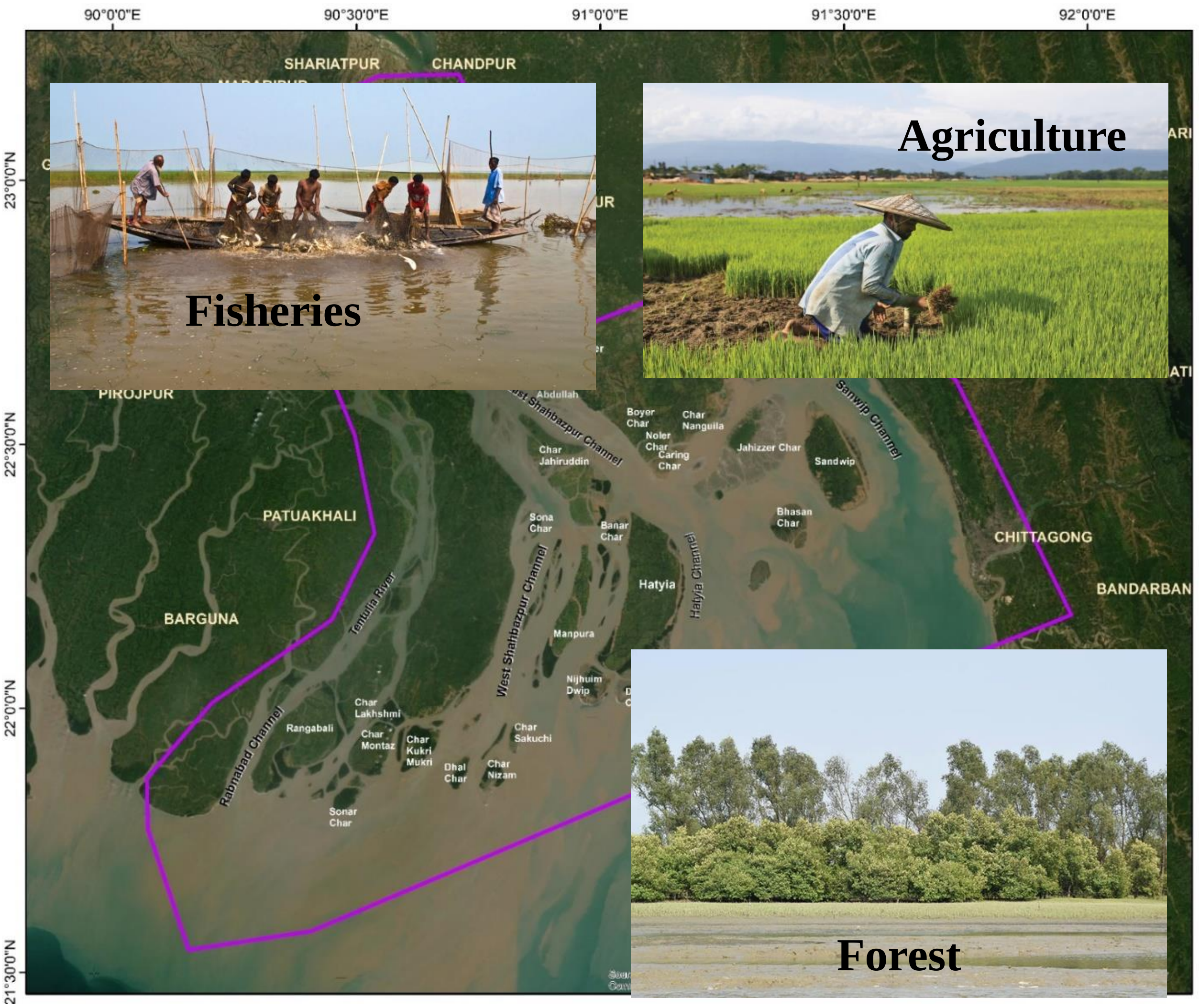
Government of the People's Republic of Bangladesh
Ministry of Water Resources

BANGLADESH WATER DEVELOPMENT BOARD

Hydro–morphological Model Study and Strategic Planning for Char Development in the Meghna Estuary under Char Development and Settlement Project–Bridging (Additional Financing) (BWDB Part)



VOLUME I
FINAL REPORT

June 2022

INSTITUTE OF WATER MODELLING

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
ADM	Adaptive Delta Management
AR	Assessment Report
BBS	Bangladesh Bureau of Statistics
BDP 2100	Bangladesh Delta Plan 2100
BoBM	Bay of Bengal Model
BWDB	Bangladesh Water Development Board
CBD	Char Bagar Dona
CC	Climate Change
CDS	Coastal Development Strategy
CDSP	Char Development and Settlement Project
CEIP	Coastal Embankment Improvement Project
CEGIS	Center for Environmental and Geographic Information Services
CSPS	Cyclone Shelter Preparatory Study
CZ	Coastal Zone
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
DPP	Development Project Pro forma
DS	Drainage Sluice
EDP	Estuary Development Program
EKN	Embassy of the Kingdom of the Netherlands
FM	Flexible Mesh
FGD	Focus Group Discussion
GoB	Government of Bangladesh
HD	Hydrodynamic Module
ICZM	Integrated Coastal Zone Management
IFAD	International Fund for Agricultural Development
IMED	Implementation Monitoring and Evaluation Division
IP	Investment Plan
IPCC	Intergovernmental Panel on Climate Change
IWM	Institute of Water Modelling
LRP	Land Reclamation Projects
LTRAM	Long-term Research, Analysis and Monitoring

MES	Meghna Estuary Study
MSL	Mean Sea Level
MorFac	Morphological Acceleration Factor
NAM	Nedbør-Afstrømings-Model (Rainfall-Runoff Model)
NWMP	National Water Management Plan
PWD	Public Work Department
RCP	Representative Concentration Pathway
RE	River and Estuaries
SDG	Sustainable Development Goals
SIBDP	Support to the Implementation of the Bangladesh Delta Plan Project
SWRM	Southwest Regional Model
WARPO	Water Resources Planning Organisation

1. INTRODUCTION

1.1 Background

This Final report on "**Hydro-morphological Model Study and Strategic Planning for Char Development in the Meghna Estuary under Char Development and Settlement Project-Bridging** (**Additional Financing**) (**BWDB Part**)" is prepared in accordance with the ToR of this study. There are two major components are included as pre-requisite are (a) "Hydro-Morphological Model Study" and based on that (b) "Preparation of a Strategic Planning" for the Meghna Estuary and its surrounding areas. Therefore, this study has two parts/ volumes.

Volume I: Hydro-morphological Model Study
Volume II: Strategic Planning for Char Development in the Meghna Estuary

The study considers the entire estuary area of the Meghna River (bounded area in). The Meghna Estuary extends from Chandpur in the Lower Meghna River to the Bay of Bengal in the north-south direction and from the outfall of the Tetulia River to the outfall of the Karnaphuli River in the east-west direction. The Meghna Estuary covers the islands in this region and includes, as main channels, Tetulia River, Shahbazpur Channel, Hatia channel and Sandwip channel.

The Meghna Estuary is morphologically very dynamic and changes its planform in every year. The estuary is being shaped by interactions between tide, upstream water flow, sediment transport, wind and waves. Total annual sediment load into the Lower Meghna River is on average about 1.1 to 1.4 billion metric tons, of which about one-fifth is retained in the Meghna estuary. This enormous volume of sediment load plays dominant role in forming bars/Chars in the estuary area. The net deposition results in formation of deltas of varying sizes in this estuary and gradually develop into big islands known as 'Chars' in Bangla. These areas are low-lying and consequently vulnerable to tidal flooding and cyclonic storm surges. Soils of char areas are high in salinity and low in organic materials. The youngest chars are mud flats supporting little vegetation, dissected by tidal creeks, subject to frequent flooding during high tides. The oldest chars are already consolidated lands, supporting annual cropping and more or less permanent homesteads, despite the fact that the lands are unprotected and vulnerable to extensive crop damage from cyclones and cyclonic surges.

To reduce the physical, social and environmental hazards faced in char areas, development interventions were necessary to provide a sense of security at different levels and to create an enabling environment for development in multi-sectors. Over the past two decades, the '*Char Development and Settlement Project* (*CDSP*)' has implemented in four Southern coastal areas, in four phases (CDSP-I, II, III and IV see), cumulatively benefitting over 90,000 ultra-poor and destitute households, or 500,000 people, across the Noakhali, Laxmipur, Feni and Chattogram and part of Bhola Districts of the south-eastern coastal areas of Bangladesh.

Over the last few years, the bank erosion problem has worsened in the chars under CDSP II and in proposed CDSP V project areas. In places, infrastructures like sluices and embankments either have already damaged/eroded or are at increased risk. Thus, understanding, assessing and predicting the hydro-morphology and a continuing hydro-morphological monitoring system is a very important aspect of water resources planning, development and management in this fragile area. Based on the hydro-morphological understanding around the Meghna estuary, a Strategic Planning Exercise is urgently necessary for future sustainable land development and settlement in this dynamic area.

In view of the above, Bangladesh Water Development Board has undertaken this study. Institute of Water Modelling (IWM) has been entrusted to cary out this study. The study period is, as stipulated in ToR, to be about 8 months commencing in June 2021 and ending in January 2022. **Figure 1.1** shows the location map of the study area. Apendix- A of this report contain Comments and Responses Matrix.

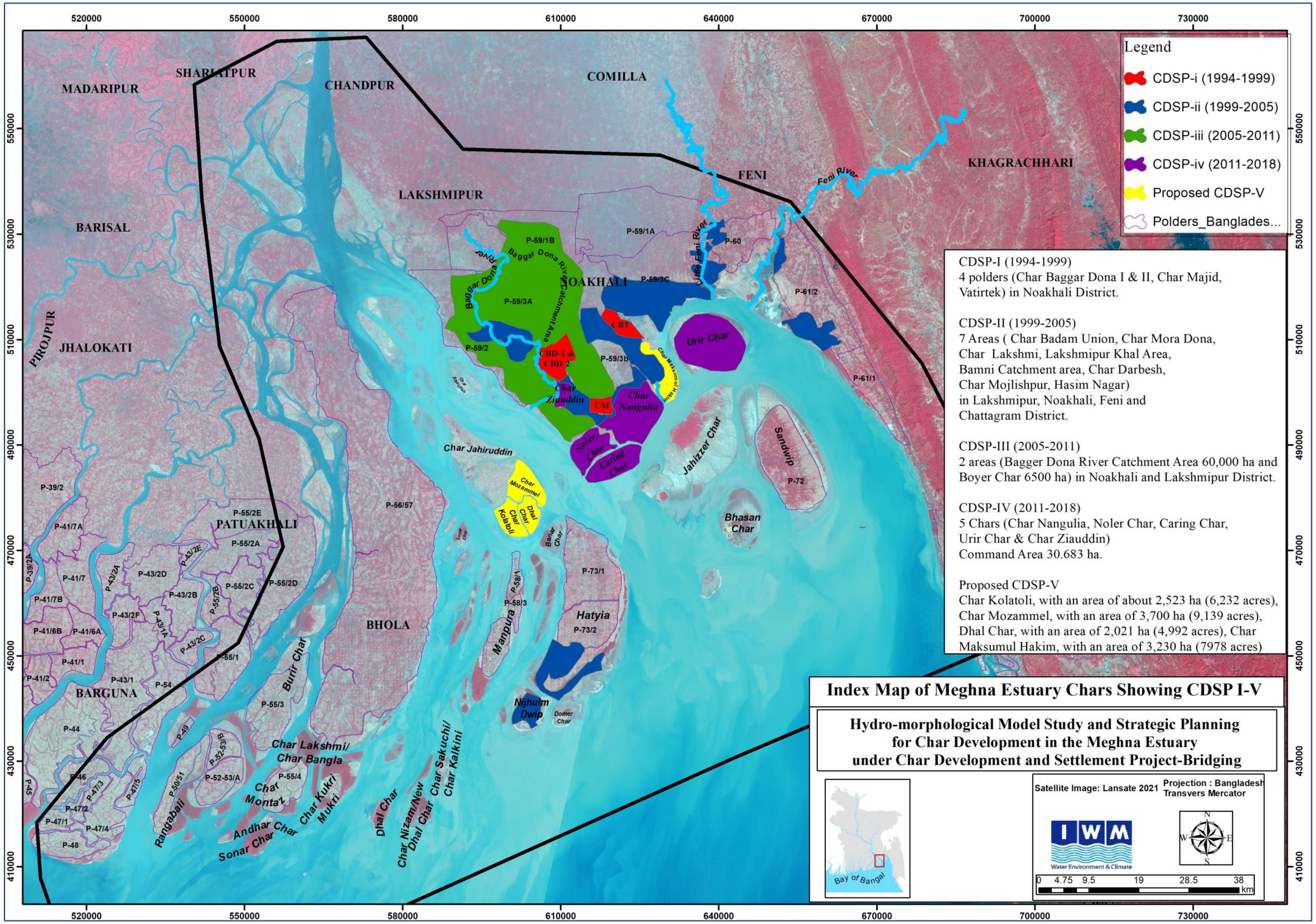


Figure 1.1: Map showing the study area

1.2 History of CDSP

To reduce the social, institutional and environmental vulnerability faced in char areas, development interventions were necessary to provide a sense of security at different levels and to unleash the development potential that the chars offer (Wilde, 2000). The Governments of Bangladesh and the Netherlands cooperated to work on char development and settlement, starting with the inception of the Netherlands-supported Land Reclamation Project (LRP) in 1977. During this project, which ended in 1991, the focus shifted from surveys and trials of land accretion to the development of new land. In order to continue both planning and land development activities, the LRP was then split into two separate projects: the Meghna Estuary Study (MES), for water-based surveys and trials, and the Char Development and Settlement Project (CDSP), a land-based rural development project.

In its first phase, CDSP-I (1994-1999) developed three chars covering 6,800 ha in Noakhali District: Char Baggar Dona II, Char Majid and Char Bhatir Tek. A wide variety of activities were undertaken, ranging from infrastructure and water management to community development and health. Experience with char development in LRP and CDSP-I had led to the accumulation of considerable knowledge of the physical and socio-economic characteristics of the char areas as well as the potentials and constraints in char development.

An important factor that shaped CDSP-II (1999-2005) was the Integrated Coastal Zone Management (ICZM) concept that started to gain impetus in the late nineties. With the establishment of the ICZM framework, the demand for the experience gained in the coastal areas increased. CDSP-II (1999-2005), covers 7 areas, including 5 non-poldered areas in Lakshmipur, Noakhali, Feni and Chittagong Districts. CDSP-II also covered a larger project area (33,000 ha with a population of 400,000), but with a more limited range of activities and a stronger institutional base. It took a more regionally based approach and dealt with both protected and unprotected areas. CDSP-II resulted in a number of ‘lessons learned’; there are two ‘lessons’ which are of particular relevance: (i) the sustainability of CDSP interventions and closely related to this (ii) the internalisation of char development concepts as developed during CDSP-I and II into the government agencies.

CDSP-II was followed by CDSP-III (2005-2011) which was meant to consolidate and monitor the achievements of earlier phases, while at the same time embarking on an intervention programme, specifically in Boyer Char covering about 6,500 ha in Noakhali and Lakshmipur districts. Also, the project needed to establish a bridge to a future char development programme by undertaking feasibility studies.

CDSP-III was followed by CDSP-IV, which was implemented from March 2011 until December 2018. The area consists of the following three main chars: Char Nangulia, with an area of about 8,664 ha (21,400 acres), Noler Char, with an area of 2,519 ha (6,222 acres), Caring Char, with an area of 740 ha (1,828 acres). The project was financially supported by the United Nations International Fund for Agricultural Development (IFAD), the Netherlands Government, and the Government of Bangladesh. The focus of the activities of CDSP-IV was on the development of five new chars: Char Nangulia, Noler Char and Caring Char (these three chars are contiguous); Urir Char and Char Ziauddin. The total extent of these chars is around 25,000 ha, with an estimated population of 170,000 in 29,000 households. The chars are located in Noakhali and part of Chittagong district. Caring char and three regulators have already been washed away.

Urir Char: In the Meghna Estuary, erosion and accretion along the boundaries of the chars or islands are very common morphological processes. Urir Char is a perfect example. Since its emergence in the early 1970s, Urir Char has shown a very dynamic character and developed through erosion, accretion and shifting of several kilometres. During the last 35 years the landmass of Urir Char increased from 12 km2 to 100 km2. At the same time the char shifted about 8 kilometres towards the north. The existing area of Urir Char is about 10,300 ha (25,442 acres). Along with livelihood and other physical development activities, large scale settlement and land titling will be done to support about 4,000 households. Other development activities will be carried out by the five implementing agencies.

Char Ziauddin: Char Ziauddin accretion started in 1970 and people started living there in 2001. The char is under the jurisdiction of Char Jubilee Union and is located west of Char Mora Dona near Boyer Char, in the southwest corner of Subarnachar Upazilla under Noakhali District. Boyer Char lies to the south, CBD-1 to the north and the Bagar Dona River to the west. The existing area is about 1,943 ha (4,799 acres). No settlement and land tiling activities will be done in this char and other development activities will be carried out by the five implementing agencies.

As currently planned the future CDSP V phase includes four coastal chars:

- Char Kolatoli, with an area of about 2,523 ha (6,232 acres)
- Char Mozammel, with an area of 3,700 ha (9,139 acres)
- Dhal Char, with an area of 2,021 ha (4,992 acres)
- Char Maksumul Hakim, with an area of 3,230 ha (7978 acres)

Urir Char with an area of 10,300 ha (25,442 acres). Limited number of interventions like construction of Deep Tube Well and sanitary latrines, Killa (raised land to be used for shelter of cattle) and Multipurpose Cyclone Shelters will be built by implementing agencies. Three cyclone shelters have already been built on Dhal char, Char Mozammel and Char Maksumul Hakim.

1.3 Study Area and Major Problem

In selecting the study area in order to carry out a comprehensive study, the study considers the entire estuary area of the Meghna River (bounded area in Figure 1.1). The Meghna Estuary extends from Chandpur in the Lower Meghna River to the Bay of Bengal in the north-south direction and from the outfall of the Tetulia River to the outfall of the Karnaphuli River in the east-west direction. The Meghna Estuary covers the islands in this region and includes, as main channels, Tetulia River, Shahbazpur Channel, Hatia channel and Sandwip channel. The Meghna Estuary is a disaster -prone area and also morphologically very dynamic. This estuary is exposed to a multitude of natural hazards such as cyclones, storm surges, floods, droughts, water logging, river-bank erosion and salinity intrusion. The entire Meghna Estuary specially CDSP area is highly vulnerable to erosion. The people and their livelihood are vulnerable with these natural calamities.

The study area is mainly focusing on CDSP areas specially on Boyer char, Noler char and Char Nangulia. Over the past two decades, the 'Char Development and Settlement Project (CDSP)' has been implemented in four Southern coastal areas, in four phases (CDSP-I, II, III and IV), cumulatively benefitting over 90,000 ultra-poor and destitute households, or 500,000 people, across the Noakhali, Laxmipur, Feni and Chattogram and part of Bhola Districts. The entire CDSP areas are highly vulnerable to erosion. Under CDSP-IV project, around 254 km road network, 203 nos Bridge/Culvert, 36 Cyclone Shelter cum School and many others infrastructure were constructed which are under threat due to the severe erosion. About 11.6 km embankment, four no of sluices and entire Caring Char had already been washed away. People lost their land, valuable properties and infrastructures. Noler Char, Boyar Char and Char Nangulia are under threat of erosion and in near future most of the areas of these Chars will be diminished if quick appropriate measures are not taken up. Immediate and long-term measures are essential for protecting these areas.

Over the last few years, the bank erosion problem in the CDSP II and in proposed CDSP V chars has worsened. Large infrastructure objects like sluices and embankments are at increased risk or have collapsed/eroded already.

The entire CDSP areas are highly vulnerable to erosion. About 11.6 km embankment, four no of sluices and entire Caring Char had already been washed away. People lost their land, valuable properties and infrastructures. Noler Char, Boyar Char and Char Nangulia are under threat of, long-term measures are essential for protecting these areas. The erosion vulnerable areas are shown in Figure 1.2.

Figure 1.2: Erosion Vulnaerable area of CDSP IV

1.4 Objective

The objectives of the hydro-morphological study and strategic planning for char development and settlement are followings:

i. To understand the hydraulic and morphodynamical processes that are going on in the estuary, linked to the findings of previous studies and of new survey results;
ii. To define areas of high risk, medium risk, low risk and riskless steady areas in the existing CDSP areas (a) if no further bank erosion control actions are taken, (b) with BWDB bank protection in place and (c) with cross dam to Urir Char-Noakhali, Jahajer Char or Sandwip Island (proposed and included in priority list of BDP2100-IP, DPP under process);
iii. To define areas of high risk, medium risk, low risk and riskless steady areas in the whole estuary as part of a pre-feasibility study for the selection of chars to be developed under CDSP V.
iv. To check for conformity, agreement/disagreement with Historical National Planning and Policy documents of Water Sector and related sectors during the formulation of the Hydro-Morphological Study Outcomes and Recommendations;
v. To define multipurpose development of stable, publicly accessible and safe chars by empoldering or other environmental-friendly interventions;
vi. To identify/define potential areas where accretion process could be accelerated for land reclamation by human (engineering) interventions along with identification of appropriate measures/intervention.
vii. To define appropriate action plan for protection of land and settlement at risk of erosion.
viii. Cost estimate, analysis of individual chars;

1.5 Study Activities

Formal contract agreement for carrying out the consultancy services in connection with “Hydro-morphological Model Study and Strategic Planning for Char Development in the Meghna Estuary under Char Development and Settlement Project-Bridging **(**Additional Financing**)** **(**BWDB Part**)**” under GoB Financing was signed between BWDB and IWM on the 4th Day of the Month July 2021, to be effective from 1th June of 2021. The Consultant started their activities on the 2nd of June 2021 by mobilizing study and modelling teams to work on the study activities.

2. DATA COLLECTION AND ANALYSIS

Secondary data that are available with BWDB, BIWTA and other related organizations are collected during the study period. In addition, since the Coastal Embankment Improvement Project Phase-I (CEIP-I) has already taken up a study entitled "Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics)" and conducted surveys in and around the Tetulia River, the same data have been used for this study. However, the bathymerty, Water level , dischage, sediment concerntration and bed matrerial have been collected under this study collection as shown in **Figure 2.1.** Moreover, the consultant has collected and reviewed relevant study reports on the Meghna estuary including historical data on water flow and time series bathymetry, satellite images, maps, salinity, sediment concentration and information relevant to this study. Review and analysis of the historic data has been carried out to understand the prevailing hydrodynamic and morphological processes in greater details in the CDSP char areas of the Meghna estuary. Time series bathymetric data and satellite images data have been analyzed to investigate the morphological changes that occurred over the years. The analysis of these data are discussed below.

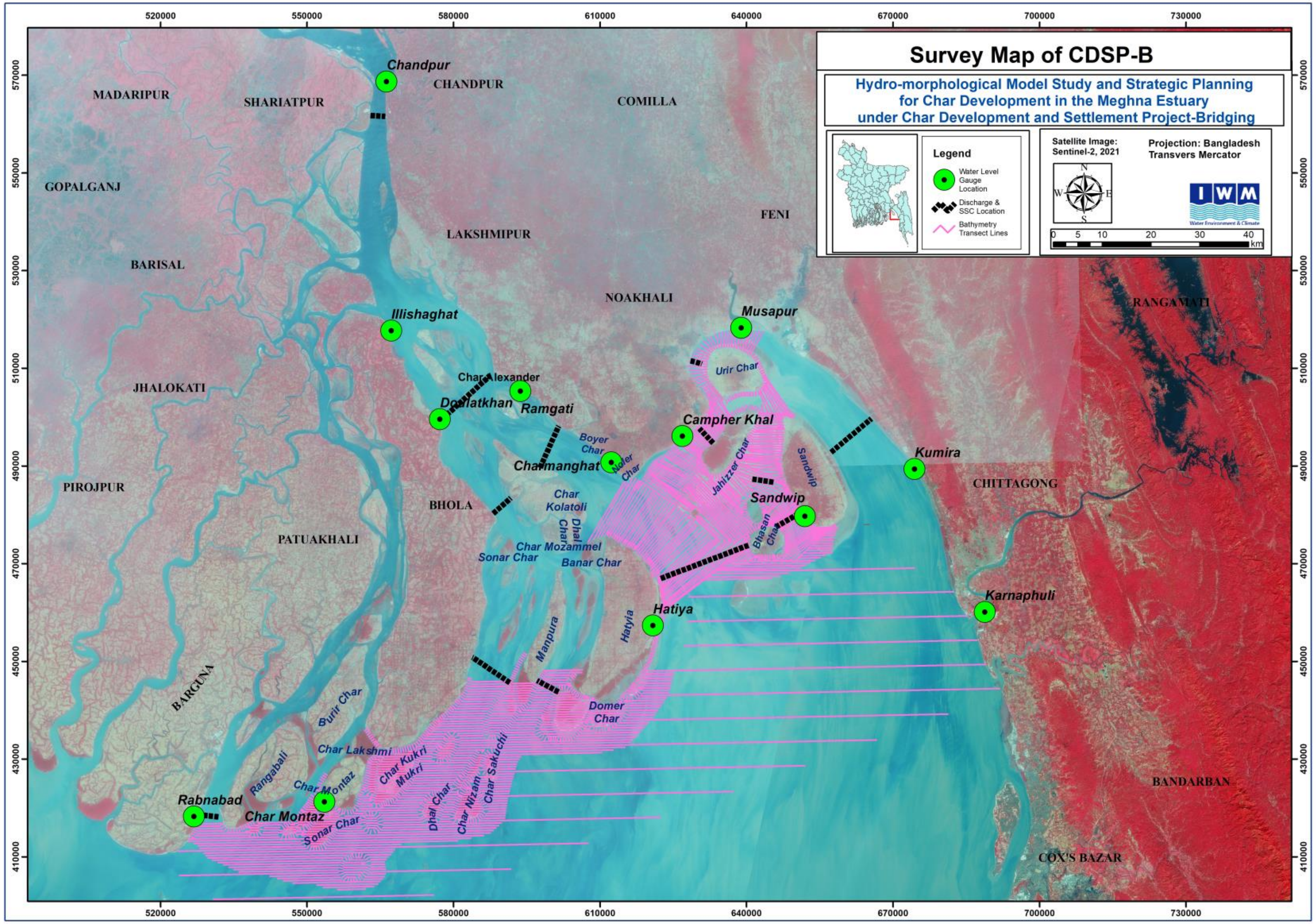


Figure 2.1: Map showing the survey specification under CDSP project connection

2.1 Collection and Analysis of Data and Images

Water levels data are important to know the variation of water depth over the year, tidal characteristics and to calibrate the water flow model. Water level observations were made at thirteen locations: Chadpur, Ellisha ghat, Dawlatkhan, Char Alexander (Ramgati), Chairman ghat, Nalchira Ghat (Hatiya), Charmontaj, Dhulaswar, Camper khal (Urir Char), Musapur, Kumira, Sarikait,Sandwip West Channel, and 15 no ghat, Outfall of Karnaphuli shown in Figure 2.1 .

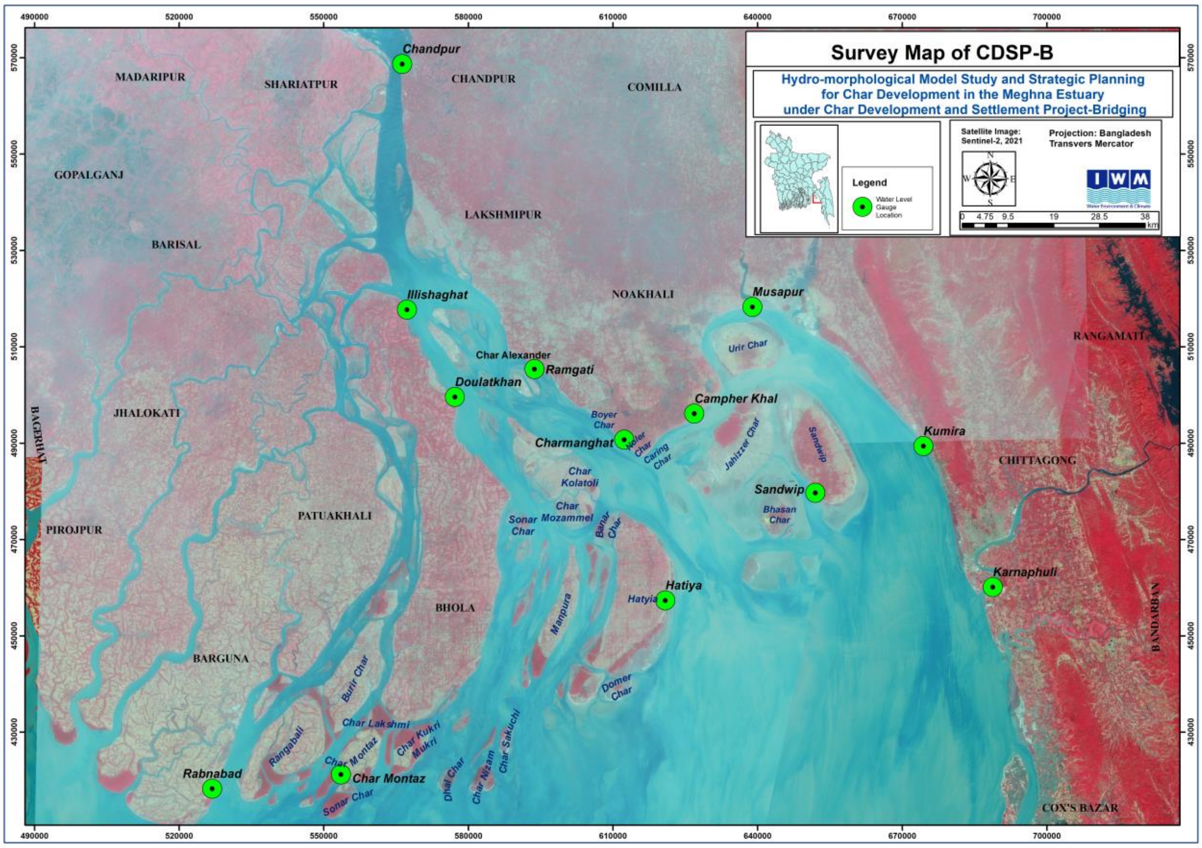


Figure 2.2: Map showing the Water Level Locations

Thirteen (13) Water level observations station have been carried out for 2 months at 10 minutes interval during dry and monsoon period. All water level data are referred to Mean Sea Level Datum (MSL). A sample water level plot at Chadpur, Elisha Ghat and Sandwip (Kumira) Ghat are shown in **Figure 2.3, Figure 2.4,** and **Figure 2.5** respectively.

