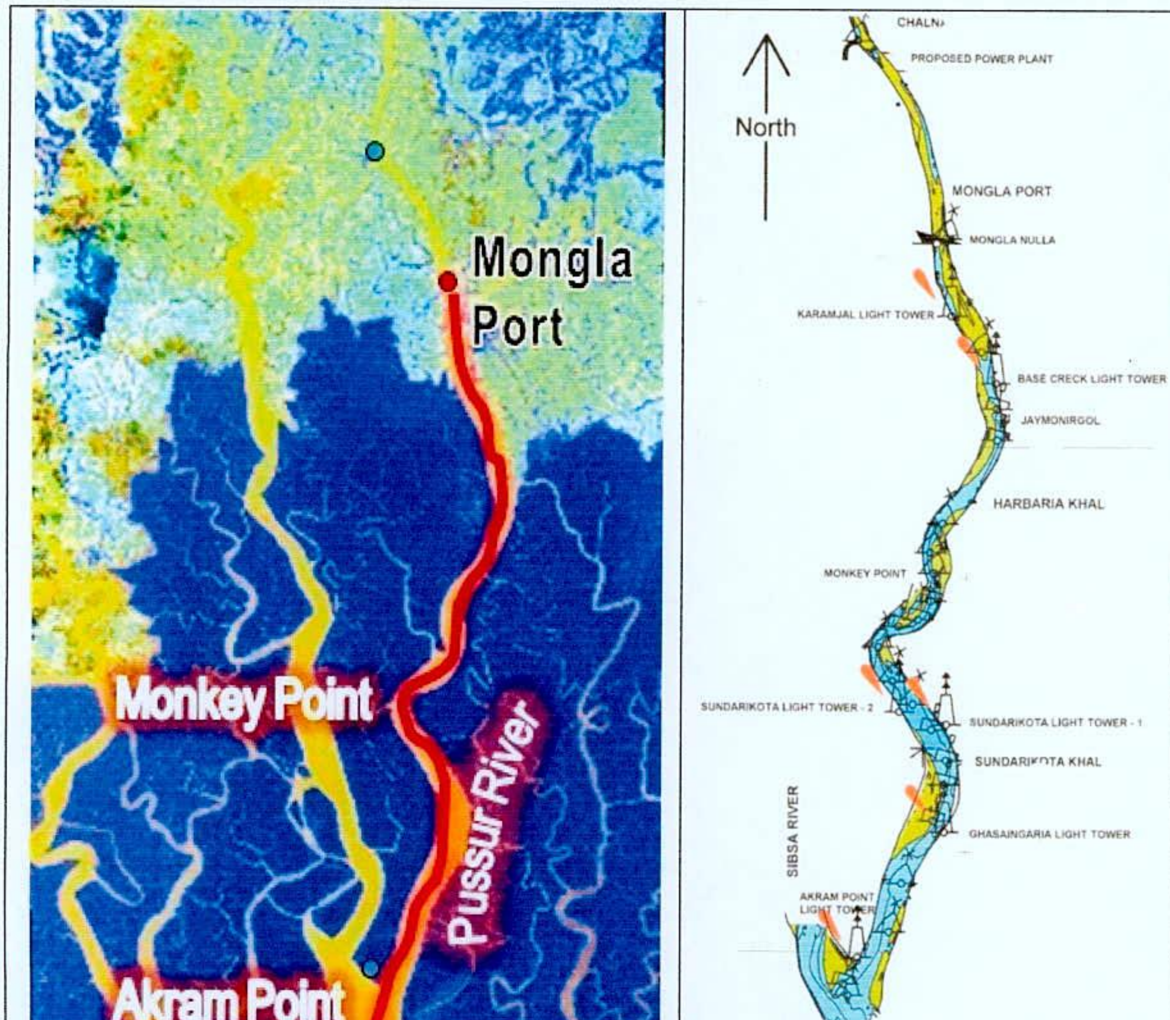


Figure 3.1: Study reach of Pussur river

3.3 Data Collection

Data collection comprises the primary data collected from the field and secondary data from different sources. Bathymetric data surveyed by MPA is the main secondary source of the bathymetric data. MPA bathymetric charts surveyed for different years from Chalna to Fairway buoy have been collected to analyse the past changes in the morphology of the Pussur River. The hydrographic Chart of Pussur Channel collected from MPA for detailed analysis has described in Table 3.4 and details of primary data collection has described in Table 3.5.

Table 3.4 : List of Hydrographic Charts Collected from MPA

Sl.	Chart No.	River Reach	Year
01	MPA/AP/1	Fairway Buoy to Hiron Point	2006, 2007, 2008, 2012, 2014, 2016
02	MPA/HP/2	Hiron Point to Tinkona Dwip	2008, 2012, 2013, 2014, 2016
03	MPA/AK/3	Tinkona Dwip to Kagaboga Khal	2015
04	MPA/SK/4	Kagaboga Khal to Sundorikota Khal	2015
05	MPA/CK/5	Sundorikota Khal to Cheilabogi Khal	2015
06	MPA/MP/6	Mazhar Point to D'Suza Point	2015
07	MPA/HB/7	Harbaria to Joymonirgol	2015
08	MPA/SAC/8	Base Creek to Mongla Nulla	2005, 2010, 2011, 2014, 2015
09	MPA/AC/9	Mongla Nulla to Digraj	2005, 2010, 2011, 2014, 2015
10	MPA/CLN/10	Digraj to Chalna	2013, 2015
11	MPA/HP-CB/12 (a)	Hiron point to Cheilabogi Khal	2008
12	MPA/CB-D/12 (b)	Cheilabogi Khal to Digraj	2008

Table 3.5 : Details of Primary data collection

Sl.	Events	Specification	Location	Description
01	Water Level	24 Hourly at 1 station	Dacope (Chunkuri)	At 1 Stations for 07 days from 01 July to 07 July 2015
02	Bed sample	04 bed sample were collected	Between MPA Jetty to Chalna	Bed materials were collected from MPA Jetty to Chalna area.
03	Discharge	13 hours at 30 m interval	Mongla	Tide measurements were done during Spring and neap tide
04	Velocity	13 hours at 30 m interval	Mongla	Tide measurements were done during Spring and neap tide
05	Suspended Sediment	13 hours at 01 hour interval	Mongla	Spring Tide

The primary data was collected in collaboration of Institute of Water Modelling (IWM) using their equipments.

3.3.1 Water Level Observation

Water level at one location of the study reach has collected by installing pressure cell as well as by installing staff gauges for cross checking. The gauge reading has taken by gauge readers and as well as automatic recoded by pressure cell. The gauges were connected from a nearest TBM which connected again from the existing SOB Benchmark. Observations have taken for one week. The purpose of water level collection is to understand the flow profile of study area.

3.3.2 Bed Sample Collection

The bed sampling has made from 04 planned locations. These samples have taken to the laboratory for analyzing grain size distribution. Samples have selected for analysis to make the determination of limits of areas with sand bed and silt bed.

The sampler consists of cupped jaws that close to trap a sample of bed material. Closure of the jaws is obtained either by a pull on an auxiliary line or by an automatic spring arrangement. The grain size distribution of bed materials are usually estimated by sieve analysis. In the case of most cohesion less soils (gravel, sand and silt), distribution of grain size could be determined by sieve analysis. Cohesive soils (clay) cannot be separated by sieve analysis into size categories because no practical sieve can be made with openings so small; instead, particle size may be determined by observing settling velocities of the particles in the water mixture.

Sieving through a 63 microns sieve separates samples for grain size analysis. The portion above 63 microns is analyzed by dry sieving and the portion below 63 microns is analyzed by observing settling velocity of the sediments in Andresen Settling Tube. Tests were carried out in IWM laboratory.

3.3.3 Discharge and Velocity Measurement

The Pussur River is a tidal river. The tidal discharge and velocity was measured with the help of Aqoustic Dopler Current Profiler (ADCP). The ADCP was attached with a boat. The boat travels along the measuring transect. The ADCP machine creates a sound frequency that travels through the water and comes back bouncing from the river bed. The returned frequency deviates from the original. The change of frequency is proportional to the current flow. The time lag of the reflected sound is related to the depth of the river. As the boat moves forward, the ADCP continues its process and calculate the whole discharge and velocity along that transect.

3.3.4 Measurement of Suspended Sediment Concentration

The river water sample (1 liter) had collected in each vertical at 0.2, 0.6 and 0.8 of the total depth using point integrated pump bottle system. The sediment samples were analyzed in the laboratory for total suspended sediment concentration (mg/l).

3.5 Analysis of Hydrographic Charts and Assessment of Morphological Characteristics

MPA historical and recent hydrographic surveys of the navigation routes in Pussur River has analyzed to assess the trends of morphological changes at the potential sites over the years. Based on the availability of the hydrographic charts, erosion/ deposition scenarios were assessed at different year interval.

3.6 Assessment of Effect of Dredging and Siltation Rate

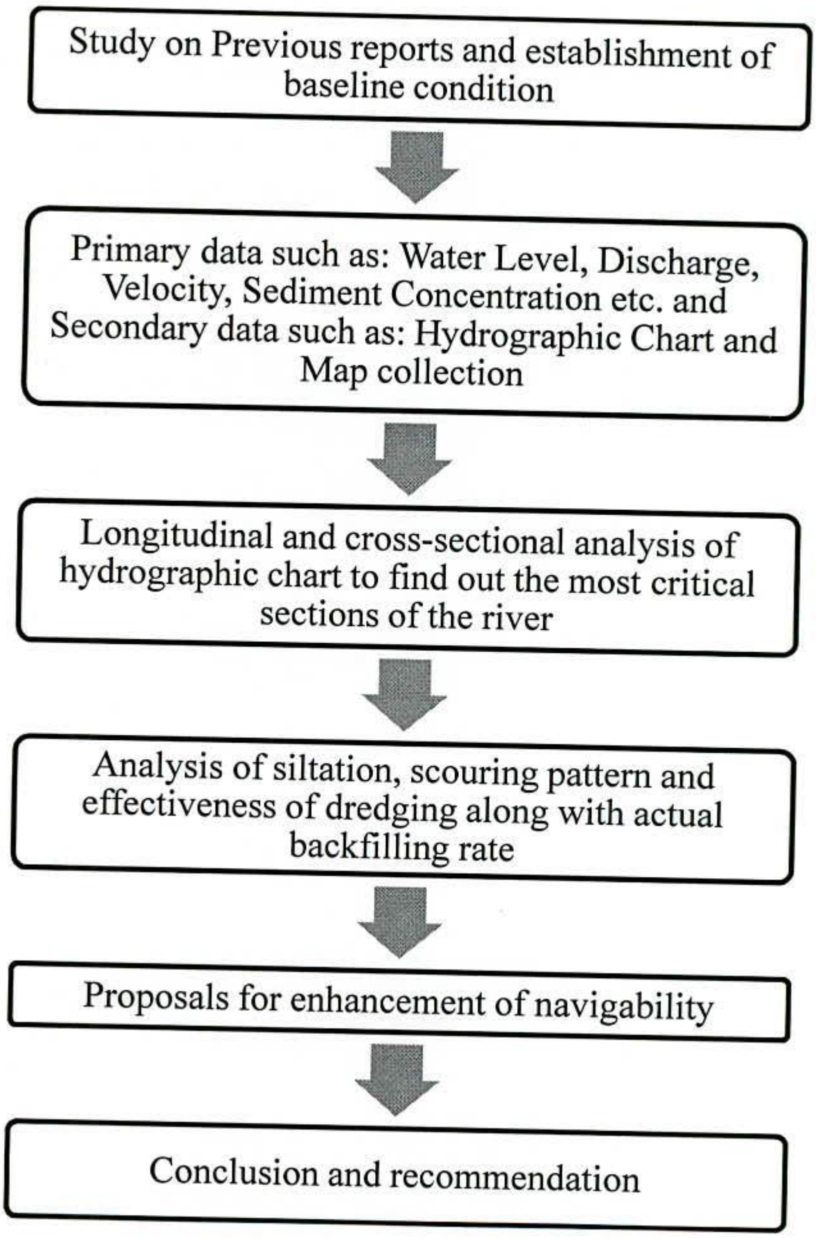
To assess the effectiveness of dredging and rate of siltation, hydrographical chart of several dredging areas before and after the dredging has analyzed. Longitudinal profile of the selected reach and cross section in both dredging area and outside of the dredging area has prepared to assess the effect of dredging. The rate of siltation/ scouring also identified based on the hydrographic chart analysis.

3.7 Proposal for Interventions

From the hydrographic chart analysis, the most vulnerable sections were identified. Then some structural/non-structural interventions to sustain the navigable depth were proposed. Proposed interventions are mainly based on the qualitative judgement and available previous studies for navigability improvement.

3.8 Overall Methodology

The overall methodology of the study can be summarized as follows:



Chapter 4

PUSSUR RIVER AND ITS NAVIGABILITY

4.1 General

The Mongla Port on the bank of Pussur River, is situated in the Southwest region of Bangladesh. The southwest area is bounded by the three major rivers (the Ganges, the Padma and the Lower Meghna) in the east-north, in the west by the Indian border and in the south is the Bay of Bengal. The Gorai River is the only remaining major spill channel from the Ganges. The Gorai is important because of a number of functions such as salinity control, maintenance of a large tidal volume at the head of the Pussur Sibsa system, and influencing the siltation rates in the tidal zone. The reduction in dry season flows in the Ganges distributaries to the southwest region is the most serious threat to the region.

4.2 River Systems in the Southwest Region of Bangladesh

The main southwest regional rivers are the Gorai-Madhumati and Gorai-Bhairab river that feed to the Pussur-shibsha river system. The Arial Khan River is in the South Central region, feed into the Baleswar, Bishkhali, Lohalia and Tentulia channels. These regional rivers play a key role in maintaining the health and vitality in the Area and detrimental changes must be guarded against. The tidal areas of the Southwest are characterized by large estuaries such as the Pussur-Sibsa, Malancha and Raimangal / Hariabhanga (marking the border with India), those are interlinked by numerous smaller channels and are sustained by tidal spill, fresh water flows. There is existence of differences in the time of tidal propagation, those causes net flow from one estuary to another. The western part of the area is saline even during the monsoon season, whereas the central part (Pussur Sibsa) is fresh during the monsoon and increasingly become saline at rest of the year. The eastern rivers are fresh due to high net flow from the Meghna though there is limited saline intrusion at the coast. Watercourses from the Ganges to the Pussur flow through the following branches: Gorai-Modhumati, Nabaganga-Atai, Atharabanki, the Atai and Bhairab join near Khulna and proceed as Rupsa, Kazibacaha and Old Pussur River to the Chalna.

The Gorai River is the major distributary of the Ganges River in the right bank and important provider of fresh water inflows to southwestern region of Bangladesh. It is an important source for maintaining both of the environment and economy of the region. It has a meandering and braiding tendencies. The length of the river is 199 km. The area of the Gorai river catchment area is 15160 km². The Gorai River is bifurcated into two streams at Bardia and its flow is distributed between the Nabaganga and Madhumati rivers. The Gorai-Modhumoti branch used to discharge into the Bay of Bengal through the

Madhumati and Baleswar Rivers (Figure 4.1). The Gorai-Nabaganga, is the another drainage path of the Gorai water, which now reaches the Bay mainly via the Passur and Sibsa rivers. It also brings fresh water in the region through Bhairab and Mathbhanga Rivers. In the downstream of Bardia, the Kumar River (which is a branch of Arial kha River) is connected with Modhumoti River.

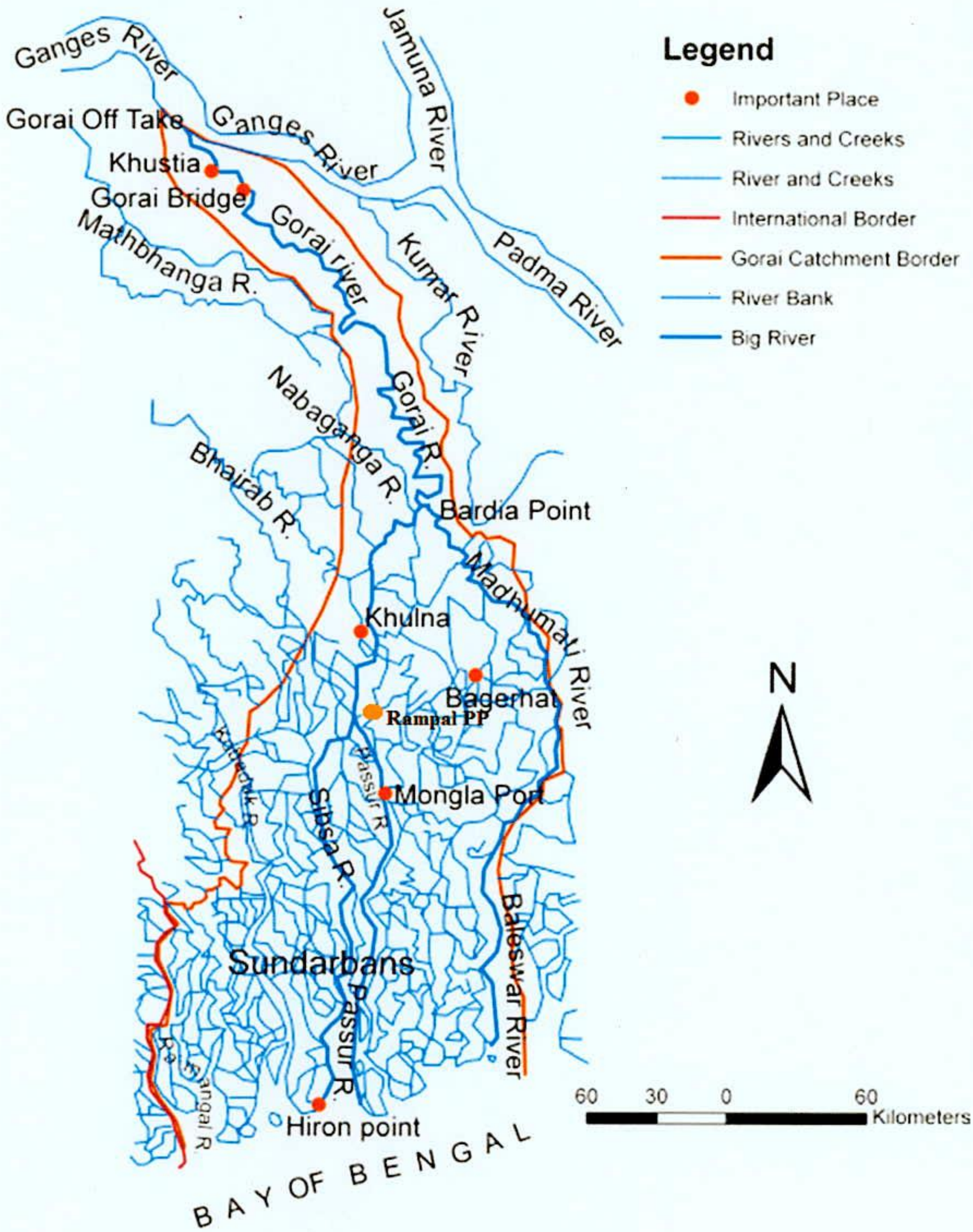


Figure 4.1: River System in Southwest region (Islam and Gnauck, 2008)

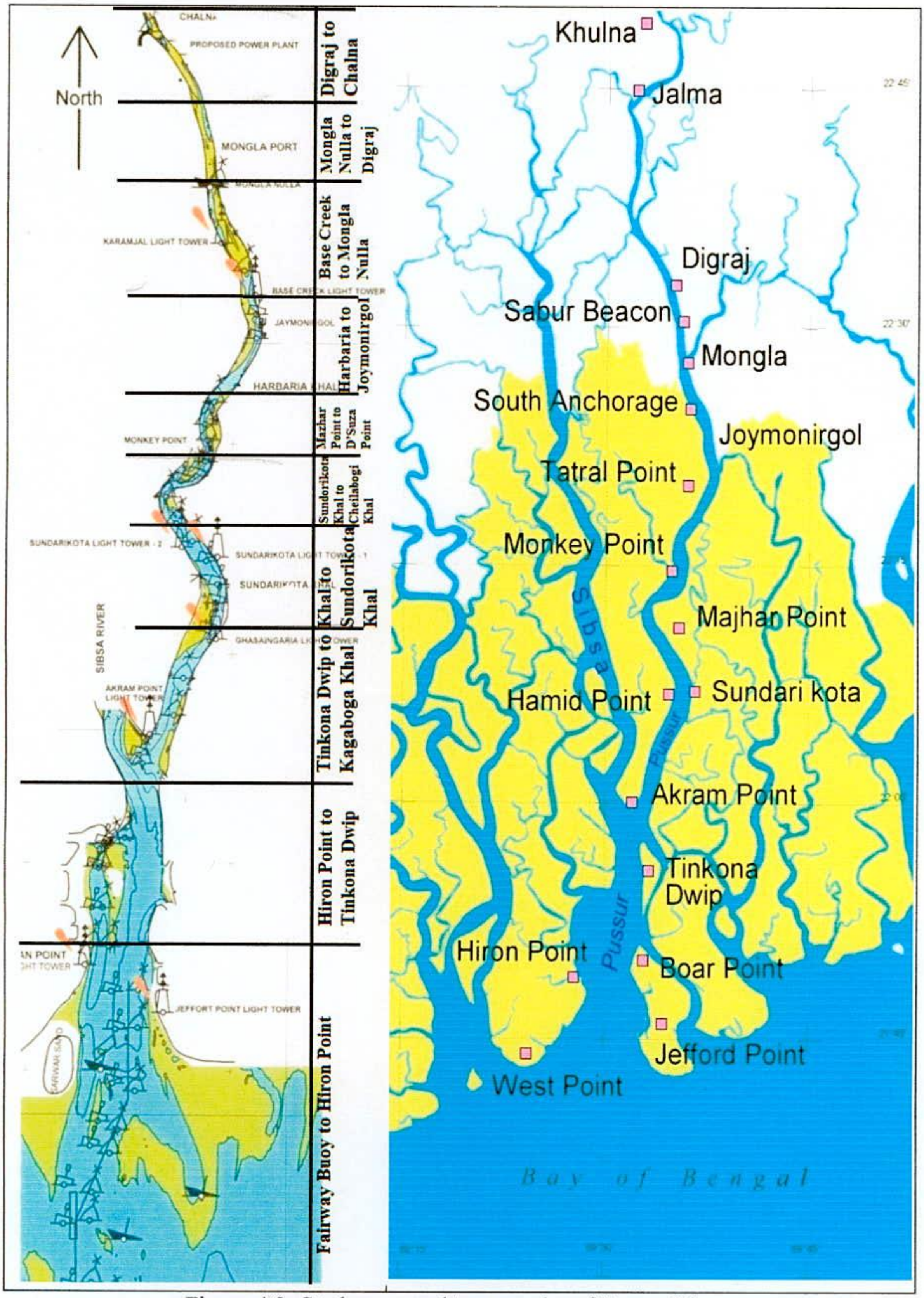


Figure 4.2: Study area and topography of Pussur River

4.3 River System near Mongla Port

The main rivers near Mongla Port area are Pussur and Mongla Nullah rivers. Jhapjhapia River takes off from the upstream of Pussur River and meets Sibsa river at its upstream end. Mongla Nullah meets the Pussur River from the eastern side at Mongla, where the present Anchorage is located and a comparatively narrow khal known as the Danger khal meets the Pussur from the west. The channel is deeper in Mongla Nullah and downstream of the confluence of Mongla Nullah and the Pussur River, than the upstream of the confluence. The ebb flow from Mongla Nullah directly flows into the western bank of the Pussur River causing minor erosion (IWM, 2004).

Chalna is about 15 km upstream of the present location of the port. It is the meeting place of the five rivers, the Kazibacha, the Pussur River, Old Pussur River, Jhapjhapia and Chunkuri Nullah. The Pussur is flowing in the north-south direction, old Pussur River being the tributary from the north –east and north –west catchments areas contribute to of the Pussur River and Chuhkuri Nullah being a distributor of the Pussur River flowing in the south –west direction branching off in to Dhaki Nullah and Sutarkhali which meet Sibsa at different location.

4.4 Topographical Features of Pussur River

The navigation channel as well as the Port limit of MP has started from Fairway Buoy, a deep point in the Bay of Bengal. After fairway to Akram point the wider approach is known as approach to Pussur. At the Akram point it is divided into streams, the eastern one is Pussur and the western one is Sibsha.

4.4.1 Channel Pattern and Sinuosity

The main stream of Pussur Channel started from Hiron Point and ended at Chalna. The downstream portion of Hiron Point is actually a part of the sea. Between Mongla Port and the sea, the Pussur River channel is generally straight, with weak meanders. Only one strong meander is observed at the confluence with Monkey point, 35 km downstream of Mongla.

Sinuosity for the whole Pussur Channel from Chalna to Hiron Point has calculated. According to MPA Hydrographic chart no. MPA/HP-CB/12(a)/2008 & MPA/CB-D/12(b)/2008, the areal distance (straight) of Hiron Point to Chalna is 55 km out of the channel length of 91 km. The ratio of straight length to channel length is found as 1:1.65, which implies that the channel is mildly meandering. According to Leopold and Wolman (1957), a river can be considered straight till the sinuosity 1.5. For Pussur river, the sinuosity just crossed the limit.

4.4.2 Channel Width and Depth

Based on the MPA Hydrographic charts and available informations from hydrographic section of Mongla port, it is observed that the width of the Pussur River varies at different sections between 700 m to 3000 m and approach to the Pussur is about 6000 m. The width and available minimum and maximum depth of those sections are described in Table 4.1. The minimum depth is found to be varied from 1.4 m to 11.7 m below CD. It can be noted that the lowest depth is found at upstream (Chalna) that gradually increases towards downstream with the highest minimum depth at Mazhar Point to D'Suza Point and again decreases at further downstream near Fairway Buoy. The maximum depth is found to be varied from 7.5m to 29.6 m below CD from upstream to downstream, respectively. The details analysis on temporal variation of longitudinal and cross-sectional bed profiles are discussed in Chapter 5.

Table 4.1: Width and Depth of Pussur River at different segments.

Sl.	River Reach	Length of River Reach (km)	Width of Channel (m)	Min. Width of Navigation Channel (m)	Min. Depth (m Below CD)	Max. Depth (Below CD)
01	Fairway Buoy to Hiron Point	46.30	10,500-6,000	1500	6.2	23
02	Hiron Point to Tinkona Dwip	18.52	7,500 3,750	3500	10.9	22.6
03	Tinkona Dwip to Kagaboga Khal	16.67	4,000-2,500	1800	9.7	19.4
04	Kagaboga Khal to Sundorikota Khal	9.26	2,625-2,125	1000	9.1	22.5
05	Sundorikota Khal to Cheilabogi Khal	9.26	2,150-1,250	900	8.5	29.6
06	Mazhar Point to D'Suza Point	9.26	2250-950	700	11.7	28.0
07	Harbaria to Joymonirgol	9.26	1,800-1,125	550	6.3	23.2
08	Base Creek to Mongla Nulla	9.26	1,750-760	300	5.2	9.8
09	Mongla Nulla to Digraj	9.26	1,500-700	200	5.0	7.5
10	Digraj to Chalna	9.26	1,000-7,00	200	1.4	7.5

4.5 Hydrological Characteristics of Pussur River

4.5.1 Water Level

The variation of water depth and tidal characteristics in the study area over the years is studied by water level. The water level data analysis shows that the maximum tidal ranges at Mongla during the dry and monsoon period at spring tide in 2015 are about 3.75 m and 3.4 m, respectively. In neap tide the maximum tidal ranges for the dry and monsoon period are 2.0 m and 1.9 m. The seasonal variation at Mongla port between March and September is obtained about 0.9 m. In this study, water level was measured at Chalna for 7 days. The observed tide data has plotted in Figure 4.3. The observed data shows that the tidal range is higher at Chalna than Mongla.

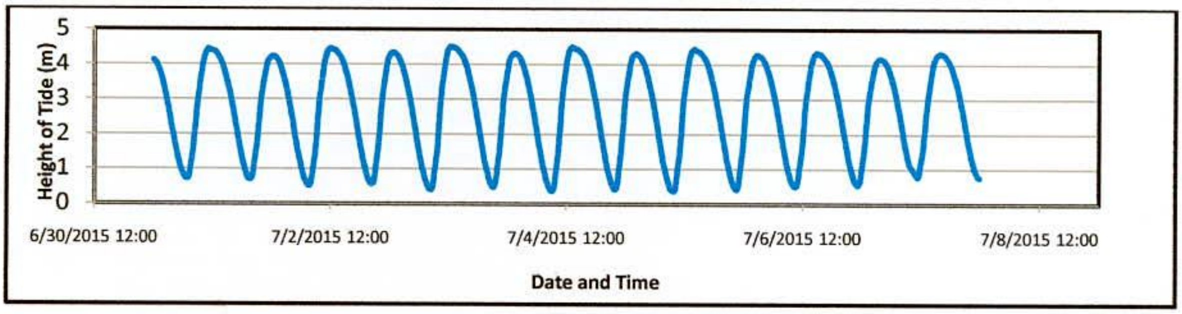


Figure 4.3: Water level at Chalna

Table 4.2: Maximum, Minimum and Mean water level and Maximum Tidal range.

Location	Duration	Max WL (mPWD)	Min WL (mPWD)	Mean WL (mPWD)	Max Tidal Range (m)
Chalna	07/01/2015 to 07/07/2015	4.518	0.314	2.41	4.204

During weeklong study, the measured water level was 0.314 to 4.518 mPWD (Table 4.2). Here, the mean water level shows the calculated arithmetic average value of all the measured water level during the measuring period. The tidal range was calculated by the algebraic difference of two consecutive high tide and low tide. Near the Rampal Power Plant at Dacop the tidal range is about 4.204 m.

Semi-diurnal tides with a tidal period of about 12 hours 25 minutes are predominant in the Bay of Bengal. According to the Bangladesh Tide Tables 2015, the mean Tide Levels at Mongla, and Hiron Point along Pussur River are 2.31m and 1.7m in CD respectively (Table 4.3). The tidal regime is larger at Mongla than at Hiron Point.

Table 4.3: Tidal levels at Mongla and Hiron Point

Stations	Lowest	Mean	Highest
Mongla (Bangladesh Tide Tables, 2015)	-0.261	2.310	4.882
Hiron Point (Bangladesh Tide Tables, 2015)	-0.256	1.700	3.656

4.5.2 Discharge

Discharge is an important key factor for the navigability of Pussur Channel. Siltation or scouring of river bed is directly related with the discharge. To understand the hydrology of study area, discharge has measured during spring and neap covering both flood tide and ebb tide. The observed data has plotted in Figure 4.4 and 4.5. The summarized observed data has given in Table 4.4 which shows that the flow in ebb tide is always higher than flood tide at Mongla.

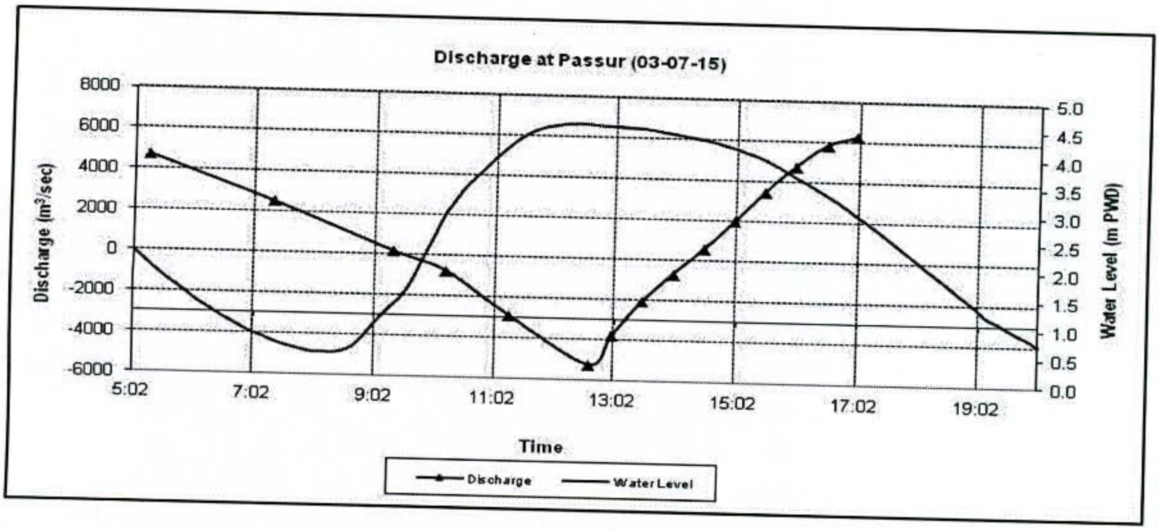


Figure 4.4: Discharge and water level during spring tide at Mongla

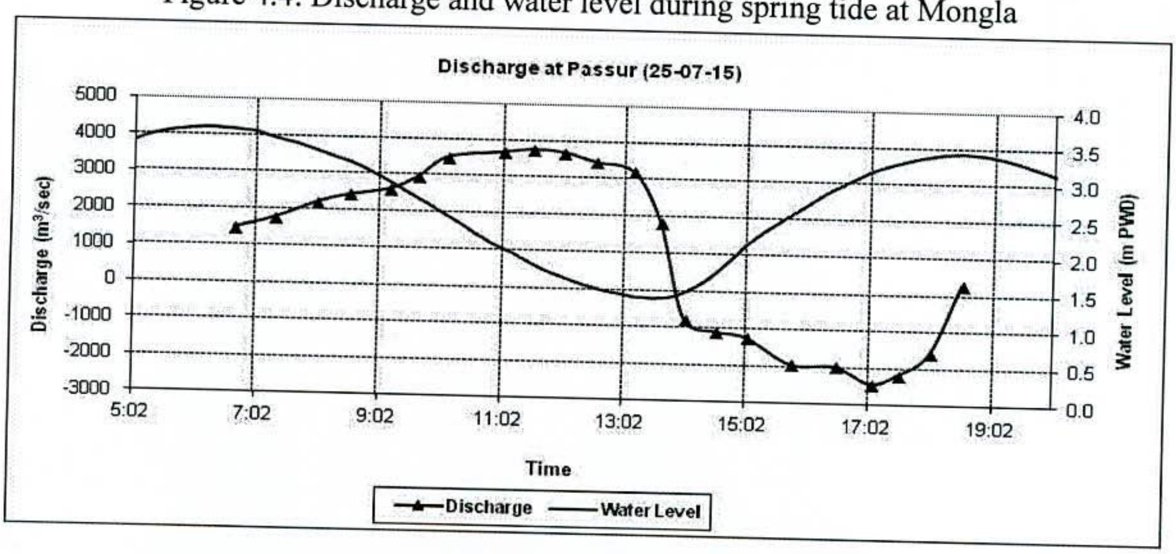


Figure 4.5: Discharge and water level during neap tide at Mongla

Table 4.4: Maximum discharge during flood tide and ebb tide.

Location	Measurement Period	Type of tide	Max flow during flood tide (m^3/sec)	Max flow during ebb tide (m^3/sec)
Mongla	03-07-2015 (half hourly)	Spring	5227	6272
Mongla	25-07-2015 (half hourly)	Neap	2434	3771

4.6 Sediment Transport in the Pussur River

The navigability of Pussur channel is mainly suffering for high sedimentation in the main stream. Sedimentation mainly occurs in dry season when the flow velocity reduces significantly. According to the discussion with the concerned officials of MPA, it was found that the area of tidal prism has reduced significantly after constructions of polders and sluice gates at the mouth of khals of Pussur River. Before those interventions, tidal flow with high sediment volume was allowed to enter into khals and open areas where most of the sediments were deposited and fresh water returned in the river at ebb tide. But now most of the sediments deposit in the river due to those interventions.

DHI (1993) has collected a large quantity of data on this river, based on which the governing physical processes and the nature of the sediment transport processes in the Pussur River can be understood. From the suspended samples analysis, DHI concluded that the main part of the suspended sediment material consists of silt which is only represented in the bed material by approximately 5 percent. Consequently, the suspended sediment picked up in the measurements for the main part consists of wash load. Silt is generally not found in the bed along the main flow of Pussur River indicates that suspended silt contribute in any significant way to the erosion/deposition processes along the river. The bed material along the main flow areas of the bigger rivers is fine sand. Closer to the banks it is often mainly silt. The suspended fine material does not contribute significantly to erosion/sedimentation processes in the main flow regions of the bigger rivers including the navigation channel of Mongla Port. The transport of bed material is significantly smaller, of the total sediment approximately of one third (DHI, 1993).

4.6.1 Suspended Sediment

In this study, suspended sediment concentration at 0.2d, 0.6d and 0.8d (d is the water depth) has been measured during the spring tide for 13 hours. Table 4.5 presented the measured suspended sediment concentration along with water level and velocity. The water level in the section varies from 0.42 to 4.48 mPWD and the highest velocity was found as 1.1 m/s. Figure 4.6 shows the temporal variation of suspended sediment concentration for the sampling time of 13 hrs. The result shows that, sediment concentration near the river bed (i.e. at 0.8d depth from surface) is always higher than the upper layers at 0.6d and 0.2d from surface. At 0.8d, the concentration varies from 359.65 mg/l to 2096.06 mg/l in flood tide which changes inversely with water level and velocity. At 0.2d, the concentration varies from 153.6 mg/l to 1478.0 mg/l.

Table 4.5: Sediment concentration, water level and velocity at studied section of Pussur

Time (03/07/15)	Sediment Concentration (mg/l)			Water Level (m PWD)	Velocity (m/s)
	0.8d	0.6d	0.2d		
5:00	1557.31	1165.71	997.98	2.17	1.019
6:00	1741.14	1447.99	1158.91	1.35	-
7:00	1359.10	1166.11	1005.98	0.74	0.84
8:00	1413.95	1085.64	904.71	0.42	-
9:00	811.45	563.72	395.26	0.92	0.79
10:00	1733.53	1656.63	1039.21	2.48	0.75
11:00	2096.06	1899.76	1478.02	3.88	0.72
12:00	2068.81	1594.96	1343.48	4.48	0.714
13:00	1503.25	1162.51	1011.19	4.48	0.518
14:00	639.75	452.08	333.64	4.37	0.08
15:00	359.65	304.84	184.41	4.14	0.298
16:00	731.40	427.67	301.23	3.65	0.717
17:00	493.29	283.63	153.61	3.00	1.068

Figure 4.7 shows the depth-wise variation of suspended sediment concentration for three scenarios: minimum, maximum and time averaged (12 hrs) sediment concentration profile. It is observed that at low concentration the sediment concentration profile is quite stiff and nearly vertical, means sediment gradient is low. On the other hand, the profile is flatter for higher concentration, and in this case the sediment concentration gradient along the depth is high. In the time averaged profile, the concentration is found as 790 mg/l at 0.2d depth and 1270 mg/l at 0.8d depth. From the time averaged profile, the mean concentration is estimated about 1000 mg/l.

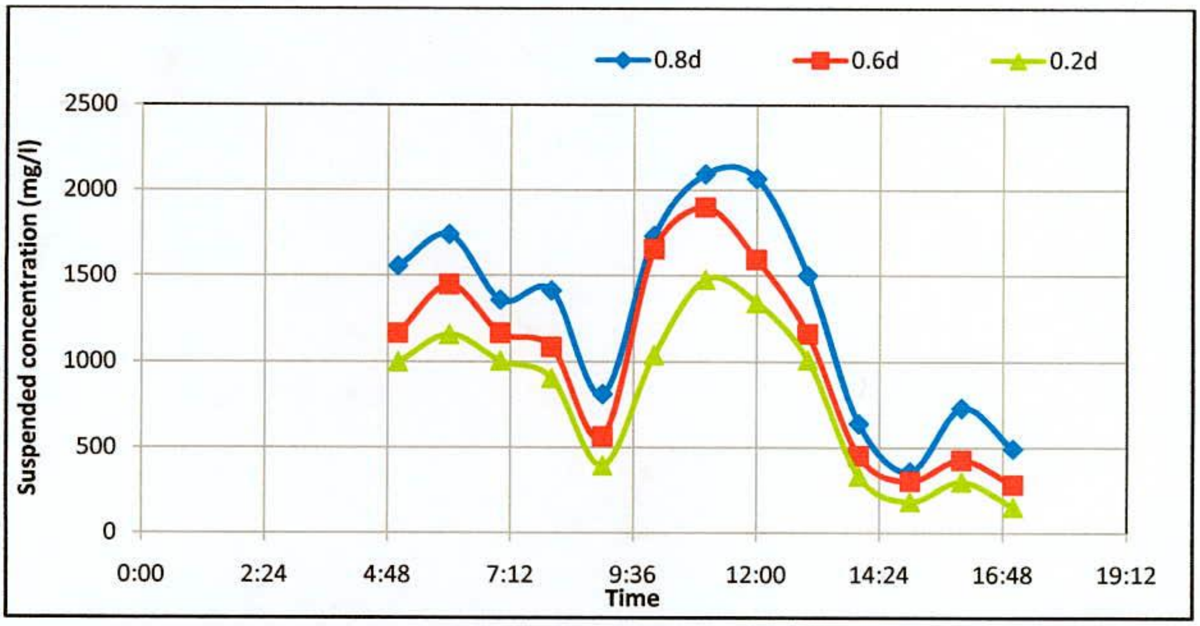


Figure 4.6: Suspended sediment concentration in Pussur River at the Mongla Port area during spring tide (d is the total depth measured from water surface)

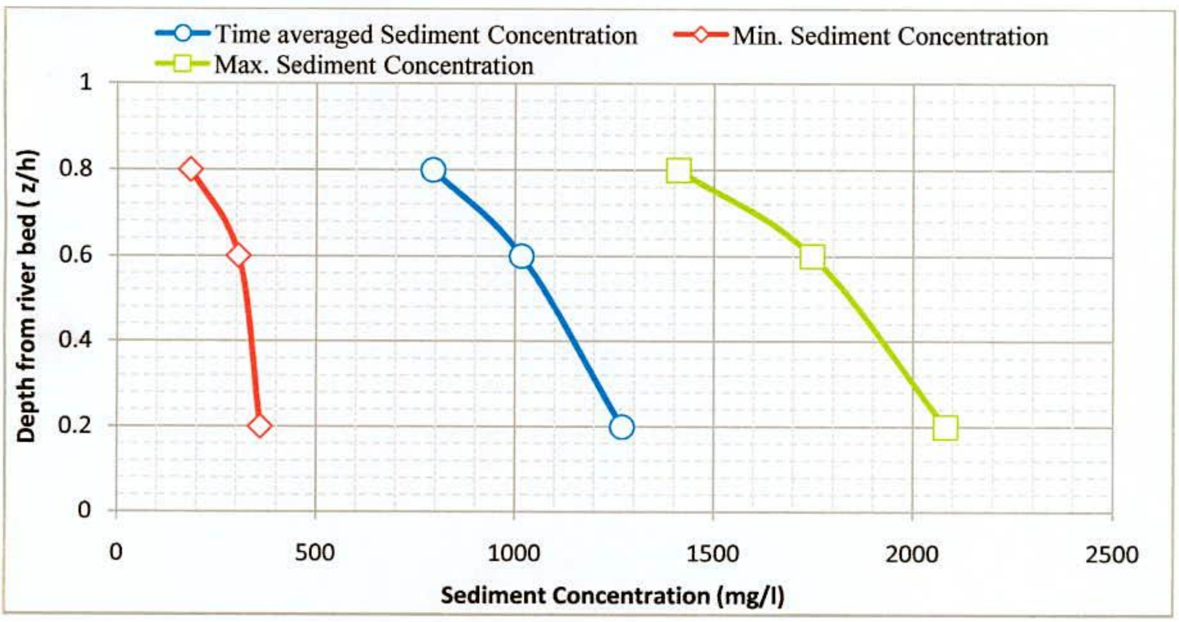


Figure 4.7: Depth-wise variation of Suspended sediment concentration in the Pussur River at Mongla Port area during spring tide

4.6.2 Bed Load Characteristics

Sediment deposits in the estuaries consist of various proportions of gravel, sand, silt, clay and organic matter. Gravel and sand are often found at the seaward ends where wave action and residual currents remove the finer fractions, while fine sand, silt, clay and organic matter (often collectively referred to as mud), is found in the upper reaches of an estuary near the limit of tidal-average salinity intrusion (Mc Dowell & O'Corner, 1977).

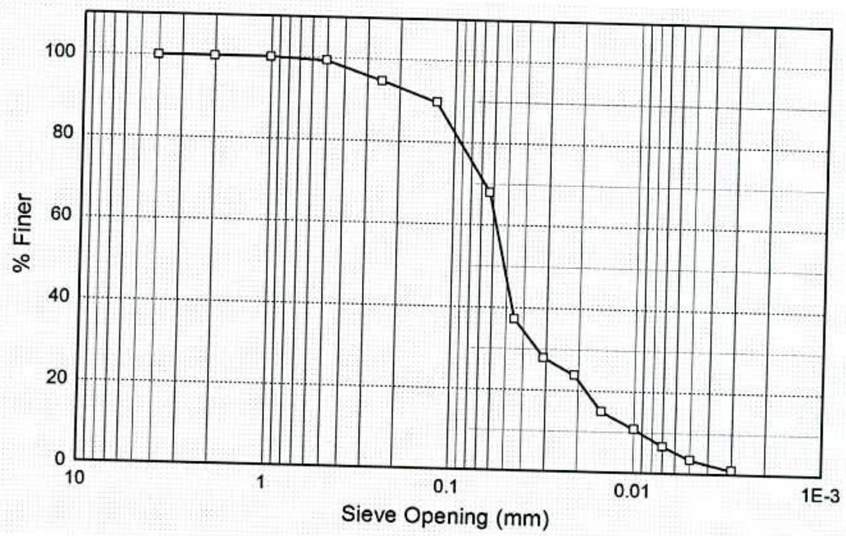


Figure 4.8: Average grain size distribution of bed material

To know the characteristics of river bed material near the Mongla Port area, 4 (four) bed samples were collected and analyzed. Sieve analysis of the bed material shows that the Fineness Modulus (FM) of the collected samples are 0.30, 0.60, 0.48 and 0.49, i.e. the bed material is mostly sandy. Figure 4.8 shows the average grain size distribution of bed material, where d_{50} is found as 0.052 mm.

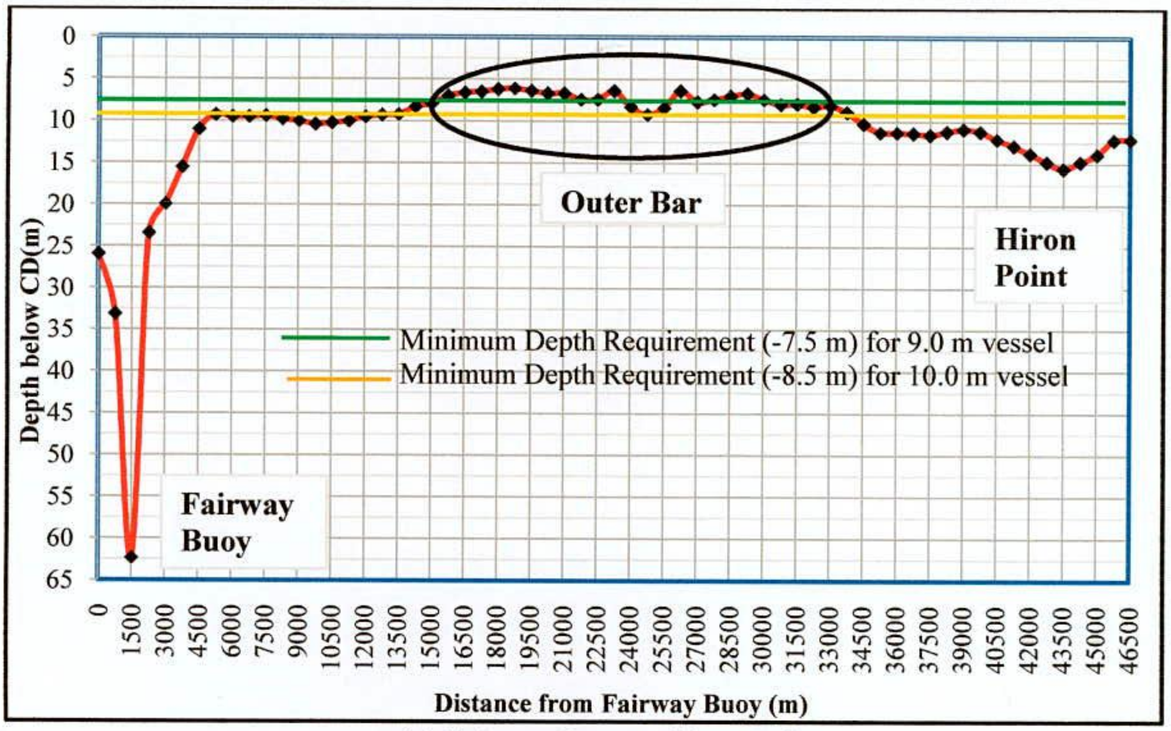
4.7 Navigation Route and Its Navigability

The port limit of MPA started from fairway buoy (in the open sea) and ends at Chalna. Total length of port limit is 149 km. The distance of different important location of Pussur River are given in Table 4.6

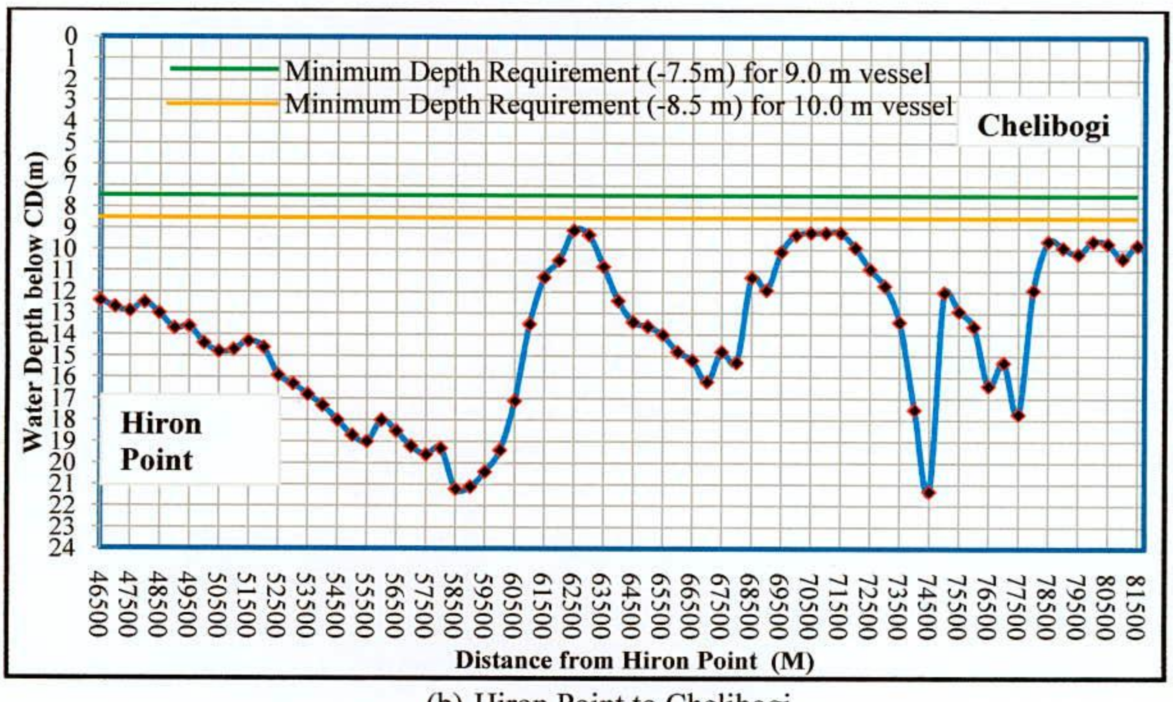
Table 4.6: The distance of different important location of Pussur River

Channel Distance	
Port Limit (North-South)	149.0 km
PP Jetty - Fairway	131.0 km
PP Jetty - Hiron Point	87.0 km
PP Jetty - Akram Point	68.5 km
Hiron Point - Fairway	44.0 km
Hiron Point - Akram Point	18.5 km
Akram Point - Fairway	62.5 km
PP Jetty - Jhapjhapia River	18.0 km
PP Jetty - Base Creek	13.0 km
PP Jetty - Harbouria Khal	22.0 km
Naval Jetty - Hiron Point	91.0 km

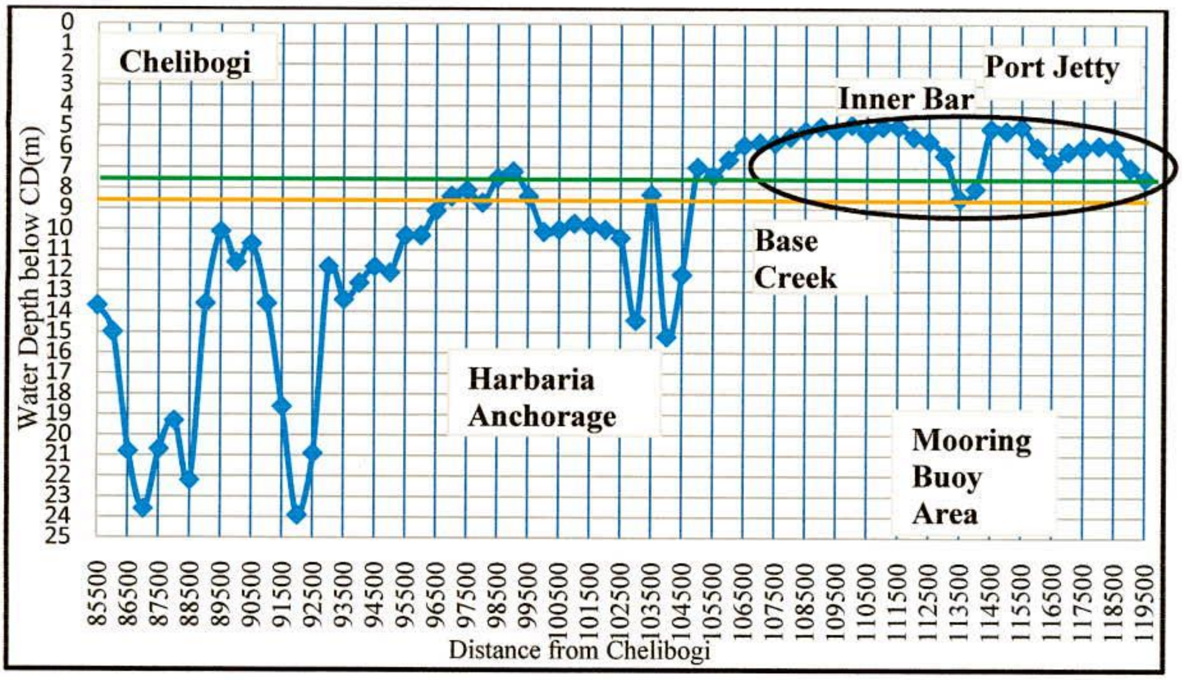
The Bathymetry of the Pussur River has been analysed reach wise from Chalna to Akram Point and also at the Pussur entrance at outer bar area based on the bathymetry charts from 2005 to 2016. The major findings on the navigability of the Pussur river is that, the river has navigation problem for the last two decades mainly from Chalna to Chilla Bazar.