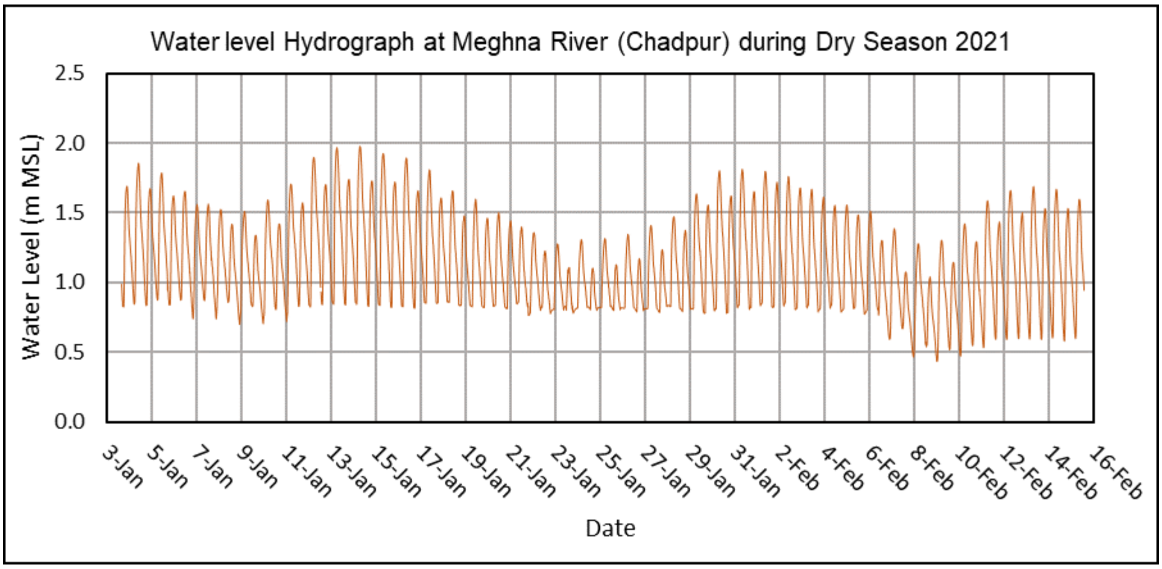


Figure 2.3: Measured Water Level at Meghna River (Chandpur) during dry season 2021

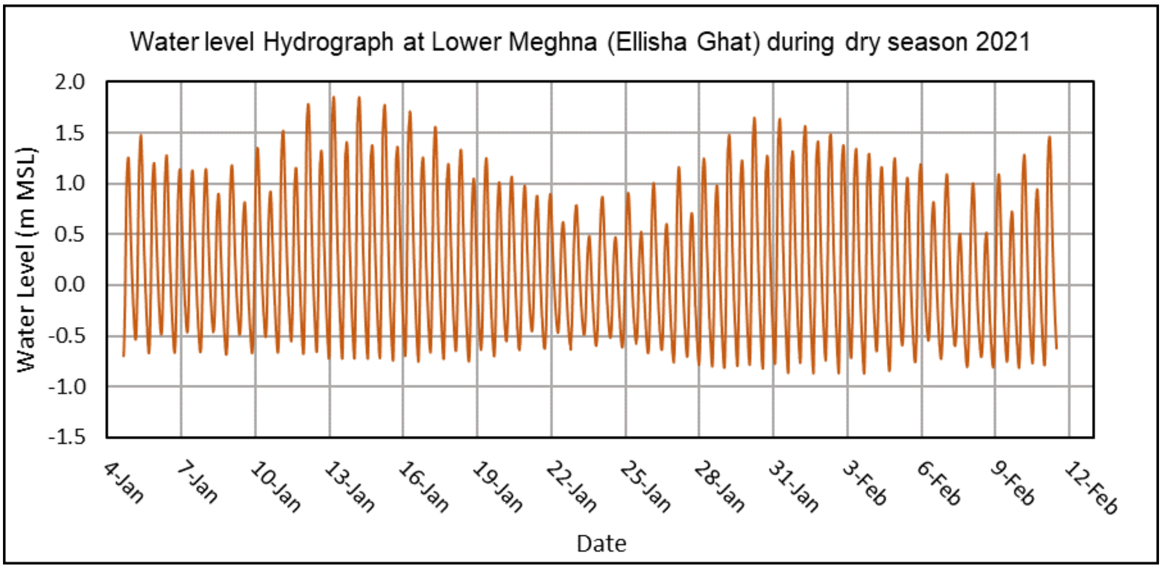


Figure 2.4: Measured Water Level at Meghna River (Elisha Ghat) during dry season 2021

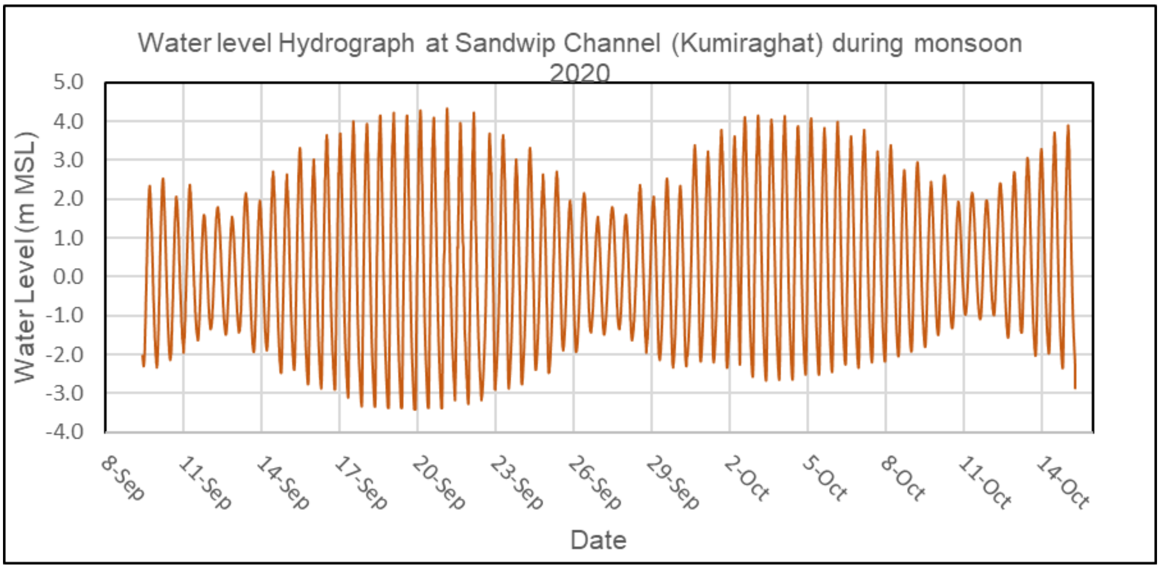


Figure 2.5: Measured Water Level at Sandwip Channel (Kumira Ghat) during monsoon, 2020

Discharge measurement was carried out for 13 hours with half hour interval at twelve locations during dry season in spring tide and twelve locations during monsoon in spring and neap to know the water flow during flood tide and ebb tide, tidal prism and to calibrate the model. The discharge and sediment concentration locations are shown in Figure 2.6

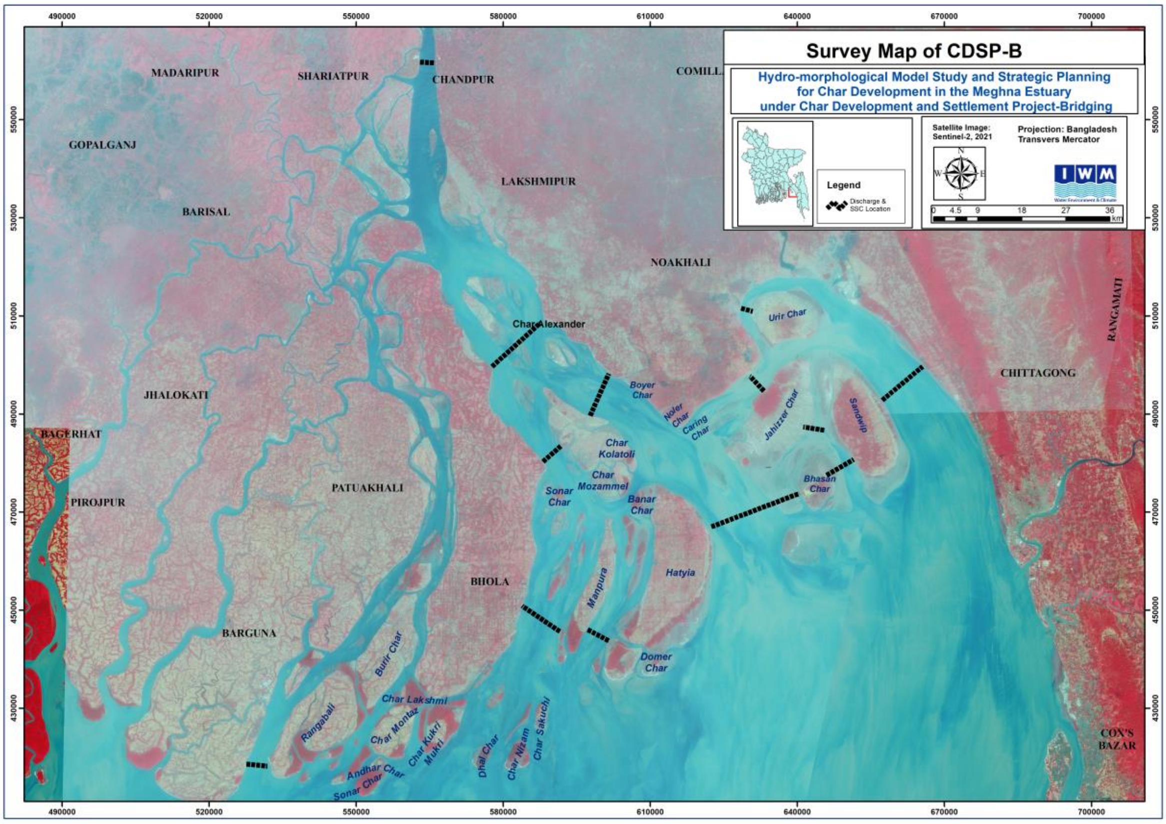


Figure 2.6: Map showing the Discharge and Sediment Concentration Locations

Sample of the measured tidal discharge data at Lower Meghna River (Chadpur) at monsoon and dry period and Nijhuim Dwip Channel at East Monpura (East Shahbazpur channel) at dry period are shown in the Figure 2.7 and Figure 2.8 and Figure 2.9 respectively.

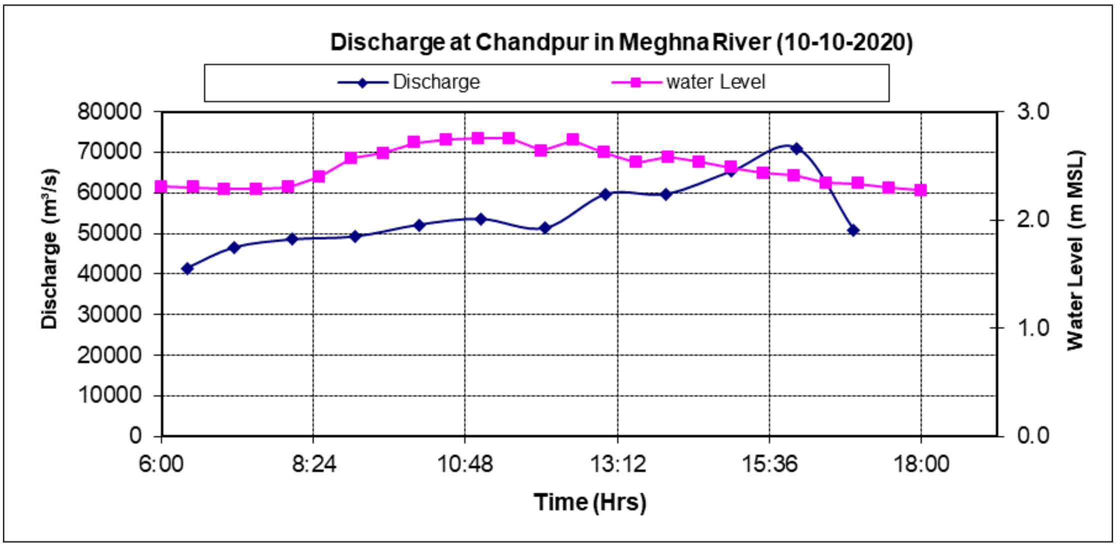


Figure 2.7: Discharge and Water Level of Lower Meghna River at Chadpur during monsoon

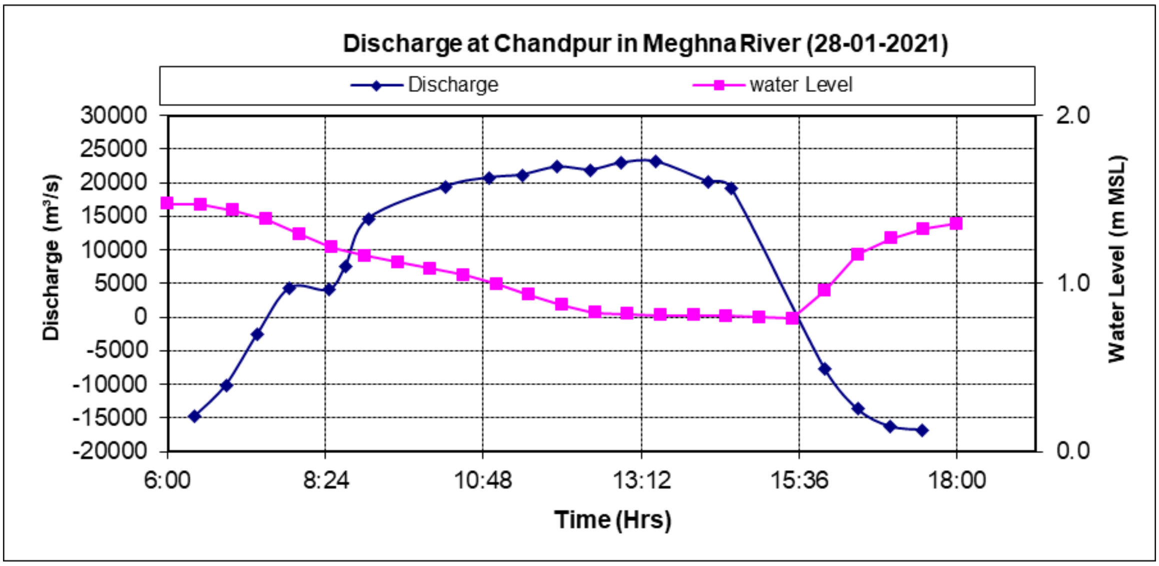


Figure 2.8: Discharge and Water Level of Lower Meghna River at Chadpur during dry season

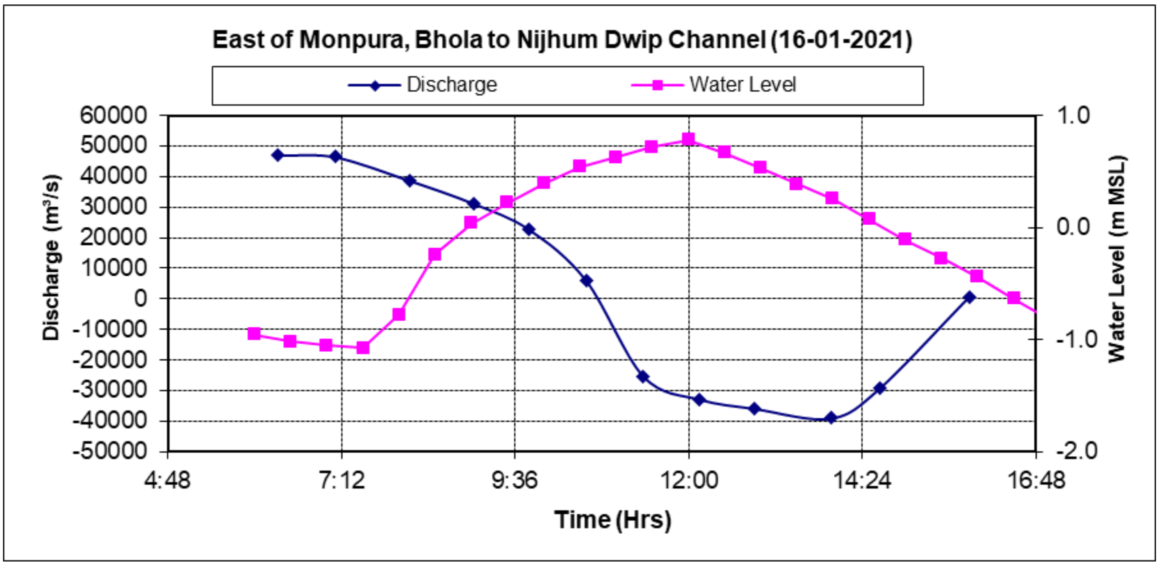


Figure 2.9: Discharge and Water Level of Nijhuim Dwip Channel at East Monpura (East Shabazpur channel) during dry season

Suspended Sediment Concentration Measurements

To know the sediment transport and calibration of morphological model sediment concentration measurement is needed. Suspended sediment concentration has been measured during discharge measurements in spring tide and neap tide. The samples have been taken every hour for the full tide cycle of 13 hours and three samples collected from surface, 0.2, 0.6 and 0.8 depths in each time.

Water Level and Discharge Data Analysis:

It is observed that tidal range varies in the project area. The tidal range variation during spring tide in the study area is shown in the Table 1.1, where the maximum tidal range is observed at Musapur and the water level varies from -3.32 m to 3.39 m during dry season and from -3.20 m to 5.32 m during monsoon. Maximum, minimum, and mean water level, maximum tidal range and measurement period are presented in Table 2.1.

Table 2.1: Maximum tidal range and maximum, minimum, and mean water level at different locations in Spring tide

SL No.	Station Name	Dry Season Water Level (mMSL) (January-February 2021)				Monsoon Season Water Level (mMSL) (August – October 2020)			
		Max WL	Min WL	Mean WL	Max Tidal Range (m)	Max WL	Min WL	Mean WL	Max Tidal Range (m)
1	Chadpur	1.95	0.83	1.30	1.12	3.76	2.63	2.95	1.13
2	Ellisha ghat	1.94	-0.79	0.36	2.73	3.52	0.62	1.83	2.90
3	Dawlatkhan	0.50	-0.69	0.32	1.19	3.44	-0.75	1.45	4.19
4	Char Alexander (Ramgati)	1.78	-1.94	-0.12	3.72	3.34	0.38	1.31	**2.96**

SL No.	Station Name	Dry Season Water Level (mMSL) (January-February 2021)				Monsoon Season Water Level (mMSL) (August – October 2020)			
		Max WL	Min WL	Mean WL	Max Tidal Range (m)	Max WL	Min WL	Mean WL	Max Tidal Range (m)
5	Chairman ghat	3.03	-0.46	0.94	3.49	4.42	-0.01	1.88	4.43
6	Nalchira Ghat (Hatiya)	1.95	-2.13	-0.13	4.08	2.93	0.08	0.97	2.85
7	Charmontaj	1.46	-0.87	0.18	2.33	2.60	-0.38	1.30	2.98
8	Dhulaswar	1.28	0.57	-0.01	0.71	1.36	-1.31	0.10	2.67
9	Camper khal (Urir Char)	3.06	-2.19	0.24	5.25	4.37	-1.77	1.05	6.14
10	Musapur	3.39	-3.32	-0.26	6.71	5.32	-3.20	0.32	8.52
11	Kumira	2.92	-2.79	-0.15	5.71	4.24	-3.37	0.15	7.61
12	Sarikait,Sandwip West Channel	2.21	-2.90	-0.37	5.11	3.75	-1.81	0.38	5.56
13	15 no ghat, Outfall of Karnaphuli	2.22	-2.29	-0.15	4.51	3.60	-2.32	0.60	5.92

The tidal range variation during Neap tide in the study area is shown in the Table 2.1, where the maximum tidal range is observed at Musapur where water level varies from -1.72 m to 1.13 m during dry season and from -1.72 m to 1.96 m during monsoon. Maximum, minimum, and mean water level, maximum tidal range and measurement period are presented in Table 2.2

Table 2.2: Maximum tidal range and maximum, minimum, and mean water level at different locations in Neap tide

SL No.	Station Name	Dry Season Water Level (mMSL) (January-February 2021)				Monsoon Season Water Level (mMSL) (August – October 2020)			
		Max WL	Min WL	Mean WL	Max Tidal Range (m)	Max WL	Min WL	Mean WL	Max Tidal Range (m)
1	Chadpur	1.06	0.81	1.00	0.25	2.59	2.28	2.56	0.31
2	Ellisha ghat	0.41	-0.61	0.05	1.02	1.62	0.6	1.36	1.02
3	Dawlatkhan	0.49	-0.69	0.05	1.18	1.42	0.20	1.01	1.23
4	Char Alexander (Ramgati)	0.15	-1.34	-0.38	1.49	1.87	-0.32	0.71	2.19
5	Chairman ghat	1.30	-0.23	0.70	1.53	2.11	0.40	1.46	1.71
6	Nalchira Ghat (Hatiya)	0.42	-1.03	-0.13	1.45	0.81	-0.18	0.50	0.99
7	Charmontaj	0.33	-0.5	0.12	0.83	1.42	0.81	1.24	0.61
8	Rabnabad/Dhulaswar	0.16	-0.7	-0.06	0.86	0.11	-0.54	-0.002	0.65
9	Camper khal (Urir Char)	1.00	-0.92	0.20	1.92	2.10	-0.81	0.75	2.91
10	Musapur	1.13	-1.72	-0.26	2.85	1.96	-1.72	0.44	3.68
11	Kumira	0.83	-1.31	-0.10	2.14	1.50	-1.40	0.07	2.90
12	Sarikait,Sandwip West Channel	0.34	-1.57	-0.44	1.91	1.36	-1.38	0.24	2.74
13	15 no ghat,Outfall of Karnaphuli	0.27	-1.41	-0.42	1.68	1.52	-1.26	0.38	2.78

Discharge data has been measured in different locations of Meghna Estuary during dry (January 2020) and monsoon (August-September and October). The maximum discharge at different locations in the Meghna Estuary during dry and monsoon season are presented in the **Table 2.3**

Table 2.3: Maximum and Minimum discharge during dry and Monsoon season at different locations

SL No.	Station Name	Observed Date during Dry Season	Observed Date during Monsoon	Dry Season Discharge (m^3/s)		Monsoon Season Discharge(m^3/s)	
				Max	Minimum	Maximum	Minimum
1	Chandpur-Hariana ghat in Meghna River	28/01/2021	10/10/2020	23078.64	2460.34	70900.58	41442.01
2	Doulatkhan, Lower Meghna	12/01/2021	04/09/2020	64045.56	5374.61	102578.45	1051.82
3	Chairmanghat in East Sahabazpur Channel	10/01/2021	05/09/2020	57024.88	2568.84	117124.73	3336.08
4	Tajumuddinin, West Sahabazpur Channel	13/01/2021	06/09/2020 & 10/10/2020	48188.97	5349.27	54664.62	1171.55

SL No.	Station Name	Observed Date during Dry Season	Observed Date during Monsoon	Dry Season Discharge (m^3/s)		Monsoon Season Discharge(m^3/s)	
				Max	Minimum	Maximum	Minimum
5	East of Monpura, Bhola to Nijhum Dwip	16/01/2021	10/08/2020	47056.97	710.02	53343.77	1554.21
6	West of Monpura, Bhola to Nijhum Dwip	14/01/2021	10/09/2020	75461.35	14338.04	81344.92	256.75
7	Sitakunda, Sandwip Channel	21/01/2021	30/09/2020	97063.58	6356.62	251851.87	1018.49
8	Char Elahi,Urir Char Channel	19/01/2021	04/10/2020	16835.91	308.59	34481.65	74.03
9	Kalapani, Sandwip-Zahajer Char Channel	23/01/2021	02/10/2020	2602.46	0.00	15182.45	884.23
10	Bhasan Char-Sandwip Channel	24/01/2021		6233.30	524.78		
11	West of Zahejer Char (near Campher Khal)	18/01/2021	05/10/2020	46515.50	5670.12	80851.41	4017.90
12	Hatiya-Bhasan Char Channel	07/10/2020	25/01/2021	82767.96	3624.39	159021.38	16663.26
13	Rabnabad Channel	22/07/2020				44757.75	2001.25

It is observed that maximum discharge is about 82767.96 m3/sec and 159021.378 m3/sec at Hatiya- Bhasan Char Channel during dry and monsoon season at spring tide.

Sediment data

To know the suspended sediment characteristics, sediment transport rate and erosion-sedimentation pattern, the suspended sediment concentrations were measured at 12 locations during dry period covering spring and neap tide and 12 locations during monsoon period covering spring and neap tide. Sampling for suspended sediment concentrations have been carried out at 12 locations in neap and spring tide during the time of velocity and discharge measurement. Position and depth of sampling locations have been recorded at each location. The samples have been taken every hour for the full tidal cycle of 12-13 hours and three samples are collected. In total, 3 samples are collected per location at 0.2, 0.6 and 0.8 depths each time to represent the sediment variation during the whole tide cycle. After laboratory analysis, the sample in IWM Sediment laboratory at Dhaka, the total concentration has been computed. A sample of suspended sediment curves are shown in Figure 2.10 and Figure 2.11 respectively.

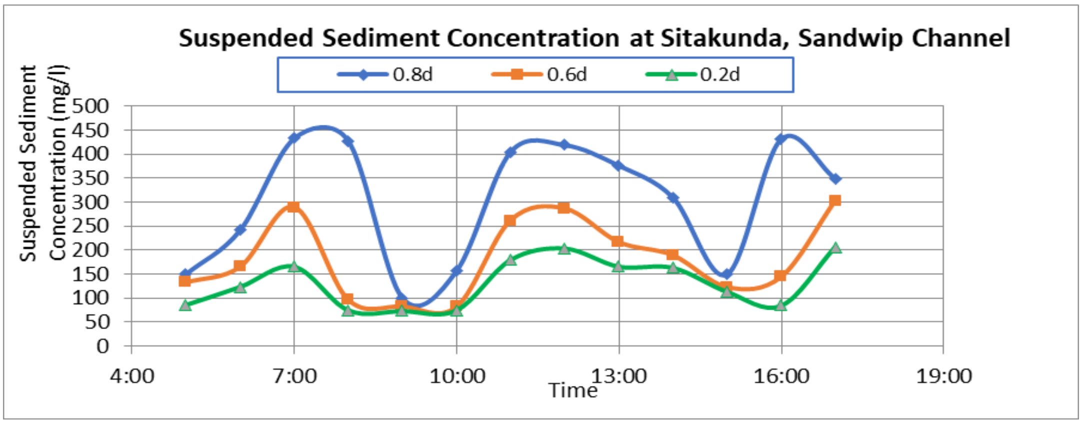


Figure 2.10: A sample of suspended sediment curve of Sandwip Channel at Kumira Ghat during dry season

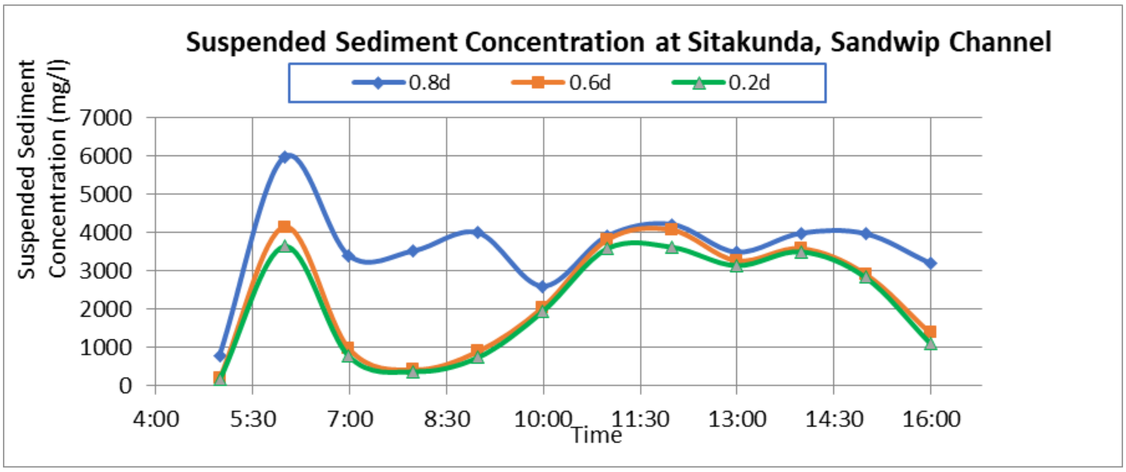


Figure 2.11: A sample of suspended sediment curve of Sandwip Channel at Kumira Ghat during monsoon season

Table 2.4: Maximum and Minimum Suspended Concentration during dry and Monsoon season at different locations

SL No.	Station Name	Dry Season Suspended Sediment Concentration (mg/l)			Monsoon Season Suspended Sediment Concentration (mg/l)		
1	Harina Ghat	0.8d	Max	98.40	0.8d	Max	512.50
			Min	18.80		Min	148.01
		0.6d	Max	31.60	0.6d	Max	487.29
			Min	11.60		Min	120.41
		0.2d	Max	28.40	0.2d	Max	441.27
			Min	4.80		Min	82.80
2	Doulatkhan	0.8d	Max	116.41	0.8d	Max	1050.42
			Min	43.20		Min	122.41
		0.6d	Max	111.20	0.6d	Max	650.56
			Min	35.60		Min	88.00
		0.2d	Max	101.20	0.2d	Max	535.71
			Min	32.80		Min	72.40
3	Chairman Ghat	0.8d	Max	218.42	0.8d	Max	1231.37
			Min	45.20		Min	255.62
		0.6d	Max	99.20	0.6d	Max	1016.39

SL No.	Station Name	Dry Season Suspended Sediment Concentration (mg/l)			Monsoon Season Suspended Sediment Concentration (mg/l)		
			Min	40.40		Min	227.22
		0.2d	Max	87.60	0.2d	Max	930.33
			Min	27.60		Min	160.81
4	Tajumuddin	0.8d	Max	691.78	0.8d	Max	906.31
			Min	148.41		Min	236.82
		0.6d	Max	500.09	0.6d	Max	586.93
			Min	136.81		Min	135.21
		0.2d	Max	481.69	0.2d	Max	466.08
			Min	82.80		Min	21.20
5	East Monpura	0.8d	Max	1280.22	0.8d	Max	947.14
			Min	43.60		Min	371.65
		0.6d	Max	669.77	0.6d	Max	590.93
			Min	25.20		Min	261.23
		0.2d	Max	593.73	0.2d	Max	550.11
			Min	21.60		Min	187.61
6	West Monpura	0.8d	Max	2199.82	0.8d	Max	851.47
			Min	61.60		Min	82.40
		0.6d	Max	901.11	0.6d	Max	357.65
			Min	56.40		Min	66.80
		0.2d	Max	293.23	0.2d	Max	319.24
			Min	54.00		Min	54.80
7	Kumiraghat	0.8d	Max	432.87	0.8d	Max	5971.83
			Min	100.00		Min	784.23
		0.6d	Max	302.43	0.6d	Max	4136.45
			Min	82.40		Min	194.41
		0.2d	Max	206.02	0.2d	Max	3635.38
			Min	73.20		Min	156.81
8	Char Elisha	0.8d	Max	2095.26	0.8d	Max	7972.71
			Min	249.22		Min	851.87
		0.6d	Max	1907.37	0.6d	Max	4212.69
			Min	150.41		Min	786.23
		0.2d	Max	1815.24	0.2d	Max	3716.40
			Min	102.40		Min	706.19
9	zahajer Char East	0.8d	Max	698.98	0.8d	Max	32008.40
			Min	49.20		Min	3631.37
		0.6d	Max	402.86	0.6d	Max	16237.69
			Min	43.20		Min	3345.42
		0.2d	Max	321.64	0.2d	Max	11275.78
			Min	34.80		Min	3278.85
10	Bhasan Char,Sandwip	0.8d	Max	256.82	0.8d	Max	-
			Min	51.60		Min	-
		0.6d	Max	134.01	0.6d	Max	-
			Min	43.20		Min	-
		0.2d	Max	84.40	0.2d	Max	-
			Min	30.00		Min	-
11	Zahajer Char West	0.8d	Max	4113.17	0.8d	Max	14247.39
			Min	97.20		Min	1040.81
		0.6d	Max	2553.66	0.6d	Max	11519.86
			Min	54.40		Min	880.29
		0.2d	Max	1330.67	0.2d	Max	9503.96
			Min	43.20		Min	787.03
12	Hatiya	0.8d	Max	100.80	0.8d	Max	2352.09
			Min	29.60		Min	453.68

SL No.	Station Name	Dry Season Suspended Sediment Concentration (mg/l)			Monsoon Season Suspended Sediment Concentration (mg/l)		
		0.6d	Max	75.60	0.6d	Max	1737.14
			Min	22.40		Min	362.85
		0.2d	Max	59.20	0.2d	Max	1664.65
			Min	18.40		Min	303.63
13	Rabnabad	0.8d	Max	-	0.8d	Max	1162.91
			Min	-		Min	502.50
		0.6d	Max	-	0.6d	Max	638.15
			Min	-		Min	196.81
		0.2d	Max	-	0.2d	Max	559.72
			Min	-		Min	139.21

It has been observed that sediment concentration at 0.2 depths always lower than sediment concentration at 0.8 depths. It is also evident that during dry season sediment concentration is lower than in monsoon ant it varies for these locations from 4113.17 mg/l to 4.80 mg/l and during monsoon it varies from 32008.40 mg/l to 21.20 mg/l in monsoon season.

Bed samples was also collected at different locations of Lower Meghna River system. The value of d_{50} was calculated from each sample and a map of d_{50} is furnished in the Figure 2.12 and Table 2.5. From the figure, it is evident that the study area is dominated by silt/clay (particle size is less than 63 micron/ 0.063mm).

Grain size analysis of the historical sediment data shows that the sediment type is predominantly fine silt with clay. The average particle size of sediment varies from 0.031 mm to 0.047 mm.

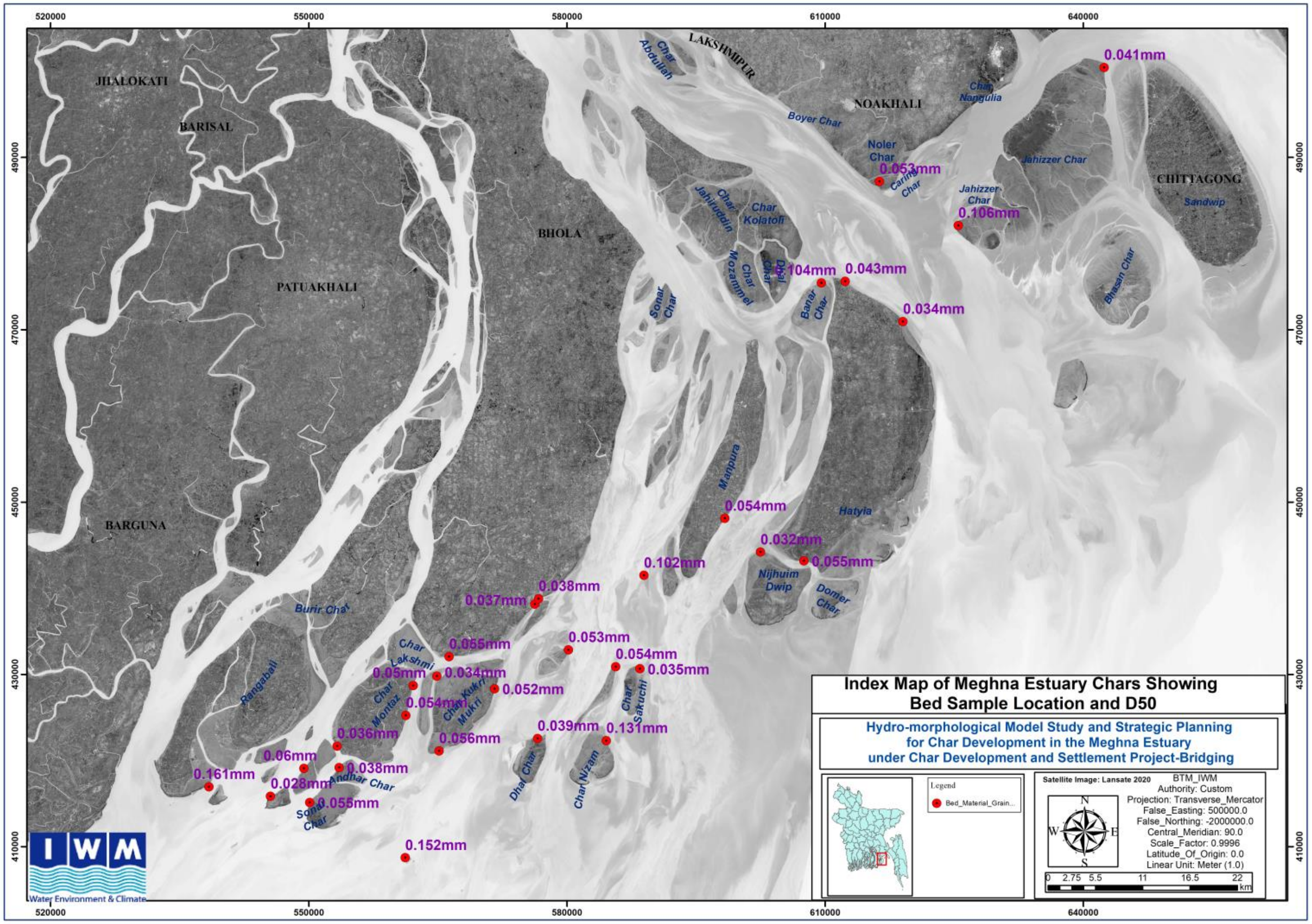


Figure 2.12: Map showing the grain size distribution (D_{50}) in the Project Areas

Table 2.5: Bed Sample collection Location and D50 value

SL	Location	Easting (m)	Northing (m)	Grain Size [D_{50} (mm)]
1	Kalagachia Char	235211	2418294	0.028
2	Shib Char	250724	2410846	0.152
3	Sonar Char	239750	2417486	0.055
4	Ander Char	243242	2421471	0.038
5	Bostin Char	251136	2427361	0.054
6	Char Kukrimukri	254919	2423171	0.056
7	Char Kukrimukri US	254825	2431863	0.034
8	Char Janu	266368	2439986	0.037
9	Gash Char	279129	2443087	0.102
10	Nizumdwip	292719	2445524	0.032
11	Jahajmara Char	228066	2419530	0.161
12	Char shotogomoshi	239160	2421455	0.06
13	Char Montaj	243065	2423955	0.036
14	Char Lakashmi	252044	2430830	0.05
15	Char Manika	256289	2434097	0.055
16	Dal char	267193	2424372	0.039
17	Char pila	261511	2430266	0.052
18	Char Khajura	266828	2440612	0.038
19	Monpura	288663	2449514	0.054
20	Hatiya South	297768	2444401	0.055
21	Mujib Nagor	307422	2488280	0.053
22	Hatiya West	300415	2476626	0.104
23	Shuk Char	303192	2476762	0.043
24	Jahazer Char	333787	2500976	0.041
25	Bangla bazar	309821	2471946	0.034
26	Char Nizam	274369	2423977	0.131
27	Char Kalkini	275628	2432553	0.054
28	Char Satkopat	270190	2434616	0.053
29	Char Sakchi	267152	2424194	0.035
30	Soto Char	316473	2482977	0.106

Salinity Data

Salinity data are collected for the whole Meghna Estuary from secondary data sources in long term monitoring and research project. The maximum salinity for the year of 2019-2020 are given below Figure 2.13. It is found from this map that around CDSP area salinity is so high. At Ramgoti maximum salinity is around 14 ppt, Little Feni outfall 25ppt, Karnafuli mouth 27 ppt and at Moju Chaudhuri Hat salinity is around only 1.9 ppt. At the upstream of Tentulia river from Ililsha to Burhanuddin salinity is less and around 2 ppt. **These zones will be used as fresh water pocket/ reservoir.**

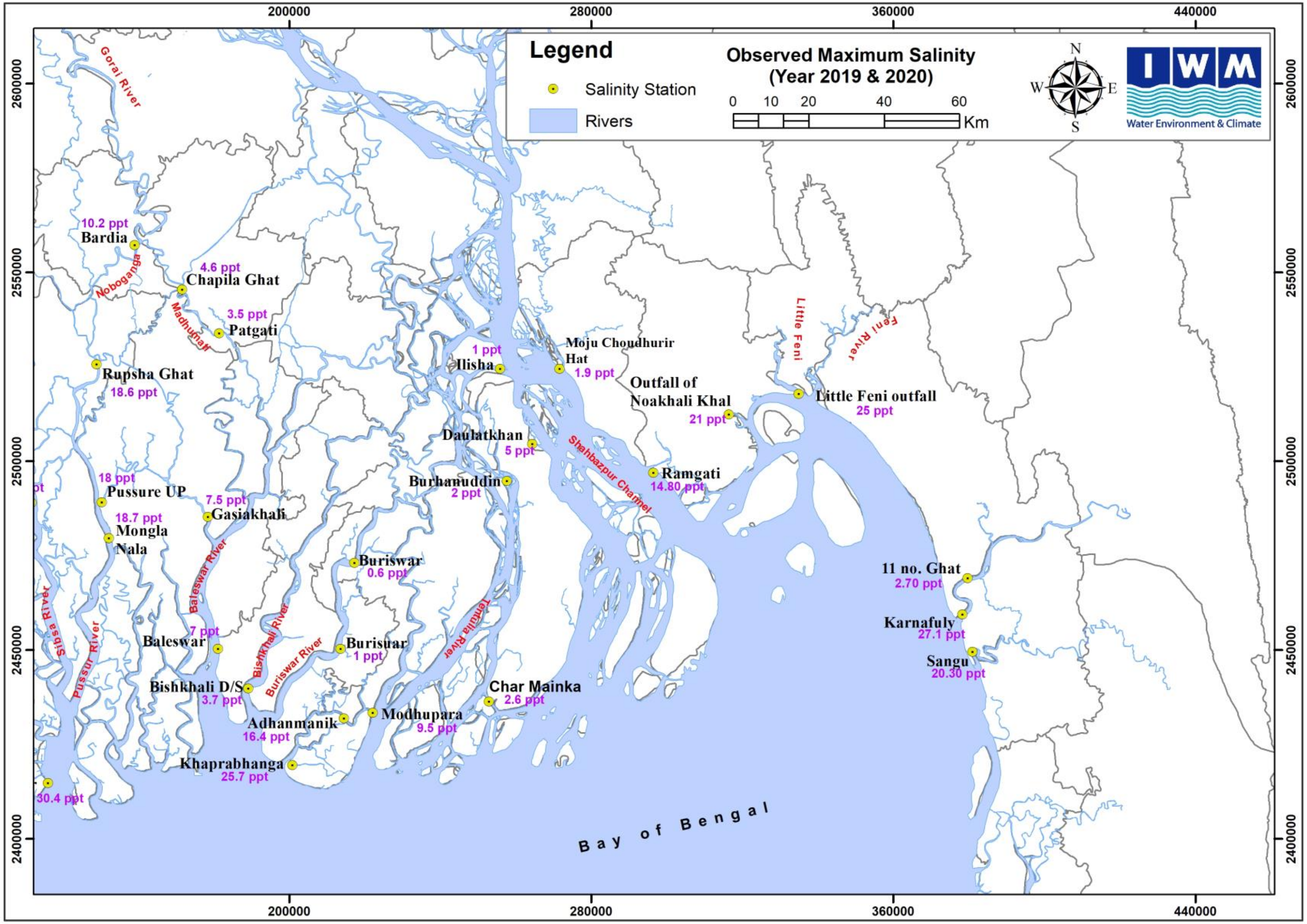


Figure 2.13: Map showing the maximum salinity in the Meghna Estuary

3. HYDRO-MORPHOLOGICAL ASSESSMENT

Meghna estuary is an area where the morphology changes continuously. For any kind of regional planning, it is important to understand the hydro-morphology of the area and how this is likely affecting existing char land and the coast. In this area new chars are emerging at locations where suspended sediment settles and at other location high velocity currents are eroding the bank. The CDSP selected their sites for development relying on the assumption of prevailing patterns of erosion and accretion during the study which by now has changed in many dimensions. To ensure future investments made by the Bangladesh Government, International Partners and the people living and working in those areas, it is very essential to have reliable predictions of how the morphology of the CDSP chars' areas is behaving now and is likely to change in the coming decades.

The present study focuses in identifying stable areas for fixing of embankment and new regulators locations around CDSP III and CDSP IV areas, in the perspective of long-term processes. The trends of erosion, prediction of future erosion rate and erosion vulnerability have been assessed using cross-section analysis, satellite images, field observation, planform analysis, distance of thalweg, near bank velocity, setback distance from the embankment to river bank and community demand. Quantification of magnitude of these criterions are quantified from water flow simulation results, satellite image analysis, field measurements and field visits. Considering these criteria, the erosion vulnerability is assessed. Detail description of the analysis is described. All of these erosion vulnerabilities are assessing below:

3.1 Time series Satellite Images and Data Analysis and Assessment of Shore line Erosion Rate

3.1.1 Time Series Bathymetry and Cross Section Analysis to Assess Channel Shifting Characteristic of Deeper channel

Time series analysis of bathymetry/cross section is carried out to examine the planform change, bar movement and shifting characteristic of river bank. Bankline shifting provides the severity of erosion vulnerability and loss of land. Therefore, overall morphological changes are evident from these bathymetry analysis, planform and bank shifting characteristic/analysis. Therefore, the cross-sectional analysis from 2000, 2009 and 2020 in different segment shows the dynamic characteristic of the estuary focus mainly on CDSP IV chars . In this report the analysis mainly focuses on the CDSP IV chars' area at Noler char, Caring char and Char Nangulia and at Urir char side. The index map is shown in Figure 3.1. Some of the cross sections were compared among one another for the year of 2000, 2009 and 2020 respectively.

Figure 3.1: Map showing the sections locations at CDSP IV chars' areas

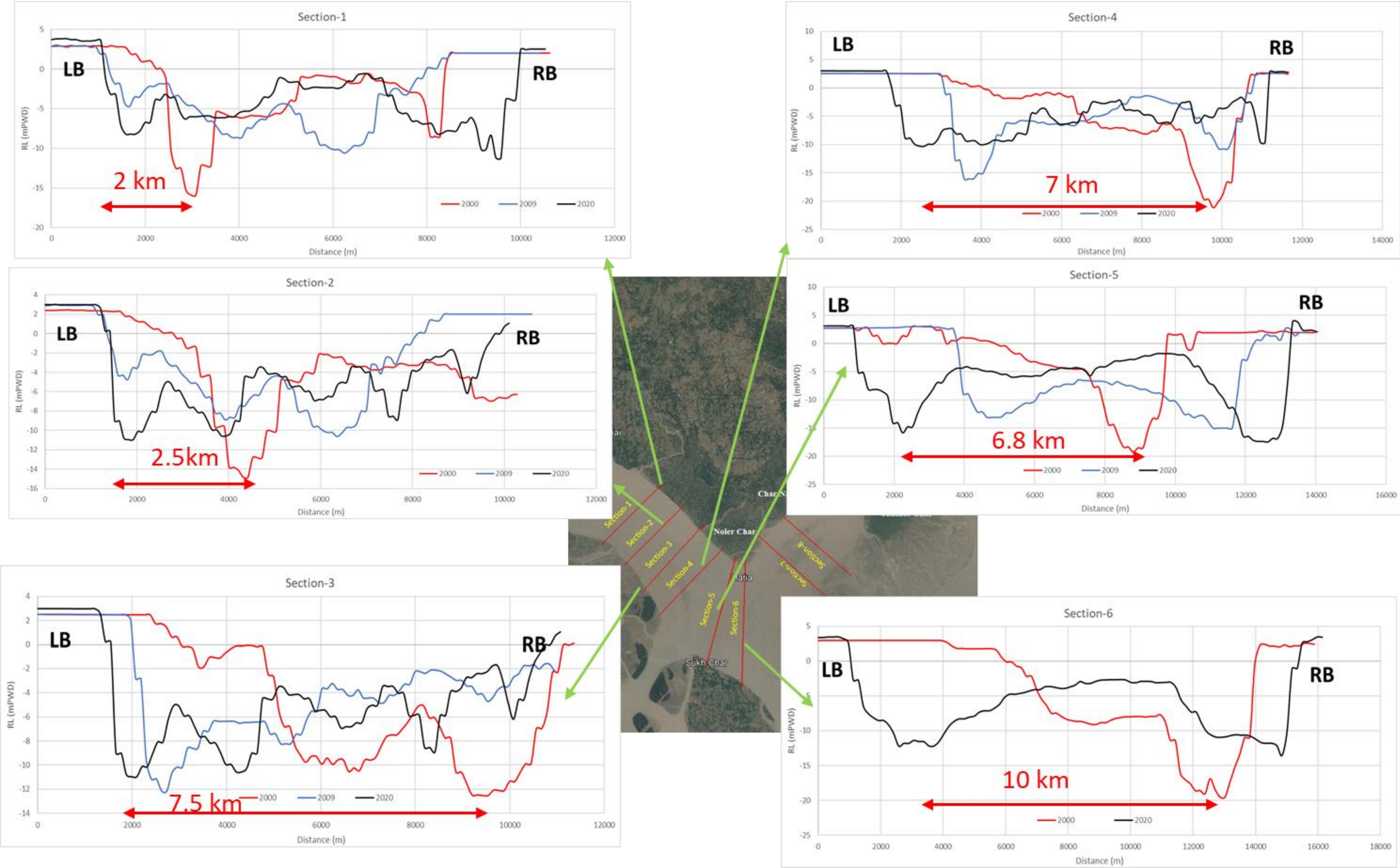


Figure 3.2: Some selected cross-section profiles of the CDSP IV chars' area in Meghna Estuary

In the Figure 3.2, at section 1, section-2, section-3 which are situated in Boyer char. It is seen that; thalweg lines are shifting towards left bank, and the shifting is around 2.0 km~ 7.5 km from 2000 to 2020. Apart from this shifting it is observed very steep slope near the bank which indicates the erosion tendency in this reach.

At Noler char and Caring char, in section 4, section-5, section-6, shows that there were chars during 2000 to 2009 near the left bank and after 2009 erosion tendency have been seen. It is found that the deep channel moved around 7 to 10 km towards the left bank from year 2009 to year 2021 which indicated that caring char is fully diminished.

In Figure 3.3, at section -7 and section-8 at Char Nangulia shows that there were chars during the period of 2000 to 2009 and after that the char's area are diminished and erosion tendency was found. The deep channel was formed which is almost 8 m depth.

Section-9, near Urir char shows a large landmass was seen during the period of 2000 to 2009. This area was eroded and gradually deepens the channel in 2020. Same pattern has been seen in Section-10 and the channel was increased in depth and width over time during 2020.

At section-11, same development was proceeded and the was more prominent. It is found from the cross-section analysis that almost in all sections have steep slope near the left bank indicating erosion tendency as well as shifting of scour hole close to the left bank.

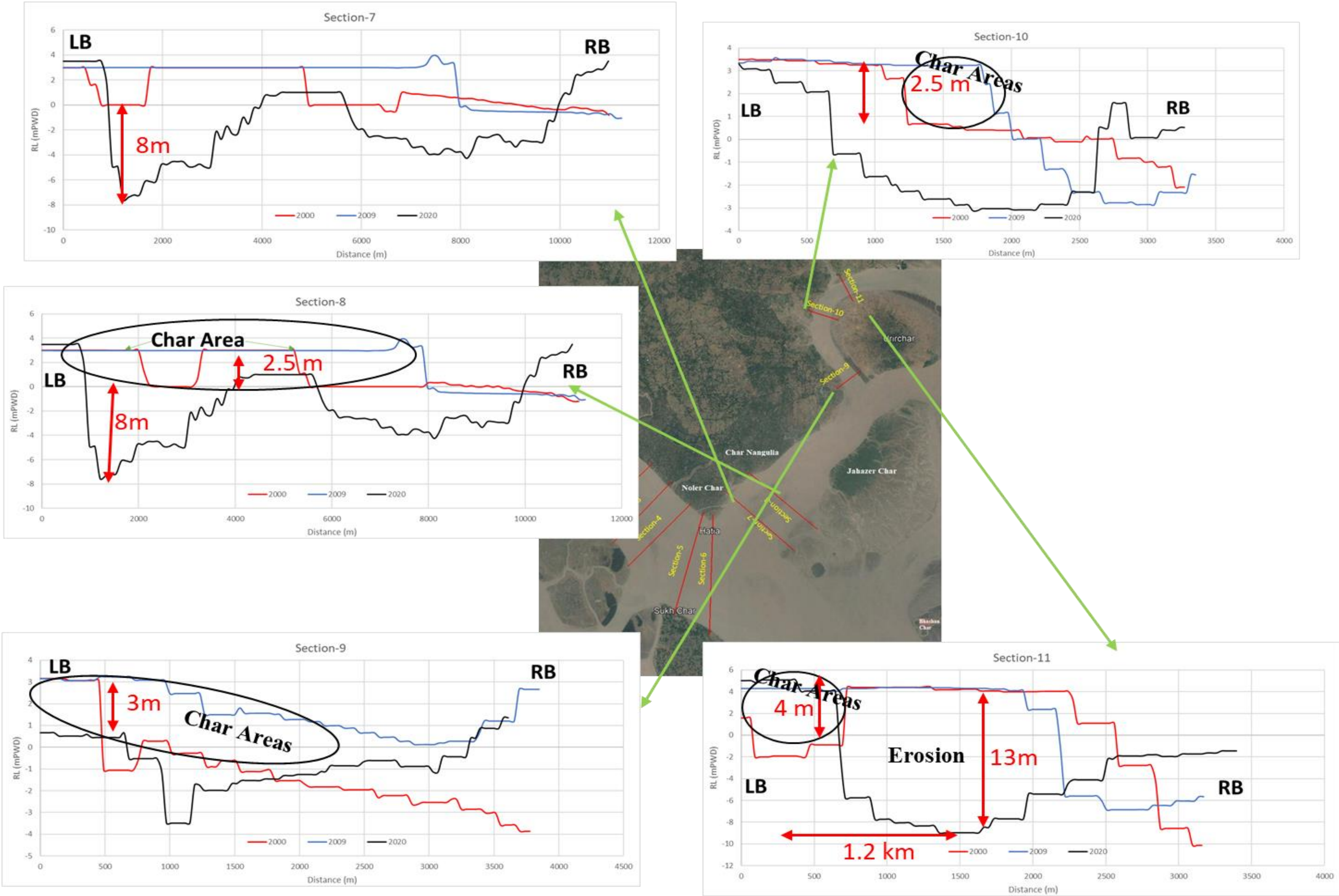


Figure 3.3: Some selected cross-section profiles of the CDSP IV chars' area in the Meghna Estuary

3.1.2 Planform Changes and Bar Movement

To identify areas vulnerable to erosion and stable areas for char development overlay technique and comparison of bathymetric charts are useful and enable to find the changes of morphology and planform over the years. Planform change and river bank shifting characteristic are important indicator in understanding the dynamic behaviour of river and estuarine morphology. Comparison of time series bathymetry and satellite images analysis are the two techniques for assessing the bank shifting characteristics and bar movement over the years. GIS technology is applied to analyse time series satellite images in assessing the bank shifting characteristics over the years. Sequential time series of available satellite imageries are provided spatial and temporal changes of the river and chars over the time. Hence, creation of new char and reduction/expansion of any char and stable areas for char's development in CDSP areas are identified and investigated effectively by comparing and interpreting of such imageries and bathymetry. Therefore, overall morphological changes are evident from these bathymetry analysis, planform and bank shifting characteristic/analysis. These indicators are utilized in assessing the erosion vulnerability and find out the stable chars.