(a) Fairway Buoy to Hiron Point



(b) Hiron Point to Chelibogi



(c) Chelibogi to Mongla Port

Figure 4.9: Long profile of Pussur River along the navigation line

After Chilla Bazar, starting from Joymonirgoal, the river shows a more stable navigable reach up to Akram Point and the river is more meandering. Figure 4.9 presents the water depth below CD along the navigation channel from Chalna to Fairway Buoy for the year 2008. From the long section of Pussur River, it has seen that about 16 km river reach called outer bar at the entrance of Pussur river don't have enough draft for 7.5 m draft vessel (Figure 4.9a). From Hiron Point to Harbaria Anchorage, the river has sufficient draft upto 10.0 m draft vessel (Figure 4.9a & 4.9b). Harbaria Anchorage has sufficient draft to handle 10.0 m draft vessel. But about 13 km in the base creek area and Port Jetty area called inner bar is suffering for scarcity of sufficient water depth even for 7.0 m draft vessel (Figure 4.9c). Since the Pussur River is surveyed by MPA by dividing into 10 segments, those following segments has described in Chapter 5. For navigational purpose, the channel can be divided into following three sections:

Section 1: Fairway Buoy to Akram Point (Downstream to upstream)

The available water depth at Fairway Buoy is above 20-25 m. This depth gradually decreases as ships approach to the river channel due to draft restriction at the outer bar. The shoals along the outer bar in the southern section of 20 km restrict entrance of larger vessel of above 20,000 DWT.

Section 2: Akram Point to Harbaria

The available water depth at Akram Point anchorage ranges from 10 to 15 m. The depth of the channel between Akram Point and Harbaria varies in different stretches. From Akram Point to Kagaboga Khal, it varies from 11 to15 m. After a short patch having 8.00 m to

9.50 m water depth, 10 m up to 21 m depth is available up to D'Souza point. After D'Souza the depth again decreases and up to Harbaria Canal, where the depth is 8 m.

Section 3: Harbaria Anchorage to Chalna

Available water depth at Harbaria Anchorage is 8.5 m~10 m. As the channel proceeds, the depth further decreases from Harbaria to Port Jetty ranging between 5.00 m to 7.50 m. This trend continues up to the proposed power plant jetty at Rampal. Minimum water depth of this stretch is about 2-3 m, only ordinary inland vessels can negotiate with this depth.

4.8 Traffic Movement

The Mongla Port was developed in 1970s just outside the Sundarbans to the north but the designated waterway from the Fairway Buoy to the Port is the Pussur River and goes across the Sundarbans. Prior to the development of port facilities at the existing site, cargo was generally unloaded from ships anchored in the river to lighter and delivered to Chalna. Fairways and channels those approach Mongla Port are unique in comparison to other maritime ports in terms of traffic. Channels are characterized by traffic movement of various types of ships, vessels and crafts. Fairways and channels are not only used for maritime transport but also shared by inland navigation, traffic of Bangladesh-India IWT Protocol, vessels for tourism in the Sundarbans and a large number of non-standard boats and crafts engaged in fishing, passenger carrying, goods carrying, tourism, diesel carrying and distribution, etc. Traffic movement in the study area may be classified into following groups:

1. Maritime traffic which includes mother vessel and lighter vessels,
2. Bangladesh-India IWT Protocol which includes vessels that operate under bilateral provisions,
3. Movement of inland vessels to and from or within the study area which include cargo vessels, oil tankers, passenger vessels, cruise vessels, technical vessels, survey vessels, inspection vessels etc, and
4. Movement of mechanized boats and crafts.

4.8.1 Maritime Traffic

Mother vessels calling at or sailing from the MP are mainly bulk carriers, container ships and Ro-Ro vessels. Most of the bulk carriers are served at anchorage while container ships and Ro-Ro vessels are served at the Port jetty. Out of the three anchorage points, bulk carriers are mainly served at Harbaria in all seasons; few ships are served as well at Fairway Buoy during fair weather period of five months from November to March. Statistical information collected from the Mongla Port manifests a significant growth of maritime traffic. In the fiscal year (FY) of 2015-16, the number of ships calling at Port was 482 as against 416 in the previous year, growth of about 16%. General descriptions of mother vessels calling at Mongla Port are as follows:

LOA	:	120-200 m.
Beam	:	25-32 m.
Draft	:	5-11 m.
BHP	:	10,000-15,000

Growth of traffic was also reflected in the total tonnage of the Port. In the FY of 2015- 16 total cargo handled at the Port was 57,97,521 tons while in the previous FY of 2014-15 volume was 45,30,279 tons. Growth of tonnage is about 28%. The following Table 4.7 describes the volume of cargo handled and Figure 4.10 represents the number of ship handled at Mongla Port during the last Twelve years:

Table 4.7: Ship and cargo handled by MPA in Last 12 years.

Year	No of Ships	IND-BD Protocol Vessel & Others	Total Ship	Import Cargo (MT)	Export Cargo (MT)	Total Cargo (MT)
2004-05	142	313	455	1254374	221798	1476172
2005-06	131	254	385	1215072	267572	1482644
2006-07	110	83	193	662263	252112	914375
2007-08	95	33	128	518309	204525	722834
2008-09	139	12	151	929714	208112	1137026
2009-10	156	34	190	1502050	147233	1649283
2010-11	272	30	302	2529853	166418	2698271
2011-12	234	31	265	2482432	137465	2619897
2012-13	282	56	338	2946222	201352	3147574
2013-14	345	2	347	3402402	141547	3543949
2014-15	416	86	502	4429449	100830	4530279
2015-16	482	154	636	5709654	87857	5797521

4.8.2 Movement of Lighter Vessels

Mongla Port is characterized by lighterage service at the anchorage. Most of the mother vessels take berth at Harbaria anchorage during all seasons and few at Fairway Buoy only during fair weather period from November to March. Lighters take load from mother vessels and then proceed to Private Jetties, Roosevelt Jetty at Khulna or to any destination beyond limit of Mongla Port.

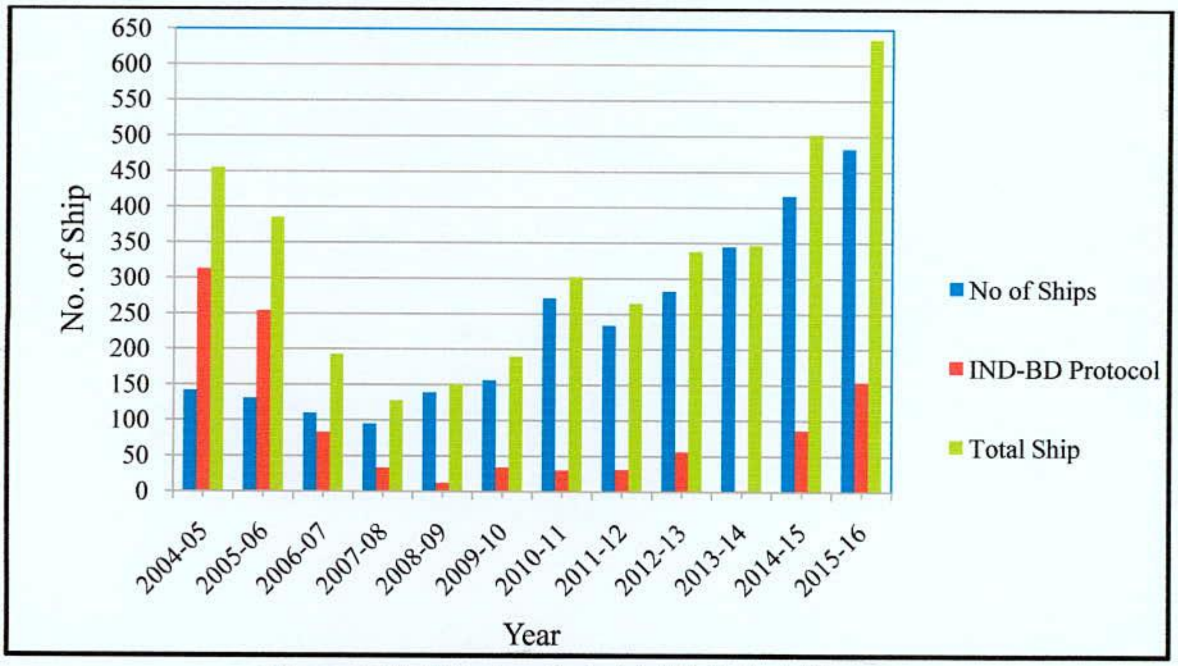


Figure 4.10: Ship handled at MPA in last 12 years

4.8.3 Movement of Inland Vessels

A large fleet of inland vessels share the river routes within the study area. Most of them are not related with the operation of MP. These vessels include:

- Vessels for trans-boundary inland navigation under the Bangladesh-India Protocol on IWT. Among those about 600 fly ash carrying vessels from India sails to the Passur River through Sibsa-Dhaki Chunkuri route.
- Passenger vessels traveling through the routes in the study area.
- Cargo vessels and oil tankers.
- Cruise Vessels.
- Vessels owned by public authorities for different purposes.

4.9 Summary

Fresh water flow of Padma Piver and Gorai River is very important for the morphology of Pussur River. Due to low velocity of Pussur River, most of the sediments deposit on river bed which is reducing navigation depth. The most critical sections of this river are: (a) Mongla Port to Rampal power plant, (b) Harbour Area and (c) Outer bar area. Due to depth restriction at outer bar maximum 8.5 m draft vessel can arrive upto Harbaria anchorage. The upstream of Harbaria anchorage is shallower and maximum 7.5 m draft vessel can arrive to MP. The movement of ships as well as handling of cargo at MP is increasing day by day since 2008.

Chapter 5

GEOMORPHOLOGY OF PUSSUR RIVER

5.1 General

In Chapter 4, the longitudinal profile of water depth in below CD along the navigation channel is presented. From the long section analysis of Pussur River it has found that, the Outer bar area and inner bar area are the most venerable sections for safe movement of sea going vessels. An intensive analysis on these areas by preparing cross sectional variation in bed profile for several years can establish the pattern of changing in the thalweg line. Since the Pussur River from Chalna to Akram Point is surveyed by MPA by dividing into 10 segments, the temporal and spatial change in bathymetry is analyzed segment-wise. In this chapter, firstly the Bathymetry of Pussur river has been analysed reach wise from Chalna to Akram Point, and then that at the Pussur entrance at outer bar area has been analysed based on the available bathymetry charts from 2005 to 2016.

5.2 Chalna to Digraj (Chart-10)

At present, this segment is mainly used by inland bulk cargo vessels, oil tankers and passenger vessels. But after commissioning of Rampal Coal Based power plant, this section will also play a vital role for the operation of Mongla Port. MPA not carry out hydrographic survey frequently, due to less importance of this section. Only Hydrographic Chart of the year 2013 has found from MPA and chart of 2015 has collected from IWM. Figure 5.1 shows the hydrographic chart from Power Plant to Digraj for 2015. The width of river in this section varies between 700 m to 1,000 m. Long profile of this section has presented in Figure 5.2, which shows that, the channel is very shallow at Chalna to Maidara. Depth varies in this segment between 1.5 to 4.6 m below CD. From Maidara to Digraj, the depth varies 4.5 to 6.2 m below CD. But the width of deeper portion is not sufficient for safe movement of 5.5 m or more draft vessel. MPA has already taken initiative to dredge this segment to ensure safe movement of coal carrying vessels at Rampal Coal Based Power Plant.

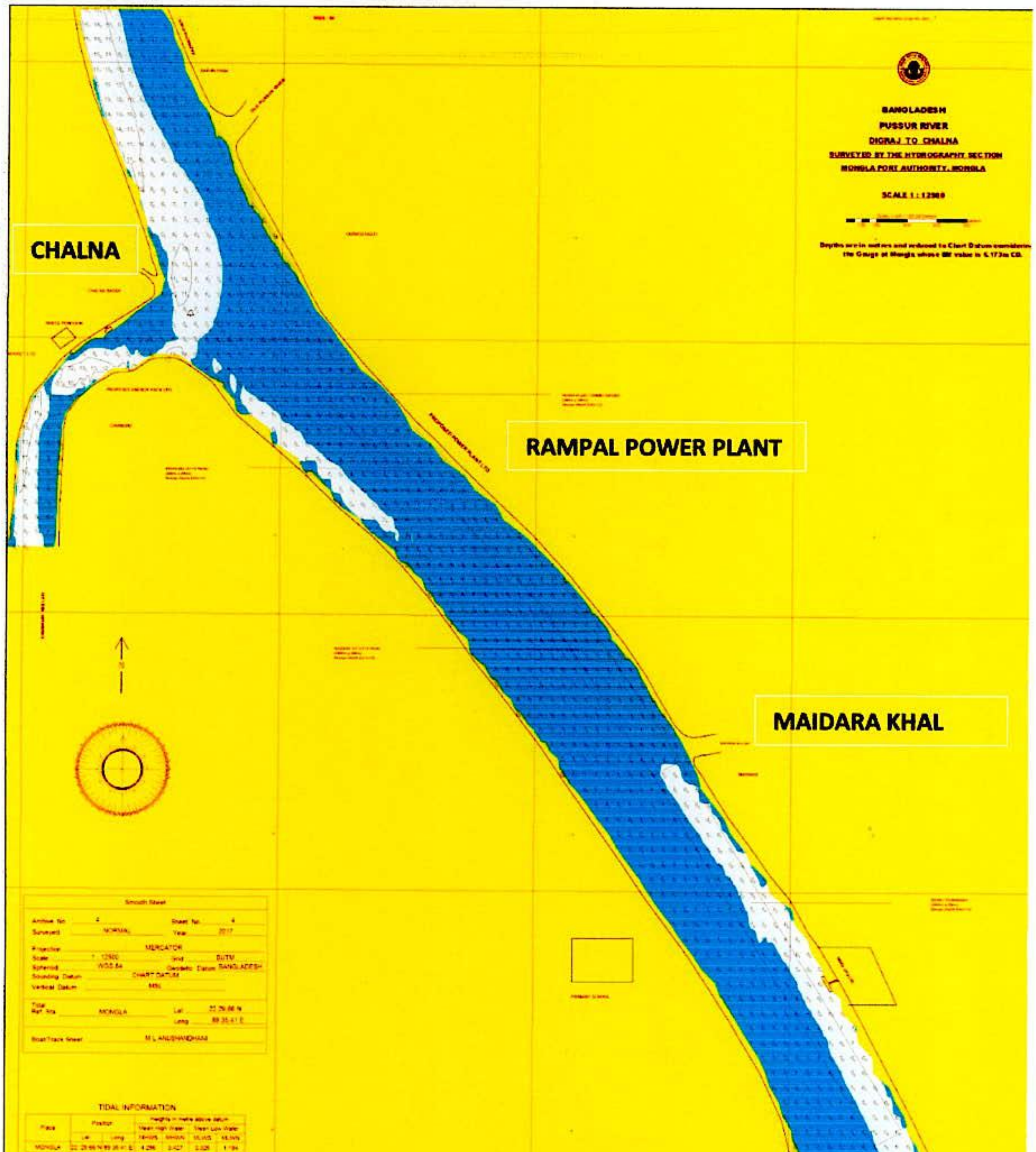


Figure 5.1: Hydrographic Chart of Pussur river from Chalna to Digraj in 2015 (Source: MPA)

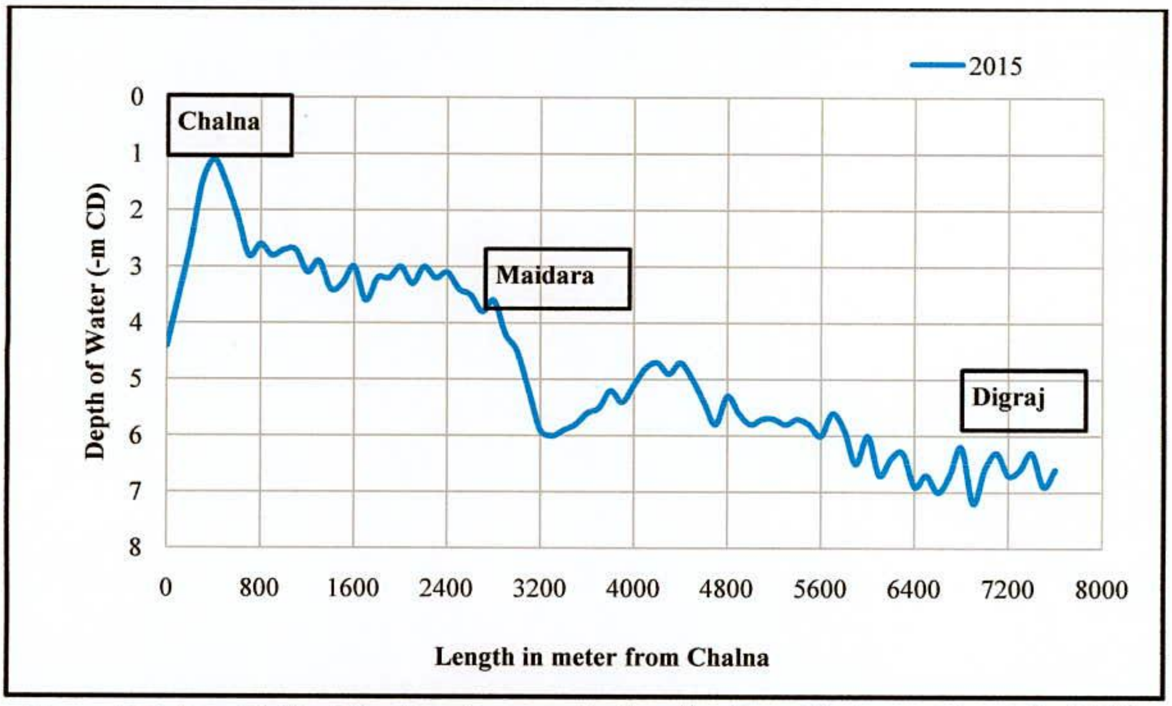


Figure 5.2: Longitudinal Section along navigation line from Chalna to Digraj (in 2015)

5.3 Digraj to Mongla Nulla (Chart-9)

Digraj is about 5 km upstream of Mongla Port. Figure 5.4(a) shows the hydrographic chart from Digraj to Mongla Nulla for 2015. The width of river in this segment varies between 700 m to 1,500 m. The east bank of this segment is occupied by lot of industrial jetties. MPA jetties also situated at the same side of total 915 m length. MPA is planning to construct another 03 jetties adjacent to the old jetties. These jetties obstruct the natural movement of water, which is causing siltation on both sides of jetty. This segment is very important for operation of Mongla Port. Normally 6 to 7.5 m draft vessels are called at MPA jetty. These entered into port channel with the help of high tide. During the high tide, the depth of water increases on an average 2.5 m. For the safety of ship minimum 0.5 m keel clearance is considered. This implies that, for 7.5 m draft vessel minimum channel depth requirement is 8.0 m during the high tide. To address the issue, the approach channel is required to have at least -5.5 m CD depth. But ships stay at jetty front in both high and low tide and for that, minimum 6.5 to 8.0 m below CD depth is required at Jetty front for 6.0 to 7.5 m draft vessels. Longitudinal profile of Pussur navigation route from Digraj to Mongla Nulla has presented in Figure 5.3 for the years of 2008, 2012, 2013, 2014 and 2015. The profile shows that the depth at MPA jetty in the year of 2008, 2012 and 2013 was - 4.3 m, - 5.0 m and - 4.9 m CD, respectively. Minimum depth in the approach channel in the same years was - 3.4 m, - 3.8 m & - 4.1 m CD, respectively. To increase the depth at jetty area and approach channel, MPA carried out a Capital dredging project in the year of 2014 which has reflected in the longitudinal profile of the year 2014 and 2015.

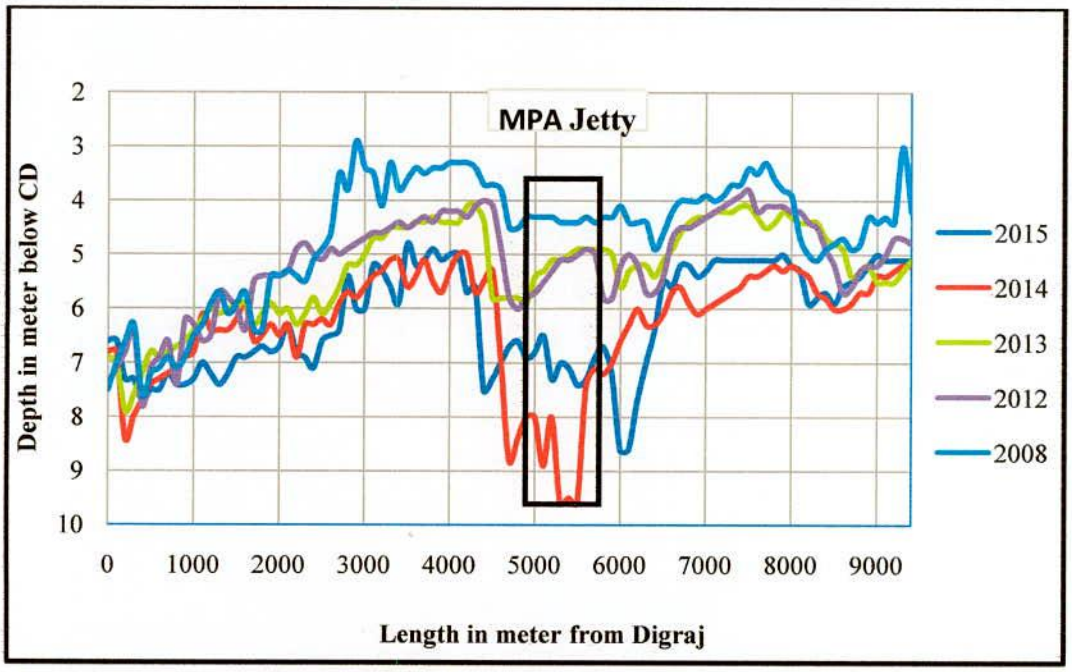
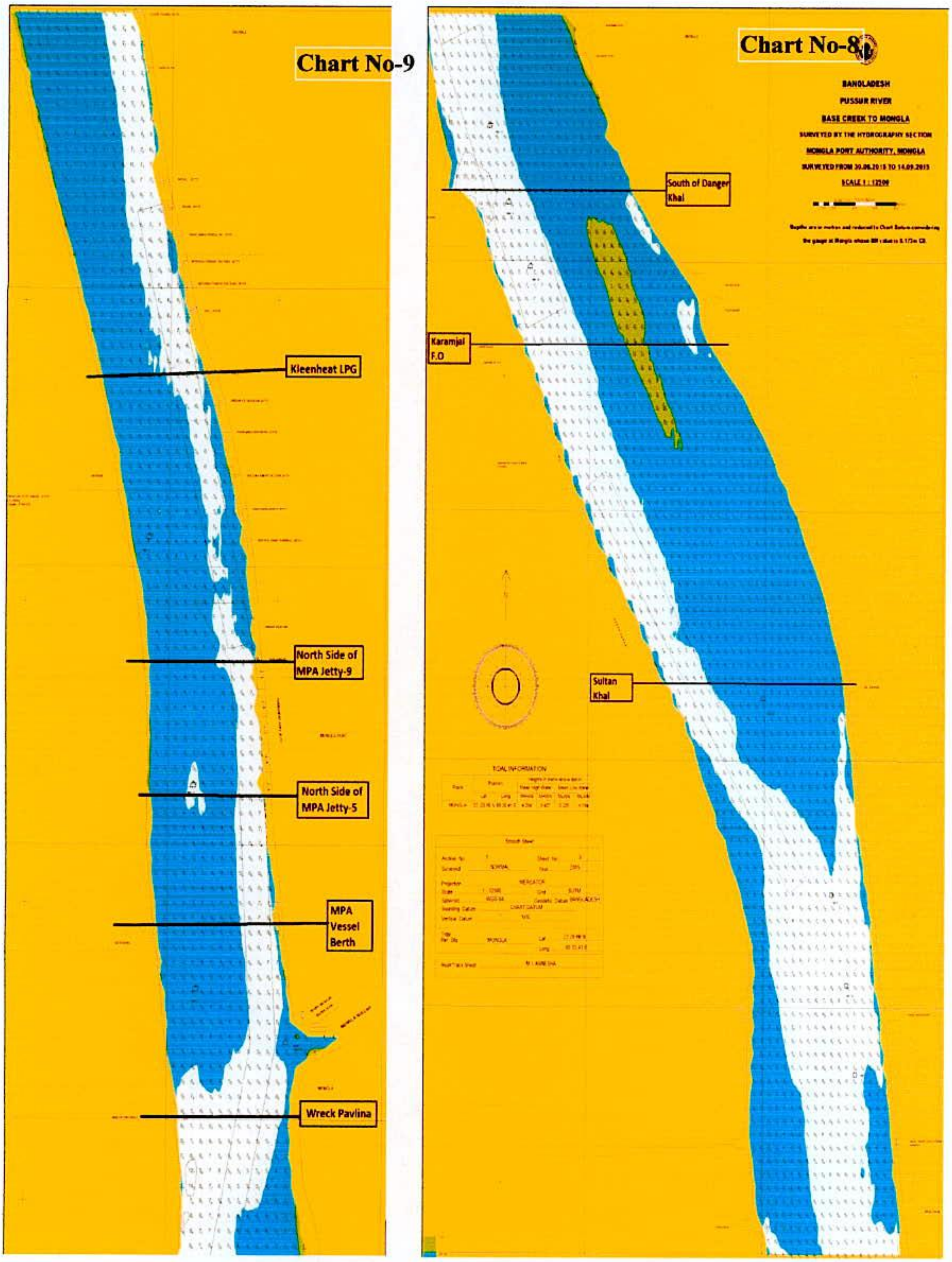


Figure 5.3: Longitudinal Profile along navigation line of Digraj to Mongla Nulla

To assess the changing pattern of river bed near MPA jetty area, following five segments was analyzed using the hydrographic chart of 2015, 2014, 2003, 2011 and 2008:

- Front of Kleenheat LPG Jetty (Upstream of MPA Jetty)
- North side of MPA Jetty no-9
- North Side of MPA Jetty no.-5
- Front of MPA Vessel Berth
- Along Wreck Pavlina

Figure 5.4 shows the hydrographic chart no. 9 and 8, where the sections chosen for the detailed cross-sectional analysis are shown. The cross sectional water depth profile for different years are prepared at selected sections and presented in Figure 5.5 to Figure 5.9. In those figures, the main navigation channel was used for sea going vessels has also marked. MPA normally carried out hydrographic survey in these two segments every year. These two segment also very much important for inland vessels. Most of the inland vessels normally entered into Pussur through Mongla-Ghosiakhali channel at the confluence of Mongla nullah and through Shella River at Joymonirgol. The inland vessels which engaged in lighterage from mother vessels are normally anchored at few hundred meters below of wreck pavlina.



a) Digraj to Mongla Nullah

b) Mongla Nullah to Base Creek

Figure 5.4: Hydrographic chart no. 9 and 8 showing the selected sections chossen for the detailed cross-sectional analysis (Source: MPA)