Sattelite images have been analyzed to assess the erosion vulnerability of the study area. Figure 3.4 and Figure 3.5 show the planform changes of the study area from 2000 to 2010 and 2010 to 2020 respectively. It is found from this analysis that net erosion occurred at the both bank of Lower Meghna. It is found that at the left bank of Lower Meghna like Ramgati, Caring char, char Elahi etc. have the erosion tendency over the last 10 years (2010 to 2021). Same tendency was found at the right bank of Lower Meghna such as Char Illisha, Bara Manik (see Figure 3.4). Moreover, at Urir char, Shandwip, Sharnadwip, Vasanchar net accretion were occurred during this period as shown in Figure 3.4

From Table 3.1, it is found the at Caring char and Noler char the accretion tendency were found and it was 29.27km^2 and 1.13 km^2 during period 2000 to 2010. After that sever erosion were happened during period 2010 to 2021 and it was -60.78km^2 and -4.97km$^{2.}$

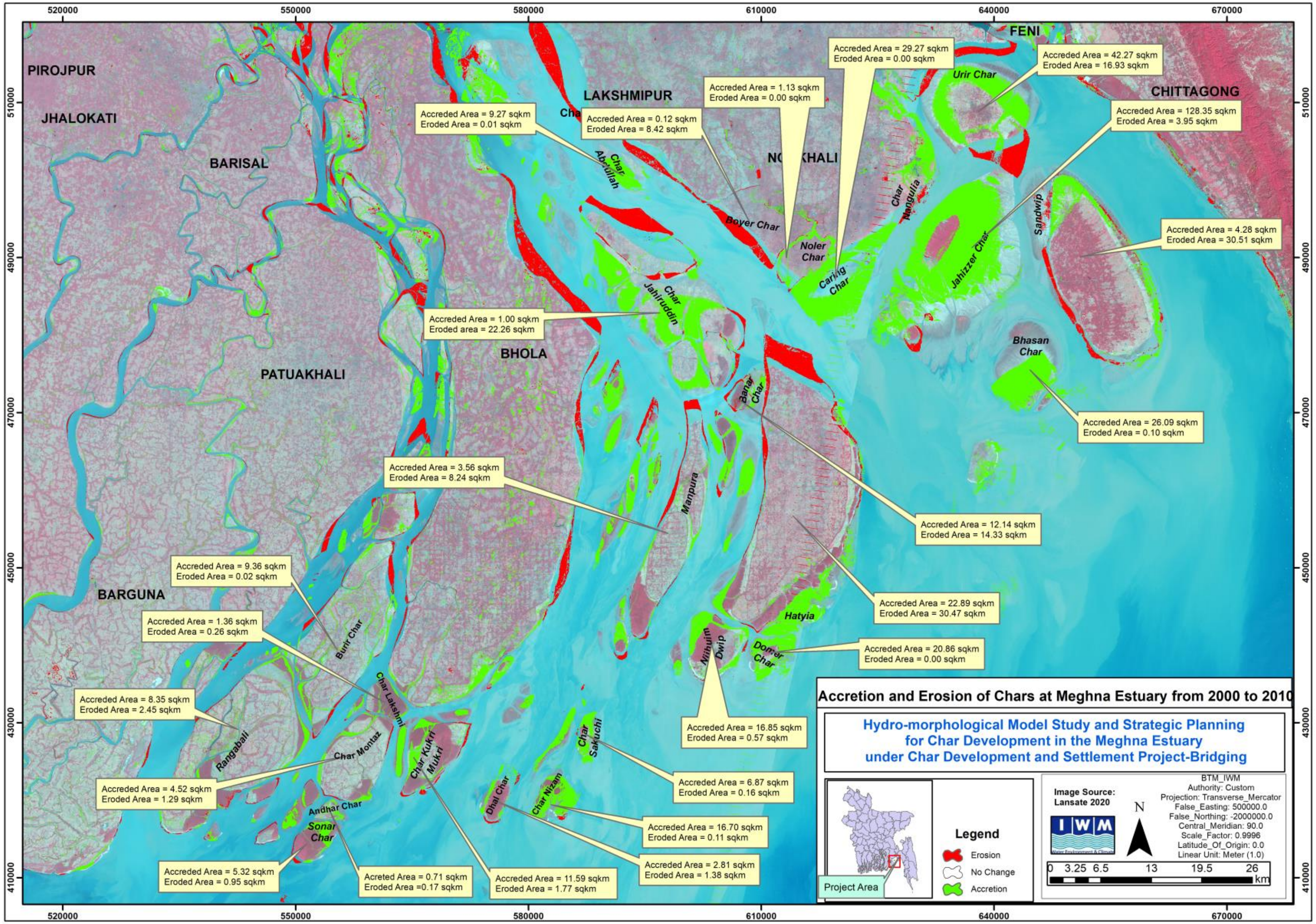


Figure 3.4: Erosion-Sedimentation Map in the Meghna Estuary (2000~2010)

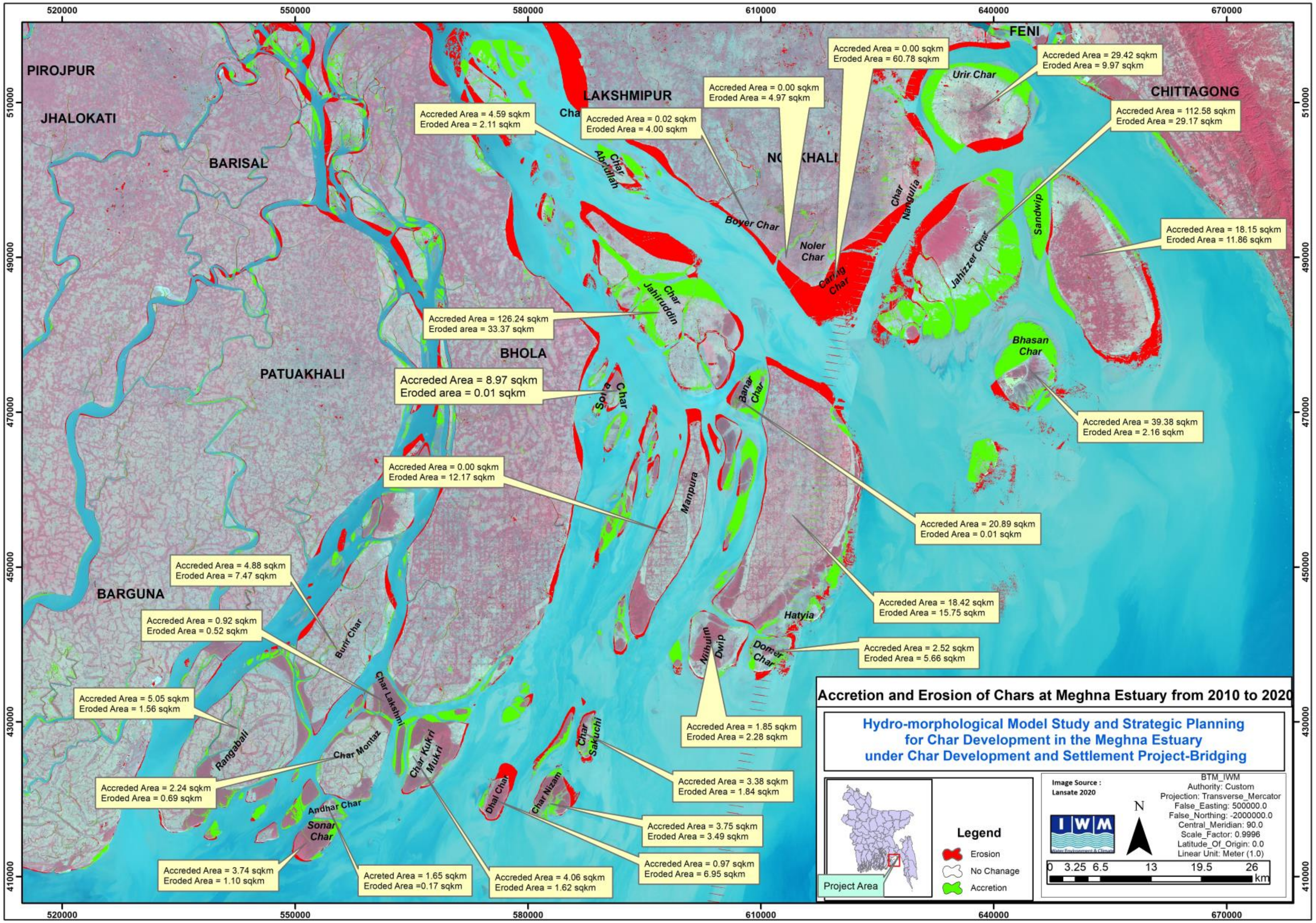


Figure 3.5: Erosion-Sedimentation Map in the Meghna Estuary for the Last 10 years (2010~2020)

Table 3.1: Erosion/ Accretion area over the last three decades

Sl No.	Char Name	1990-2000			2000-2010			2010-2020		
		Accreded Area (sqkm)	Eroded Area (sqkm)	Net Accretion/Erosion(sqkm)	Accreded Area (sqkm)	Eroded Area (sqkm)	Net Accretion(sqkm)	Accreded Area (sqkm)	Eroded Area (sqkm)	Net Accretion/Erosion(sqkm)
1	Andhar Char	0.92	0.31	0.61	0.71	0.17	0.54	1.65	0.17	1.48
2	Banar Char	35.83	2.95	32.88	12.14	14.33	-2.19	20.89	0.01	20.88
3	Bhasan Char	Char does not exist			26.09	0.1	25.99	39.38	2.16	37.22
	Boyer Char	1.20	5.29	-4.09	0.12	8.42	-8.30	0.02	4	-3.98
4	Burir Char	14.68	7.97	6.71	9.36	0.02	9.34	4.88	7.47	-2.59
5	Char Abdullah	0.00	5.36	-5.36	9.27	0.01	9.26	4.59	2.11	2.48
6	Char Jahiruddin	22.11	37.55	-15.44	1.00	22.26	-21.26	126.24	33.37	92.87
7	Char Kukri Mukri	3.24	3.47	-0.23	11.59	1.77	9.82	4.06	1.62	2.44
8	Char Lakshmi	1.86	0.44	1.42	1.36	0.26	1.10	0.92	0.52	0.40
9	Char Montaz	0.33	3.11	-2.78	4.52	1.29	3.23	2.24	0.69	1.55
10	Char Nizam	4.91	0.19	4.72	16.70	0.11	16.59	3.75	3.49	0.26
11	Char Sukuchi	0.23	0.77	-0.54	6.87	0.16	6.71	3.38	1.84	1.54
12	Dhal Char	0.21	3.04	-2.83	2.81	1.38	1.43	0.97	6.95	-5.98
13	Domer Char	0.10	0.12	-0.02	20.86	0.00	20.86	2.52	5.66	-3.14
14	Hatyia	2.45	33.12	-30.67	22.89	30.47	-7.58	18.42	15.75	2.67
15	Jahizzer Char	17.31	34.53	-17.22	128.35	3.95	124.40	112.58	29.17	83.41
16	Manpura	0.00	8.77	-8.77	3.56	8.24	-4.68	0.00	12.17	-12.17
17	Nijhuim Dwipi	0.26	2.98	-2.72	16.85	0.57	16.28	1.85	2.28	-0.43
18	Rangabali	6.17	8.62	-2.45	8.35	2.45	5.90	5.05	1.56	3.49
19	Sandwip	47.09	18.14	28.95	4.28	30.51	-26.23	18.15	11.86	6.29
20	Sona Char	0.10	1.84	-1.74	Char does not exist			8.97	0.01	8.96
21	Sonar Char	4.08	0.73	3.35	5.32	0.95	4.37	3.74	1.10	2.64
22	Urir Char	35.67	2.28	33.39	42.47	16.93	25.54	29.42	9.97	19.45
23	Caring Char	18.92	0.10	18.82	29.27	0.00	29.27	0.00	60.78	-60.78
24	Noler Char	26.99	3.00	23.99	1.13	0.00	1.13	0.00	4.97	-4.97

*** Here in Net Accretion column 'Positive' value means Accretion and ‘Negative' value means Erosion**

Shoreline Shifting Characteristic

Shoreline shifting along the East Shabazpur channel to Sandwip Channel through various chars were significant during the last 21 years. Shoreline shifting during last 20 years has been measured by bank line analysis. The analysis is done by considering a reference line along the shorelineline. Transect line is generated perpendicular to the reference line at an interval of 2.5 to 3 km. The distance of each year shoreline from the reference line along the transect line is measured from which the shoreline shifting per year is measured. Figure 3.6 and Figure 3.7 shows the average shoreline shifting rate for years 2000 to 2010 and 2010 to 2020.

It is seen from Figure 3.5, that there was small amount of accretion at char Nangulia, between transect chainage 24+800 to transect chainage 25+950 during 2010 to 2020, but overall erosion trend is observed in the full domain such as Boyer char, Noler char and Char Nangulia. Maximum erosion is found at Noler char and it is around 759.42 m/year.

At Boyer char location from transect 0+000 to transect 12+000, the average erosion rate is 50 m /year for the last ten years. At Noler char location from transect 12+000 to transect 14+000, the average erosion rate is 400m/year, which is the most critical portion of CDSP -IV area and at Char Nangulia erosion rate is less than Noler char and it is around 175 m /year at transect 17+950 to transect 22+000 from 2010 to 2021 and shown in Figure 3.7.

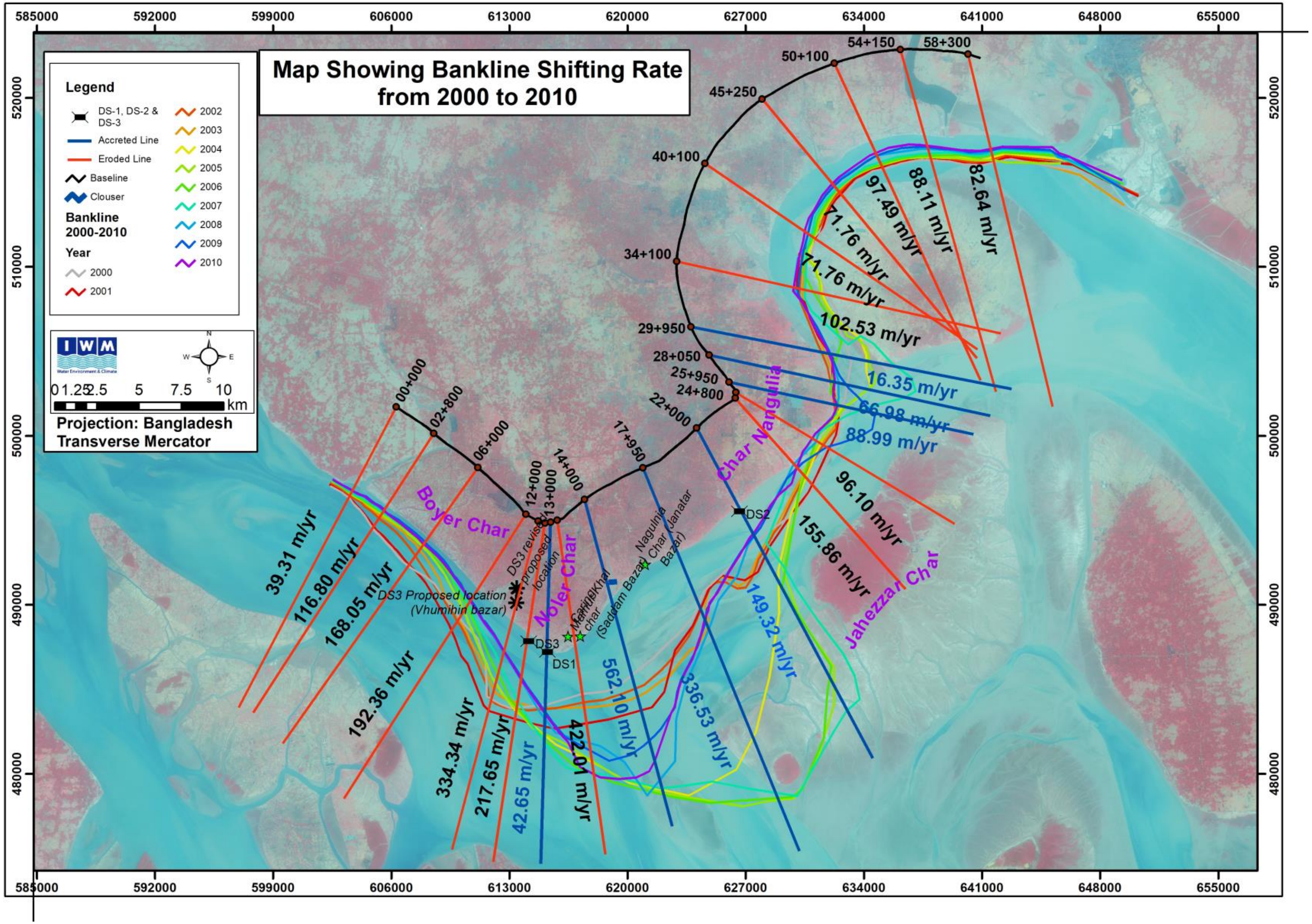


Figure 3.6: Map showing the shoreline shifting rate from 2000 to 2010

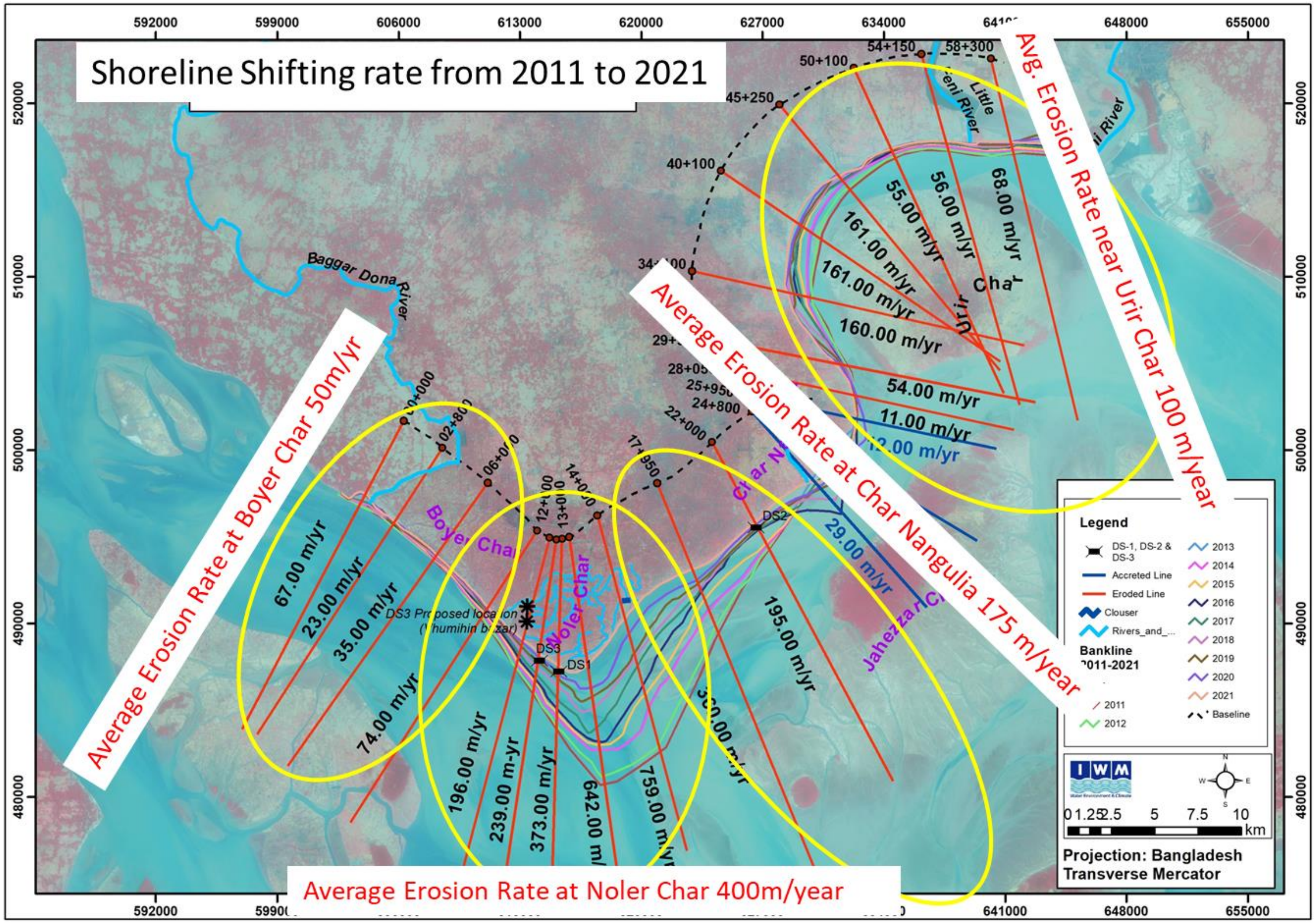


Figure 3.7: Map showing the shoreline shifting rate from 2011 to 2021

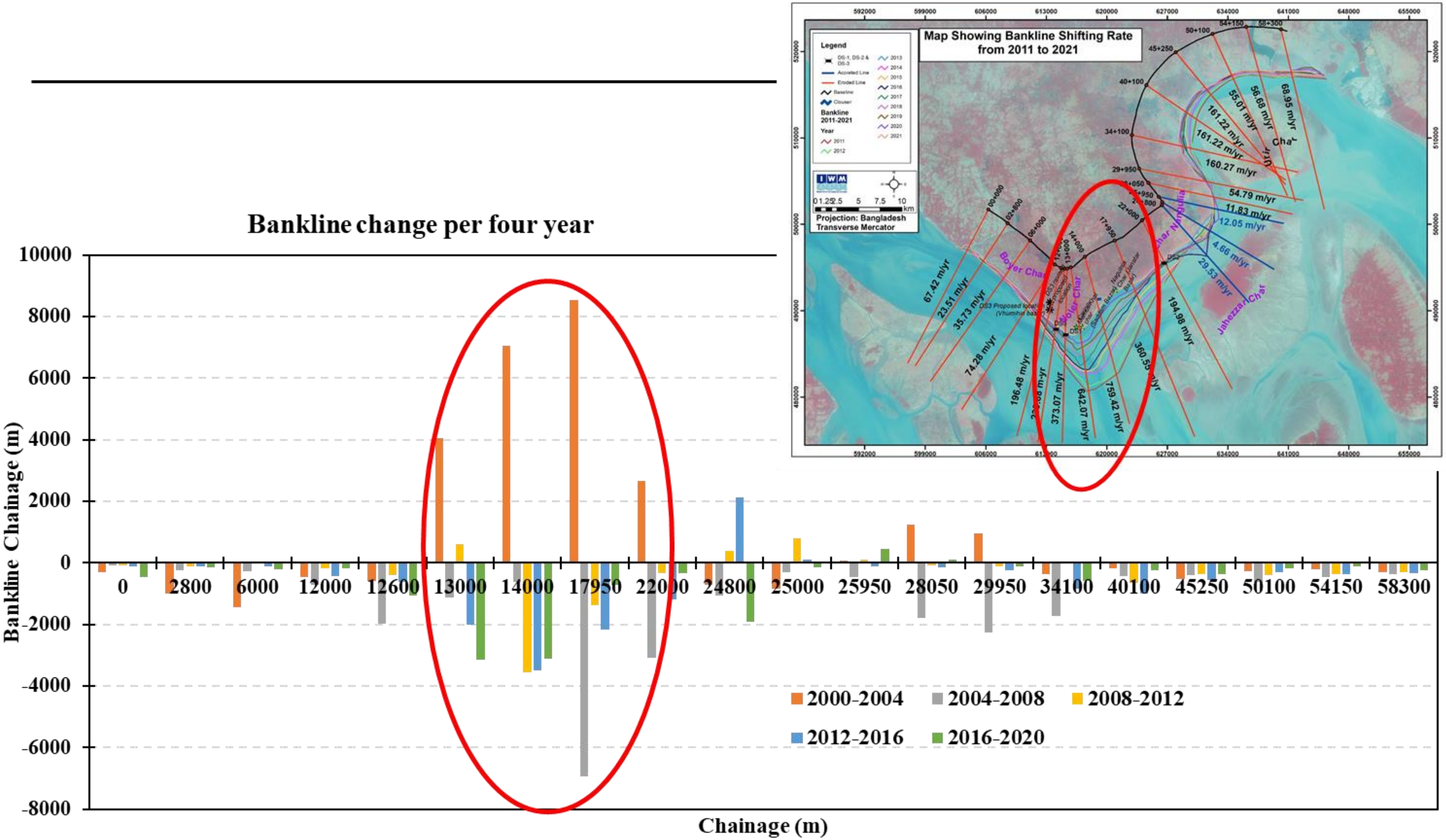


Figure 3.8: Bar chart showing the shore line changes per four years from 2000 to 2020

20 transect line have been selected for shoreline shifting analysis at Noler char, Charing char and Char Nangulia. Transect chainage 0+000 to transect chainage 12+500, all have erosion tendency during the period of year 2000 - 2020. Transect chainage 13+000 to transect chainage 22+000, they have erosion tendency except accretion tendency during the period of 2000-2004 (orange color) as shown in Figure 3.8 . This reach is the most critical part of the CDSP IV chars (red circle). Transect chainage 22+000 to transect chainage 45+000, all of them have almost erosion trend for the last 20 years but the shoreline shifting rate is less compared to Transect chainage 13+000 to transect chainage 22+000.

3.1.3 Identification of the Location of Thalweg Line and Scour Hole

Thalweg is the line of lowest elevation within a river or watercourse, and it is an important parameter in assessing the erosion vulnerability. If the thalweg line is close to the bankline, then the location is considered susceptible for erosion. Moreover, presence of a scour hole near the bank makes the bank slope much steep and the current speed increases near the scour hole which make the bank more vulnerable to erosion.

The timeseries bathymetry/hydrographic data, surveyed in 2009 and 2020 under the present study, have been analysed to locate the thalweg lines of the river and presence of any scour holes near the CDSP IV area in order to assess erosion vulnerability of riverbank near the potential sites for regulator. It is found from Figure 3.9 that the thalweg line shifted to the left bank of the Lower Meghna River near Char Munshi. At Char Munshi thalweg line shifted around 4.5 km and at Caring and Noler Char it is around 7 km. It is found from this figure that the Thalweg line moves to the CDSP IV area, char Nangulia and Urir char which indicates that these are vulnerable to erosion. Figure 3.10 shows the bed level difference map of the year 2009 to 2020 which also indicate erosion tendency near Char Nangulia, Caring char and Urir char and the scour hole depth is almost 11m to 17m (Red circle zone). It is also seen that the Caring Char is almost diminished in this period.

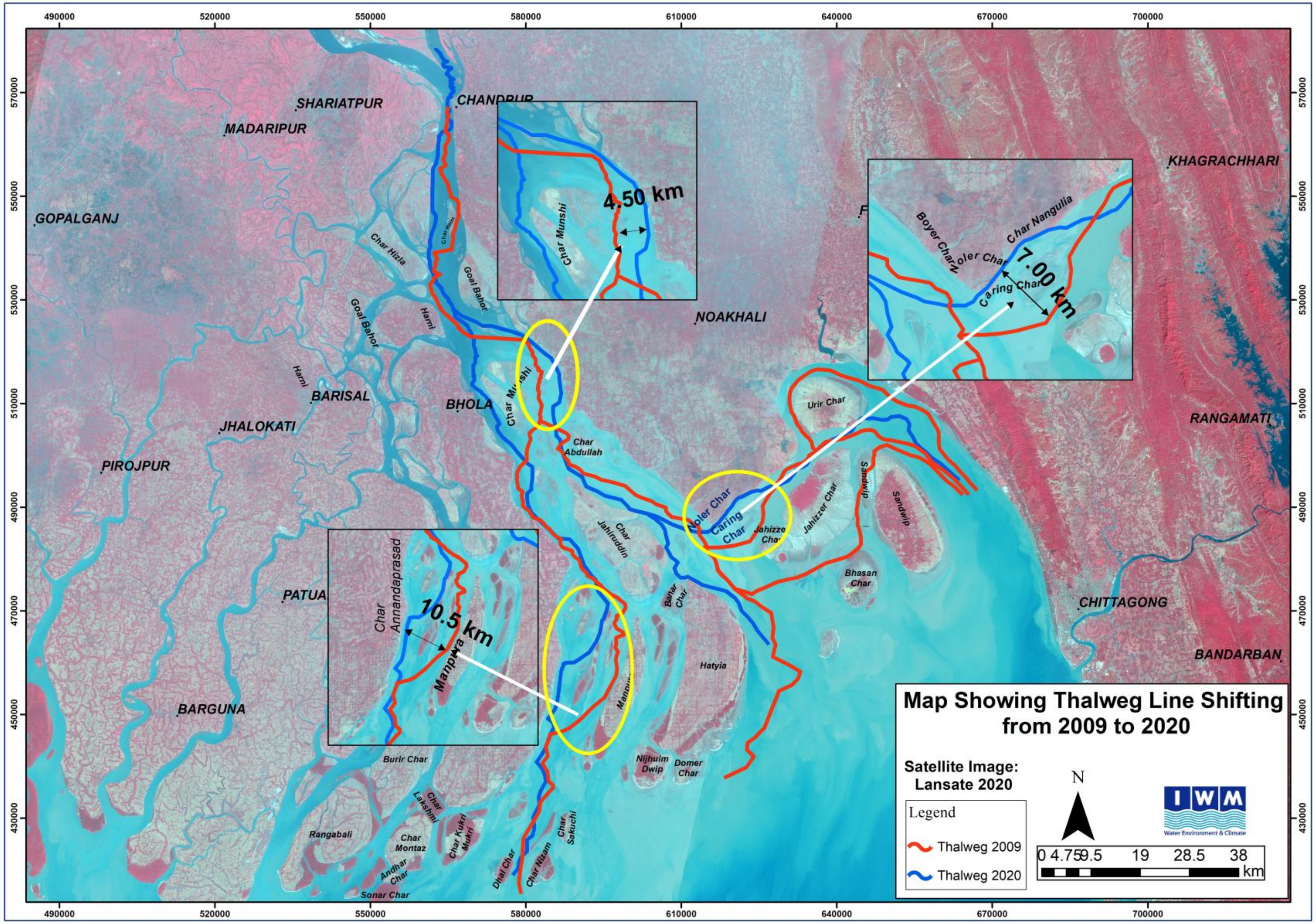


Figure 3.9: Map showing the Thalweg line shifting in 2009 and 2020 (Thalweg line in 2020 bathy)

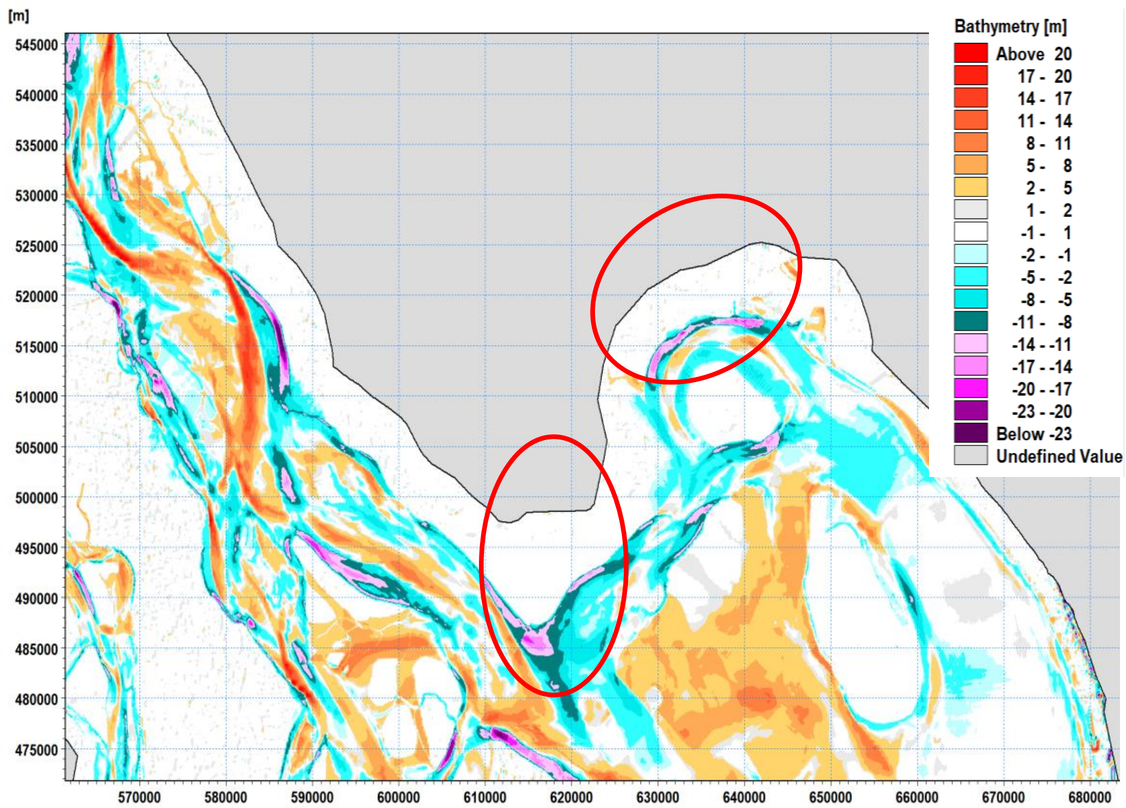


Figure 3.10: Map showing bathymetry difference between 2009 to 2020

3.2 Development of Lower Meghna Hydro-Morphological Model

3.2.1 Hydraulic and Morphological Analysis

Grid and bathymetry

The long-term Meghna Estuary (MES) model is covered the whole Meghna Estuary including the Tentulia river. This model is developed using the Delft3D FM modelling system under a research project of BWDB titled "Long Term monitoring, Research and Analysis of Bangladesh Coastal Zone (sustainable polders adapted to coastal dynamics), CEIP-1". The Lower Meghna‒Tetulia River system is modelled in one numerical grid, combining both Lower Meghna and Tetulia systems in a single model. The grid size varies between 1600 m (open sea) and 200 m (near the char land). The previous version grid system excluded the char and land area. In this study the grid is included the all the chars and mainland area upto few kilometer (about 5 km near the CDSP area). Thus this model can give the char and land migration in the Meghna Estuary area. Figure 3.11 shows the upgaded interpolated bathymetry from the previous version. The bathymetry of the model is already updated with the 2020 survey data as well as other relevant projects data.

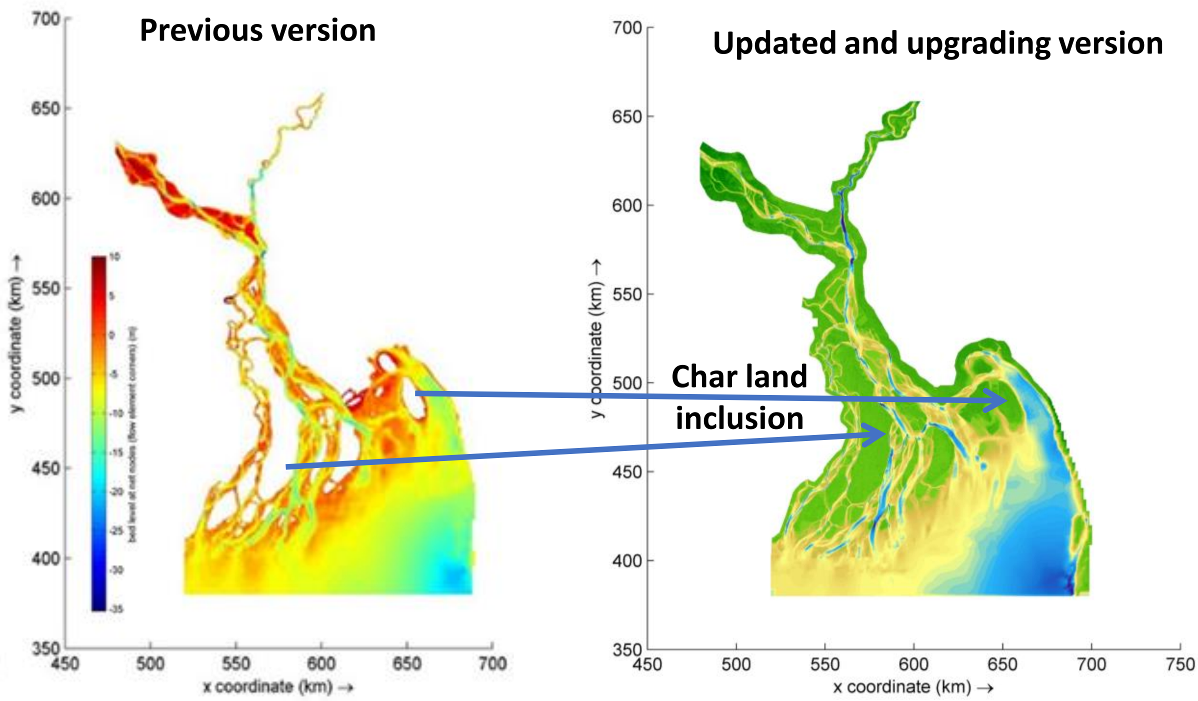


Figure 3.11: Updating and upgrading of the previous MES model

Boundary conditions (hydrodynamic model)

The Lower Meghna-Tentulia River system model has two open upstream boundaries and two open downstream boundaries. Four open boundaries are defined in the model, two in the north: one in the Padma River at Baruria and one in the Upper Meghna River at Bhairab Bazar; and two in the south of Bay of Bengal. The northern boundaries at Baruria in the Padma River and Bhairab Bazar in the Upper Meghna River have been defined by daily rated discharge time series for the year 2020-21. The southern boundary has been predicted from the Global Tidal Model of DHI software package. However, the predicted boundary does not have seasonal variation in the monsoon. Thus, seasonal variation was calculated from previous long-term water level measurement and was included with the predicted boundary. Figure 3.12 shows all boundary locations.

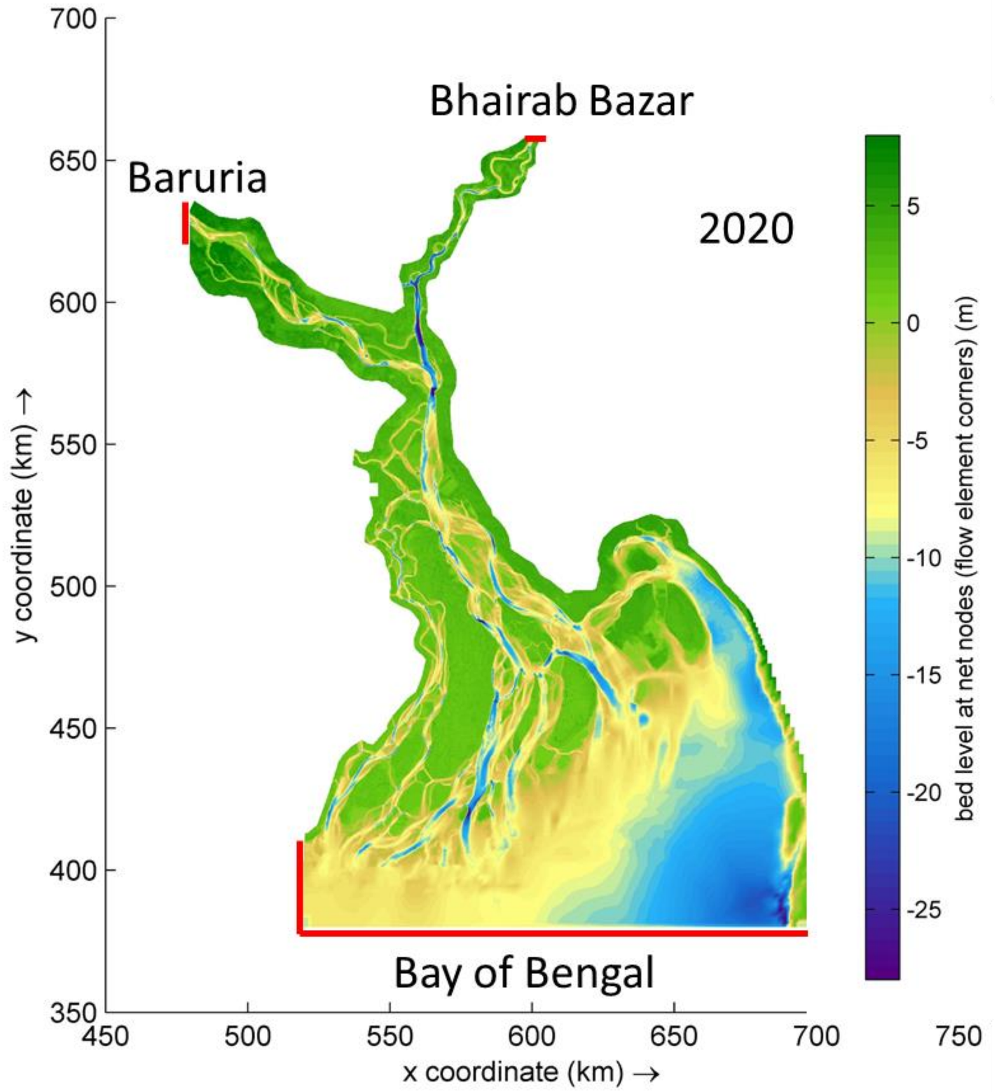


Figure 3.12: All the boundaries (red lines) of the MES model

Bed resistance

From the bed sediment samples, it can be derived that the Lower Meghna-Tentulia River system is cohesive in nature, and low bed friction is expected. Muddier environments will lead to a smoother bed and lower resistance. Based on numerous hydrodynamic calibrations run, a spatially varying roughness was adopted, specified by Chezy values, in order to match the hydrodynamic model results with observed discharge values. The values range between 50 $m^{1/2}/s$ in the sandy upper reaches of the estuary, and 100-120 $m^{1/2}/s$ in the muddy mouth area.

Wind fields

Wind and pressure fields are needed in the hydrodynamic simulations to drive monsoon-related wind-driven circulation which improved the hydrodynamic result. DHI has carried out global forecast model for different part of the world. In this study, wind and pressure data extracted from this global model for wind and pressure field in the Lower Meghna Estuary area.

Hydrodynamic calibration and validation

The Delft3D FM sediment transport model calculates transport rates on a flexible mesh (unstructured grid) covering the area of interest based on hydrodynamic data obtained from a simulation with the Hydrodynamic Module (HD) as well as with information about the characteristics of the bed material. This means that a well calibrated and validated hydrodynamic model is needed to develop a reliable sediment transport model. The hydrodynamic model was calibrated with field data from the 2020-21 measurement campaign, both for dry and monsoon season. The locations of the field data sampling points are shown in Figure 3.13.

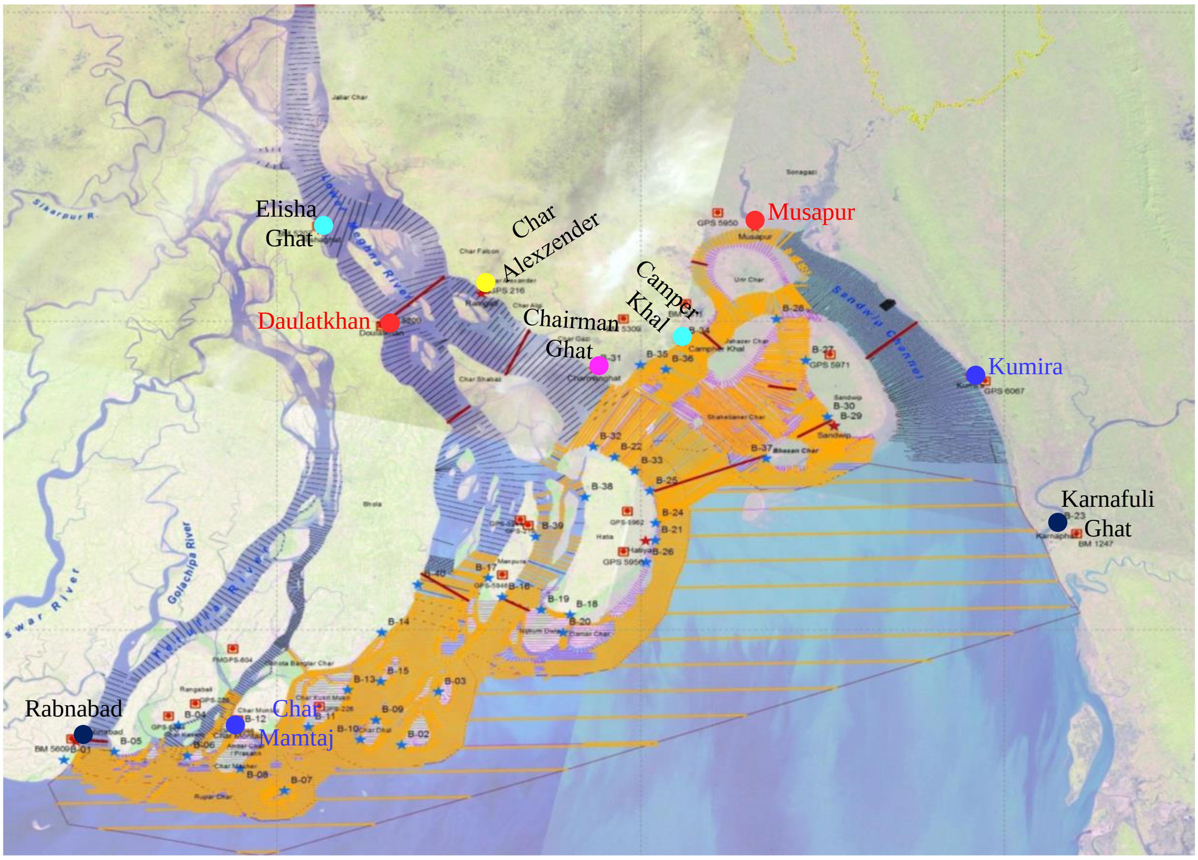


Figure 3.13: Location of the calibration stations in the lower Meghna Estuary area.

Calibration for water levels and discharge

The hydrodynamic model of Meghna Estuary Model was calibrated with the field data collected in 2020-21 during both dry and monsoon season to achieve satisfactory model performance. The water level calibration at Kumira, Musapur, and Char Momtaz are illustrated from Figure 3.14 to Figure 3.18. Figure 3.19 to Figure 3.22 shows the calibration of discharge for different channels. The water level and discharge show good correlation with measured and simulated data, especially with respect to the tidal phasing. Most of the location seems to well fit with the observed water levels and discharge during dry and season.

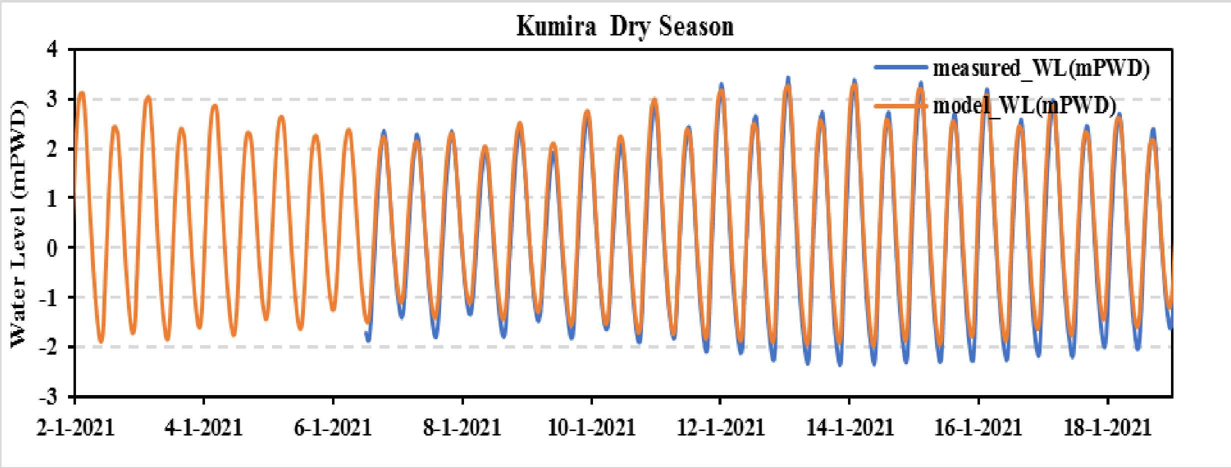


Figure 3.14: Water level calibration at Kumira for dry period

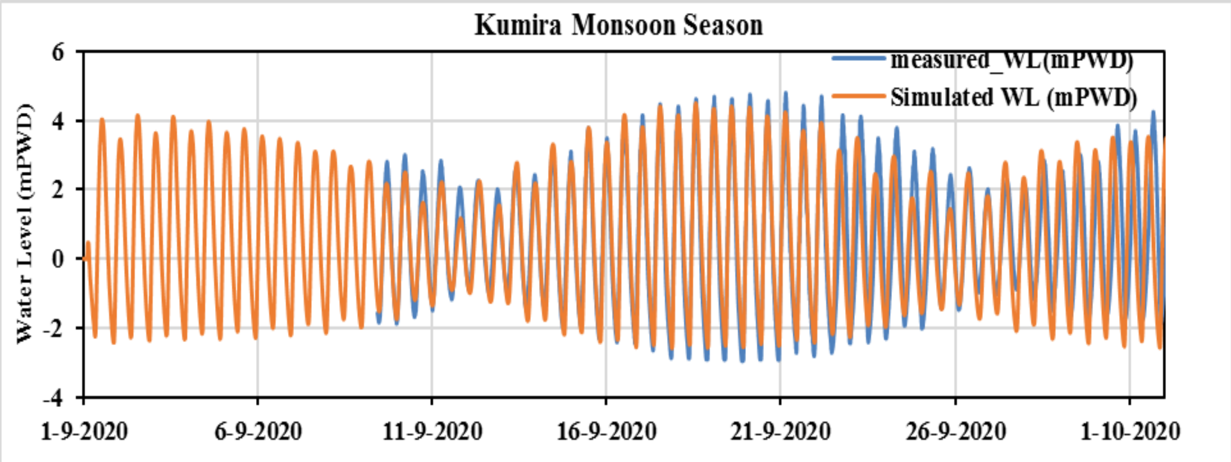


Figure 3.15: Water level calibration at Kumira for monsoon period

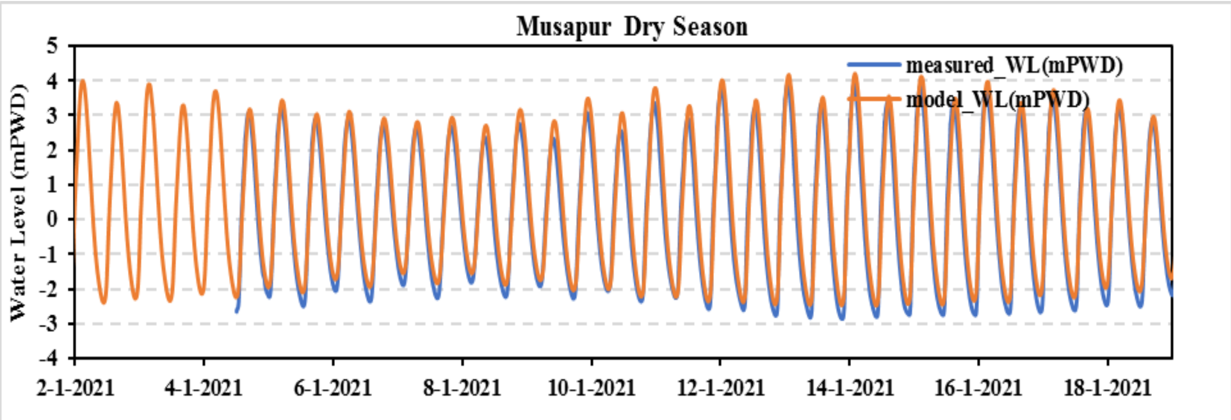


Figure 3.16: Water level calibration at Musapur for dry period

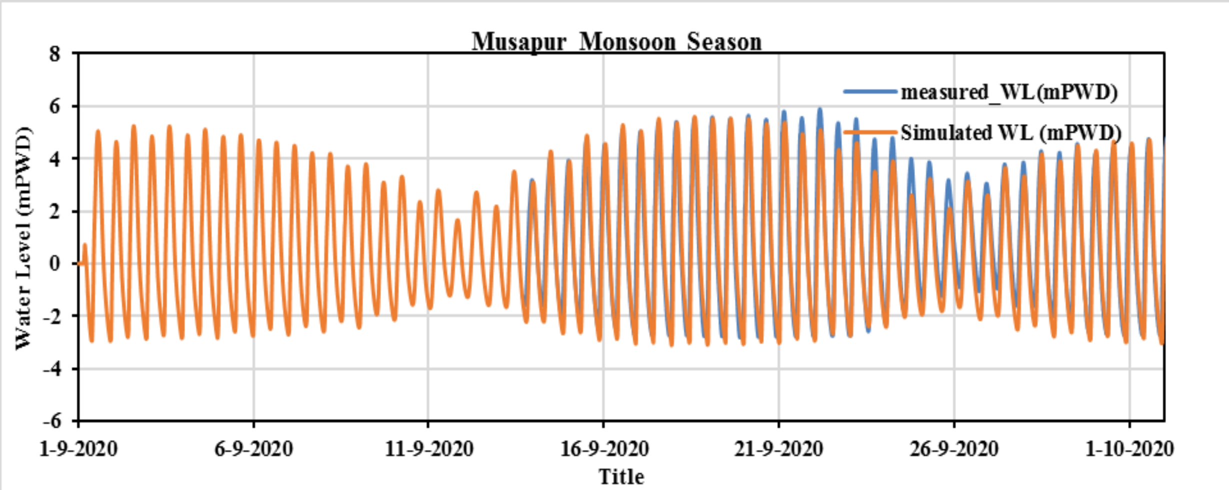


Figure 3.17: Water level calibration at Musapur for monsoon period

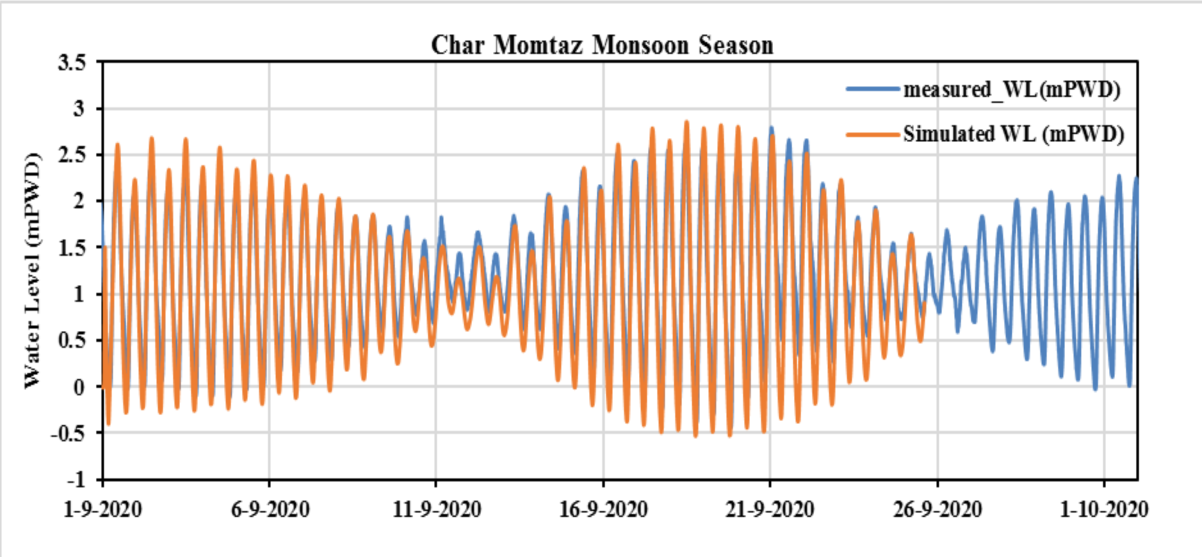


Figure 3.18: Water level calibration at Char Momtaz for monsoon period

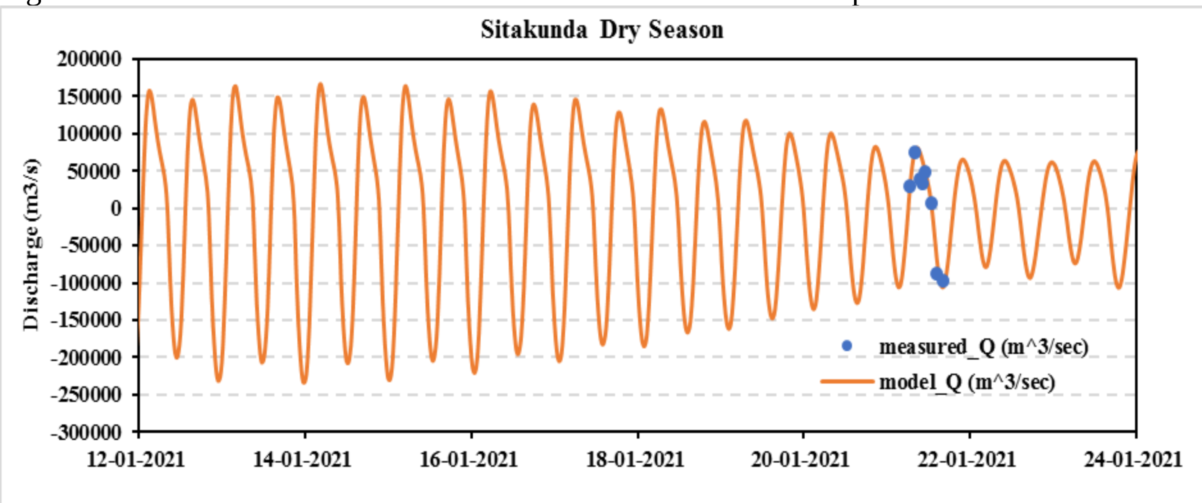


Figure 3.19: Discharge calibration Sandwip Channel at Sitakundu during dry season