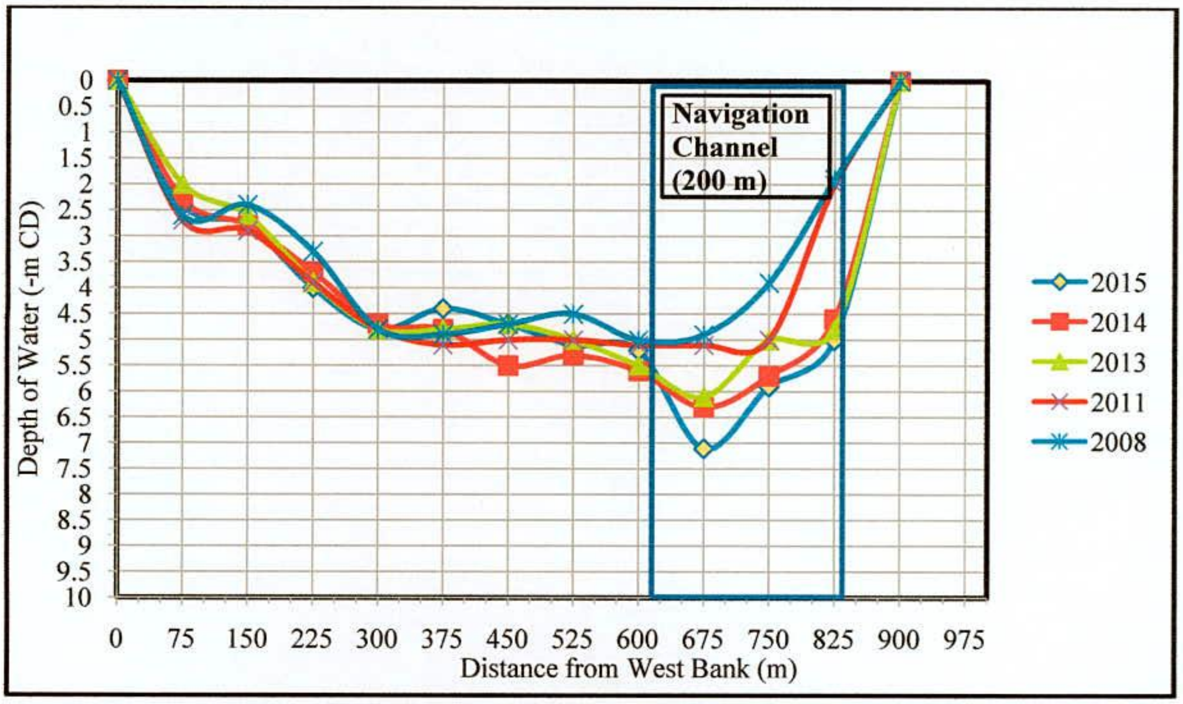


Figure 5.5: Cross Section at front of Kleenheat LPG Jetty

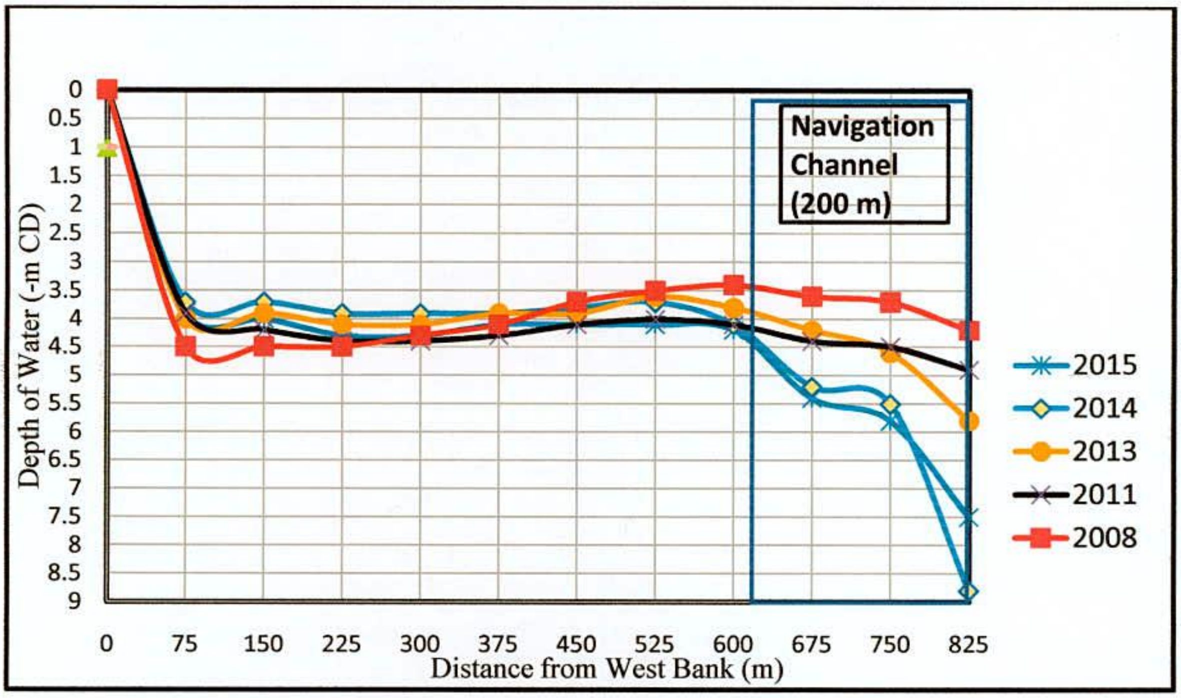


Figure 5.6: Cross Section at Middle of MPA jetty-09

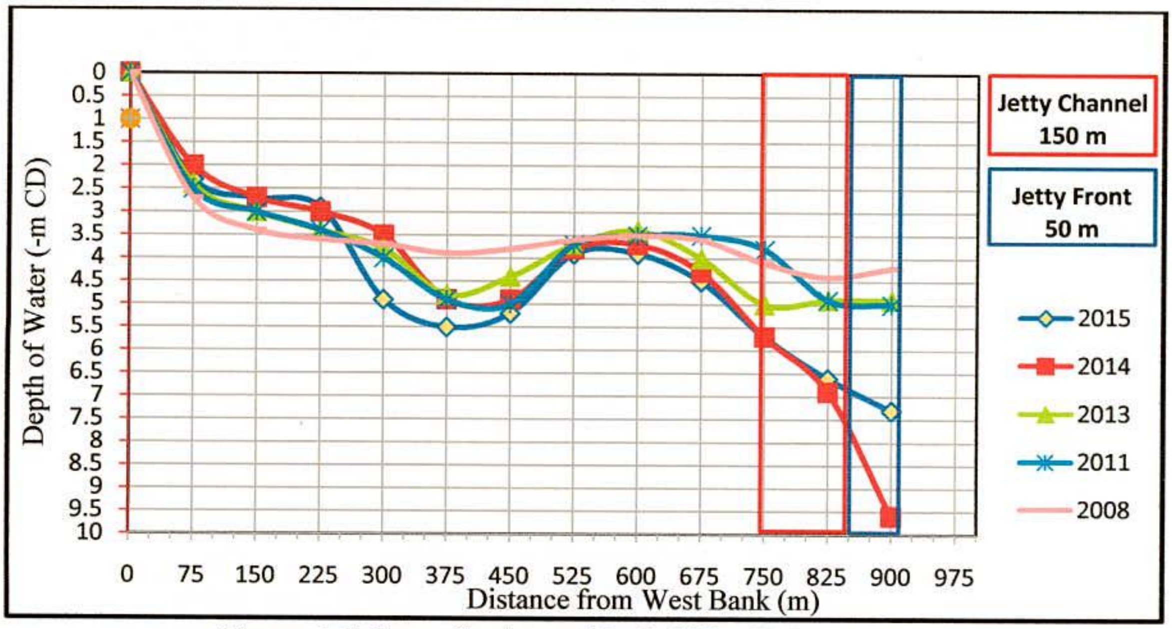


Figure 5.7: Cross Section at North Side of MPA Jetty-05

The Cross section of MPA Jetty area shows that, in the year 2008 the minimum depth at MPA jetty front was only -4.2 m CD (Figure 5.6 and 5.7). For safe berthing of vessels at jetty minimum depth requirement is -7.5m to -8.0 m CD. So in the year of 2008, it was very urgent to dredge the jetty front upto minimum -7.50 m CD. From 2008 to 2013 there was a natural deepening near jetty front and approaches due to increasing of ship movement and increase of fresh water flow from upstream after Gorai river dredging. In that period, the depth of channel was increased 0.5 - 1.80 m. MPA has carried out a capital dredging project in the year 2014 and after completion of that project depth at jetty front was more than -8.0 m CD and in channel -5.50 m CD. After one year of that dredging i.e in 2015, the depth at jetty front is reduced to near -7.5 m CD and at the middle of navigation channel is increased by about 0.25 m. But at upstream of jetty no-9 i.e in front of Kleenheat LPG jetty, the channel scoured naturally about 1.5-2.0 m between 2008 to 2015 (Figure 5.5).

The profiles at MPA vessel berth and wreck pavlina area show that, the river bed hasn't changed significantly after 1 year of dredging. The vessel berth area has scoured about 0.5 m, though silted up slightly along thalweg. Wreck pavlina is situated at the cross-over portion of the meander, where the navigation channel changes its route from clockwise bend at east bank to anticlockwise bend at west bank. Therefore, this section moved towards west compared to MPA vessel berth.

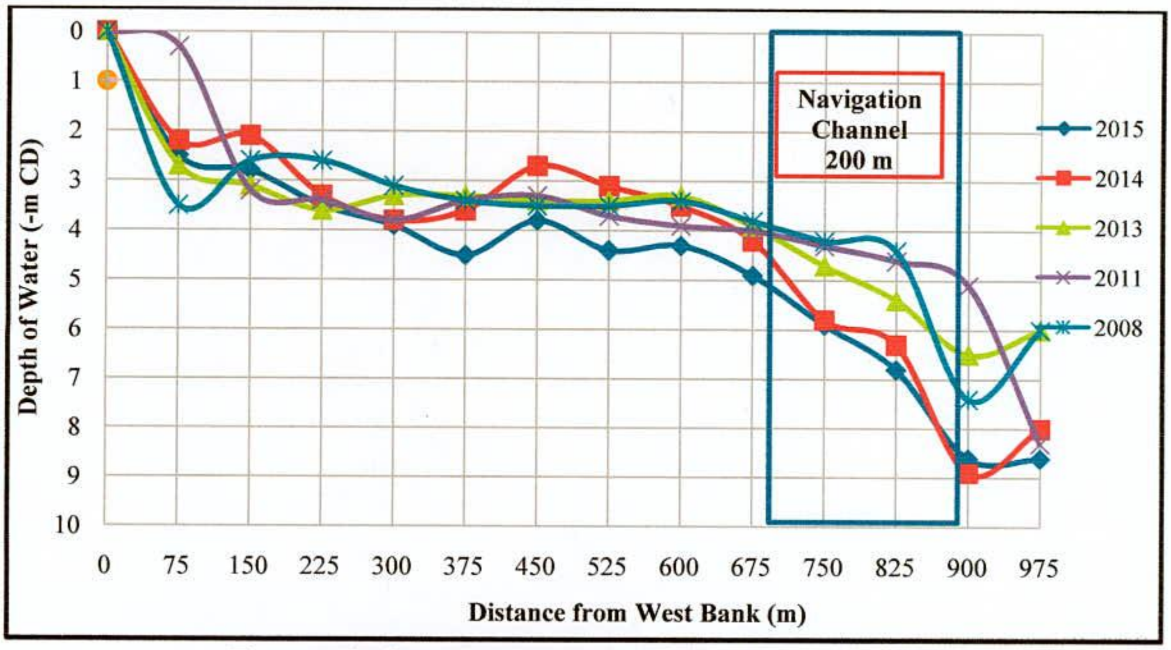


Figure 5.8: Cross Section at front of MPA Vessel Berth

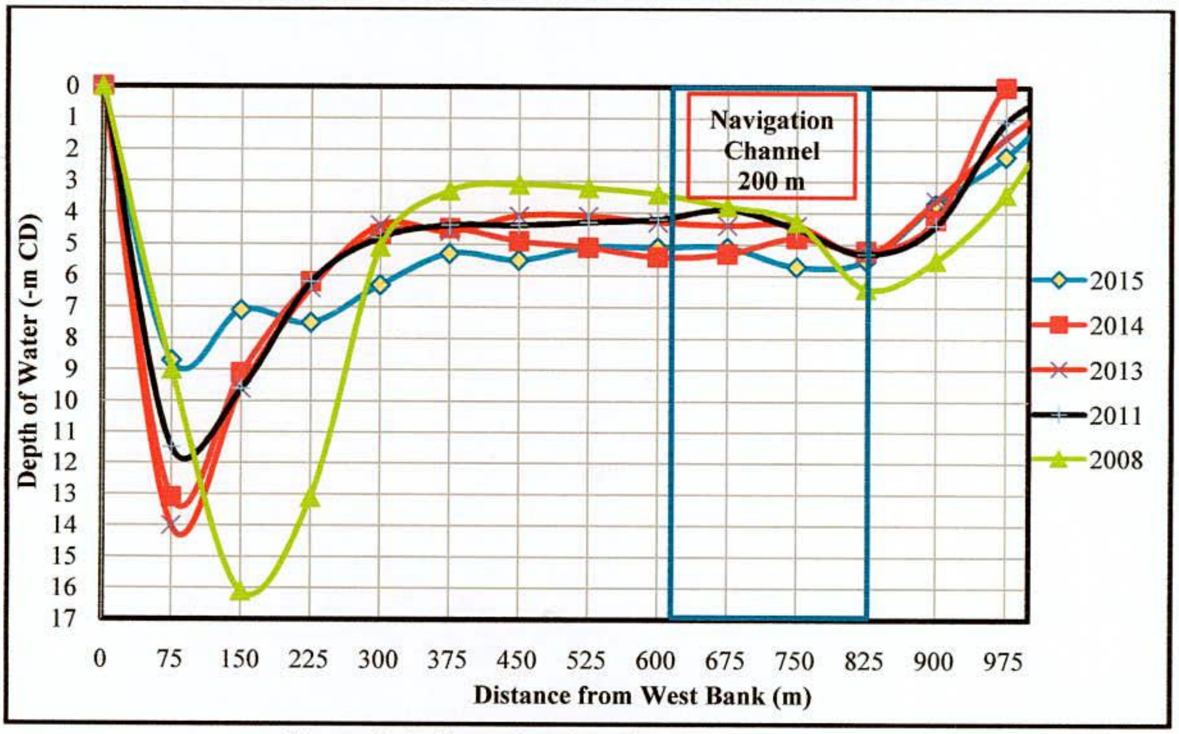


Figure 5.9: Cross Section along Wreck Pavlina

Within the navigation channel along wreck pavlina, the bed has silted up about 0.25 m in west side and scoured about 0.75 m in east side within one year of dredging (Figure 5.9). It is observed that the thalweg line near the west bank is silted up about 4 m within one year after dredging the navigation route at east side.

For determining natural siltation/scoring characteristics, the change of bed level in the middle of navigation channel is evaluated comparing bed elevation in 2013 with that of

2008. It can be noted that in this area the capital dredging is performed in the year of 2014, and within 2008 to 2013 period no capital dredging was performed. Table 5.1 has summarizes the rate of siltation/ scouring for the 05 sections at MPA jetty area before performing any capital dredging. It is observed that upto 2013 the navigation channel is in degrading type where scouring rate varies from 0.12 to 0.32 m per year. From Figure 5.4 it is observed that, the navigation channel is at concave side of the river. It may be one of the reasons for natural scouring. Moreover the ship movement would be another cause for the scouring.

Table 5.1: Rate of siltation/ scouring at MPA jetty area (2008 to 2013)

Sl.	Section	Bed Level (m below CD)		Siltation (+)/ Scouring (-)	Rate (m/yr.)
		2008	2013		
01	Kleenheat LPG Jetty	4.9	6.1	-1.2	-0.24
02	Middle of MPA jetty-09	4.2	5.8	-1.6	-0.32
03	North Side of MPA Jetty-05	4.2	4.9	-0.7	-0.14
04	MPA Vessel Berth	4.4	5.4	-1.0	-0.20
05	Wreck Pavlina	3.8	4.4	-0.6	-0.12

5.4 Mongla Nulla to Base Creek (Inner Bar) [Chart-8]

The east side of this segment is very shallow which called "the inner bar". The width of river in this section varies between 760.0 m to 1,750.0 m. Inner Bar is a region, where coarse sand gets deposited. Over the long period of the to-and-fro movements, a considerable net drift occurs and more stable inner bar is formed. The changes of bathymetry over a period of 10 years have analyzed. It reveals that inner bar has raised by 2-3 m and formed a stable bar. To assess the changing pattern of river bed in this segment, following sections were analyzed using the hydrographic charts of 2015, 2014, 2011, 2010 and 2005:

- Along Danger Khal
- Along Karamjol Forest Office (F.O)
- Along Sultan Khal
- Along Food Silo Jetty

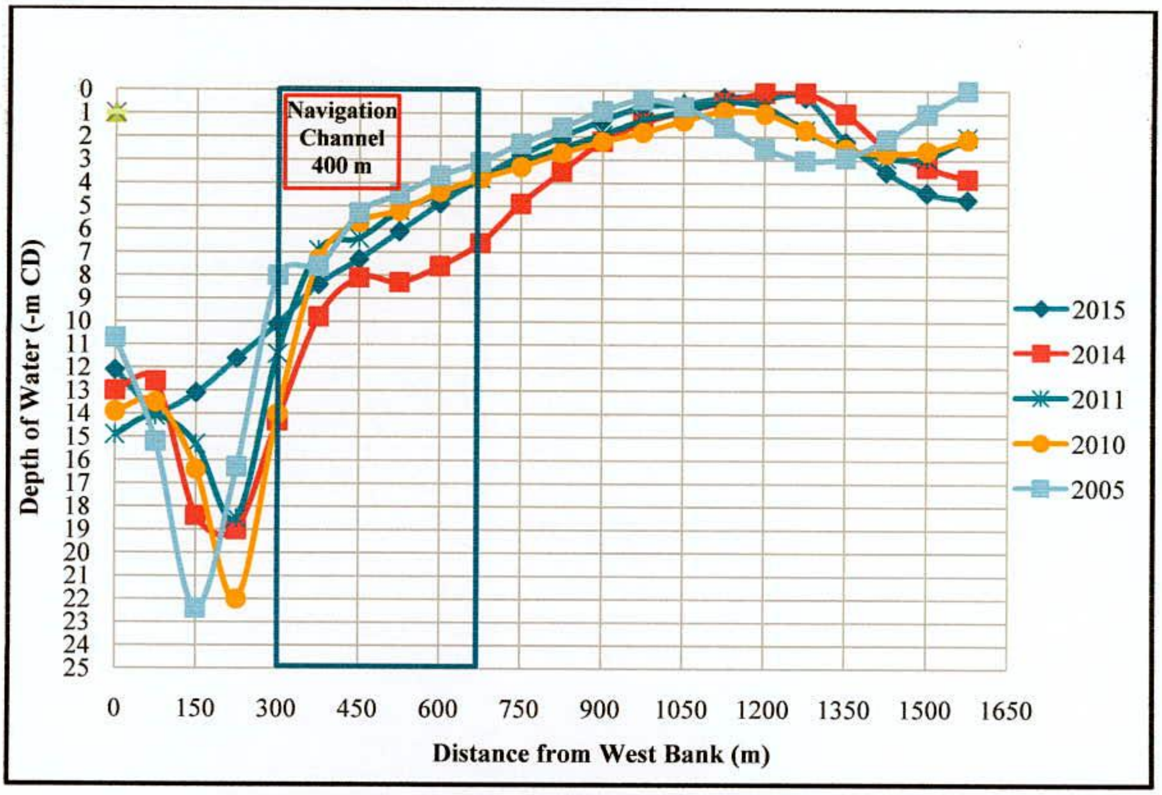


Figure 5.10: Cross section along Danger Khal

The Cross section of Danger Khal area shows that, there is a deep pocket of 18-22 m depth at the confluence of danger khal (Figure 5.10). This deep pocket is found to be gradually silted up by about 4.0 m from 2008 to 2014. After dredging of the navigation channel at the east side of the pocket in 2014, this deep pocked was found to be silted up by about 7.0 m within one year. At the middle of the navigation channel, the bed is silted up by about 1.0 m within one year. The depth of main navigation channel in this section is more than -6.5 m CD. The adjacent area in downstream is called "Mooring Buoy" which is used for mooring of bulk carrier vessels. The draft of these vessels varies between -6.5m to -7.5m CD.

In the year 2005 the minimum depth at Mooring Buoy area was only - 5.0 m CD. During the capital dredging project in the year 2014 this area was dredged upto -7.5 m CD. After one year of that dredging i.e in 2015, the depth has not changed too much i.e this segment is found quite stable after the dredging.

The profile of Karamjol F.O area (Figure 5.11) shows that, the river bed elevation in the year 2010 was about -5.50 m CD i.e this section do not require dredging for 7.50 m draft vessel. Bed profile of the year 2015 shows that the depth is increased to -6.50 m CD. This segment naturally scoured more than 1.0 m in last 05 years.

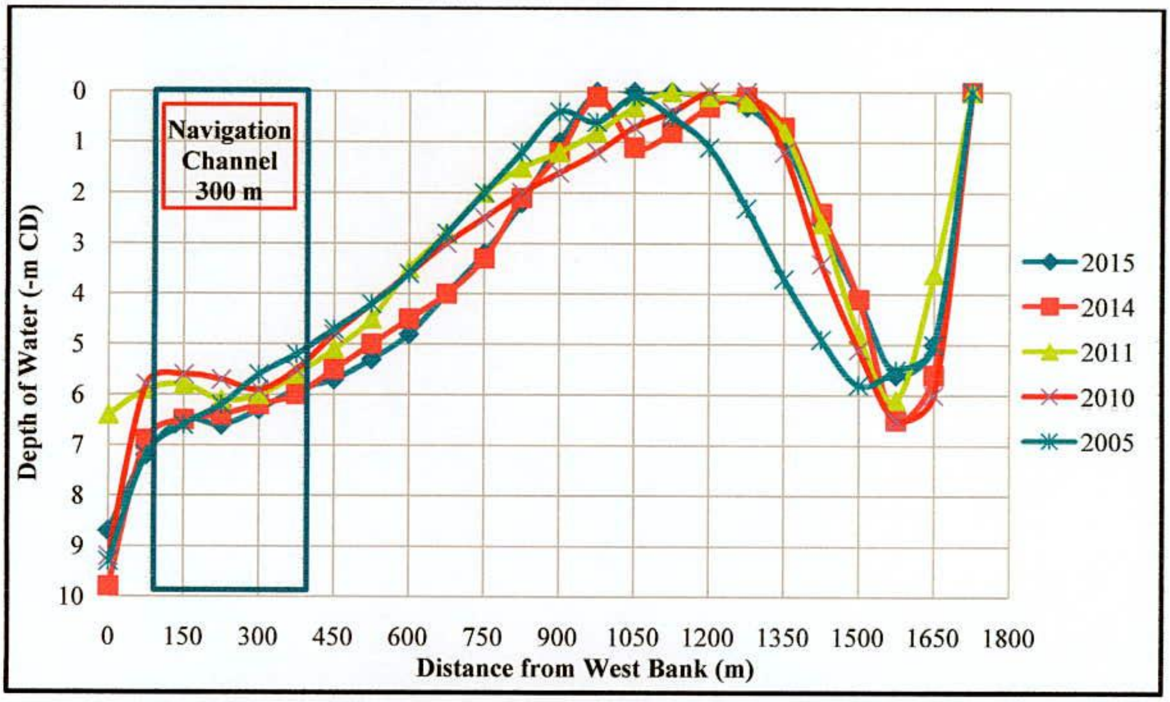


Figure 5.11: Cross section along Karamjol Forest Office

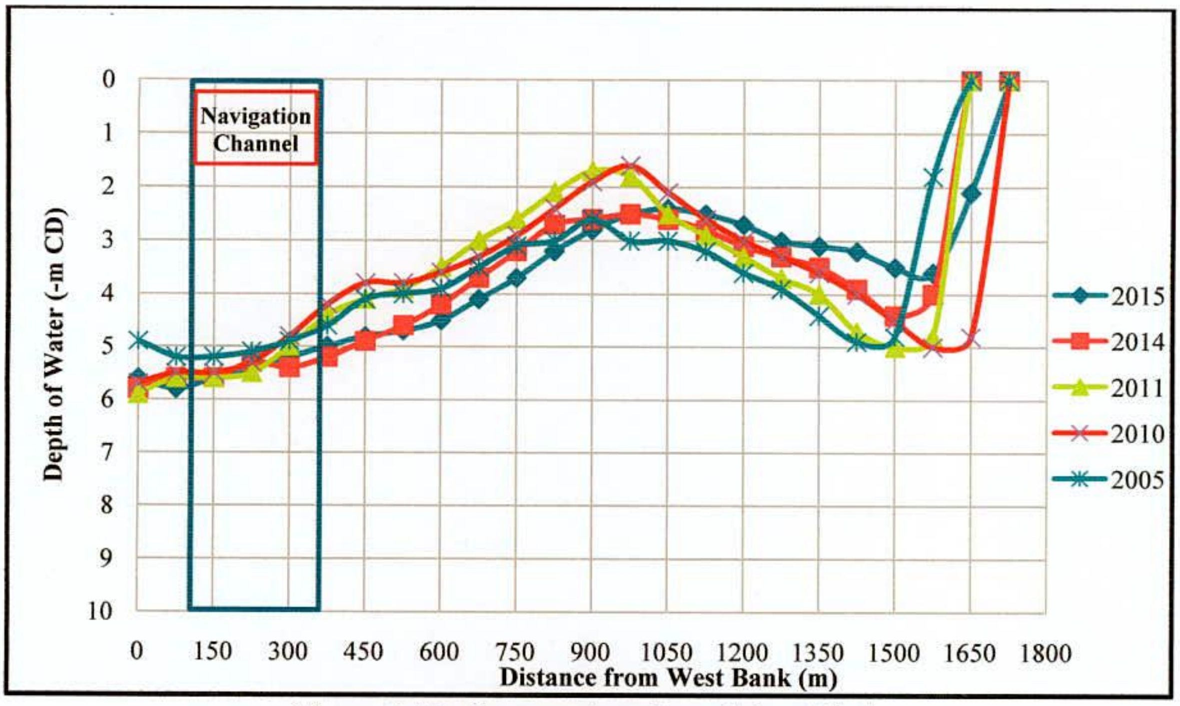


Figure 5.12: Cross section along Sultan Khal

The profile of Sultan Khal area (Figure 5.12) shows that, the river bed elevation of navigation channel in the year 2005 was more than -5.0 m CD i.e this section do not require dredging for 7.00 m draft vessel. Bed profile of the year 2015 shows that the depth increased to -5.50 m CD. This segment naturally scoured more than 0.5 m in last 10 years.

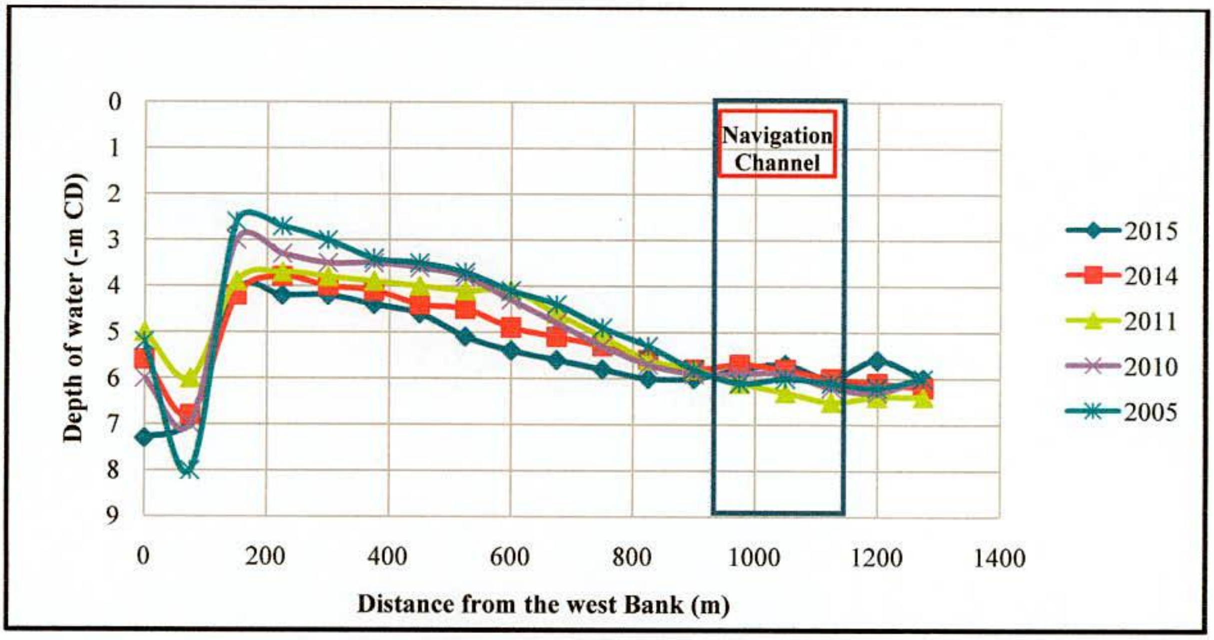


Figure 5.13: Cross section at Food Silo Jetty

The river bed of navigation channel at food silo area shows mild siltation pattern (Figure 5.13). Before construction of silo jetty, the bed profile was -6.5 m CD in the year 2011. The construction of silo jetty started in the year 2013. After completion of that jetty, siltation has started in adjacent areas. Within two years i.e at 2015 the river bed raised to -5.8 m CD.

Table 5.2: Rate of siltation/ scouring at the approach channel of MPA jetty

Sl.	Section	Bed Level (m below CD)		Siltation (+)/ Scouring (-)	Rate (m/yr.)
		2005	2011		
01	Danger Khal	5.3	5.7	-0.4	-0.067
02	Karamjol Forest Office	5.6	6.2	-0.6	-0.10
03	Sultan Khal	5.1	5.4	-0.3	-0.05
04	Food Silo Jetty	5.9	6.1	-0.2	-0.03

For determining natural siltation/scoring characteristics, the change of bed level in the middle of navigation channel is evaluated comparing bed elevation in 2011 with that of 2005. It can be noted that in this area the capital dredging is performed only for Danger Khal segment in the year of 2014, and other segments do not require the capital dredging. Table 5.2 has summarizes the rate of siltation/ scouring for the 04 sections at the approach channel of MPA jetty. It is observed that upto 2011 the navigation channel is in slightly degrading type where scouring rate varies from 0.03 to 0.1 m per year.

5.5 Joymonirgol to Harbaria [Chart-7]

The river reach from Joymonirgoal to Harbaria is quite stable in last few decades. The width of river in this section varies between 1,125.0 m to 1,800.0 m. The shallow reach of -2m to -6m CD is due to the divergence of flood and ebb channel. A typical cross section near Joymonirgol has presented in Figure 5.14 and harbaria khal has presented in Figure 5.15. The long profile as shown in Figure 4.9 represent that, the navigation channel of this reach have sufficient draft for movement and anchoring upto 10.5 m draft vessel. This reach is the anchorage point of bulk cargo (Fertilizer, Food Grain, Clinker etc.) vessels. These vessels unload the cargo directly on inland vessels and carried through waterway in different parts of country. Presently this anchorage area has become most important and very busy area because most of the ships called at MPA are handling here.

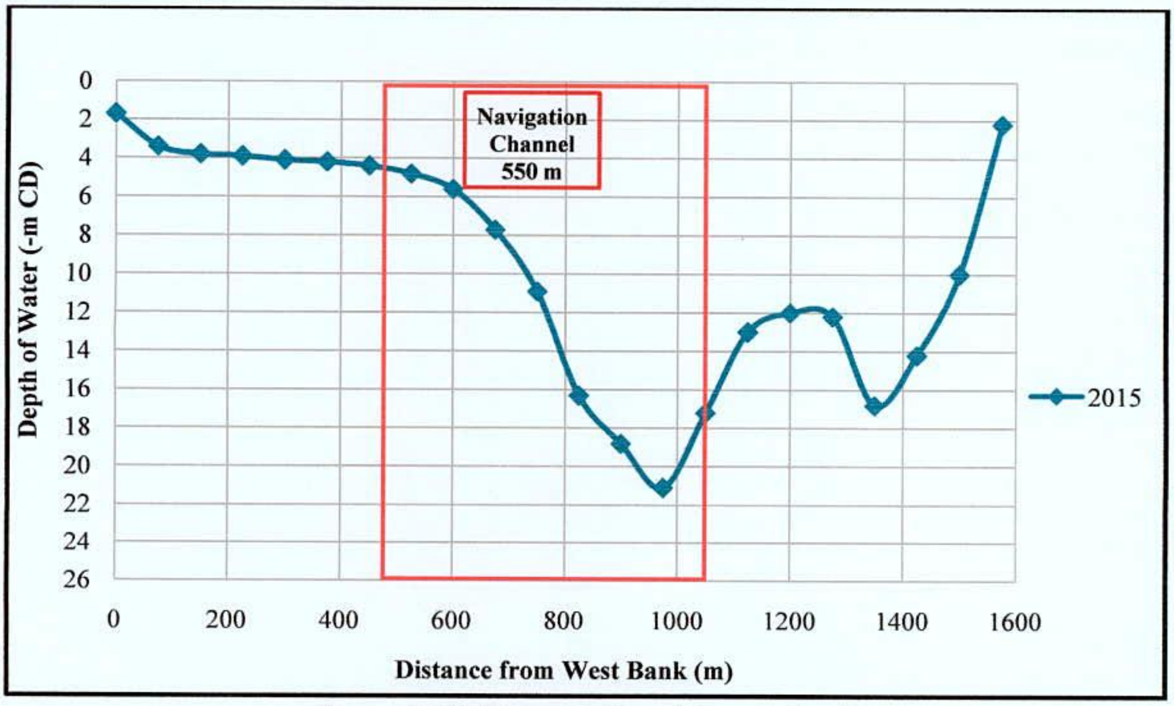


Figure 5.14: Cross section at Joymonirgol

5.6 Mazhar Point to D'Suza Point [Chart-6]

Over the last decade, the reach between Mazhar Point to D'Suza Point has found to be stable. The width of river in this section varies between 950.0 m to 2,250.0 m. Hydrographical analysis shows that the deeper navigable channel is following the outer bank and has continued up to Charputia in the recent years. A typical cross section near Monkey Point has presented in Figure 5.16.

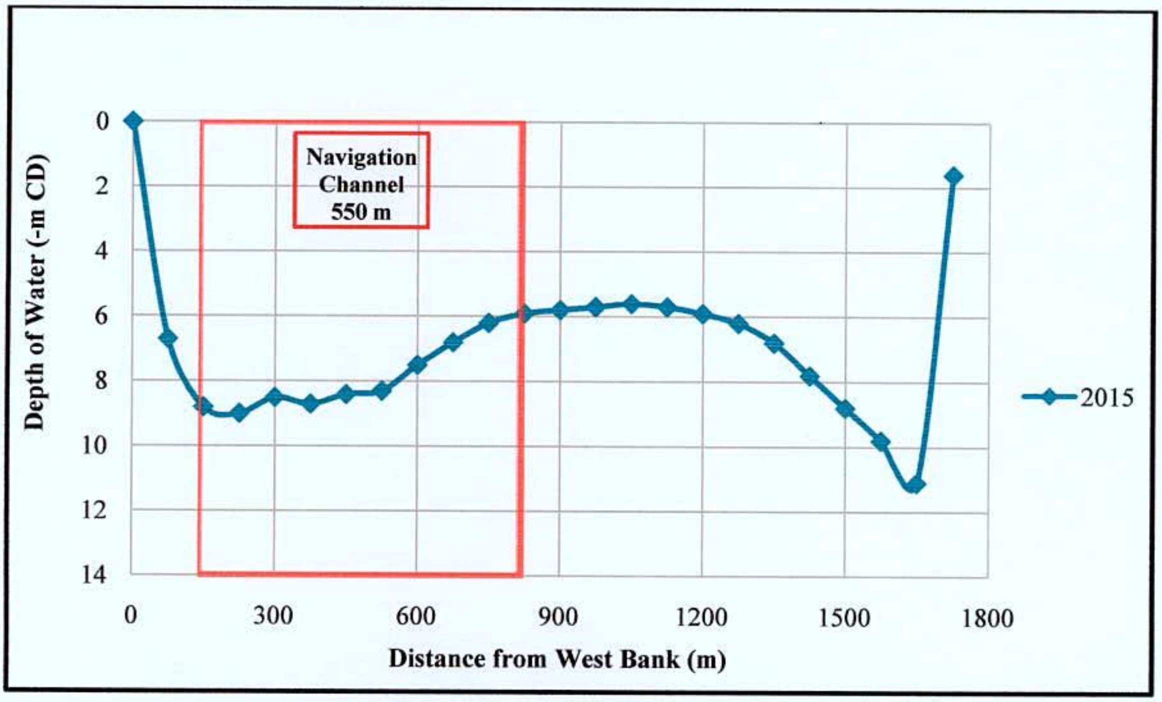


Figure 5.15: Cross section at Harbaria Khal

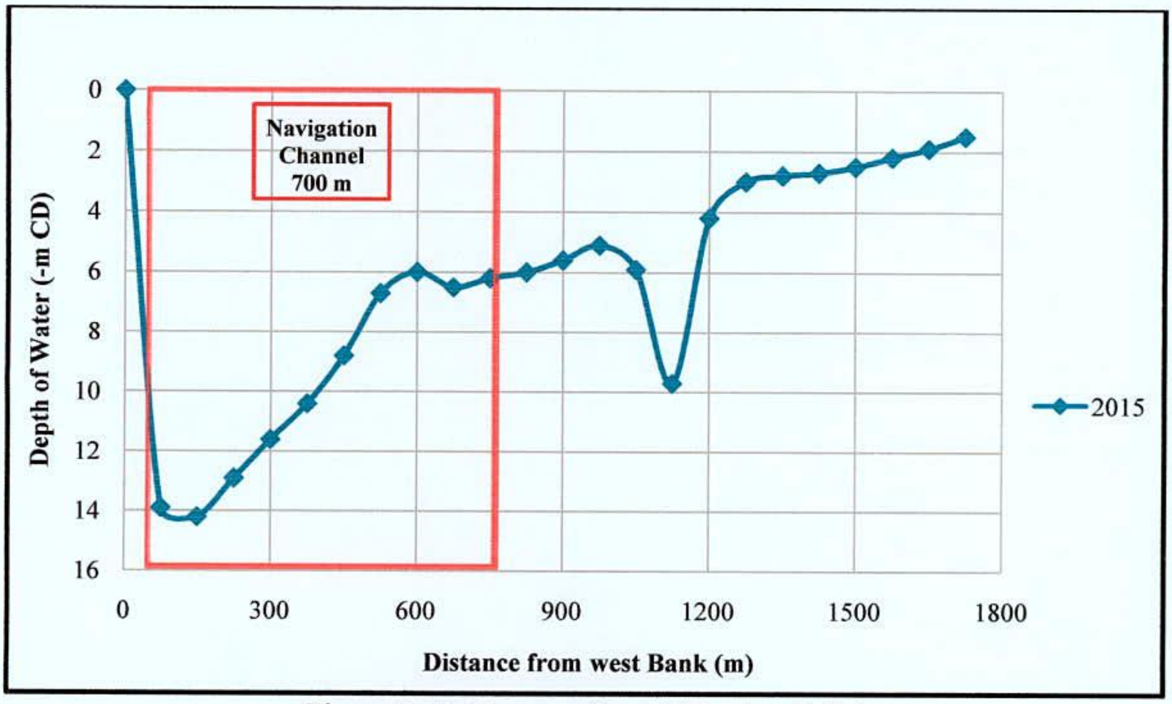


Figure 5.16: Cross section at Monkey Point

5.7 Sundorikota Khal to Cheilabogi Khal [Chart-5]

Over the last decade, the reach between Sundorikota Khal to Cheilabogi Khal has found to be stable. The width of river in this section varies between 1,250 m to 2,150 m.

Hydrographical analysis shows that the deeper navigable channel is spread over the full channel. A typical cross section near Charputia Khal has presented in Figure 5.17

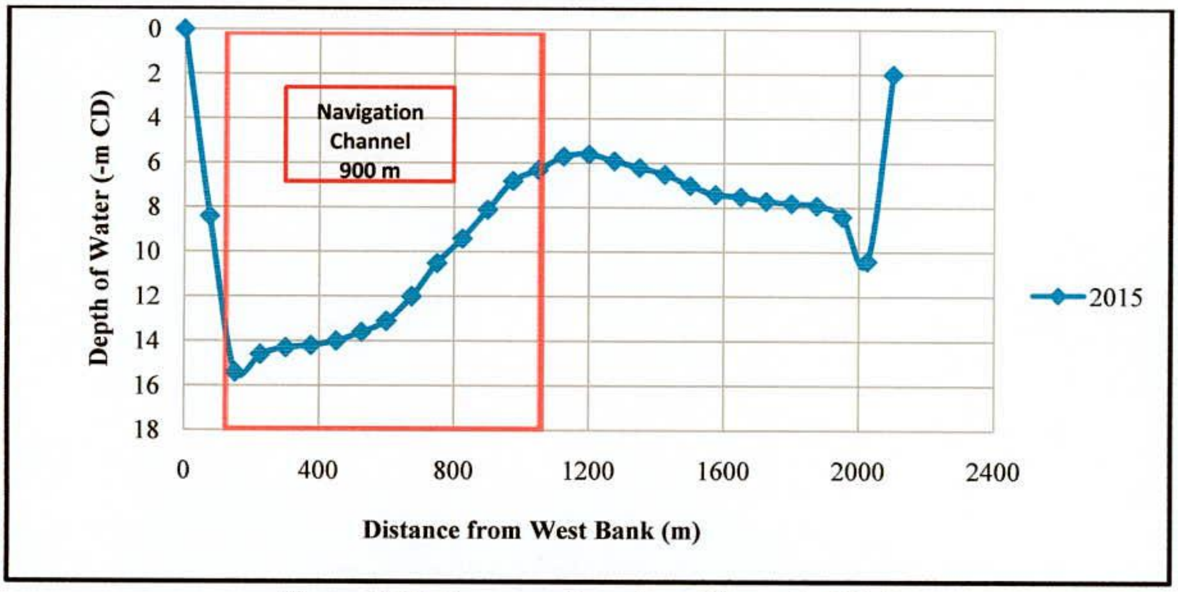


Figure 5.17: Cross section along Charputia Khal

5.8 Kagaboga Khal to Sundorikota Khal [Chart-4]

Over the last decade, the reach between Kagaboga Khal to Sundorikota Khal has found to be stable. The width of river in this section varies between 2,125 m to 2,625 m. Hydrographical analysis shows that the deeper navigable channel is following the outer bank. A typical cross section near Enam Khal has presented in Figure 5.18

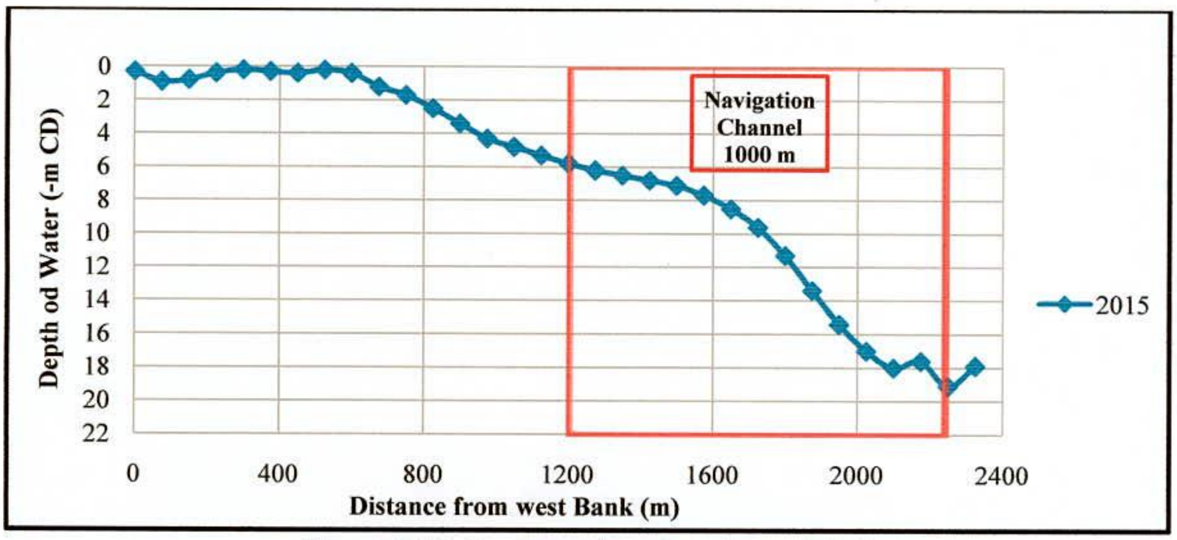


Figure 5.18: Cross section along Enam Khal

5.9 Tinkona Dwip to Kagaboga Khal [Chart-3]

Over the last decade, the reach between Tinkona Dwip to Kagaboga Khal has found to be stable. The width of river in this section varies between 2,500 m to 4000 m. Hydrographical analysis shows that the deeper navigable channel is following the outer bank. A typical cross section near Akram Point has presented in Figure 5.19

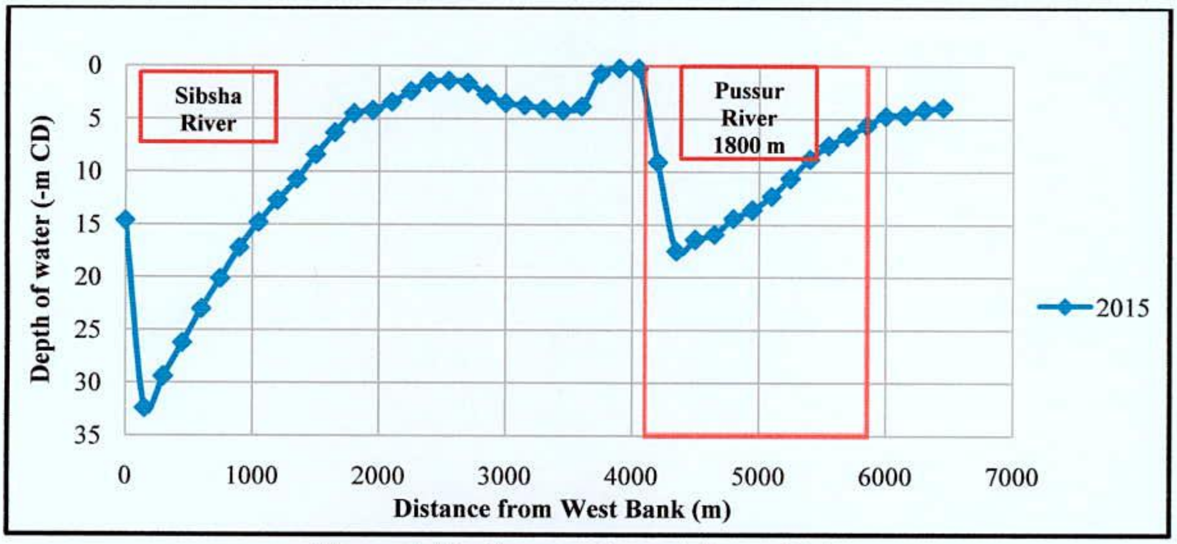


Figure 5.19: Cross section at Akram Point

5.10 Hiron Point to Tinkona Dwip [Chart-2]

Over the last decade, the reach between Hiron Point to Tinkona Dwip has found to be stable. The width of river in this section varies between 3,750 m to 7,500 m. Hydrographical analysis shows that the deeper navigable channel is following the outer bank. A typical cross section near Boar Point has presented in Figure 5.20

5.11 Fairway Buoy to Hiron Point [Chart-1]

Over the last decade, the reach between Fairway Buoy to Hiron point is very critical for the operation of Mongla Port. The flow direction and depth of channel is varying in last two decades rapidly. Hydrographical analysis shows that depth is most critical at wreck ocean wave. Wreck ocean wave is a sunken mother vessel at the entrance of Pussur channel. The wide shallow reach at the entrance of Pussur River is known as Outer Bar which will be described briefly in following sections.

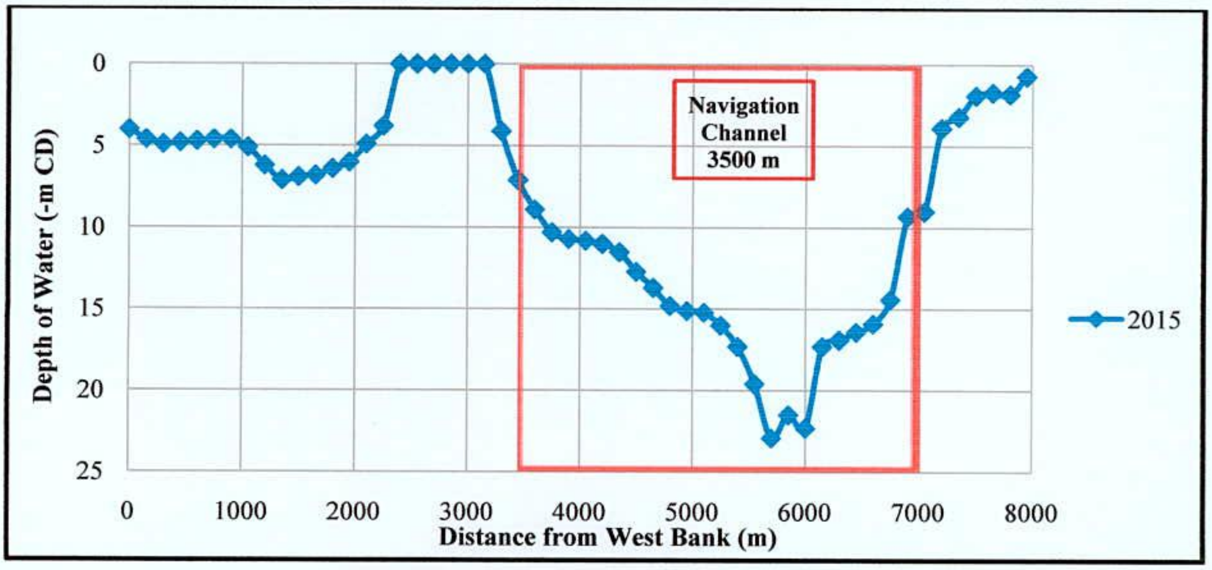


Figure 5.20: Cross section at Boar Point

5.12 Outer Bar

The outer delta areas is characterized by numerous islands with inter linked tidal channels and backwaters. Freshwater flow in the Pussur-Sibsa river system is significant during the monsoon (rainy season), that brings a very high sediment load. The high sediment supply from the river systems has resulted in the formation of numerous shoals, bars and islands within and around the entrance to the Zulfiquar channel. These shoals and bars are of significant importance to the navigability to the outer approaches to Mongla port and characterization of their formation and evolution is important for assessing the suitability of various approaches to improve the navigability of Mongla Port.

The coastal topography appears to be linked with the presence of a very deep trough in the center of the sea-bed, running in a NE-direction, the so-called Swatch of no ground which has its Northern extremity in the immediate vicinity of the Pussur entrance. The outlets of all channels are apparently directed towards this deep trough (IWM, 2004).

The layout of the coastline, channels and the bar area is shown in Figure 5.21. The bar area is enclosed with a 2 to 4 m contours. From the Pussur channel, two channels reach well into the Bar, a wide central channels and narrow western channel, separated by a spits. Zulfiqar channel crosses the bar along an alignment with a minimum depth of about -6 to -8 m CD. The figure further shows a large third channel, on the west, an extension of Malancha outlet, which can be considered for the navigational route from the Fairway Buoy.

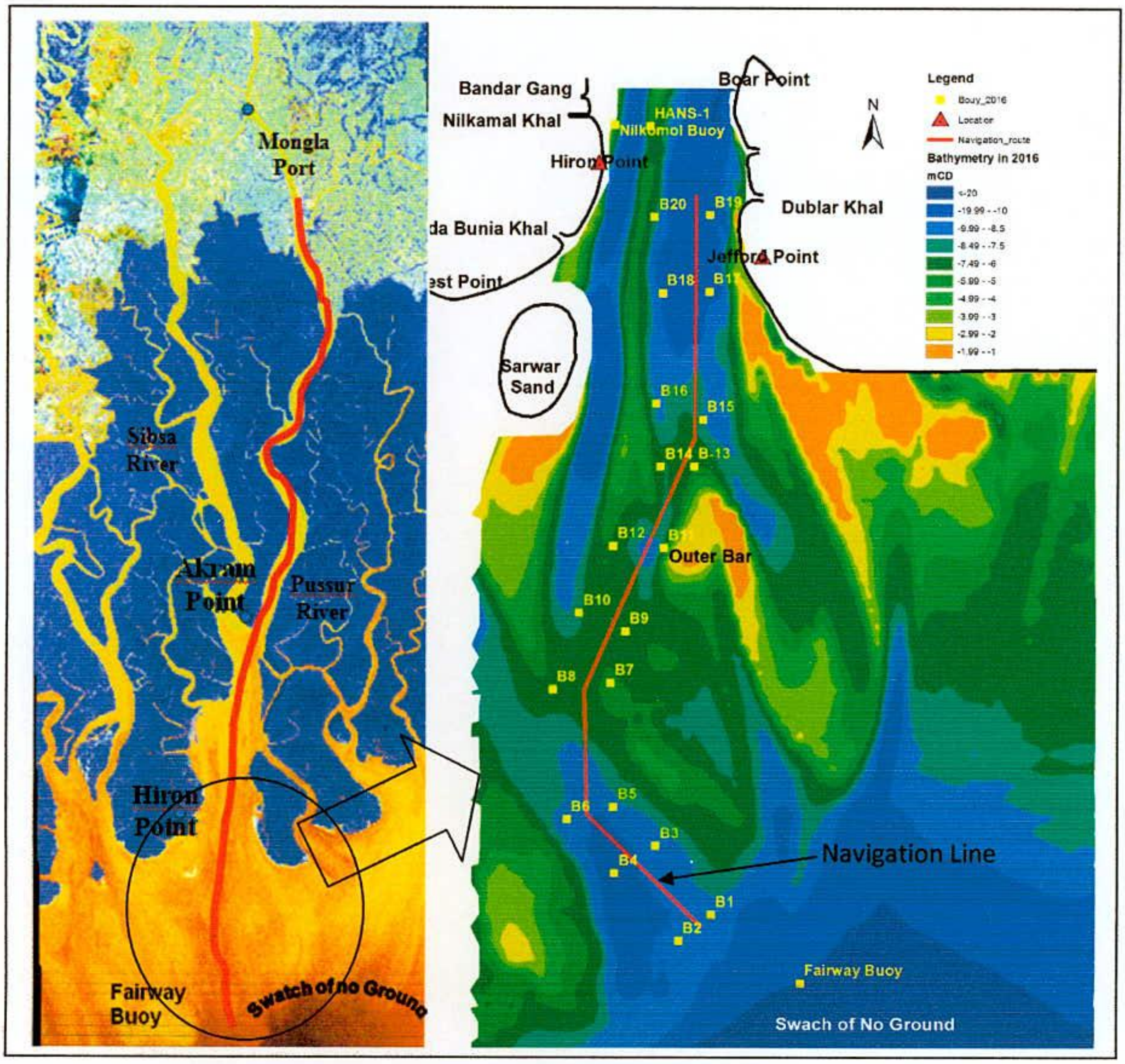


Figure 5.21: Location of Outer Bar (Source: IWM, 2004)

The northern tip of the Swatch of no ground is right opposite the Pussur outlet. The proximity of this deep trough causes the seaward slopes of the central part of the bar to be extremely steep.