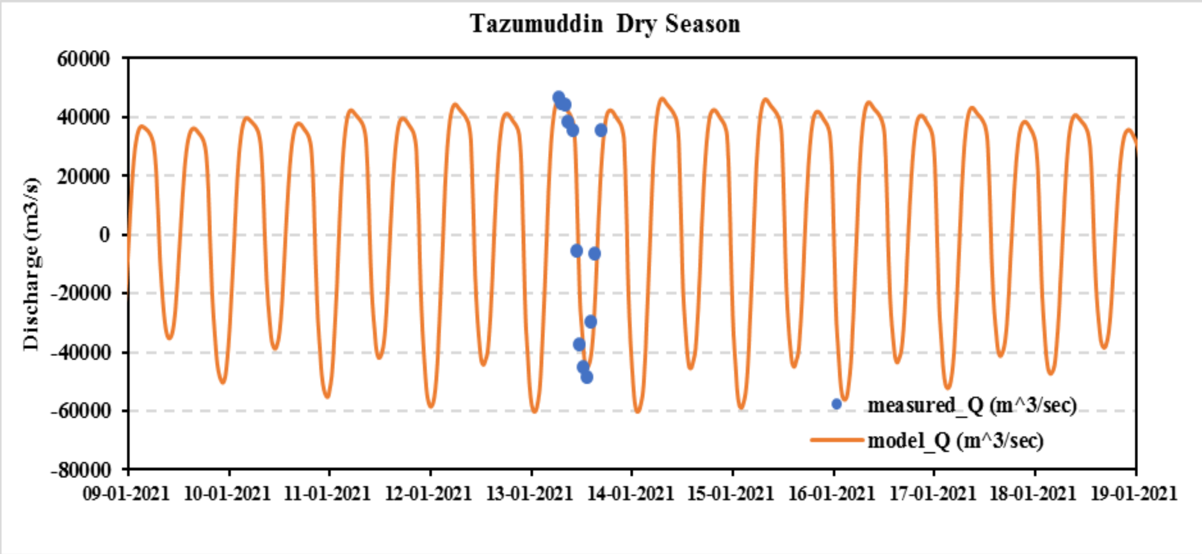


Figure 3.20: Discharge calibration east Shabazpur Channel at Tazumuddin during dry season

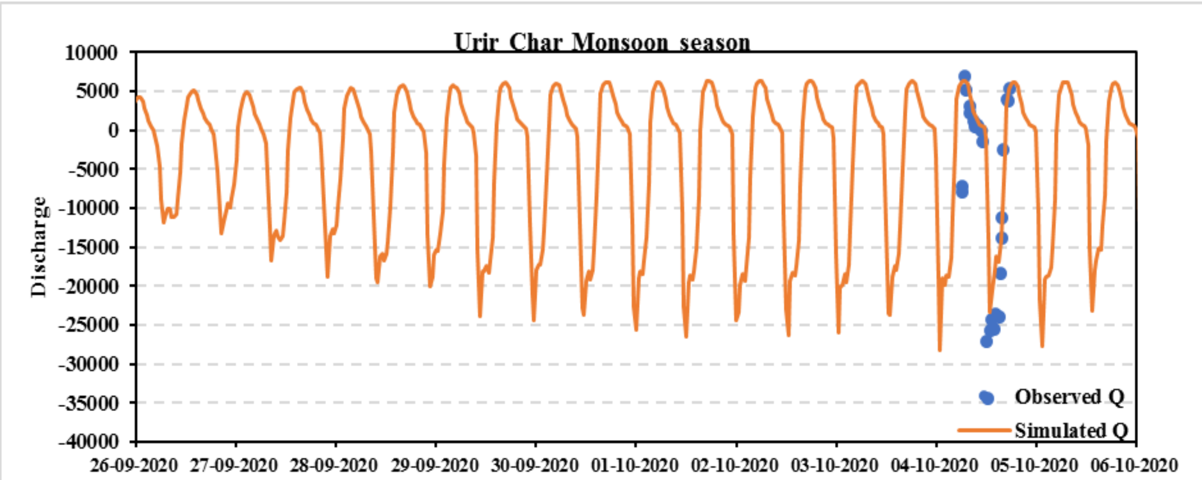


Figure 3.21: Discharge calibration channel between Urir Char & Char Elahi for monsoon period

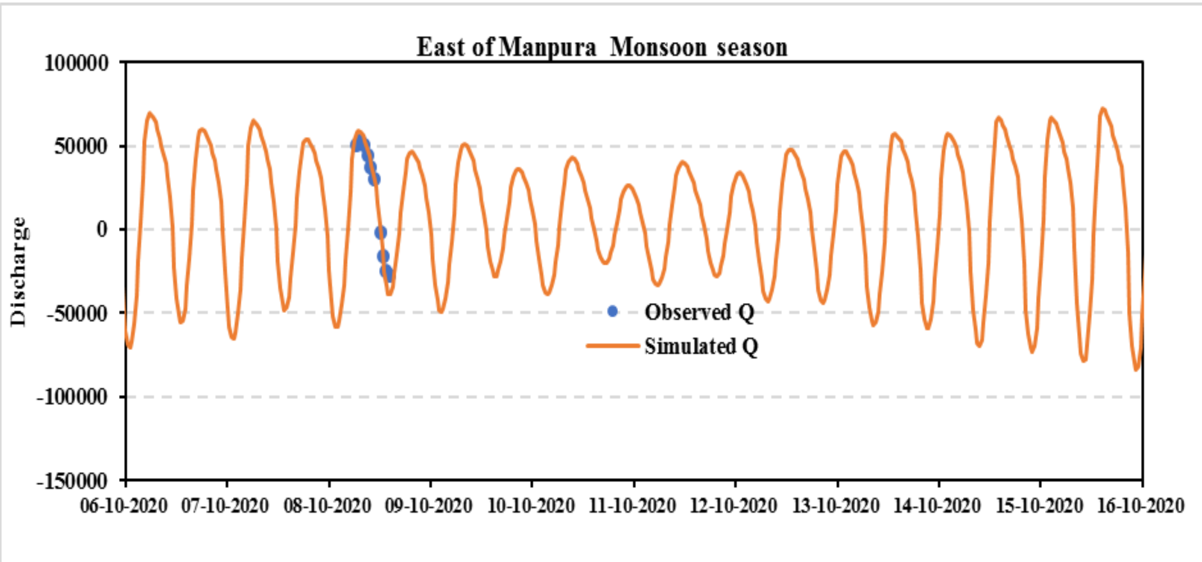


Figure 3.22: Discharge calibration channel between Monpura and Hatiya for monsoon period

Validation for water levels and discharge

The hydrodynamic model of Meghna Estuary Model was validated with the field data collected in 2009 for EDP project (Figure 3.23) during both dry and monsoon season to achieve satisfactory model performance. The water level calibration at Batua and Sandwip West are illustrated in Figure 3.24. The discharge validation at Sandwip Channel and Bhola-Monpura in the West-Shahbazpur Channel during monsoon season are illustrated in Figure 3.25. The water level and discharge validation show good correlation with measured and simulated data.

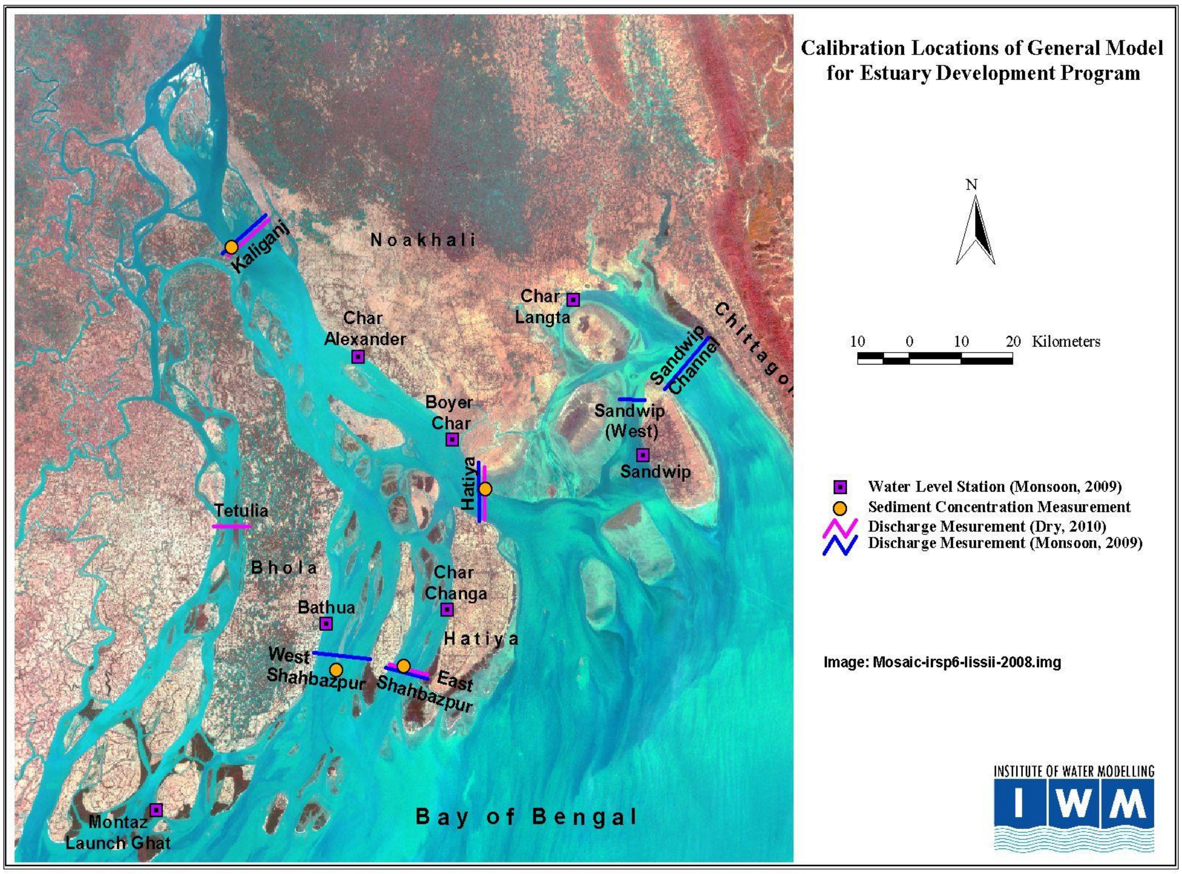


Figure 3.23: Field data collection map of the Estuary Development Program (Source: IWM, 2009-10)

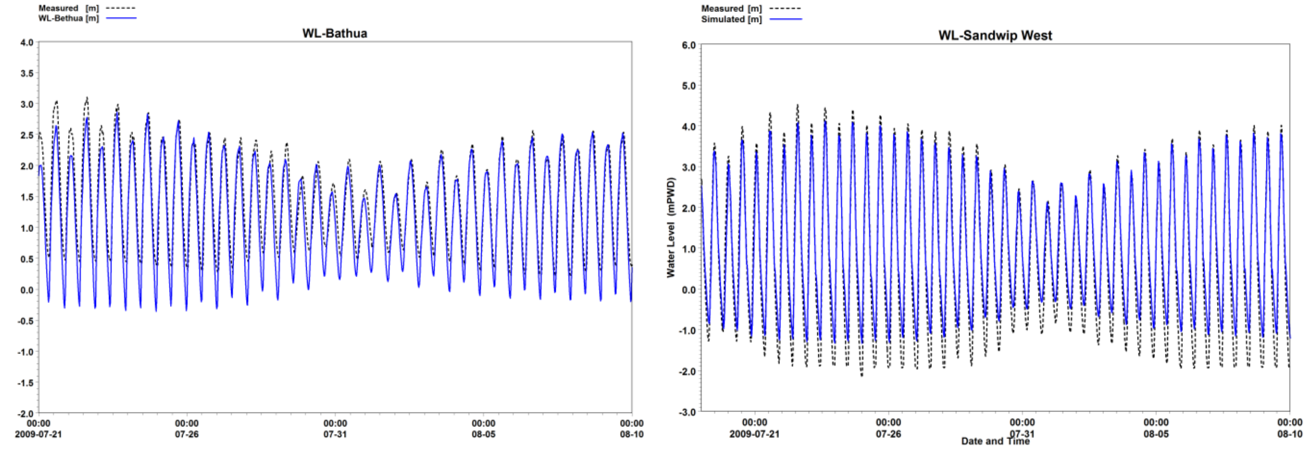


Figure 3.24: Comparison between observed and computed water level at Lower Meghna Estuary during monsoon season

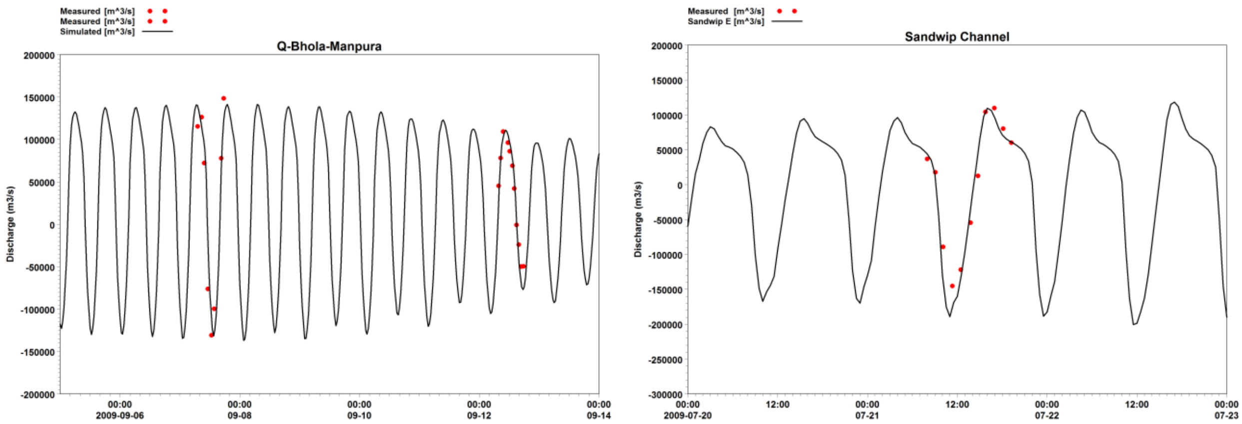


Figure 3.25: Comparison between observed and computed discharge at Lower Meghna Estuary during monsoon season

3.2.2 Morpho dynamic Model

Method

The computational time for simulating a single year of hydrodynamics and morphology with a model such as this is in the order of 12-24 hours on a heavy computational cluster; therefore, 'brute-force' simulations of the morphological evolution over decades would be extremely cumbersome. Therefore, the well-established approach of 'morphological acceleration' or MorFac method (Roelvink 2006, Ranasinghe et al, 2011) has been applied. This works as follows: in Delft3D the model solves hydrodynamics, sediment transport and bed level updating at every timestep; however, the morphological changes are multiplied by the MorFac (the Morphological Acceleration Factor), effectively accelerating the morphological evolution. Thus, after one tidal cycle, the effect on the morphology is as if a number of cycles equal to MorFac had been run. This approach is acceptable as long as the changes within one tidal cycle, even accelerated, are small relative to the water depth.

The tidal cycle can be left unchanged or can be schematized to a single representative tide. However, the yearly discharge curve has a much longer timescale and needs therefore to be treated in a different way. As long as the discharge curve changes slowly, the flow distribution can be considered quasi-stationary. The hydrograph can then be accelerated, or 'squeezed' into a shorter time period, by the same MorFac. Squeezing the yearly hydrograph into two weeks does not fundamentally alter the flow distribution; after these two weeks all flow and transport events of a year have passed by. If now a MorFac of 26 (52 weeks divided by 2) is applied, then after one two-week cycle the morphological evolution of one year will have been simulated at the correct (morphological) speed; one hydrodynamic year with 26 such cycles are thus equivalent to 26 years of morphological change.

Domain and initial bathymetry

The domain and grid for the morpho dynamic model are described in Section 3.1.1. The calibration of the morphological model was initiated with the bathymetry of 2000 as measured in the Meghna Estuary Study (MES). Starting from this dataset, only the areas that were covered by this survey were interpolated to the grid by triangulation. Areas that where land in 2000 were used from national DEM land value.

Hydrodynamic boundary conditions

For the long-term simulations of the period between 2000 and 2009, the boundaries were 'squeezed' in time by a factor of 26, equal to the MorFac; the seasonal variability was represented as a two-week hydrodynamic variation, which in morphological terms represents one year. The following three time series are shown in Figure 3.26: mean discharge, seasonally varying discharge and measured time series. Although there still is a small tidal variation at Baruria, this was neglected in the boundary conditions.

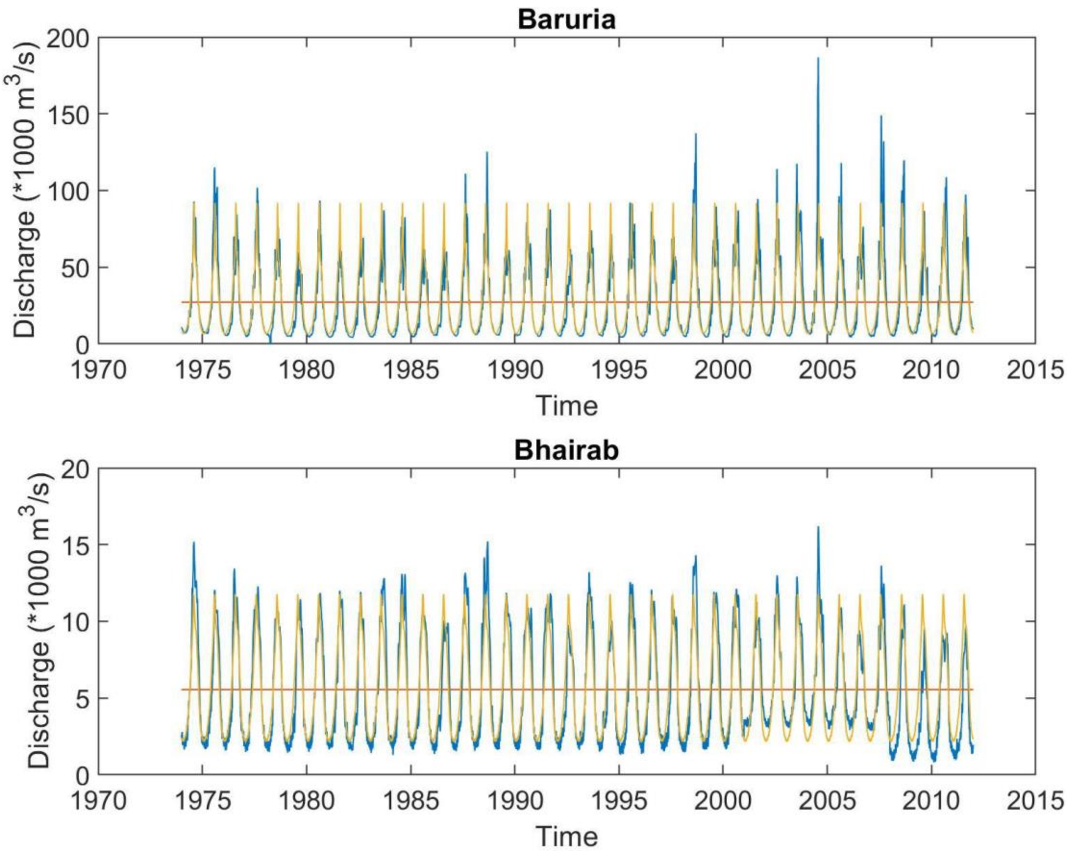


Figure 3.26: Morphodynamics Discharge boundaries of Bhairab Bazar and Baruria (Mean (orange) and seasonally varying (yellow) vs measured (blue))

For the seaward boundaries, a procedure was followed as in Roelvink and Reniers (2012) where the different tidal components were reduced to a limited set of C1 (an artificial component representing the effect of O1 and K1), M2 (enhanced to represent al semi-diurnal components), M4, M6 and M8, the latter three contributing to tidal asymmetry. These components were prescribed in the boundary support points as harmonic constituents with periods of 1490, 745, 372.5, and 186.2 minutes, respectively.

Sediment transport boundary conditions

Based on the previous study and given the wide variation in estimates of the sediment loads, the following simple conditions were taken, where the seasonal variation of the suspended load and wash load concentration was neglected. For both Ganges and Jamuna rivers a constant concentration of 0.9 kg/m3 was assumed, well within the reported range of 0.75-1.25 kg/m^3; for the Meghna at Bhairab Bazar a much lower value of 0.1 kg/m3.

Sediment and Morphological settings

Following the data described in literature, the model includes both finer (mud) and coarser (sand) sediment fractions, each forced by its own sediment transport formula. Mud transport will dominate suspended sediment concentrations, so that mud sediment settings play a major role in the calibration of concentrations and transports. The Krone-Partheniades transport formula describes the erosion and deposition of mud, while an advection-diffusion equation transports the mud (Krone 1962, 1993; Ariathurai 1974).

Values for the different parameters applied in the standard settings of current study are taken from previous model which was developed under the LTRAM (Long-term Research, Analysis and Monitoring) project of CEIP-1. For the bed and suspended transport of non-cohesive sediment, Van Rijn et al. (2000) is followed as described in the D-morphology user manual (Deltares, 2020). However, we consider the dry cell erosion which allow the bank erosion and char movement which was not considered in the previous study. The principle of the 'dry cell erosion' mechanism is explained in Lesser et al (2004). Where there is erosion next to a dry cell, a fraction thetSD of that volume is not eroded locally but taken from the adjacent dry cells, which would otherwise be fixed. This simple mechanism greatly improves the dynamic behavior of shallow shoals and channels, but also allows for retreat of banks. Table 3.2 shows the morphological setting for simulation.

Table 3.2: Overview of morphological parameters current model

[Morphology]			
MorFac	26	[-]	Morphological scale factor
MorStt	86400	[s]	S pin-up interval from TStart till start of morphological changes (2 d)
Thresh	0.05	[m]	Threshold sediment thickness for transport and erosion reduction
MorUpd	true	[-]	Update bathymetry during FLOW simulation
NeuBCMud	false	[-]	Neumann condition for upstream mud boundary
NeuBCSand	true	[-]	Neumann condition for upstream sand boundary
AksFac	1	[-]	van Rijn's reference height = AksFac* ks
AlfaBs	1	[-]	Streamwise bed gradient factor for bed load transport
AlfaBn	100	[-]	Transverse bed gradient factor for bed load transport
Sus	1	[-]	Multiplication factor for suspended sediment reference concentration
Bed	1	[-]	Multiplication factor for bed-load transport vector magnitude
SusW	0	[-]	Wave-related suspended sed. transport factor
BedW	0	[-]	Wave-related bed load sed. transport factor
SedThr	0.2	[m]	Minimum water depth for sediment computations
ThetSD	1	[-]	Factor for erosion of adjacent dry cells
Wetslope	0.02	[-]	Threshold bed slope for avalanching
[Underlayer]			
IUnderLyr	2	[-]	Flag for underlayer concept 1 = one well mixed layer 2 = multiple layers
ExchLyr	false	[-]	True/false separate exchange layer
TTLForm	1	[-]	Transport layer thickness formulation
ThTrLyr	0.25	[m]	Thickness of the transport layer
MxNULyr	2	[-]	Number of underlayers (excluding final well mixed layer)
ThUnLyr	0.25	[m]	Thickness of each underlayer

Calibration

The observed and computed sedimentation-erosion patterns are shown in Figure 3.27. First, the general trend in the observations is one of accretion, which the simulations with both settings largely follow. The Tetulia river on the left is strongly accretive in the observations and similarly, in the model. The area around Sandwip Island is strongly accretive in both observations and model during 2000-09. The erosion of land areas is taking place in the model, due to the inclusion the dry cell erosion e.g. in the north of Hatiya island erosion well reproduce.

The volumetric analysis for the model was based on observed differences between the 2000 and 2009 bathymetries. Figure 3.28 shows the volumetric change quantity in seven blocks from EDP project and modelled calculated volume change. Table 3.3 shows the quantitative comparison with each block volume change with observed. Figure 3.29 shows the quality indices of the model performance. Overall, the trends of the model result are quite acceptable, with a correlation of 0.98 and a slope of 1.46 for the net sedimentation.

Table 3.3: Observed and modelled volumetric changes

	Observed volume change (Mm3)			Modelled volume change (Mm3)		
	Neg.	**Pos.**	**Net.**	**Neg.**	**Pos.**	**Net.**
1	-1467	892	-574	-2323	1269	-1054
2	-2050	1908	-142	-3334	2440	-894
3	-1408	1941	533	-1841	2719	878
4	-366	1594	1228	-933	3254	2321
5	-547	1492	944	-1833	3230	1397
6	-672	1138	465	-1359	2394	1035
7	-139	444	305	-454	799	345
Total	-6649	9409	2759	-12076	16104	4028

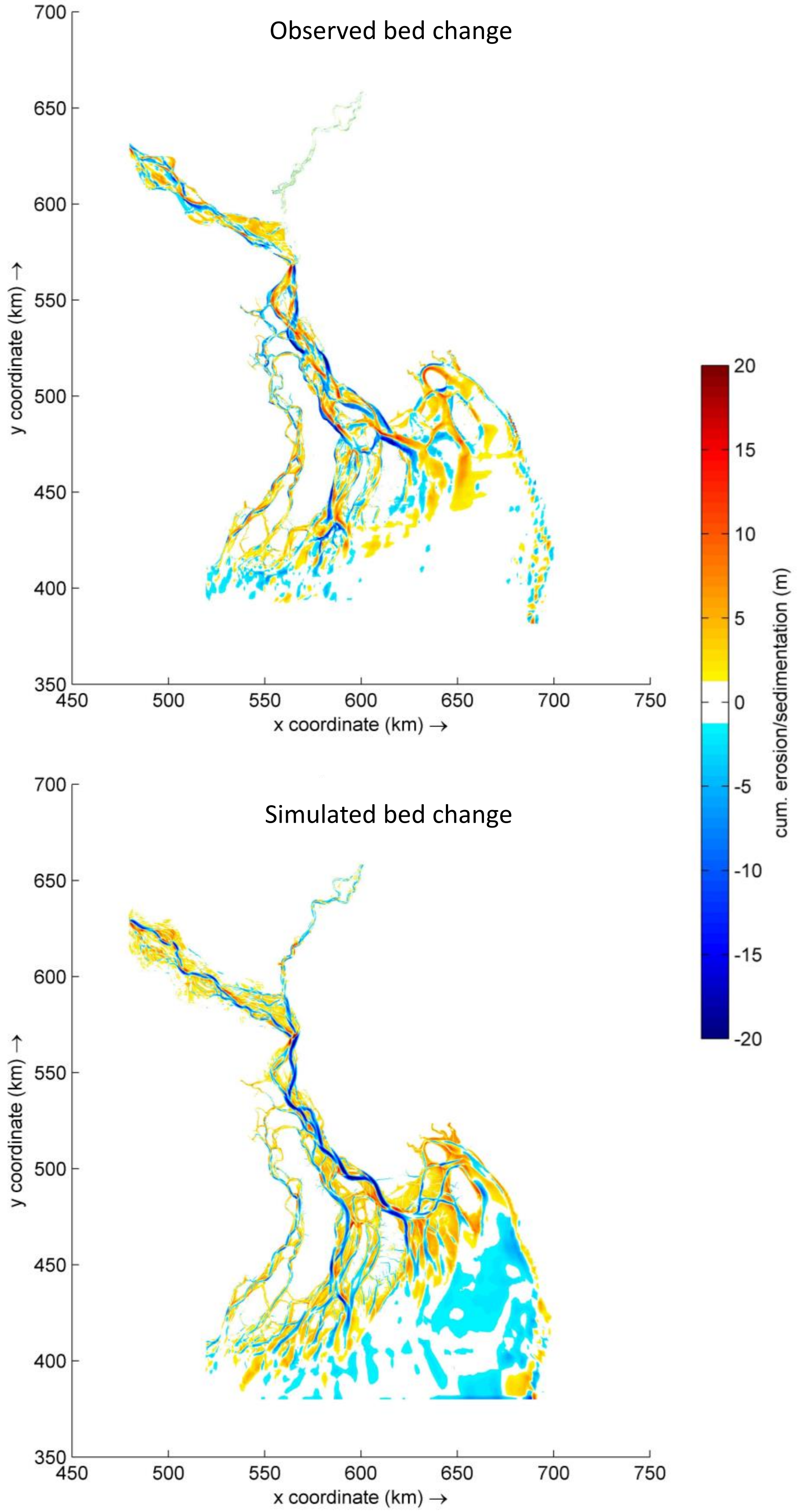


Figure 3.27: Observed (upper panel) and simulated (bottom panel) bed level changes, 2000-2009.