5.12.1 Hydraulic Characteristics of the Pussur Entrance

Tidal waves approaching the coastal areas of Bangladesh are affected at least by four factors causing amplification and deformation of the wave: i) Coriolis acceleration ii) the width of the transitional continental shelf iii) the coastal geometry and iv) the frictional effects due to fresh water flow and bottom topography. Tide arrives from the deep sea and approaches at Hiron point and Cox's Bazar at about the same time. Tidal range is different in different locations. Tidal range at Hiron point near outer bar area varies from 3.22 m to

1m in spring and neap tide respectively (IWM, 2004). According to the Bangladesh Tide Tables 2016, the mean Tide Level at Hiron Point along Pussur River is 1.7m (CD).

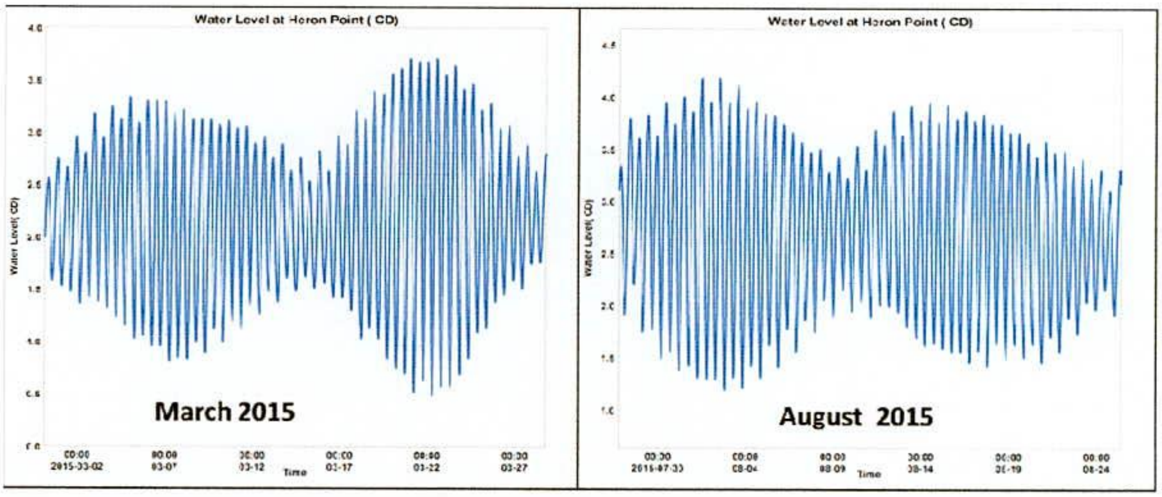


Figure 5.22: Tidal variation of at Hiron point during spring and neap

The variations of water depth and tidal characteristics in the study area over the years are identifying by water level. The water level data analysis shows that the maximum tidal ranges at outer bar area during the dry and monsoon period at spring tide in 2015 are about 3.22m in March 2015 and 3.02 m in August 2015 respectively (IWM, 2016). In neap tide the tidal ranges for the dry and monsoon period are 1.03 (March 2015) m and 1.28 (August 2015) m. The seasonal variation at Hiron point between March and September as obtained is about 0.79 m. Water level Characteristics of Hiron Point is presented in Figure 5.23. Tidal characteristics of Hiron Point according to 2016 tide tables are presented in Table 5.3.

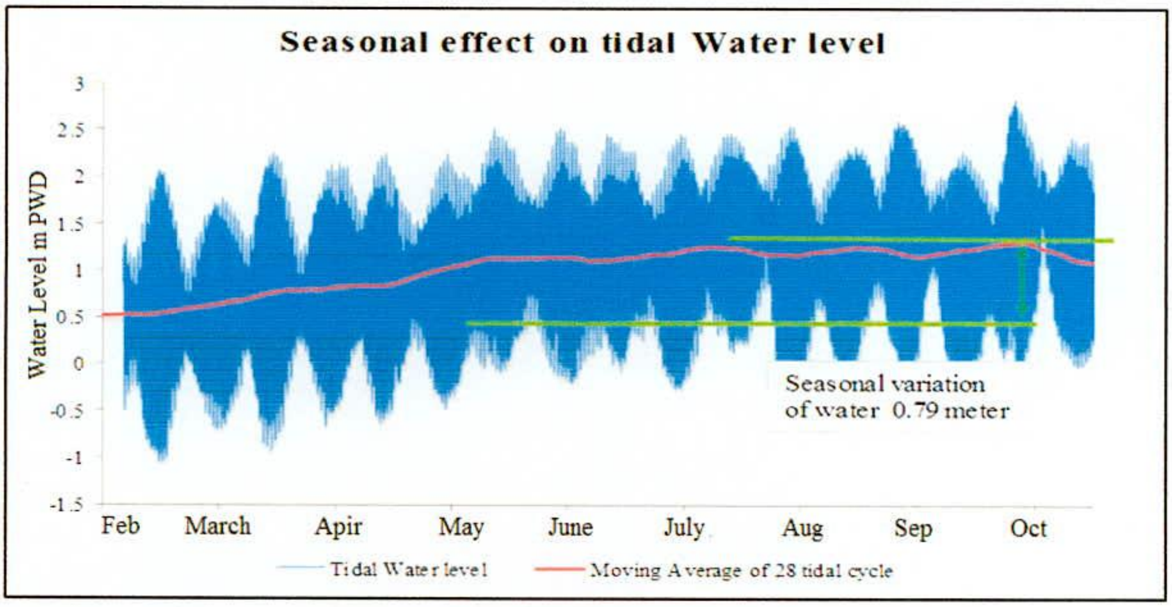


Figure 5.23: Water level Characteristics of Hiron Point Year 2010

Table 5.3: Tidal Characteristics at Hiron Point (Tide Table 2016)

Station	LAT	MLWS	MLWN	ML	MHWN	MHWS	HAT
Hiron Point	-0.256	0.225	0.905	1.7	2.495	3.175	3.656

5.12.2 Sediment Characteristics of the Outer Bar Area

Usually Sediment depositions found in the estuaries are comprised of various proportions of gravel, sand, silt, clay and organic matter. Generally sand, silt, clay and organic matter which is collectively known as mud are found in the upper reaches of the estuary and gravel and sand are found in the seaward ends of the estuary where wave action and residual currents remove the finer fractions (Mc Dowell & O'Corner, 1977). The river system transports a substantial amount of fine material into the coastal zone. However, analyzing the bottom sediment samples at our study location it was found that a significant amount of cohesive material is transported out of the Pussur entrance and deposited in some remote locations where tidal currents and wave actions are not strong enough to cause resuspension (DHI, 1993). Hence the non-cohesive sediments carried by Pussur-Sibsa and other nearby river systems dominate the coastal morphology around the outer bar area.

5.12.3 Morphological Changes of Outer Bar over 11 years [2005-2016]

Outer bar is situated some 45 km seaward of Hiron Point and exposed to the open sea. Zulfiqar channel crosses the bar along an alignment with a minimum depth of about -6 to -8 m CD. The major physical process controlling the morphology of the outer bar is the decrease in ebb current speed seawards of Hiron Point, where the tidal prism is no longer confined to a distinct channel.

Towards the mouth of the Pussur-Sibsa entrance, where the shores widen, there is a considerable divergence between flood and ebb channel. After the cyclone in 1988, the outer bar has been raised up to 0 to -2 m CD and widening in the east-west direction and the trend is continuing until the recent year as presented in Figure 5.25. The approach channel near Hiron Point is found to be splited more prominently after flood 1987 & 1988, even after 1998 flood, this could be related to huge volume of sediment carrying flow from upstream and deposited in more wider part of the Pussur river entrance.

The outer bar at the level of -2 to -4 m CD is found to be in a similar shape until even at the end of flood 1987 and 1988 as was in 1986. For detailed analysis of Outer bar area, long profile of Hiron Point to Fairway buoy for the year 2006, 2007, 2008, 2012, 2014 & 2016 has prepared which has presented in Figure 5.25.

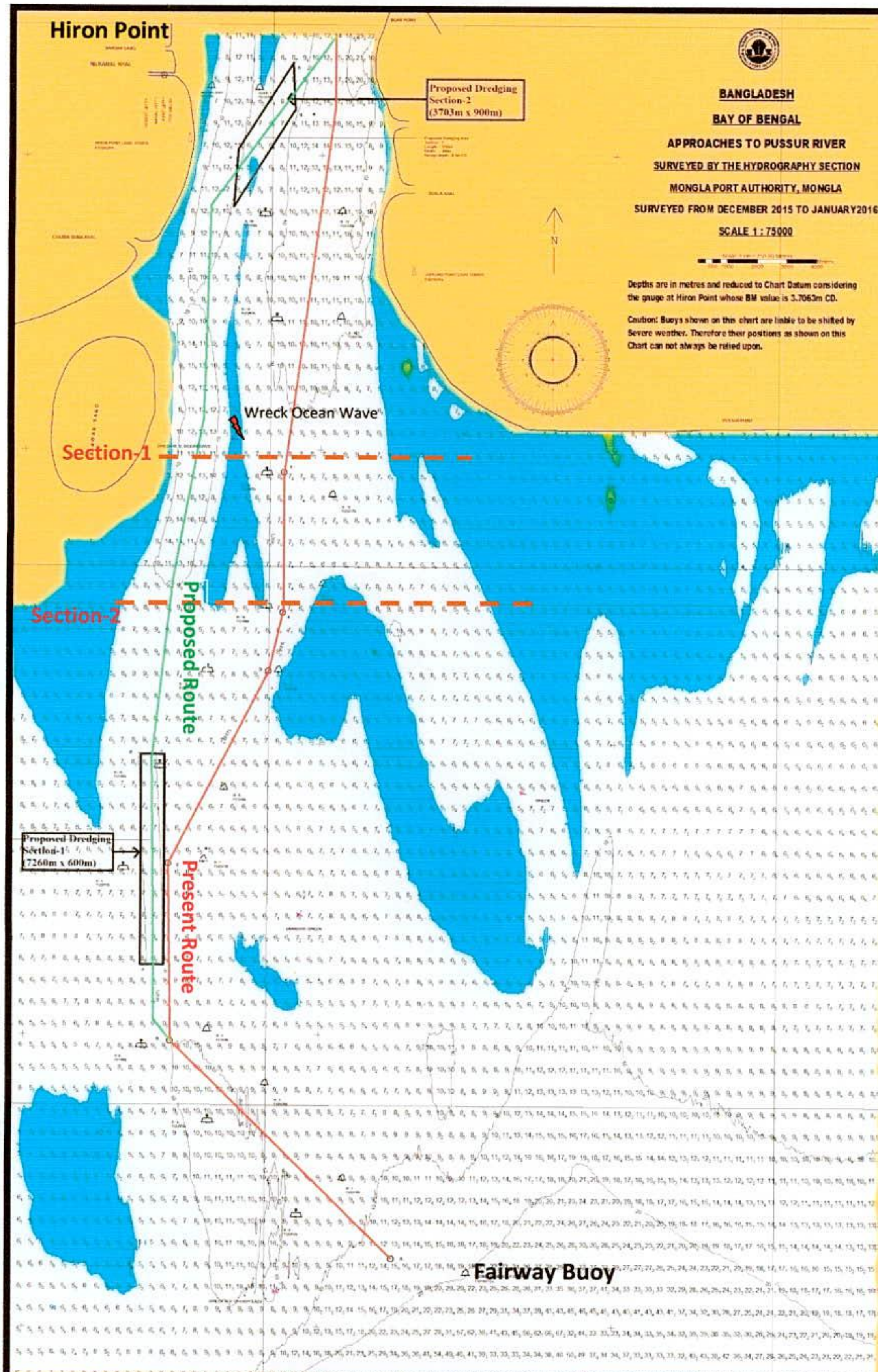


Figure 5.24: Hydrographic Chart of Outer Bar Area (Source: MPA)

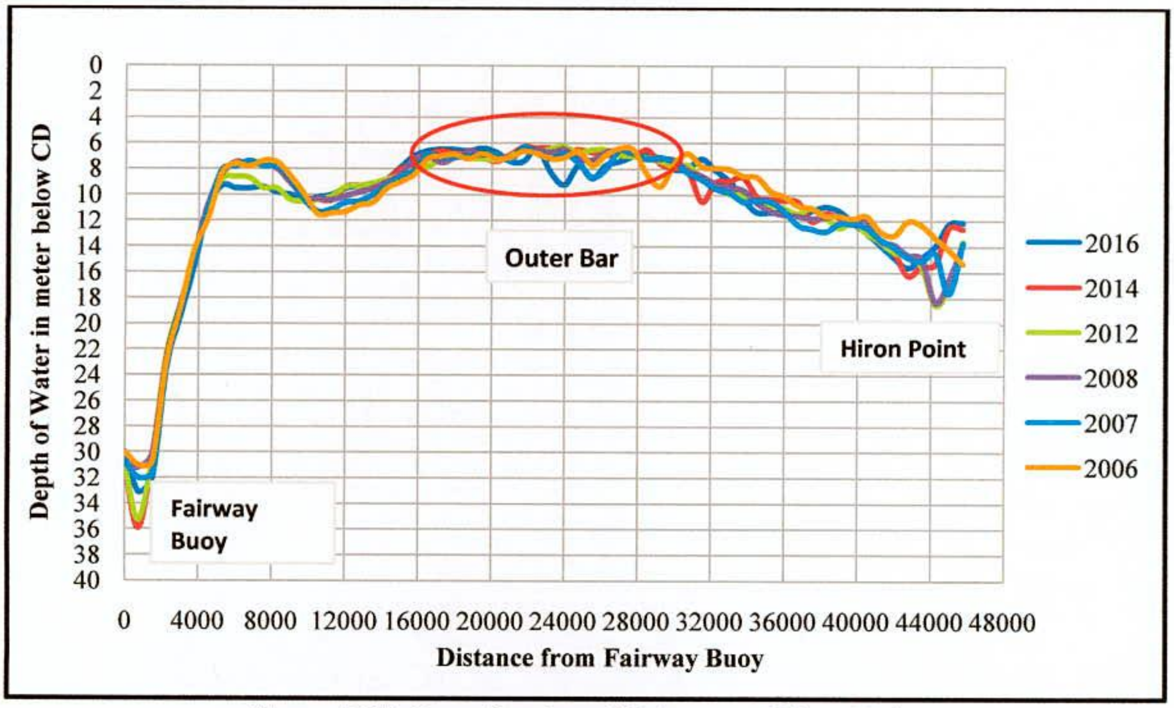


Figure 5.25: Long Section of Fairway to Hiron Point

At fairway buoy channel has sufficient depth for mother vessels (20-25 m draft). From fairway buoy to outer bar, this 16 km is quite stable in last few decades. At outer bar area presently shipping channel is on the eastern side of wreck ocean wave as indicated in Figure 5.24. But this channel is being silted up and the shallow portion is extending towards east side day by day. Cross section of wreck ocean wave (section-1) and below buoy 14 (section-2) is presented in Figure 5.26 & 5.27. It is observed that the width of existing navigation channel is also decreasing. In the west side of wreck ocean wave, the channel is quite stable is last ten years. If two segment of this western channel could be dredged then it will sustain more than the eastern channel. In the Figures *a, b, c* and *d* are the locations where the siltation rate is calculated (Figure 5.26 and 5.27).

Table 5.4 shows the calculated results of sediment deposition rate comparing the bed profile for 2016 with that of 2012 for two points in each of wreck ocean wave and buoy-14 sections. It is observed that near the west bank in section-1(lateral position a), the channel is silted up by 4.3 m in 4 years; and on the bar at point b, the bar is silted up by 0.5. In the downstream of buoy 14 (section 2), the bar is found to be gradually raised up, where the sedimentation rate at two points are found to be about 1.3 and 1.5 m in 4 years. According to the hydrographic chart of 2007, 2012, 2013, 2014 and 2016, the changes of outer bar area in proposed dredging sections is given in Table 5.5.

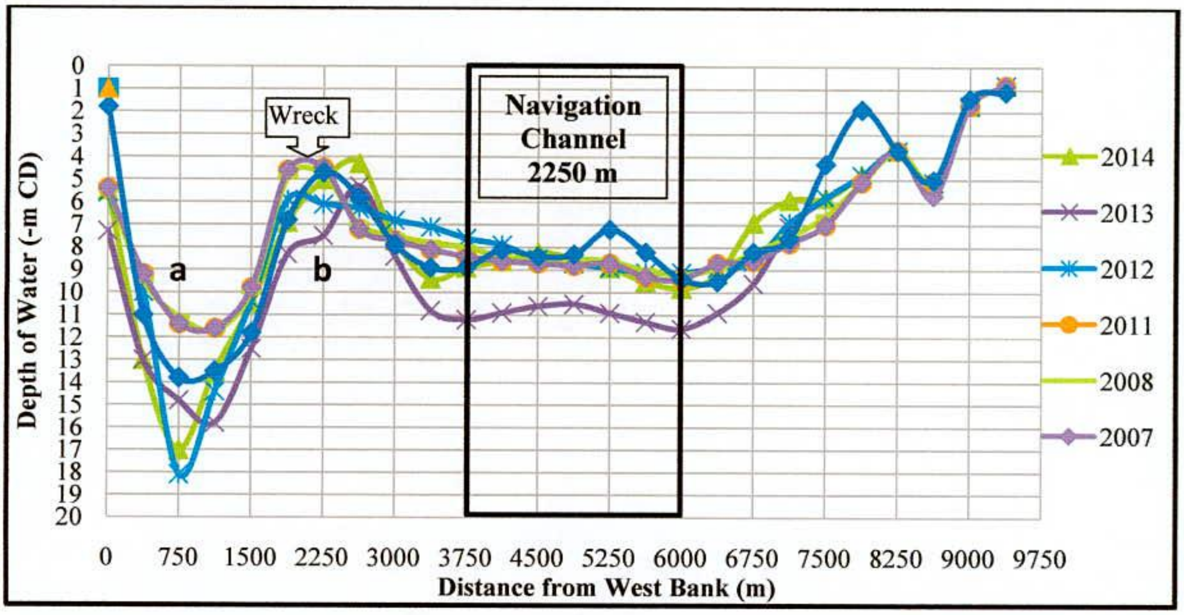


Figure 5.26: Cross section below wreck Ocean Wave (Section 1 in Fig. 5.24)

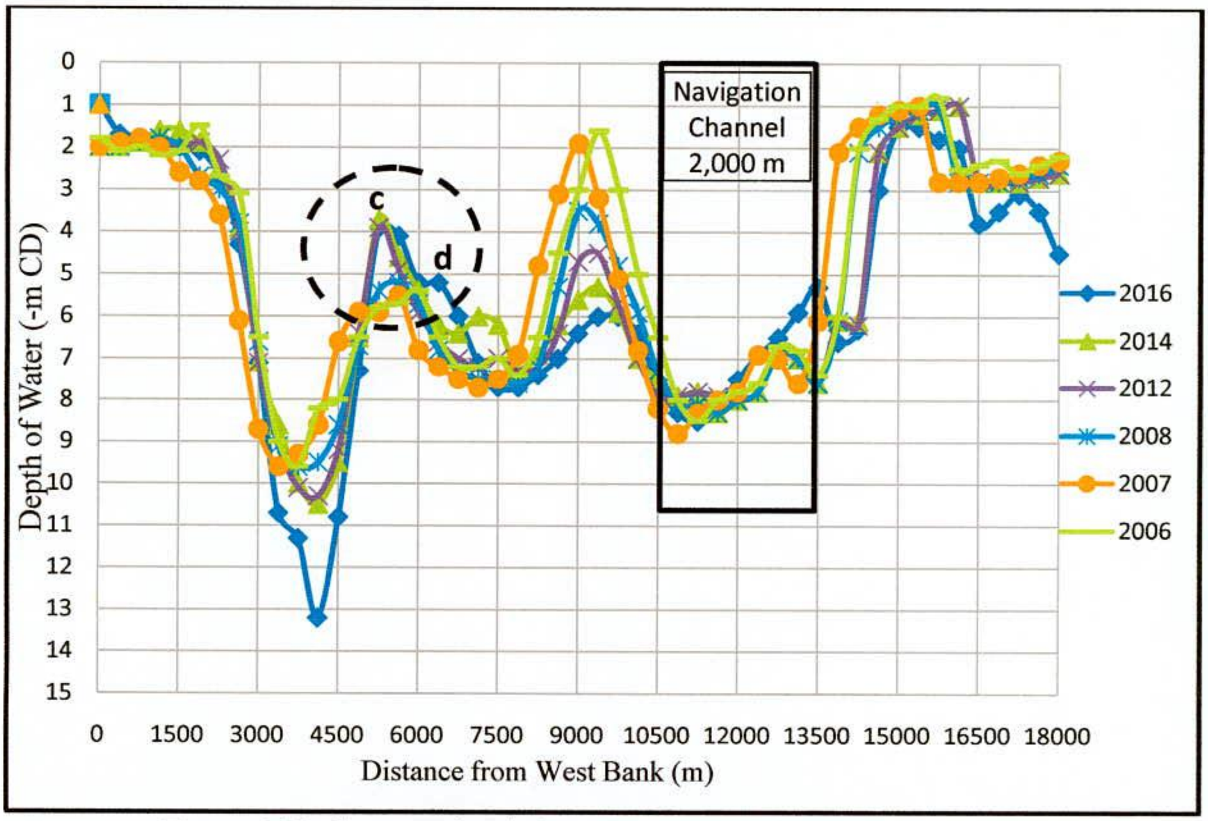


Figure 5.27: Cross section below Buoy 14 (Section 2 in Fig. 5.24)

Table 5.4: Calculated siltation/scouring rate in Outer bar area around navigation route

Longitudinal position	Transverse distance from west bank (m)	Bed level in 2012 (-m CD)	Bed level in 2016 (-m CD)	Siltation between 2016-2012 (m)
Wreck Ocean Wave (Sec. -1)	750	18.1	13.8	4.3
	2250	6.3	5.8	0.5
Buoy 14 (Sec.-2)	5250	5.4	3.9	1.5
	6375	6.5	5.2	1.3

Table 5.5:Siltation/scouring pattern in Outer bar area at proposed dredging area (IWM'16)

Sedimentation Pattern	Changes Between years 2007-2012	Changes Between years 2013-2014	Changes Between years 2014-2016	Changes Between years 2007-2016
	(Mm^3)			
In the Channel (Area: 3703m x 900 m)				
Deposition	0.156	0.843	3.716	2.804
Scouring	1.057	0.367	7.086	6.599
Net Deposition	-0.901	0.475	-3.369	-3.795
In the open Estuary (Area: 7260 x 600 m)				
Deposition	0.669	0.487	0.580	1.688
Scouring	0.048	0.337	0.352	1.834
Net Deposition	0.621	0.149	0.228	-0.146

5.13 Summary

The approach channel and upstream of MP is scouring in last few years which may resulting from the increasing of ship movement. But depth at jetty front cannot sustain effectively after dredging and it is a big problem for berthing the ships in low tide. If depth at outer bar area could be increased to at least -8.5 m CD, then MP will able to handle more than 10.5 m draft vessel at Harbaria anchorage. Management of dredged material is a big challenge for outer bar area dredging

Chapter 6

INTERVENTIONS FOR NAVIGATION ENHENCEMENT

6.1 Introduction

Pussur River from chalna to Fairway Buoy has presented in previous chapters. In this Chapter, the causes of navigation problem, previous intervention and future plan of MPA to improve navigability, dredging history of the river and effectiveness of dredging are discussed based on the results obtained in previous chapters and information collected from MPA. Some potential measures to enhance navigability are also suggested.

6.2 Potential Causes of Navigation Problem in Pussur River

During the establishment of MP at present location, there was sufficient depth for berthing of 8.5 m draft vessel. Siltation started at Jetty area and its approaches after 1980. One of the main reasons of siltation is reducing the upland flow after construction of Farakka barrage and construction of polders around the Pussur River. Another threat for navigability is the wrecks at different position of Pussur River.

6.2.1 Channel Bed Siltation

Siltation in Pussur River mainly happens in three segments which are: (a) Chalna to Digraj- upstream of MP (b) Mongla Port to Base Creek Khal- Harbour area and (c) Downstream of Hiron Point- Outer Bar. The rate and amount of siltation/ scouring in those three area has identified in various study and which are summarized below:

(a) Chalna to Digraj- upstream of MP: In the feasibility study for capital dredging of Pussur River from Mongla port to Rampal power plant, IWM (2015) pointed the sedimentation and scouring in 05 dredging areas as follows:

Table 6.1: Sedimentation in different segments between Mongla jetty to Chalna (considering changes between years 2013-2015)

Location of navigation channel segment	Average Siltation depth (m/year)
Power Plant Turning Ground (600 m × 300 m segment)	0.97
Power Plant Jetty Front (500 m × 200 m segment)	0.43
Maidara - Jetty Front (2400 m × 200 m segment)	0.45
Digraj – Maidara (3140 m × 200 m segment)	0.21
Sabur Beacon – Digraj (3000 m × 200 m segment)	0.21

(b) Harbour Area: Table 6.2 shows the natural siltation/scouring rate at harbor area calculated from hydrographic chart comparing the data of 2013 with 2008. Note that

within this period no dredging was performed in the channel. It is observed that the channel is slightly degrading type with yearly lowering of bed level varies from 0.12 to 0.32 m. However, in this area, the high backfilling rate after capital/maintenance dredging is the main problem to get sufficient draft. Figure 6.1 shows the longitudinal bed profile from Digraj to Mongla showing backfilling within one year after dredging the channel in the year of 2014. This issue is further discussed in the following section of Art. 6.4. After completion of Harbour Area Dredging project, the monitoring consultant IWM carried out monitoring survey and develop mathematical model to access the backfilling rate of dredging. According to their opinion backfilling rate was 50-80% of capital dredging per year.

Table 6.2: Natural siltation/scouring rate at harbor area calculated from hydrographic chart.

Sl.	Sections	Bed Level (m below CD)		Siltation (+)/ Scouring (-) rate (m/yr.)
		2008	2013	
01	Kleenheat LPG Jetty	4.9	6.1	-0.24
02	Middle of MPA jetty-09	4.2	5.8	-0.32
03	North Side of MPA Jetty-05	4.2	4.9	-0.14
04	MPA Vessel Berth	4.4	5.4	-0.20
05	Wreck Pavlina	3.8	4.4	-0.12

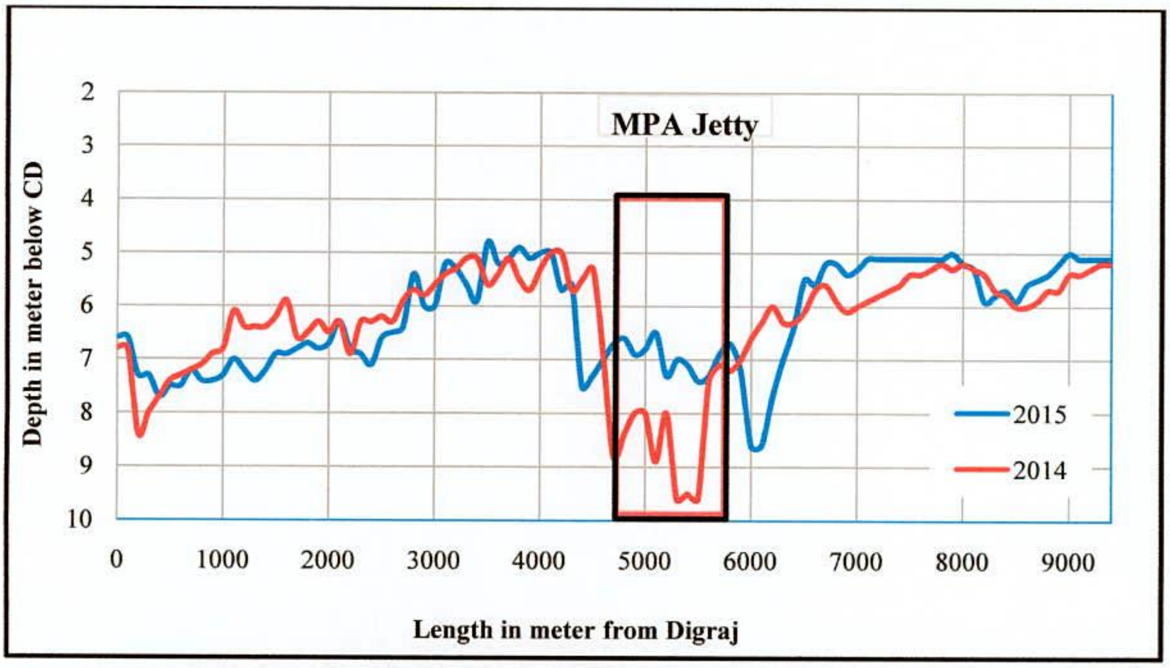


Figure 6.1: Longitudinal bed profile From Digraj to Mongla showing backfilling within one year (2014 is the dredging year).

(c) Outer Bar Area: Table 6.3 shows the natural siltation/scouring rate at Outer bar area calculated from hydrographic chart comparing the data of 2009 to 2016. At outer bar area

presently shipping channel is on the eastern side of wreck ocean wave. But this channel is being silted up and the shallow portion is extending towards east side day by day. Note that within this period no dredging was performed in the channel. In the downstream of buoy 14, the bar is found to be gradually raised up, where the sedimentation rate at two points are found to be about 0.35 m/year.

Table 6.3: Sedimentation and scouring in Outer Bar

Longitudinal position	Transverse distance from west bank (m)	Siltation (m/year)
Wreck Ocean Wave (Sec. -1)	750	1.1
	2250	0.13
Buoy 14 (Sec.-2)	5250	0.38
	6375	0.33

6.2.2 Obstacle due to Wrecks

During the liberation war and thereafter, some local and foreign ships, (13 local and 5 foreign) sank at different reaches in the Pussur channel. MPA has taken steps several times to remove the wrecks. Top portion of some wrecks have been removed but the bottom and sides of these wrecks still remain in the channel. MPA has difficulty in removing all the portion of wrecks fully. Detail information of foreign wrecks are available in MPA. But information's of local wrecks are not available. MPA only have the location of those local wrecks.

For instance, one of the wrecks in the outer bar area (wreck ocean wave) as shown in Figure 5.24, causes siltation at its downstream. Thus the existing navigation route at the downstream east side of the wreck is narrowing and swallowing and causes threat to the existence of the route. MPA is planning to shift/relocate the route to the west side channel after performing the required dredging.

6.2.3 Human Disturbances

The navigability of Pussur River also suffered a lot due to human activities along with the natural reasons. After construction of MPA jetty at present location depth around jetty area started to reduce. The main reason of siltation is reducing the tidal prism in surrounding Pussur River. To maintain the Pussur with sufficient draft required for navigation, it is most significant to keep the volume of the tidal prism unchanged, or at least not decrease it.

Table 6.4: List of foreign and local ship (Wreck) sunk in Pussur Channel

Sl.	Name of Ship	Length (m)	Width (m)	GRT (MT)	NRT (MT)	Location	Year
Foreign Wrecks							
01	MV Ocean Wave	174.09	22.90	15,684	6,539	About 2 km west of buoy B-16 at the entrance of Pussur	1999
02	MV Cheri Lazu	135.43	16.00	3,776	2,119	About 6.7 km west of Fairway Buoy	1984
03	Unknown	-	-	-	-	About 3.4 km east of buoy B-7 at the entrance of Pussur	-
04	Unknown	-	-	-	-	About 13 km south of Dublar Char	-
05	MV Pavlina-1	143.66	20.65	9,627.56	4,900	At the confluence of Mongla Nulla and Pussur river (West Side)	1994
Local Wrecks							
01	Barge President-1	-	-	-	-	Mongla Anchorage Area	1993
02	Barge NSC -8/E	-	-	-	-		1995
03	MV Shah ali	42.79	8.81	344.00	-		1997
04	Barge KSY- 508	28.15	7.31	-	-		2000
05	Unknown	-	-	-	-		-
06	Unknown	-	-	-	-		-
07	Unknown	-	-	-	-	Mongla Nullah	-
08	Unknown	-	-	-	-		-
09	Unknown	-	-	-	-		-
10	Unknown	-	-	-	-		-
11	Barge Akash Prodip-5	-	-	-	-	Joymonirgol	2005
12	Unknown	-	-	-	-		2010
13	Unknown	-	-	-	-		2012

According to the observations of MPA officials, the human interventions mainly responsible for changing the morphology of Pussur River are:

(a) Construction of polders and coastal embankments, which prevents tidal water to spread over the land which has decreased the tidal prism considerably in the river.
(b) Excavation of Mongla-Ghasiakhali link channel, which diverted a great volume of tidal water from its original course
(c) Restriction of upland flow due to less discharge of water from Padma to Modhumati and Nabaganga, Kobadak Bhairab and ultimately to Pussur due to Farakka withdrawal of Ganges water.
(d) 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.

The sunken ships and sunken barges loaded with cement, billets, jute and jute goods at the bottom of the Pussur River also caused siltation and deterioration of draught. Approximately 52 wrecks are lying at Joymanirgol to Bajua. These sunken barges are acting as dangerous silt traps.

6.3 MPA Interventions to Enhance Navigability

6.3.1 Maintenance Dredging

Mongla Port was designed for berthing ships having 8.50 m draft. Upto 1980 there was not any siltation problem either in Jetty front or Channel area. But after 1980 siltation started in Jetty front Area. From that time regular maintenance dredging was performed in jetty front area. In the meantime it was seen that siltation has started in Harbour Area (About 13 km downstream from Port Jetty). For regular maintenance dredging, Mongla Port Authority has 02 nos 18" dia Cutter Suction Dredger. From the establishment of the Port, the quantity of maintenance dredging are listed in Table 6.5.

6.3.2 Capital Dredging

In spite of above maintenance dredging, to remove the siltation, 03 capital dredging projects have been implemented in the year of 1991 - 1992, 2000 - 2004 & 2013-2014. The most recent capital Dredging project titled "Harbour Area Dredging" has completed in the year 2014. After completion of this project, ships having draft of 7.50 m can easily take berth at Mongla Port. The details of 03 Capital Dredging Project are described in Table 6.6.

Table 6.5: Details of Maintenance Dredging performed in Pussur Channel to increase the navigation depth.

Dredging period	Dredger Authority	Dredging Area	Dredging Quantity (Mil. cu.m)	Dredger Type
1979-1981	BWDB	Jetty front (J5-J9)	0.325	CSD
1983-1987	BIWTA	Jetty front (J5-J9)	0.695	CSD
1988-1990	BWDB	Jetty front (J5-J9) & Confluence	0.523	CSD
1993-1996	Khanak dredger of CPA (TSHD)	Southern Anchorage confluence & Sabur Beacon	0.226	TSHD
1994-2001	BWDB	Jetty front (J5-J9)	0.813	CSD
2003-2004	BWDB	Jetty no- 8 & 9	0.069	CSD
2004-2005	Basic dredging Co.	Jetty no- 8 & 9	0.054	CSD
2005-2006	BWDB	Jetty no- 8 & 9	0.069	CSD
2007-2008	BWDB	Jetty no- 8 & 9	0.108	CSD
2009-2010	BWDB	Jetty no- 8 & 9	0.071	CSD
2012-2013	MPA's own Dredger	Jetty no- 8 & 9	0.017	CSD
2015-2016	AZ dredging Company Ltd	Approach and Pontoon front of Nil Komol	0.155	CSD
Total			3.125	

Table 6.6: Details of Capital Dredging performed in Pussur Channel to increase the navigation depth.

Dredging period	Dredging Company	Dredging Area	Dredging Quantity (Million cu.m)	Dredger Type
1991-1992	China Harbour Engineering Company, China	Harbour Area	3.551	CSD
2000-2004	PT. Rukindo- Basic Dredging Partnership (a joint venture of Indonesia and Bangladesh).	Harbour Area	2.79	CSD & TSHD
2013-2014	China Harbour Engineering Company, China	Harbour Area	3.406	CSD
Total			9.747	

The total volume dredged over the period 1979 to 2016 is about 12.872 Mm^3, which is equivalent to an average of 3,47,000 m^3 per year. Out of 37 years record, around 3.0 Mm^3 dredging was done in the Jetty Front to maintain the berthing pocket alongside the jetty. This is a localized dredging requirement is a continuous problem and the practice has been for maintenance dredging using Cutter suction dredger. The dredging operations at the jetty front area were required mainly to clean up very shallow patches just along the berths. This sediment deposition is formed by the sliding down of sediment that accumulates due to the cluster of piles under the apron. This is considered the main reason of quickly filled up of the dredged areas alongside the jetties to natural river bed level.

6.3.3 MPA's Future Plan

MPA has planned to implement following two capital dredging projects to improve the navigability in the Mongla-Chalna and Outer bar area.

(i) Capital Dredging in Pussur Channel from Mongla Port to Rampal Power Plant: To ensure safe movement of coal carrying ships to 2 × 660 MW Maitree Super Thermal Power Project at Rampal, GoB has approved this project. Under this project total 3.88 million cubic meter spoil will be dredged by CSD and TSHD. According to MPA's plan the proposed dredging will be completed within December 2018. MPA has planned to dredge at 7.95 km area within 13 km of Mongla Port to Rampal Power Plant. The proposed dredging area has divided in 5 segments. Proposed length, width & depth of those 5 segments are listed in Table 6.7.

Table 6.7: Proposed length, width & depth of Dredging in Pussur Channel from Mongla Port to Rampal Power Plant

Proposed Dredging Area	Length (meter)	Width (meter)	Present Average Depth (-m CD)	Design Profile (-m CD)	Dredging Method
Power Plant Turning Ground	500	300	2.19	5.5	Cutter Suction Dredger
Jetty Front	500	200	2.44	8.0	
Maidara to Jetty Front	2400	200	1.92	5.5	
Digraj to Maidara	2900	200	5.09	5.5	Trailing Suction Hopper Dredger
Sabur beacon TG to HCF Jetty	1650	200	4.27	5.5	

(ii) Dredging at the Outer Bar Area of Pussur Channel: To achieve sufficient draft of 10.5/11 meter draft vessel (upto anchorage area) this project has been prepared by MPA, which is now under process of approval by GoB. According to MPA, in this project total 10.3 million cu.m spoil will be dredged by TSHD. According to the feasibility study

report, the designated location for dumping the dredged material is deep sea which is about 60 km downstream from Hiron point. TSHD will be used in the dredging operation and will carry dredged spoil to facilitate dumping of the materials at the designated location. Probable quantity of dredging in two sections is given in Table 6.8.

Table 6.8: Proposed Dredging Alignment of Outer Bar Area

Sl. No	Alignment Reach (km)	Dredging Length (km)	Dredging Width (m)	Design Depth (-m CD)	Tolerance Limit of Dredging (m)	Volume of Dredged Material (m^3)	Total Volume of Dredged Material (m^3)
1	Channel (Near Hiron Point)	4.6	900	8.5	0.3	5011875	10395000
	Estuary (In open Sea)	7.3	600	8.5	0.3	5383125	

6.4 Back-filling Rate and Effectiveness of Dredging

Upto now MPA has considered the dredging as the only option to improve the navigability. The dredging already completed by MPA and their future plan was presented above. However, the positive impact of dredging on navigability of Pussur channel is not found so significant due to the high backfilling rate. In this section, the backfilling rate is analyzed comparing the bed profile before and after dredging in several sections of Pussur channel. For this, the capital dredging in the year of 2014 in different segments of Pussur navigation route is considered. That time, Harbour Area (Base creek to MPA Jetty) was dredged upto 8.0 m at Jetty front, 7.0 to 7.5 m at Mooring Buoy and 5.5 m at other areas. Total 3.506 million cubic meter deposited silt was dredged at a cost of 112.0 crore taka. Figure 6.2 shows the location and alignment of the dredging in Harbour area of Pussur channel. The backfilling rate of those capital dredgings are presented below.

6.4.1 MPA Jetty Area

MPA has 5 nos Jetty having total length of 915 m. The jetty area is situated at concave end of a small mender. Ships berth here in both high and low tide and for that minimum 8.0 m draft required at 50 m wide are in front of Jetties. For movement of other vessels another 150 m required more than 5.0 m draft which called Jetty channel.

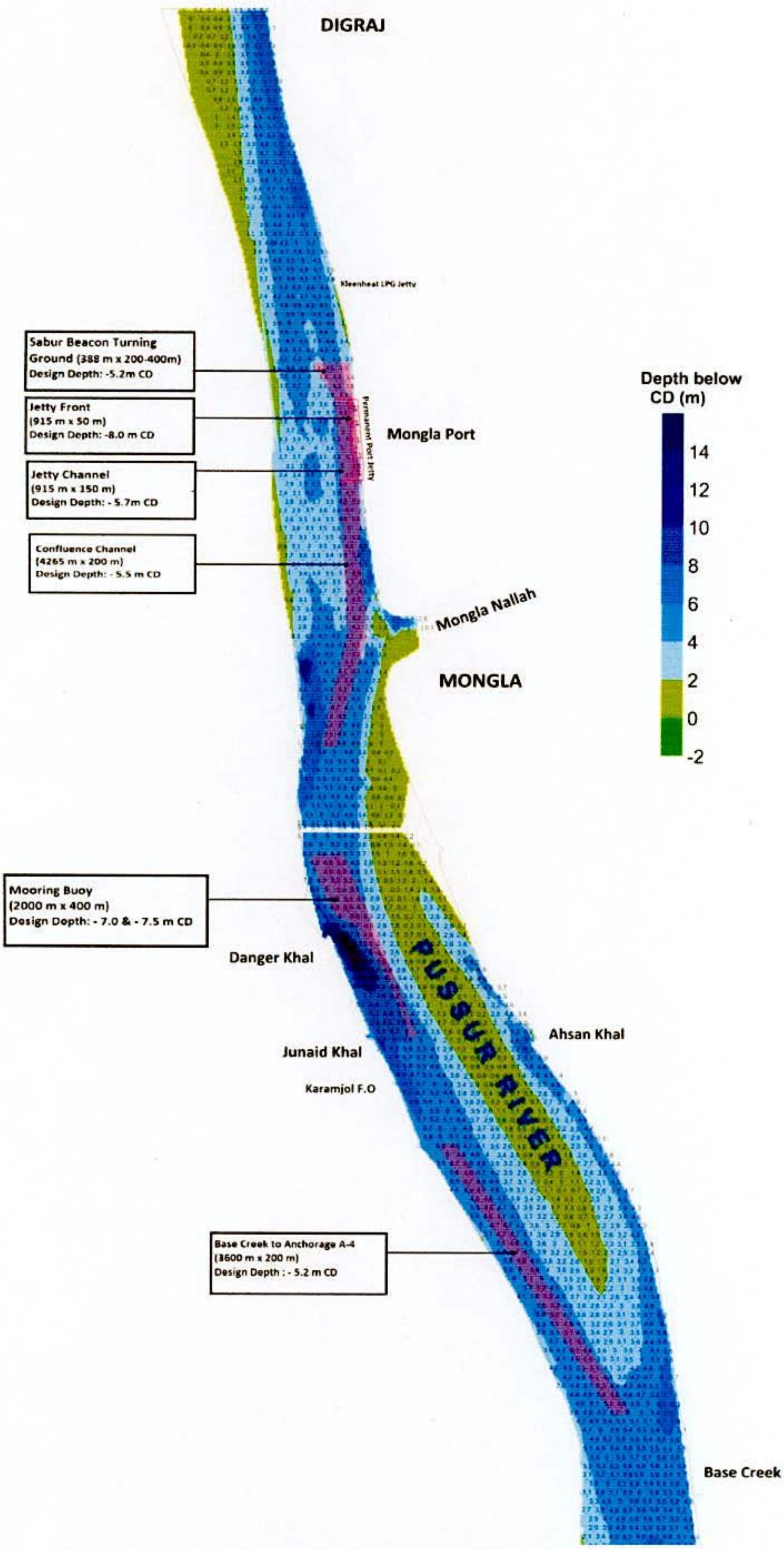


Figure 6.2: Location and alignment of dredging Segments at Harbour Area.

In the year 2013, depth at MPA jetty front & Jetty Channel was reduced to -5.50 m & -4.0 m CD which was increased to more than -8.0 m & -5.5 m CD accordingly in the year 2014. After one year the depth at jetty front & Jetty channel has reduced to -7.50 m and -5.2 m CD respectively.

But in the same time the west side of channel has deepened about 0.8 m. This implies that the concave end (East side) has silted up more than 1.0 m and convex end (West Side) scoured 0.8 m within one year. Jetty area has silted due to sliding of loose material underneath the jetty. Moreover this area was dredged like a pocket which is also a reason of quick siltation. A comparative bed profile of the year 2013, 2014 & 2015 has presented in Figure 6.3.

6.4.2 Confluence Channel

Approach at the confluence of Mongla Nullah and Pussur is known as confluence Channel. Merchant ships entered into port only in high tide and for that minimum 5.0 m draft required in this area. In the year 2013, at front of MPA vessel berth and along wreck pavlina was reduced to -4.2 m CD which was increased to more than -5.5 m CD in the year 2014.

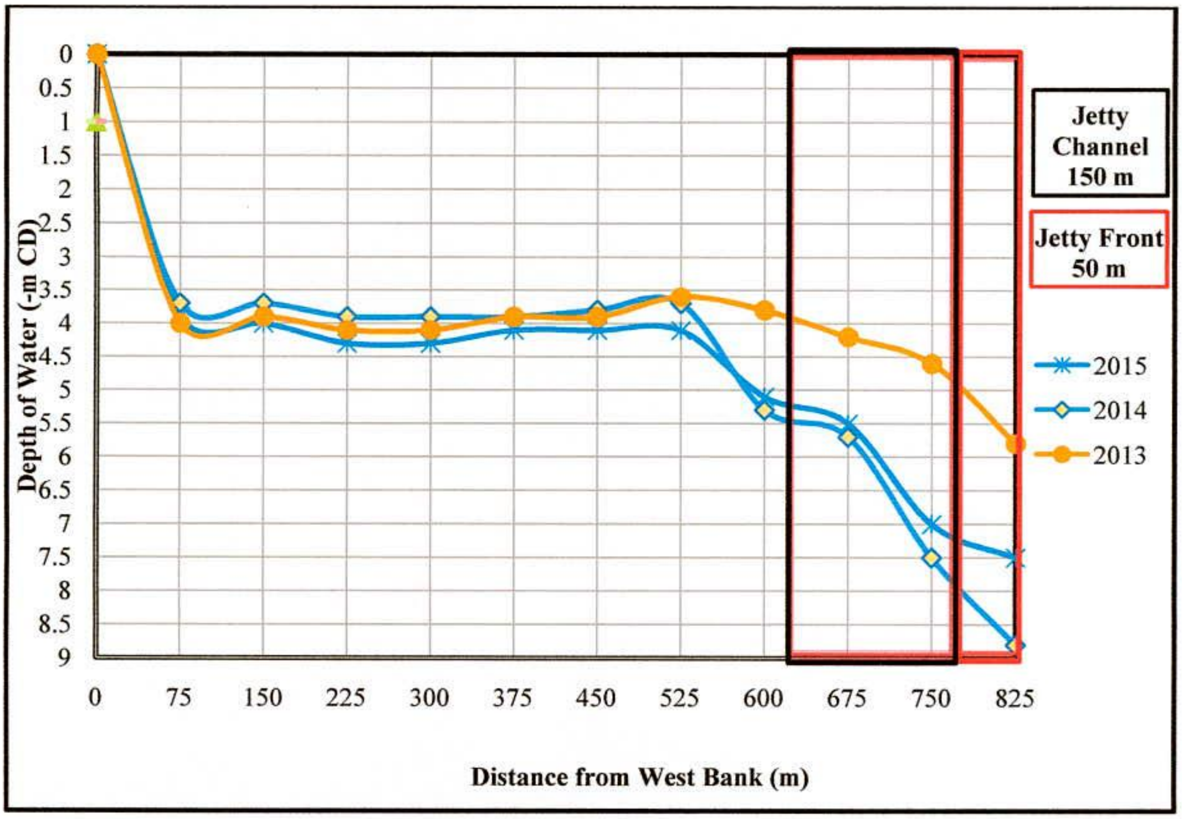
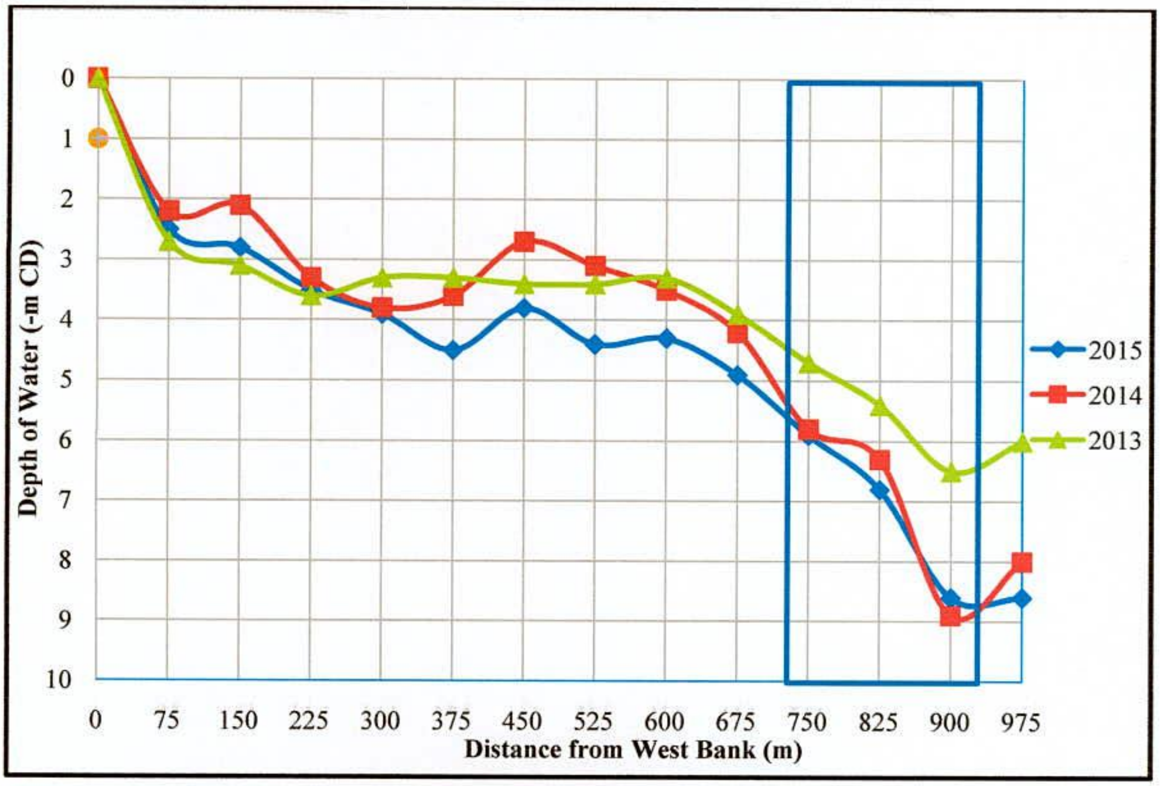


Figure 6.3: Cross section at Jetty Front before and after dredging (Dredging: 2014)



(a) Cross Section at MPA Vessel Berth

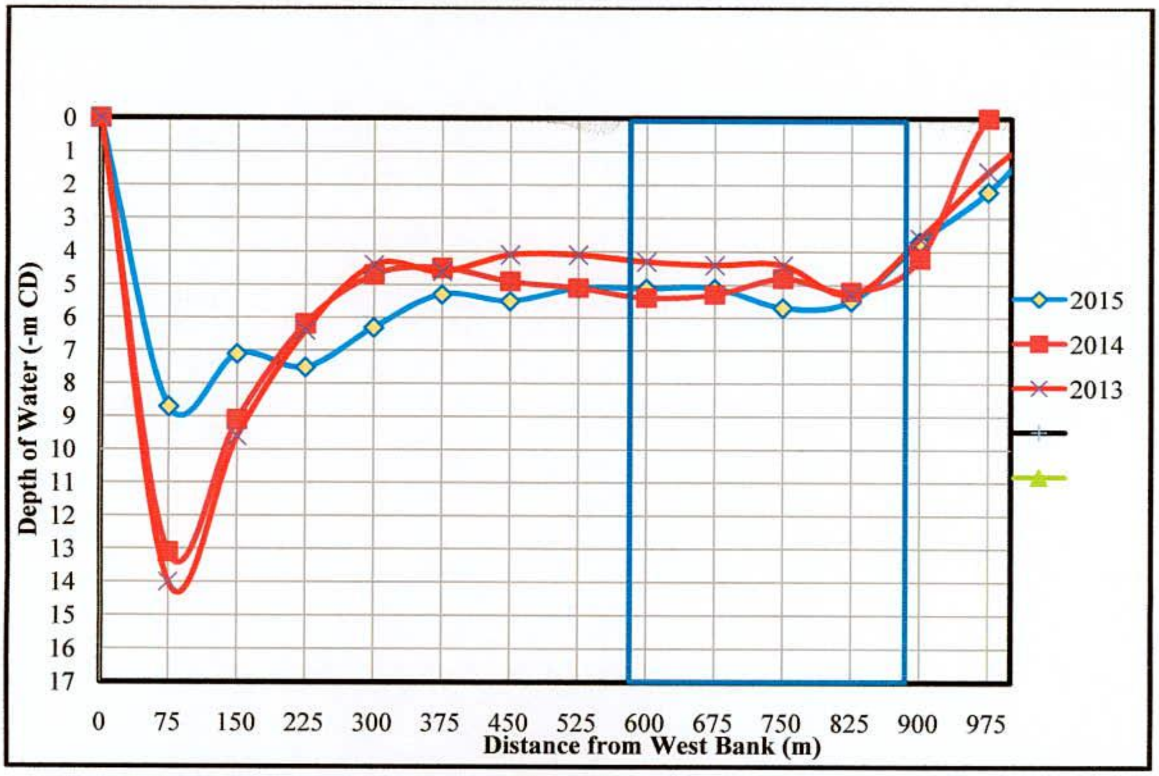


Figure 6.4: Cross section at Confluence Channel before and after dredging (Dredging: 2014).