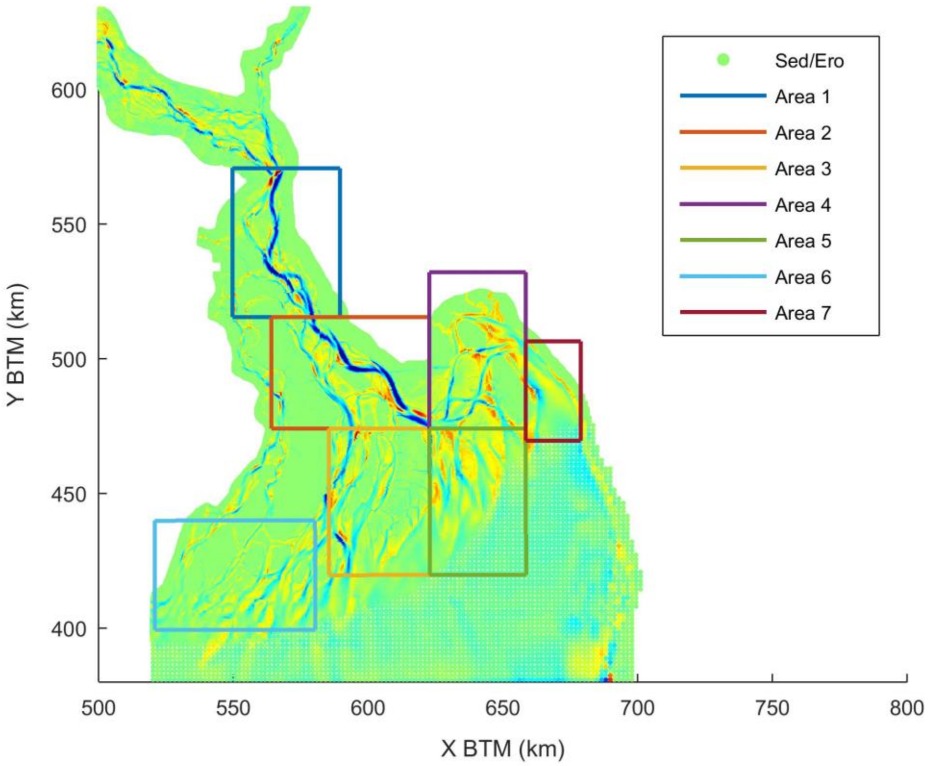
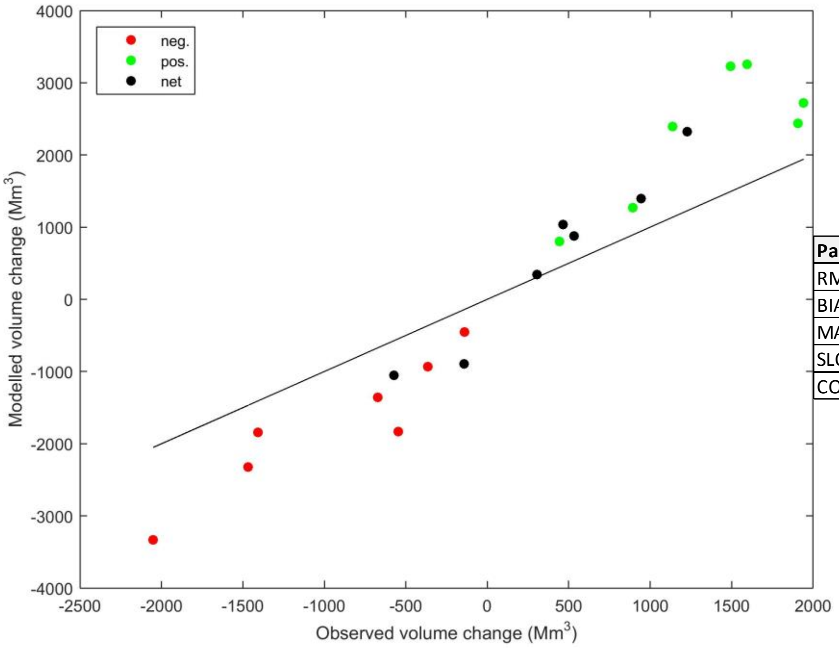


Figure 3.28: Sedimentation/erosion pattern over period 2000-2009 in lower Meghna area, and volume balance areas applied in EDP study (2009)



Parameter	Neg.	Pos	Net
RMSE	389	592	634
BIAS	-775	956	181
MAE	775	956	533
SLOPE	1.82	1.71	1.46
CORR	0.93	0.81	0.98

Figure 3.29: Computed vs. observed erosion (red), sedimentation (green) and net volume change (black), 2000-2009 with error matrix (table in the right panel).

3.3 Hydro-Morphological Assessment from Numerical Model

3.3.1 Phase lag of water level from measured and model

Tidal waves approaching the coastal belt and coastal islands of Bangladesh are affected at least by four factors causing amplification and deformation of the waves. They are the Coriolis acceleration, the width of the transitional continental shelf, the coastal geometry (e.g., the funnelling shape of coastline around north of Sandwip island) and the frictional effects due to fresh water flow and bottom topography.

The tide originates in the Indian Ocean and propagates faster along the eastern side than along the western side of the Bay of Bengal. In general, the tidal range decreases gradually going from east to west in the estuary. The tidal range at Musapur (eastern coast) is higher than that at Rabnabad (western coast) partly due to the changes in the transitional shelf width and partly due to Coriolis acceleration which provides higher tidal ranges along the eastern coast than along the western coast. LRP study (Barua and Koch, 1987) shows that the mean tidal range increases up to Sandwip (amplification) after which it gradually gets damped up the estuary along the west Hatia and Shahbazpur channels towards the Lower Meghna River with friction from river flow and bed topography. Measured data shows that the recorded maximum tidal range was 8.5 m during a spring tide during monsoon at Musapur (Western coast). In the present study, the tidal phase difference for eastern and western coast was compared between measured and numerical modelled data. Figure 3.30 and Figure 3.31 show the comparison of computed phase lag water level for eastern and southern coast.

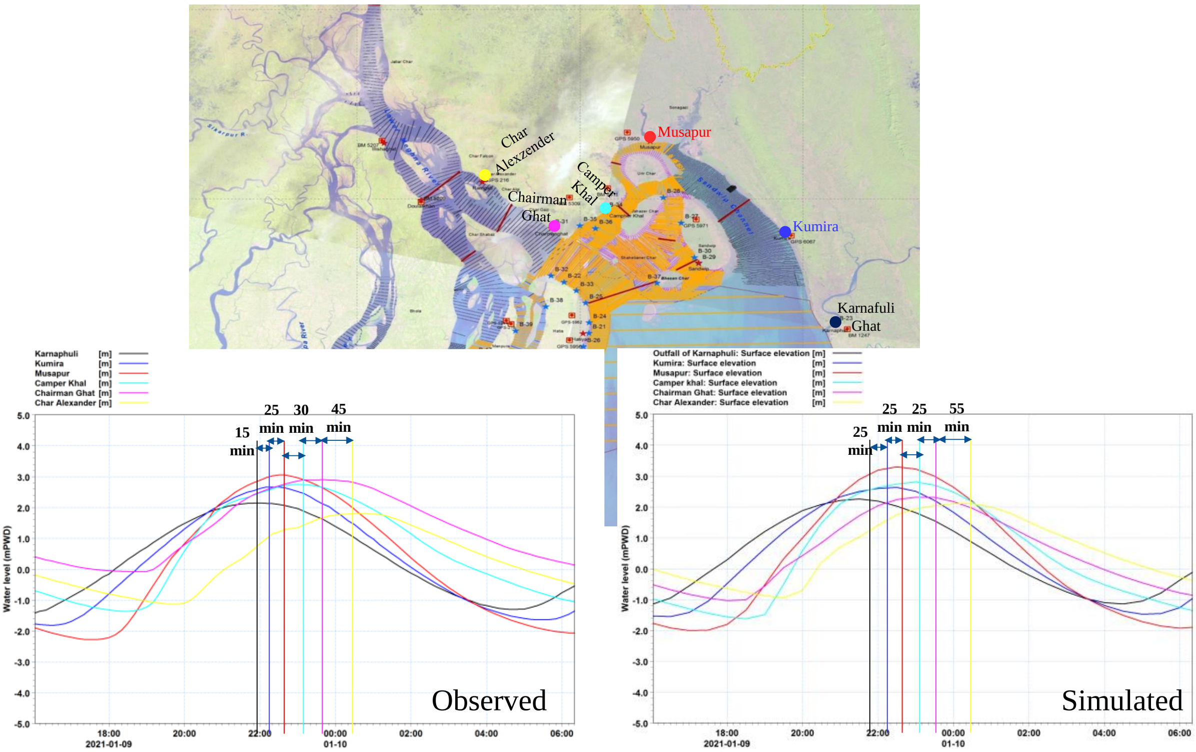


Figure 3.30: Tidal phase lag of water level in the eastern coast

In the eastern coast, tide moves Karnafully to Kumira (distance about 32 Km) station very fast due to higher depth of the Sandwip channel and it takes only 15 min. However, model result shows 10 min lag to the measured tide between these two stations. Then the tide become slow down to reach the Musapur station due to funnel shape of coastline and frictional effect. Model results shows same period of time to reach the tide from Kumira to Musapur (distance about 48 Km). Similarly other stations phase lag of water well captured in the present model.

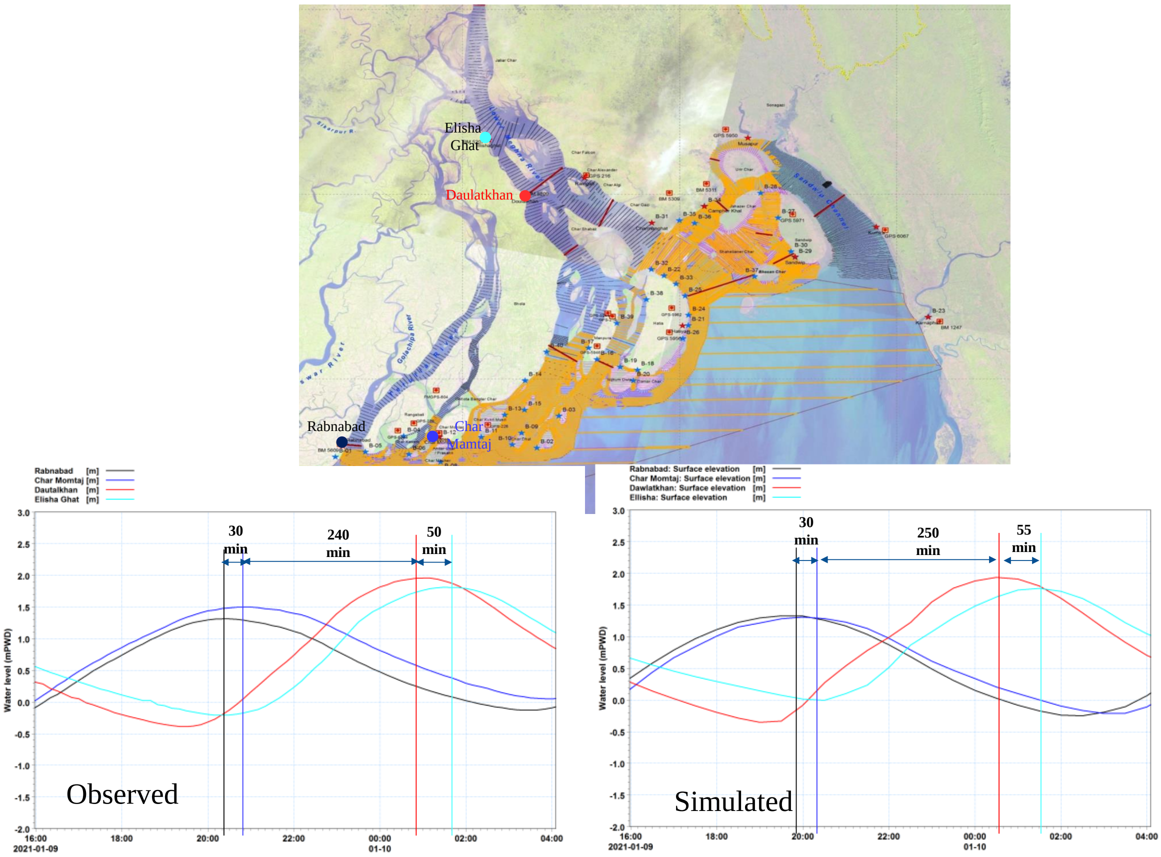


Figure 3.31: Tidal phase lag of water level in the western coast

On the other hand, in the western coast, tide travel from Rabnabad to Char Montaz station (distance about 31 Km) is about 30 min and model shows similar pattern. This area is very sallow and lots of island is situated in this area. Then the tide moves from Char Momtaz to Daulatkhan (distance about 104 Km) and the travel time is about 4 hours. Model has 10 min lag of water level. Overall model well reproduces the phase lag of water level for eastern and western coast in Meghna estuary.

3.3.2 Net flow distribution in different channel

The net flow distribution through the different channel in the Meghna Estuary is calculated using hydrodynamic model results. The net flow distribution in 14 days covering neap and spring tide is calculated for both dry and monsoon season. Dry season distribution is based on January 2021 and August 2020, which present the monsoon season distribution for this study. Flow distributions in monsoon around the study area are shown Figure 3.32.

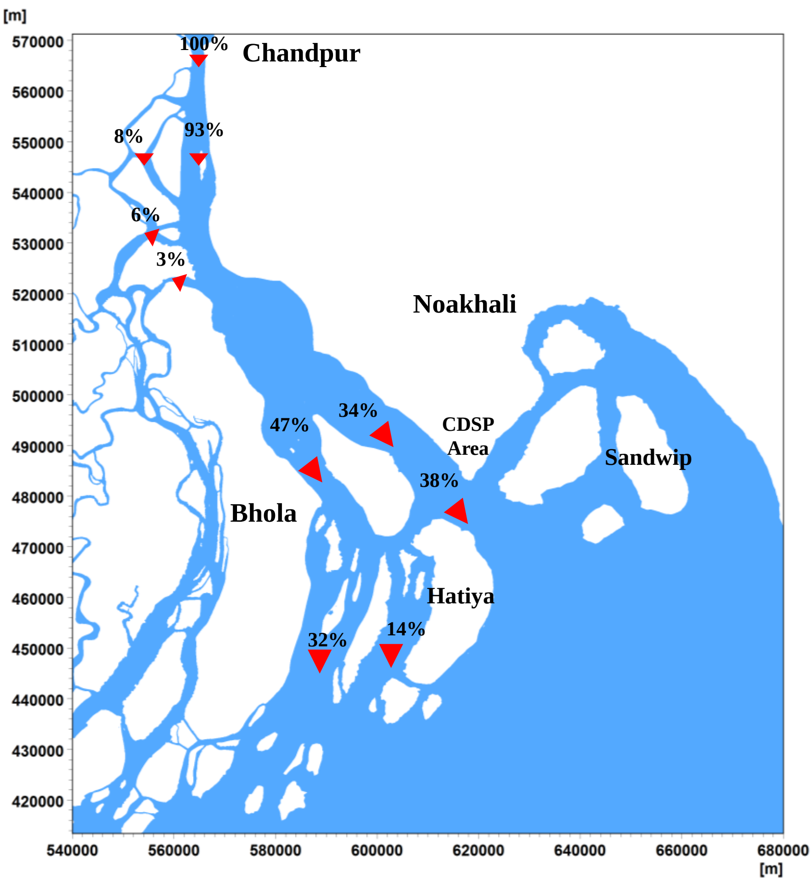


Figure 3.32: Net flow distribution in % of flow at Chandpur during monsoon season

The flow distribution near Char Bhairabi is 8% and 93% through west and east Lower Meghna River near Chandpur. The flow through Tentulia river and channel near Hijla are 3% and 6% respectively. The remaining flow distributed as 47% in the West and 34% in the east Shabazpur Channel near Char Gazaria. This flow is again distributed through three channels, 38% in Hatiya Channel,14% in East Shabazpur Channel and 32% in West Shabazpur Channel.

3.3.3 Statistical analysis on water level, current speed

Water Level

The 2-D maps of maximum water levels in Sandwip-Urirchar-Noakhali area for base condition during monsoon and dry period are shown in Figure 3.33 and Figure 3.34. The statistical maximum water level shows higher in monsoon due to seasonal variation. East and west coasts of Sandwip island in the Sandwip and Hatia channels show that some reflection of the tidal wave occurs contributing to the increase of tidal range around the northeast and northwest of Sandwip and Urirchar area.

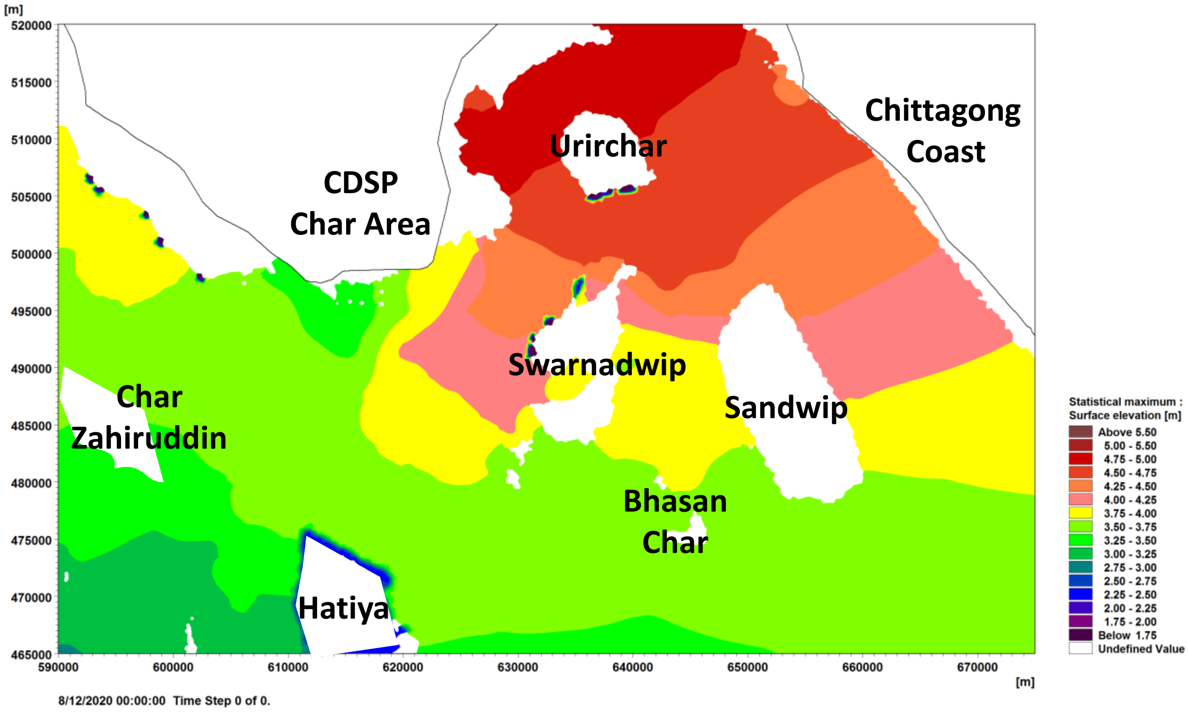


Figure 3.33: Statistical maximum surface elevation during monsoon season

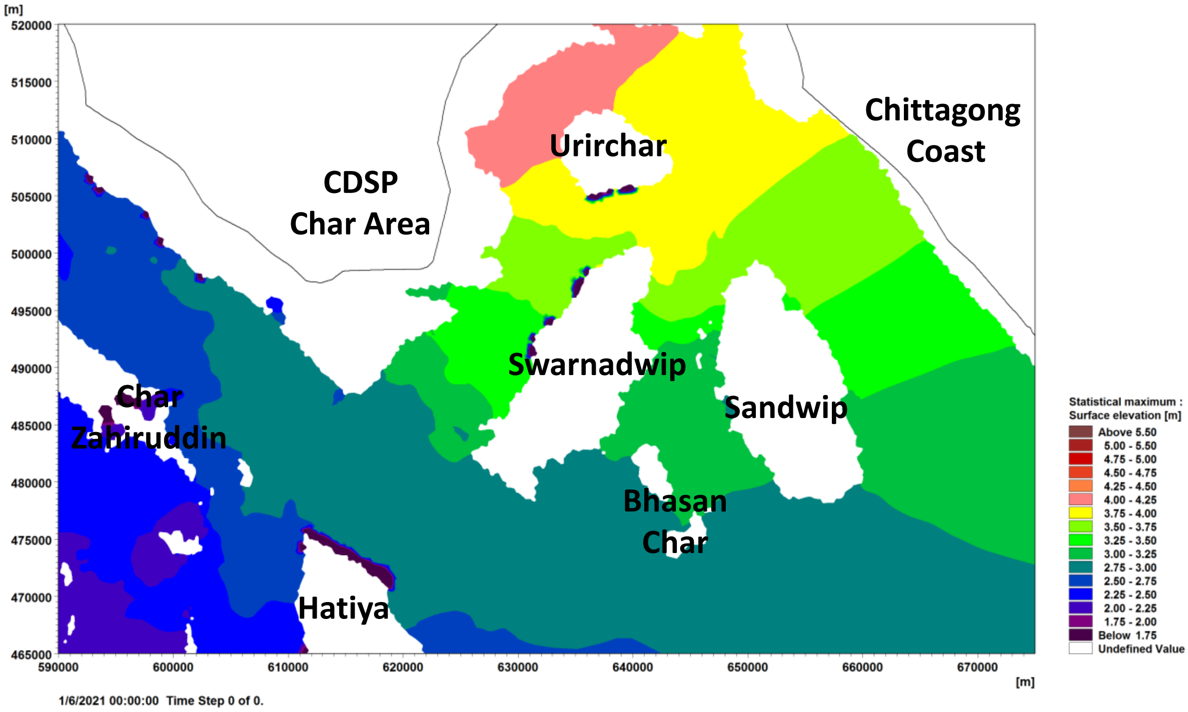


Figure 3.34: Statistical maximum surface elevation during dry season

Current Speed

The 2-D maps of maximum current speed in Sandwip-Urirchar-Noakhali area for base condition during monsoon and dry period are shown in Figure 3.35 and Figure 3.36. During dry season upland freshwater flow into the Bay through the Lower Meghna River is very much lower than that of monsoon season. Tidal action becomes stronger and dominates water flow pattern in the estuary. The maximum depth average current speeds of about 2 to 3 m/s are found mainly in the west and east Shabhazpur channel, north Hatiya channel, near south of Noler char and Char Nagulia, west Monpura channel, west of Swarnadwip (channel between Urirchar and Swarnadwip) and north of Urirchar during monsoon. In the dry season, velocity reduced most of the locations except south of Noler char and Char Nagulia, west Monpura channel, west of Swarnadwip (channel between Urirchar and Swarnadwip) and north of Urirchar.

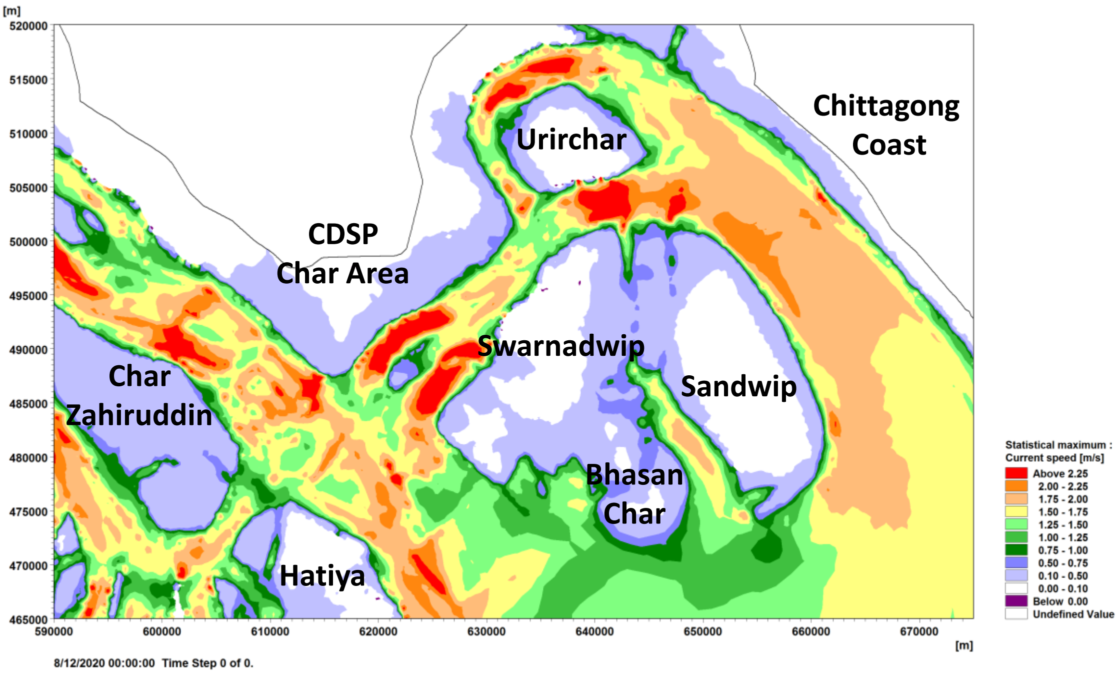


Figure 3.35: Statistical current speed during monsoon season

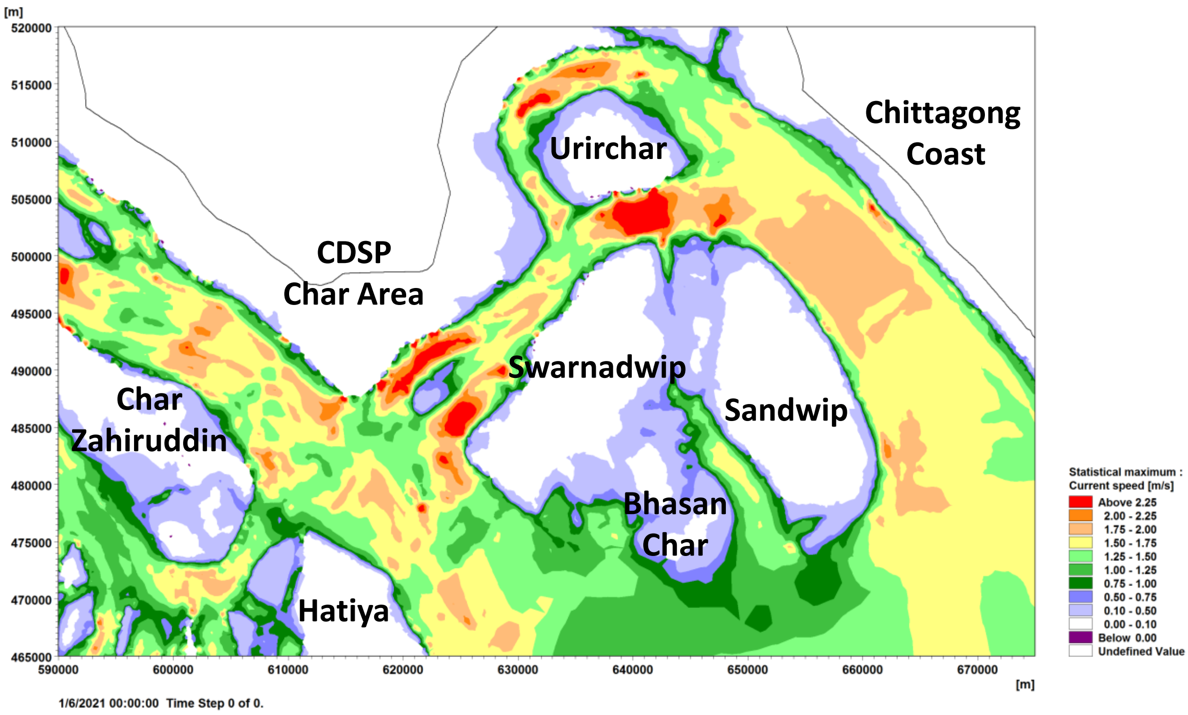


Figure 3.36: Statistical current speed during dry season

3.3.4 Residual flow

The residual flow has been established based on the simulation results of one month covering spring and neap tides both for dry and monsoon season. Simulation result shows a net water flow out of the Meghna estuary through West Shabhazpur channel and easterly flow outside the estuary during monsoon season. A prominent anti-clockwise circulation is prevailing around the Sandwip Island, which is mainly forced by tide. In the Sandwip channel, the residual anti-clockwise circulation during monsoon is similar to the circulation during dry season, **which implies the area is dominated by tide both in dry and monsoon seasons**. The net anti-clockwise circulation traps the sediment in this area. The net flow in between Sandwip and Hatia Island is influenced by the river discharge during monsoon season. The residual flow and mean current speed are shown in Figure 3.37 and Figure 3.38 for wet and dry season respectively.