After one year the depth at MPA vessel berth and along wreck pavlina has increased to near 6.0. But in the same time the west side of channel has silted up. This implies that the concave end (East side) has scoured and convex end (West Side) has silted. A comparative bed profile of the year 2013, 2014 & 2015 has presented in Figure 6.4. After the confluence channel, the navigation route is shifted from east bank to west bank side.

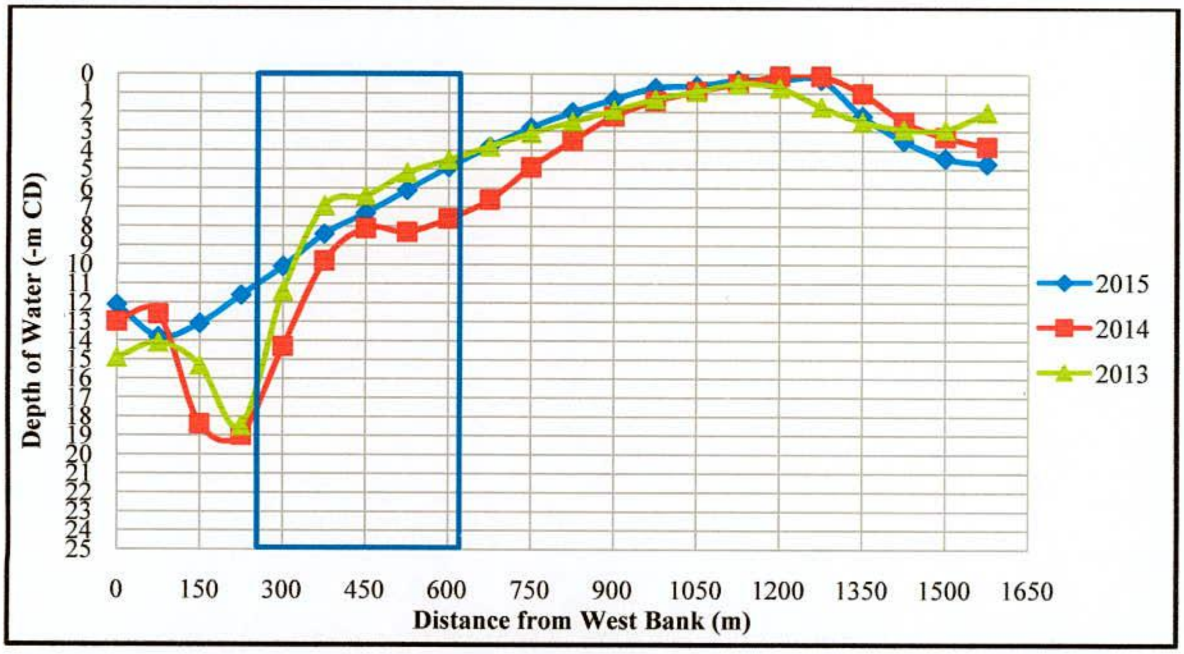


Figure 6.5: Cross section at Mooring Buoy Area before and after dredging (Dredging: 2014).

6.4.3 Mooring Buoy Area

At this section, the river is braided with two channels having the main navigation route near the west bank of the river and a small channel near the east bank with a shoal in between. In 2013, the depth at mooring buoy area was reduced to - 4.0m CD. Ships anchor in this area for unloading and for that minimum -7.5 m CD depth required. This area was dredged to more than -7.5 m CD in the year 2014 which has decreased to -6.0 m CD within one year. This area has silted mostly because of creating a deep pocket like jetty front (west side). Siltation happens along the full segment here. A comparative bed profile of the year 2013, 2014 & 2015 has presented in Figure 6.5.

6.4.4 Base Creek Area

Braided condition with two channels is continued up to this section having the main navigation route near the west bank of the river and a small channel near the east bank with a shoal in between. Before the capital dredging in the west side navigation channel, the depth in this area was reduced to -4.5 m CD. Ships only pass this area during the high tide and considering that base creek area was dredged upto -5.2 m CD. After one year of dredging the main navigation channel hasn't changed significantly. But the East side of this channel (Convex side) has deepened about 0.8 m naturally. A comparative bed profile of the year 2013, 2014 & 2015 has presented in Figure 6.6. The channel near the east bank of the river is found to be silted up by about 0.5 m in 2014 and about 1.0 m in 2015 compared to previous years. The rate of backfilling after dredging obtained from above analysis has compared with the predicted rate of IWM (2014) which has given in Table 6.9.

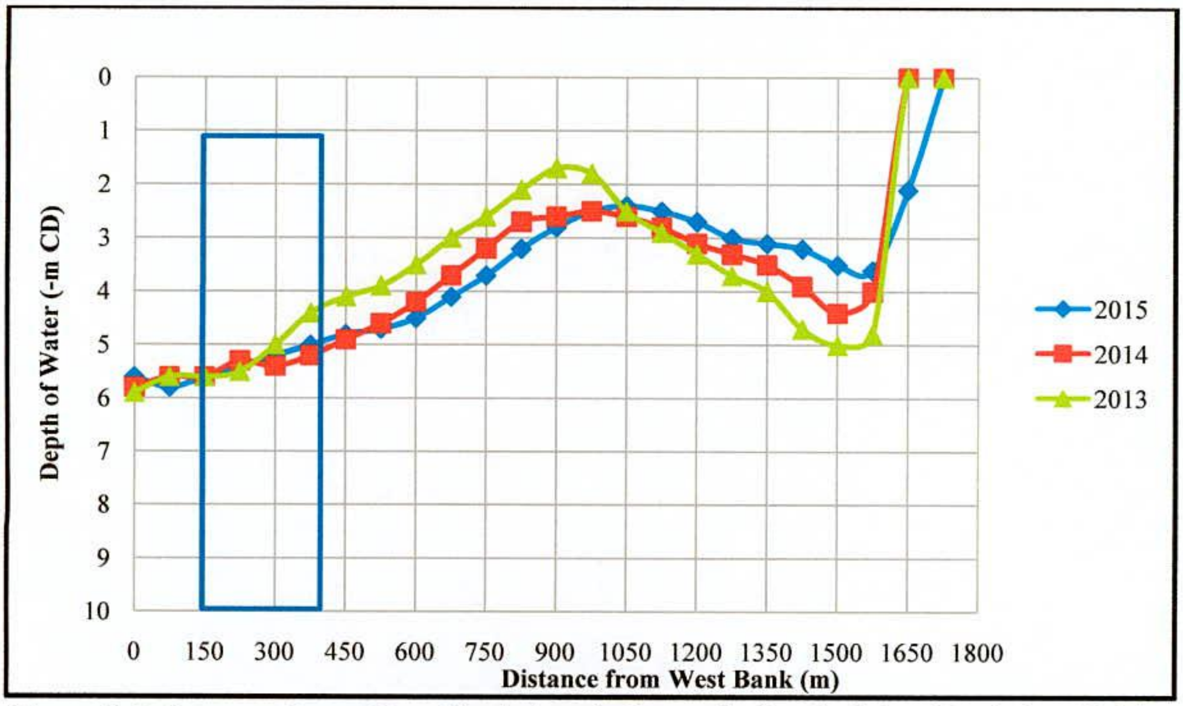


Figure 6.6: Cross section at Base Creek Area before and after dredging (Dredging: 2014).

Table 6.9: Backfilling rate in the dredged navigation route of harbor area

Area/ Section	Field Measurement of backfilling rate (m/year)	Backfilling rate Predicted by IWM (2014) (m/year)
Jetty Front	1.00	0.55
Jetty Channel	0.30	0.50
Confluence Channel	-0.50	0.22
Mooring Buoy	1.50	1.34
Base Creek to Anchorage A-4	No Change after dredging	0.33

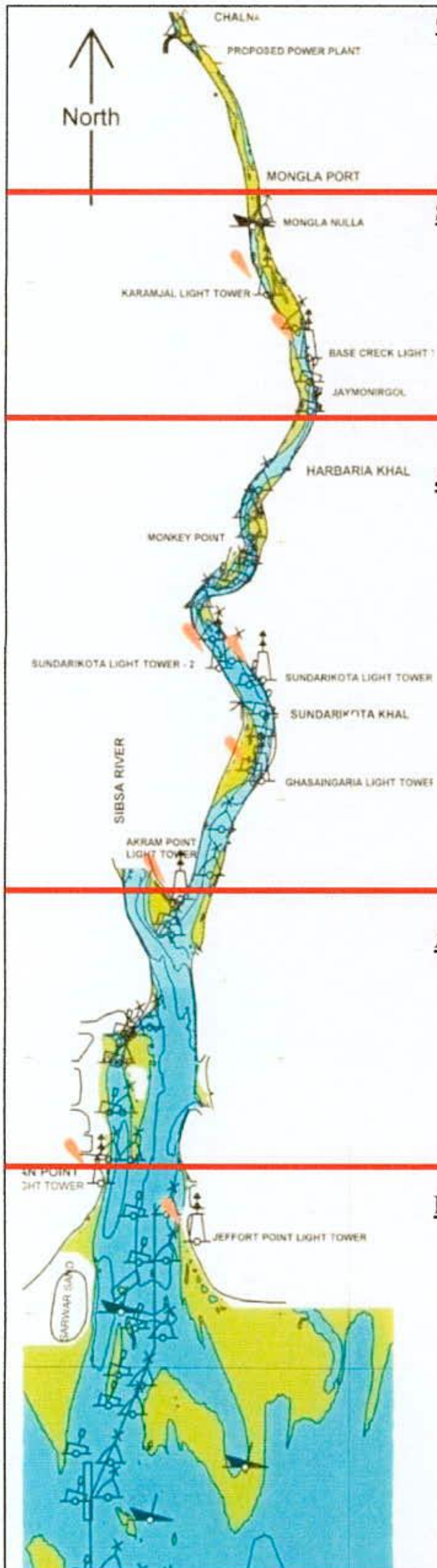
Table 6.9 shows that, Jetty front has silted about twice than the prediction. Siltation at Jetty channel and Mooring Buoy is very close to the prediction. But the scenario at confluence channel is totally different from the prediction. The prediction was 0.22 m/year siltation, but this area is scouring 0.50 m/year. For the Base creek area, it was predicted that, it will be silted 0.33 m/year, but after one year no siltation/ scouring has observed.

6.5 Proposals for Enhancement of Navigability

From the analysis of result, the summary on the geomorphic characteristics, navigability and required interventions are presented in Figure 6.7 classifying the segments of Pussur channel having similar nature. It is found that the MPA jetty area and its approaches is mildly scouring where the upstream i.e Chalna to Digraj is being silted up. Downstream of mooring buoy is also slightly silted in last few years. The channel is quite stable in Joymonirgol to Hiron point. The current navigational channel at outer bar has siltation pattern where the west channel is scouring. To enhance the navigability of Pussur channel following interventions are proposed.

- Capital dredging is required to get required draft for navigation from Sabour Beacon to Rampal Power Plant and for outer bar area to remove the sediment in the existing route or fix up a new route in the nearby area.
- To improve the berthing pocket depth in front of the jetty, in addition to maintenance dredging, sheet piling could be proposed as a solution. The rapid siltation rate in front of the jetty is due to the sliding of the sediment from the jetty underneath.
- The main reason of siltation is low velocity of flood and ebb flow. If the velocity of flow could be increased in vulnerable sections such as MPA Jetty area and danger khal area, then the bed could be scoured naturally.
- Velocity could be increased by contracting the channel using structural interventions. For the canalization effect near the jetty area, spur dykes/groins/ guide bund opposite to jetty may also require as a structural intervention. The deflected flow due to the structural intervention in east bank may cause bank erosion at the upstream of the jetty area, a bank revetment may propose to prevent this.
- For the canalization of the Mooring Buoy area, structural measures can be proposed to close the eastern channel along the inner bar. For more effective result, a bank revetment at the western bank, opposite to inner bar may be required.

However, these structural measures require in depth study to establish the effectiveness.



Chalna to Sabur Beacon

- Very shallow depth (-1 to -5 m CD)
- High siltation rate (0.22 to 0.95 m/yr)
- Capital dredging is required to get required draft for navigation

Sabur Beacon to Joymonirgol

- Shallow depth (>-6 m CD)
- Mildly scour prone (scour rate 0.20 m/yr)
- High backfilling rate after dredging (upto 1.3 m/year)
- Maintenance dredging and structural intervention are required

Joymonirgol to Akram Point

- Depth is more than -9m CD
- Quite stable
- Slightly scour prone (scour rate 0.06 m/yr)
- No dredging is required
- Structural intervention can be done to channelize the flow and increase the draft.

Akram Point to Hiron Point

- Depth > -9m CD
- Quite stable
- No dredging is required

Hiron Point to Fairway Buoy

- Outer bar area relatively shallow (Depth < -7.5m CD)
- Obstacled by Wreck
- High siltation rate (0.35 m/yr.) at downstream of wreck
- Capital dredging and shifting of navigation route is required

Figure 6.7: Segment-wise characterization for navigability and geomorphic features of Pussur River

Chapter 7

CONCLUSION AND RECOMMENDATION

7.1 General

The study comprises of mainly secondary data i.e hydrographic chart analysis of Pussur River. Pussur River is the only approach of Mongla Port situated in the South east part of Bangladesh. Due to high siltation rate, smooth port operation is interrupting day by day. Hydrographic chart of Pussur River has been analyzed to identify the venerable section and siltation rate. MPA has carried out a capital dredging project at Mongla Port jetty to Base Creek area. The backfilling pattern and rate in dredging areas also identified. Based on the study, the summary of the key findings are discussed below.

7.2 Summary of the Findings

In the navigation route of Pussur river, the areal distance (straight) of Hiron Point to Chalna is found as 55 km where the channel length is 91 km. The ratio of straight length to channel length is found as 1:1.65, which implies that the channel is mildly meandering. Only one strong meander is observed at the confluence with Monkey point, 35 km downstream of Mongla. Based on MPA Hydrographic charts and available informations from hydrographic section of Mongla port, it is observed that the width of the Pussur River varies at different sections between 700 m to 3000 m and approach to Pussur is about 6000 m. The minimum depth is found to be varied from 1.4 m to 11.7 m below CD. It can be noted that the lowest depth is found at upstream (Chalna) that gradually increases towards downstream with the highest minimum depth at Mazhar Point to D'Suza Point and again decreases at further downstream near Fairway Buoy. The maximum depth is found to be varied from 7.5 m to 29.6 m below CD from upstream to downstream, respectively. Semi-diurnal tides with a tidal period of about 12 hours 25 minutes are predominant in the Bay of Bengal. According to the Bangladesh Tide Tables 2015, the mean Tide Levels at Mongla, and Hiron Point along Pussur River are 2.31m and 1.7m in CD respectively. The tidal regime is larger at Mongla than at Hiron Point. The suspended sediment concentration in river water is measured for a sampling time of 13 hrs. The result shows that, sediment concentration near the river bed (i.e. at 0.8d depth from surface) is always higher than the upper layers at 0.6 and 0.2d depth from surface. At 0.8d depth, the concentration varies from 359.65 mg/l to 2096.06 mg/l in flood tide which changes inversely with water level and velocity. At 0.2d depth, the concentration varies from 153.6 mg/l to 1478.0 mg/l. In the time averaged profile, the concentration is found as 790 mg/l at 0.2d depth and 1270 mg/l at 0.8d depth. From the time averaged profile, the mean concentration is estimated about 1000 mg/l. Sieve analysis of bed material shows that the

Fineness Modulus (FM) of the collected 4 samples are 0.30, 0.60, 0.48 and 0.49, i.e. the bed material is mostly sandy. From the average grain size distribution of bed material, d_{50} is found as 0.052 mm.

Pussur River has navigation problem for the last two decades mainly from Chalna to Chilla Bazar. After Chilla Bazar, starting from Joymonirgoal, the river shows a more stable navigable reach up to Akram Point. After that, about 16 km river reach called outer bar at the entrance of Pussur River don't have enough draft for 7.5 m draft vessel. In this study the Pussur river was divided into ten segments which are: Fairway Buoy to Hiron Point, Hiron Point to Tinkona Dwip, Tinkona Dwip to Kagaboga Khal, Kagaboga Khal to Sundorikota Khal, Sundorikota Khal to Cheilabogi Khal, Mazhar Point to D'Suza Point, Harbaria to Joymonirgol, Base Creek to Mongla Nulla, Mongla Nulla to Digraj and Digraj to Chalna.

From 2008 to 2013, it is observed that there was a natural deepening near jetty front and approaches due to increasing of ship movement and increase of fresh water flow from upstream after Gorai river dredging. In that period depth of channel increased 0.5 - 1.80 m. Jetty front was dredged upto 8.0 m in 2014 which has silted up 1.0 m within one year where the predicted rate was 0.55 m/year. But at upstream of jetty no-9 i.e at front of Kleenheat LPG jetty, the channel scoured naturally about 1.5 to 2.0 m between 2008 to 2015. MPA vessel berth and wreck pavlina area hasn't changed significantly after 01 year of dredging. The vessel berth area has scoured about 0.5 m instead of predicted siltation 0.22 m/year and the channel along wreck pavlina has silted about 0.25 m in west side and scoured about 0.75 m in east side. The backfilling rate in mooring buoy dredging area has found very high. Near the danger khal the dredged area has filled up 1.5 m within one year. The main reason of siltation here is creating a deep pocket where the surrounding areas are shallower. The base creek area was dredged upto -5.2 m CD in the year 2014. After one year of dredging the main navigation channel hasn't changed significantly. But the East side (Convex side) has deepened about 0.8 m naturally. Depth at Karamjol F.O area in the year 2010 was about -5.50 m CD i.e this section don't require dredging for 7.50 m draft vessel. Bed profile of the year 2015 automatically increased to 6.50 m. This segment naturally scoured more than 1 m in last 5 years. Similarly the Sultan khal area scoured more than 0.5 m in last 10 years. The food silo area has a mild siltation pattern. Before construction of silo jetty, the bed profile was -6.5 m CD in the year 2011. After completion of that jetty, siltation has started in adjacent areas. Within two years i.e at 2015 the river bed raised to -5.8 m CD.

The river reach from Joymonirgoal to Harbaria is quite stable in last few decades. The shallow reach of -2 to -6 m CD is due to the divergence of flood and ebb channel. The navigation channel of this reach has sufficient draft for movement and anchoring upto 10.5 m draft vessel. This reach is the anchorage point of bulk cargo (Fertilizer, Food

Grain, Clinker etc.) vessels. After Joymonirgol the river has found very much stable and have sufficient draft for 10.50 m draft vessel upto Hiron Point. But the reach between Hiron point to Fairway Buoy is very critical for the operation of Mongla Port. The flow direction and depth of channel is varying in last two decades rapidly. It has found that depth is most critical at wreck ocean wave. After the cyclone in 1988, the outer bar has been raised up to 0 to 2 m CD and widening in the east-west direction and the trend is continuing until the recent year. At fairway buoy channel has sufficient depth for mother vessels (20-25 m draft). From fairway buoy to outer bar, this 16 km is quite stable in last few decades. At outer bar area presently shipping channel is on the eastern side of wreck ocean wave. But this channel is being silted up and the shallow portion is extending towards east side day by day. In the downstream of buoy 14, the sedimentation rate at two points are found to be about 0.35 m/year. As a result the width of channel is also decreasing. In the west side of wreck ocean wave, the channel is quite stable is last ten years. MPA is now planning to dredge the outer bar upto -8.50 m CD and if that project could be implemented then ships having more than 10.0 m draft will be able to enter the anchorage area of Mongla Port.

Dredging is being a continuous activity of MPA to keep the channel operational. The total volume dredged over the period 1979 to 2016 is about 12.872 Mm^3, which is equivalent to an average of 3,47,000 m^3 per year. Out of 37 years record, around 3.0 Mm^3 dredging was done in the Jetty Front to maintain the berthing pocket alongside the jetty. The dredging operations at the jetty front area were required mainly to clean up very shallow patches just along the berths. This sediment deposition is formed by the sliding down of sediment that accumulates due to the cluster of piles under the apron. This is considered the main reason of quickly filled up of the dredged areas alongside the jetties to natural river bed level. After completion of Harbour area dredging project in 2014, IWM predicted that the required maintenance dredging will be about 50-70% of capital dredging. But the actual scenario after passing of two years is not as worse as predicted. Till now ships having 7-7.5 m draft is easily arriving upto port jetty without any maintenance dredging at channel.

7.3 Conclusion

It is found that the MPA jetty area and its approaches is mildly scouring where the upstream i.e Chalna to Digraj is being silted up. Downstream of mooring buoy is also slightly silted in last few years. The channel is quite stable in Joymonirgol to Hiron point. The current navigational channel at outer bar has siltation pattern where the west channel is scouring. To enhance the navigability of Pussur channel following interventions are proposed.

- Capital dredging is required to get required draft for navigation from Sabour Beacon to Rampal Power Plant and for outer bar area to remove the sediment in the existing route or fix up a new route in the nearby area.

- To improve the berthing pocket depth in front of the jetty, in addition to maintenance dredging, sheet piling could be proposed as a solution. The rapid siltation rate in front of the jetty is due to the sliding of the sediment from the jetty underneath.
- The main reason of siltation is low velocity of flood and ebb flow. If the velocity of flow could be increased in vulnerable sections such as MPA Jetty area and danger khal area, then the bed could be scoured naturally.
- Velocity could be increased by contracting the channel using structural interventions. For the canalization effect near the jetty area, spur dykes/groins/ guide bund opposite to jetty may also require as a structural intervention. The deflected flow due to the structural intervention in east bank may cause bank erosion at the upstream of the jetty area, a bank revetment may propose to prevent this.
- For the canalization of the Mooring Buoy area, structural measures can be proposed to close the eastern channel along the inner bar. For more effective result, a bank revetment at the western bank, opposite to inner bar may be required.

However, these structural measures require in depth study to establish the effectiveness.

7.4 Recommendations for Further Study

Recommendations for some of the future study can be outlined as follows:

- To study the Sedimentation processes at the Sibsa river system in Bangladesh
- To investigate the effect of submerged wreck in Pussur River of Bangladesh on continuous siltation in Navigation Channel.
- Case study on Pussur River of Bangladesh on the Environmental impact of dredging on river biology and Mangrove Forest the Sundarban.
- To study the Effectiveness of Structural interventions to improve the navigability of Pussur River in Bangladesh.

REFERENCES

ADB, 1996. Mongla Port Area Development Project, Final Report, Volume I & II, Asian Development Bank-prepared for Mongla Port Authority, Mongla, Bangladesh.

Akter, J., Sarker, M. H. and Haque, P. 2013. Morphological Processes and Effective River Erosion Management: a Case Study of the Arial Khan River in Bangladesh, 4th International Conference on Water and Flood management (ICWFM-2013), BUET, Bangladesh.

CEGIS, 2013. Optimizing the dredging in the Jamuna, Padma, Meghna and Arial Khan rivers and monitoring the activity including dredging volume calculation, Final Report, Bangladesh Water Development Board, Ministry of water resources, Government of Bangladesh.

CEGIS, 2001. Environmental and Social Impact Assessment of Gorai River Restoration Project, Vol. 1: Main Report, Vol. II: Annexes, Bangladesh Water Development Board, Ministry of water resources, Government of Bangladesh.

DHI, 1993. 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.

DHI, 1990. Mathematical Model Study of Pussur-Sibsa River System and Karnafuli River Entrance, Final Report, Volume l, Bangladesh Water Development Board, Ministry of water resources, Government of Bangladesh.

Farleigh, D.R.P., 1984a. Report on Mathematical Model Studies, prepared for Port of Chalna Authority, Mongla, Bangladesh.

Farleigh, D.R.P., 1984b. Pussur River Study Phase II, Final Report prepared for Port of Chalna Authority, Mongla, Bangladesh.

Farleigh, D.R.P., 1981. Pussur River Study Phase I, Final Report, prepared for Port of Chalna Authority, Mongla, Bangladesh.

GMAPS Consortium, 2011. Port and Logistics Efficiency Improvement, Final Report-prepared for Ministry of Shipping, Bangladesh

Islam, S. N. and Gnauck, A., 2008. Mangrove wetland ecosystems in Ganges-Brahmaputra delta in Bangladesh. Front Earth Sci. China, 2(4), 439–448.

IWM, 2016. Feasibility study for improvement of navigability at the outer bar area of Pussur channel, Mongla Port Authority, Mongla, Bangladesh

IWM, 2015. Feasibility study of capital dredging in Pussur River from Mongla port to Rampal power plant, Mongla Port Authority, Mongla, Bangladesh, IWM, 2014. Techno-Economic Feasibility and Environmental Study for the Development of Sea Port at Rabnabad Channel in the Patuakhali District, Final Report-prepared for Ministry of Shipping, Bangladesh

IWM, 2013a. Environmental Impact Assessment of proposed dredging project at Outer Bar Area of Pussur Channel, Mongla Port Authority, Mongla, Bangladesh.

IWM, 2013b. Morphological Mathematical Modelling for Planning, Design, Monitoring and Quality Control of Dredging for Gorai River Restoration Project, Phase-II, Final Report, Bangladesh Water Development Board, Ministry of water resources, Government of Bangladesh.

IWM, 2013c. Detailed feasibility study for drainage and navigation improvement and sustainable water management of Bhairab River basin, Final Report, Bangladesh Water Development Board, Ministry of water resources, Government of Bangladesh.

IWM, 2013d. Quality Control and Monitoring of Pilot Dredging of Jamuna River from Sirajganj Hard Point to Dhaleswari Offtake (20 Km) (1st Year Maintenance Dredging), Draft Final Report, Bangladesh Water Development Board, Ministry of water resources, Government of Bangladesh.

IWM, 2010a. Hydrodynamic & Morphological Modelling to Investigate Land Accretion & Erosion in the Estuary Development Program (EDP) Area, Final Report, Bangladesh Water Development Board, Ministry of water resources, Government of Bangladesh.

IWM, 2010b. Feasibility Study for Dredging (by dredger) of Khaprabhanga Chapalir Don river (Mohipur Channel) in the Kalapara Upazila under Patuakhali district for Improvement of Navigability, Final Report, Bangladesh Water Development Board, Ministry of water resources, Government of Bangladesh.

IWM, 2004. Feasibility Study for Improvement of Navigability of Mongla Port, Mongla Port Authority, Mongla, Bagerhat, Bangladesh

Little, C. D. 2010. Mississippi River Geomorphology & West Bay Diversion, 2nd Joint Federal Interagency Conferenceon on Sedimentation and Hydrologic Modeling, Las Vegas, Nevada, USA.

MacDonald, M., 1998. Final Report, Ports Upgrading Project, Asian Development Bank, Government of the People's Republic of Bangladesh.

Malek, A. and Ashraf, J., 2004. Improvement of Navigation of Mongla Port, B. Sc. Engg. Thesis-2010, Department of Water Resources Engineering, BUET, Bangladesh.

McDowell, D.M. and B.A.O'Connor, 1977. Hydraulic Behaviour of Estuaries, Ministry of Shipping, Government of the People's Republic of Bangladesh.