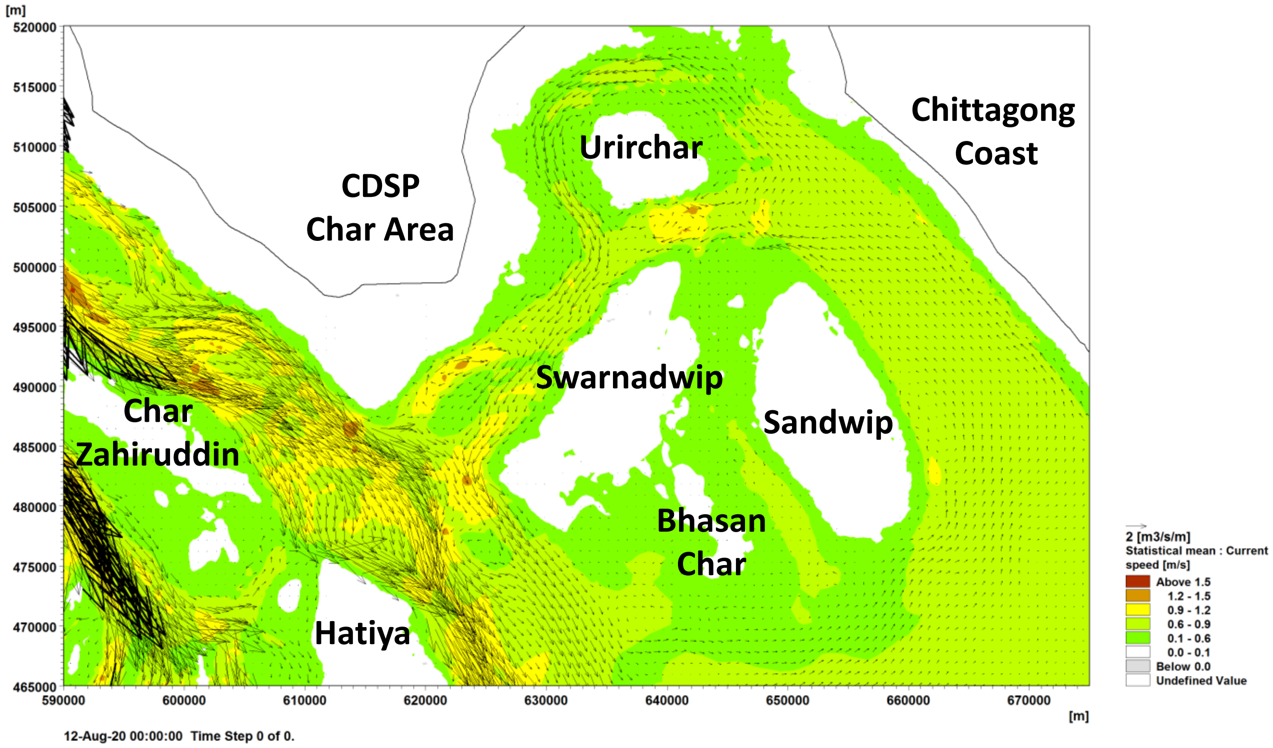


Figure 3.37: Residual Flow Pattern in the (part of) Meghna Estuary in Monsoon season (August, 2020)

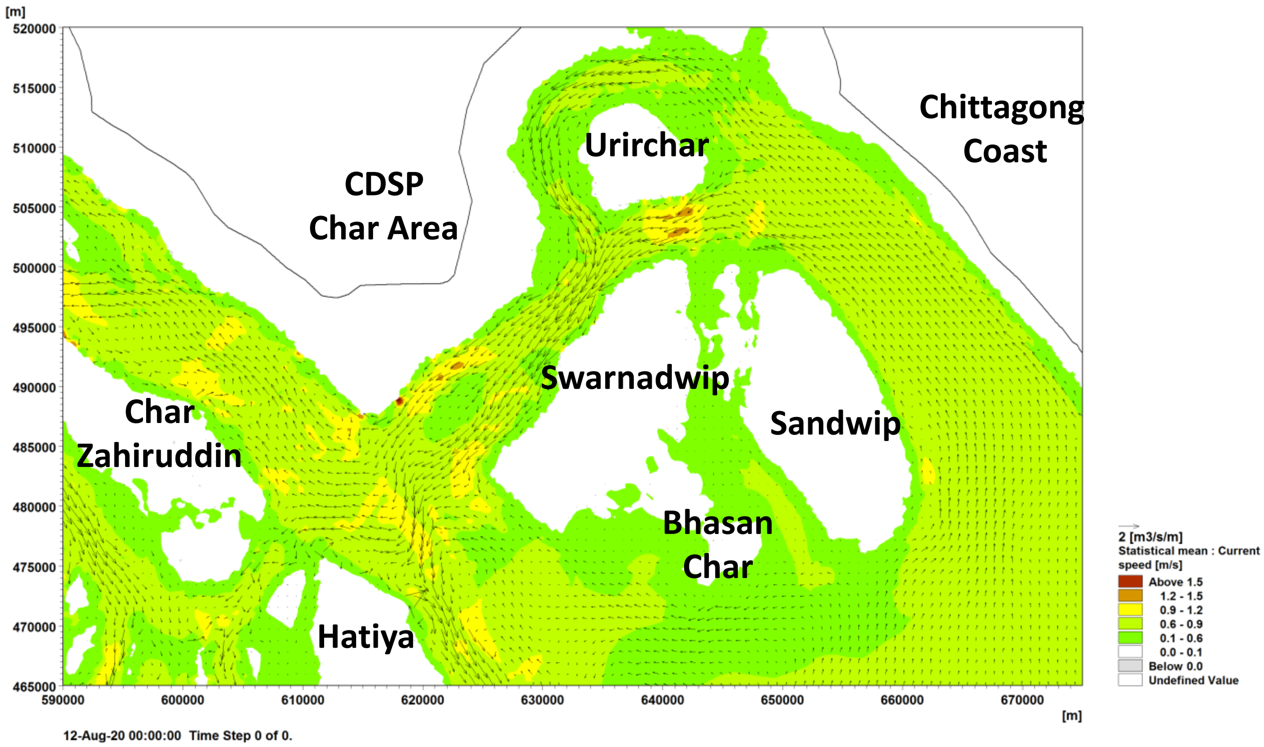


Figure 3.38: Residual Flow Pattern in the (part of) Meghna Estuary in Dry season (January, 2021)

3.3.5 Morphological Assessment from Numerical model

20-year morphological model simulation results with 26 MorFac is given in Figure 3.39 mainly focused near the CDSP area. A dominant channel has been formed along the south of Noler Char and Char Nagulia. **This area will experience huge erosion problem and after 20 year, Noler Char will be totally vanished if no measures is taken.** In real situation, this area experienced huge erosion problem for last decade and rate of erosion is very high which is very much similar to the model result. Model analysis shows north Hatiya channel is also gaining. Also from different measurement it has been found the depth of North Hatiya channel has been increased day by day. The bed level evolution has also located the deposition prone area.

Sedimentation mainly occurs at north- east side of Meghna Estuary, Sandwip-UrirChar-Jahazer Char area. Around Jahazer Char, sedimentation is more. Also a channel has been developed along the west side of Jahazer Char. Shandwip Channel experiences some erosion. At the north of Sandwip and Jahazer Char, where tidal meeting point exists, sedimentation occurs and the continuity of the channel along the west side of Sandwip Island disrupts. Two Islands are being developed at the south-west side of Sandwip Island.

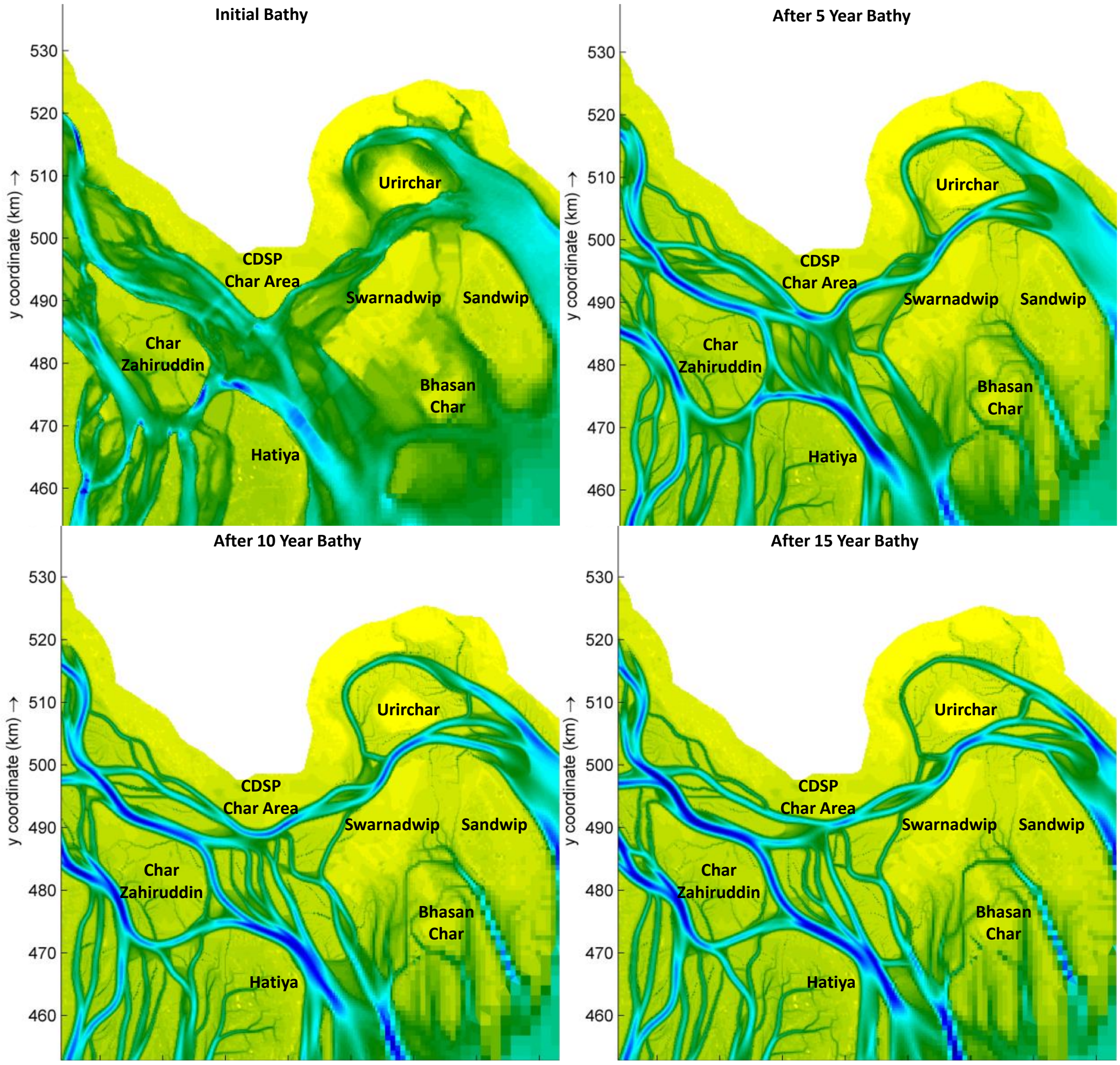


Figure 3.39: Morphological evaluation after 5,10, 15 and 20 years from present near CDSP area

4. ASSESSMENT OF HIGH, MEDIUM AND LOW RISK AREA OF MEGHNA ESTUARY

4.1 Assessment of Risk for Erosion

Assessment of the areas at low, medium & high risk and stable areas around the existing CDPS areas for relocating infrastructures eroded/at threat and in the whole Meghna Estuary for identification/selection of the Chars for potential development, considering erosion and storm surge vulnerability.

In this study, causes of erosion as well as the vulnerable locations of the Meghna Estuary area has been investigated based on the analysis of the simulation results of hydrodynamic, sediment transport and wave models, the measured data and the historical satellite imageries. Analysis of model results provided current seabed scour and sedimentation pattern. High current speed and scouring depth determines the erosion vulnerable area. Figure 3.5 shows the erosion/deposition pattern during the last decade which illustrated the existing erosion vulnerable area in Meghna Estuary. There are huge erosion at the left bank of east Shabazpur channel near Lakkhipur and Noakhali. At Ramgoti area the average erosion rate is 150m/year for the last ten years. This area is high risk zone. At the left bank of Tentulia river from Mehendiganj to Charfession the erosion rate is 10 to 30 m/year for the last five years. In CDSP IV area , at Noler char erosion rate is high and is about 756m/year and total erosded area is 4.97 km2. Caring char erosded area is 60.78 km2. At char Nangulia erosion rate is less compared to Caring and Noler char. At Noler char average erosion rate is 50m/year and at Char Nangulia it is 175m/years from 2010 to 2020. There are huge erosion at the northern part of Hatia Island and it is about 95m/year, Northern part of Monpura and Char Jahir Uddin are also erosion vurnerable. Both southern and northern part of Dhal Char are eroded and some erosion are found at Char Kukri mukri also. The western side of Andhar Char is also erosed is shown in Figure 4.1.

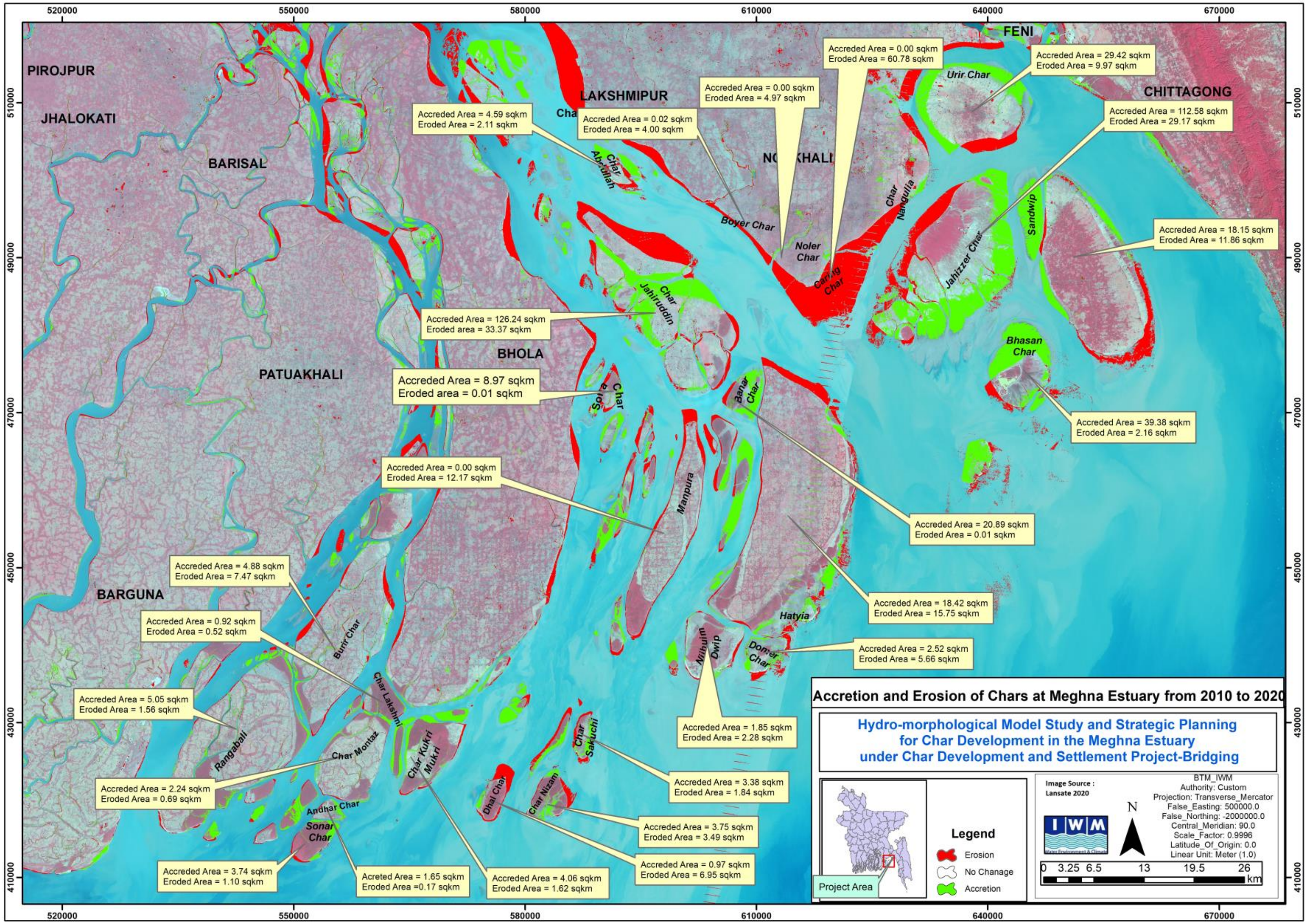


Figure 4.1: Erosion-Sedimentation Map in the Meghna Estuary for the Last 10 years (2010~2020)

The bathymetry/hydrographic data, surveyed in 2009 and 2020 under the present study, have been analysed to locate the thalweg lines of the river and presence of any scour holes near the CDSP IV area in order to assess erosion vulnerability of riverbank near the potential sites for regulator. It is found from Figure 3.9 that the thalweg line shifted to the left bank of the Lower Meghna River near Char Munshi. At Char Munshi thalweg line shifted around 4.5 km and at Caring and Noler Char it is around 7 km. It is found from this figure that the Thalweg line moves to the CDSP IV area, char Nangulia and Boyer char which indicates that these are vulnerable to erosion.

Bed level difference map of the year 2009 to 2020 which also indicate erosion tendency near Char Nangulia, Caring char and Urir char and the scour hole depth is almost 11m to 17m (Red circle zone) shown in previous chapter 3, Figure 3.10. It is also seen that the Caring Char is almost diminished in this period. Therefore, this is the most critical part of Meghna Estuary.

Sedimentation mainly occurs at north- east side of Meghna Estuary, Sandwip-UrirChar-Jahazer Char area. Around Jahazer Char, sedimentation is more. Also, a channel has been developed along the west side of Jahazer Char. Shandwip Channel experiences some erosion. At the north of Sandwip and Jahazer Char, where tidal meeting point exists, sedimentation occurs and the continuity of the channel along the west side of Sandwip Island disrupts. Two Islands are being merged at the south-west side of Sandwip Island.

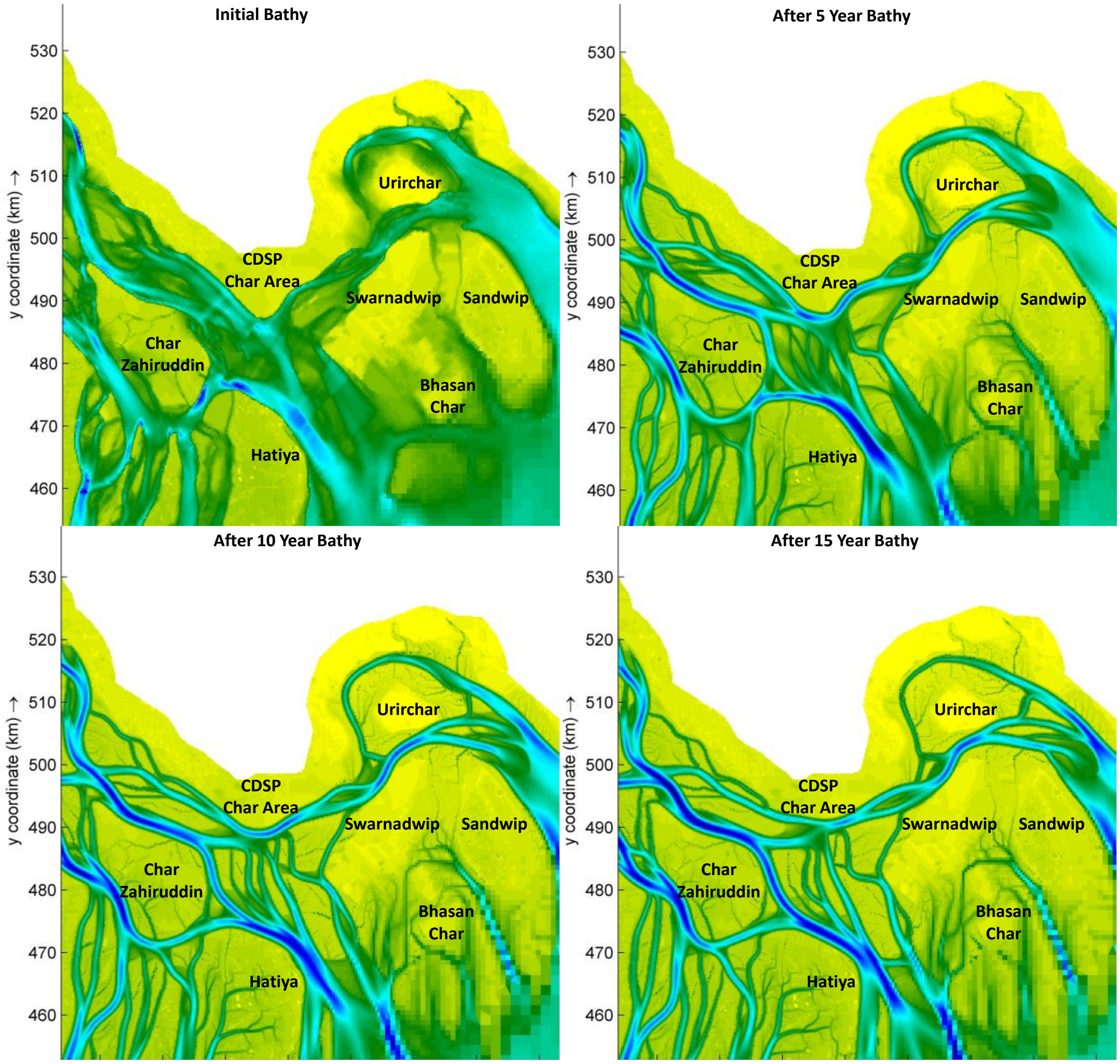


Figure 4.2: Morphological evaluation after 5,10, 15 and 20 years from present near CDSP area

4.2 Assessment of Risk for Storm Surge

Storm surge vulnerable risk area

The climate and topography of Meghna Estuary area creates an environment where local communities are exposed to multiple natural hazards, and experience recurring extreme weather events. The study area is vulnerable to cyclonic storm surges, with the propensity to damage infrastructures, agriculture and aquaculture. The frequency and intensity of cyclone induced storm surges are likely to increase in the changing climate; exacerbated by a rising mean sea level; consequently, the risk of associated Hazards is quite high. The tracks of severe cyclones from 1960 to 2016 are shown in **Figure 4.3.** This figure clearly illustrates that the Meghna Estuary area is vulnerable to cyclone and surge attack.

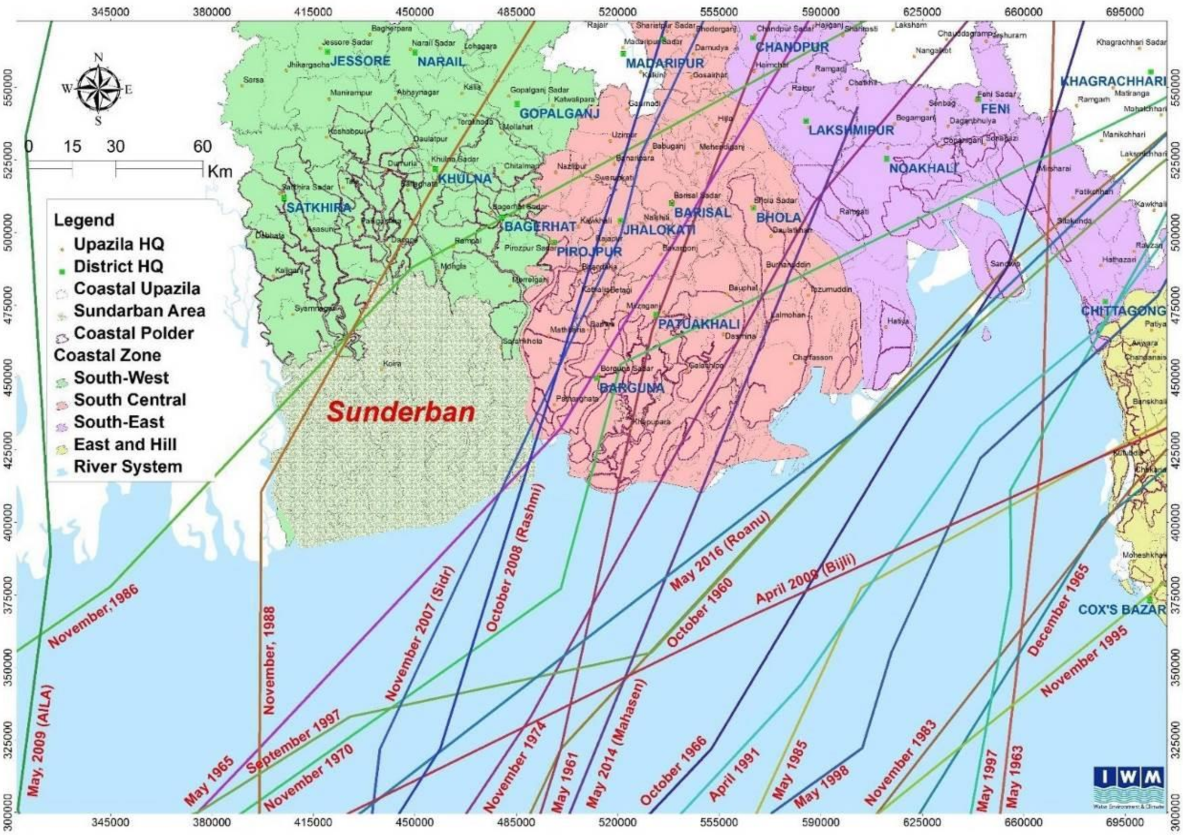


Figure 4.3: Tracks of 19 severe cyclones from 1960-2016

IWM has the existing storm surge model which is the combination of a cyclone and hydrodynamic model based on Bay of Bengal (BoB) Model. For simulating the storm surge and associated flooding, Bay of Bengal model based on MIKE21FM hydrodynamic modelling system has been further developed. In the hydrodynamic model simulations meteorological forcing due to cyclone has been given by applying wind and pressure fields derived from the analytical cyclone model. **Figure 4.4** shows a storm surge risk map for whole Bay of Bengal area for the period 1960-2009. In this study, this model is updated with recent data and include the different climate scenarios to derive new risk map for cyclonic storm surge in the Meghna Estuary. Storm surge induced inundations by the past cyclones are provided essential data for developing zoning map of different risk area.

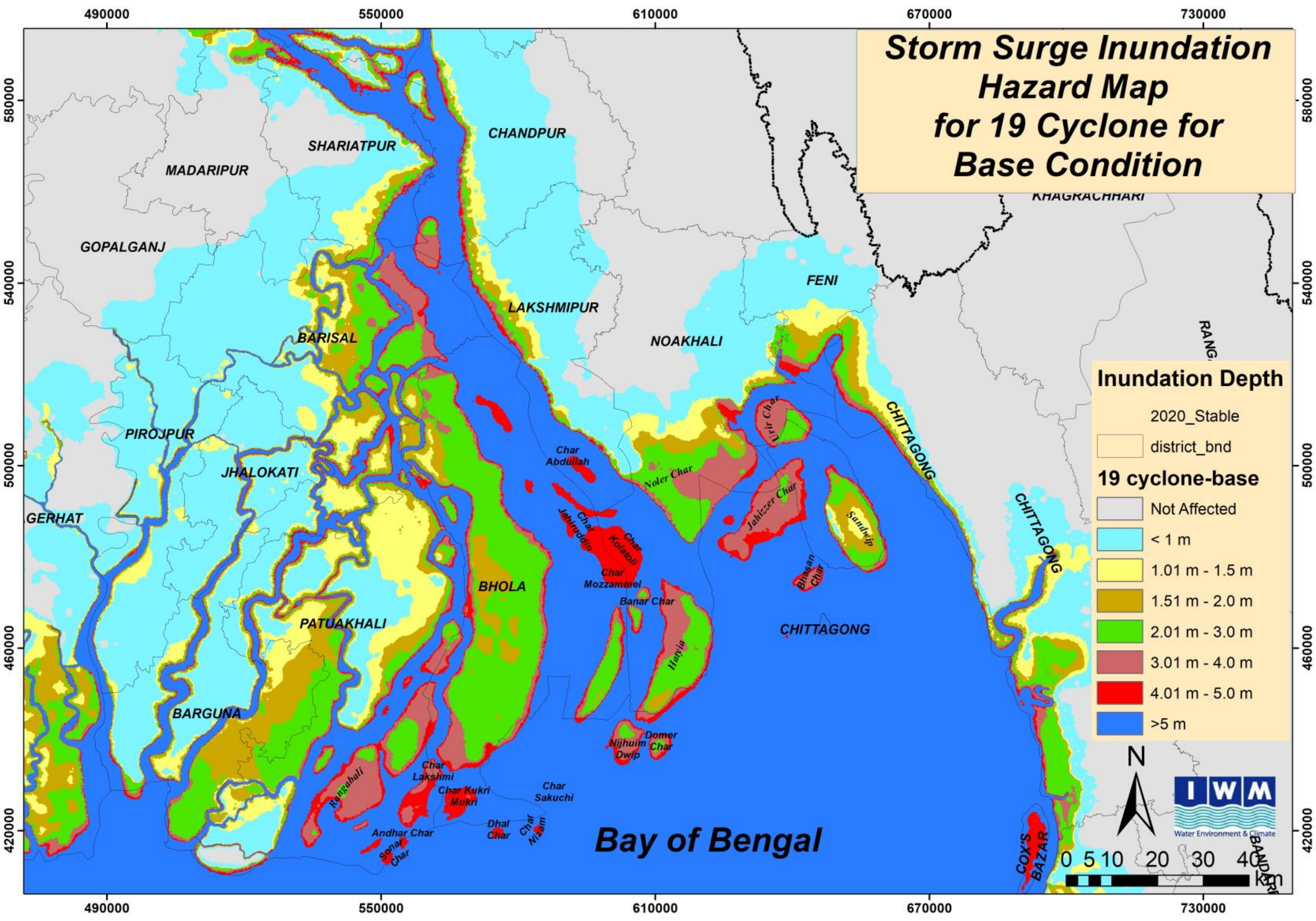


Figure 4.4: Storm surge induced inundation map from the cyclone events of 1960–2020 (Base Conditions)

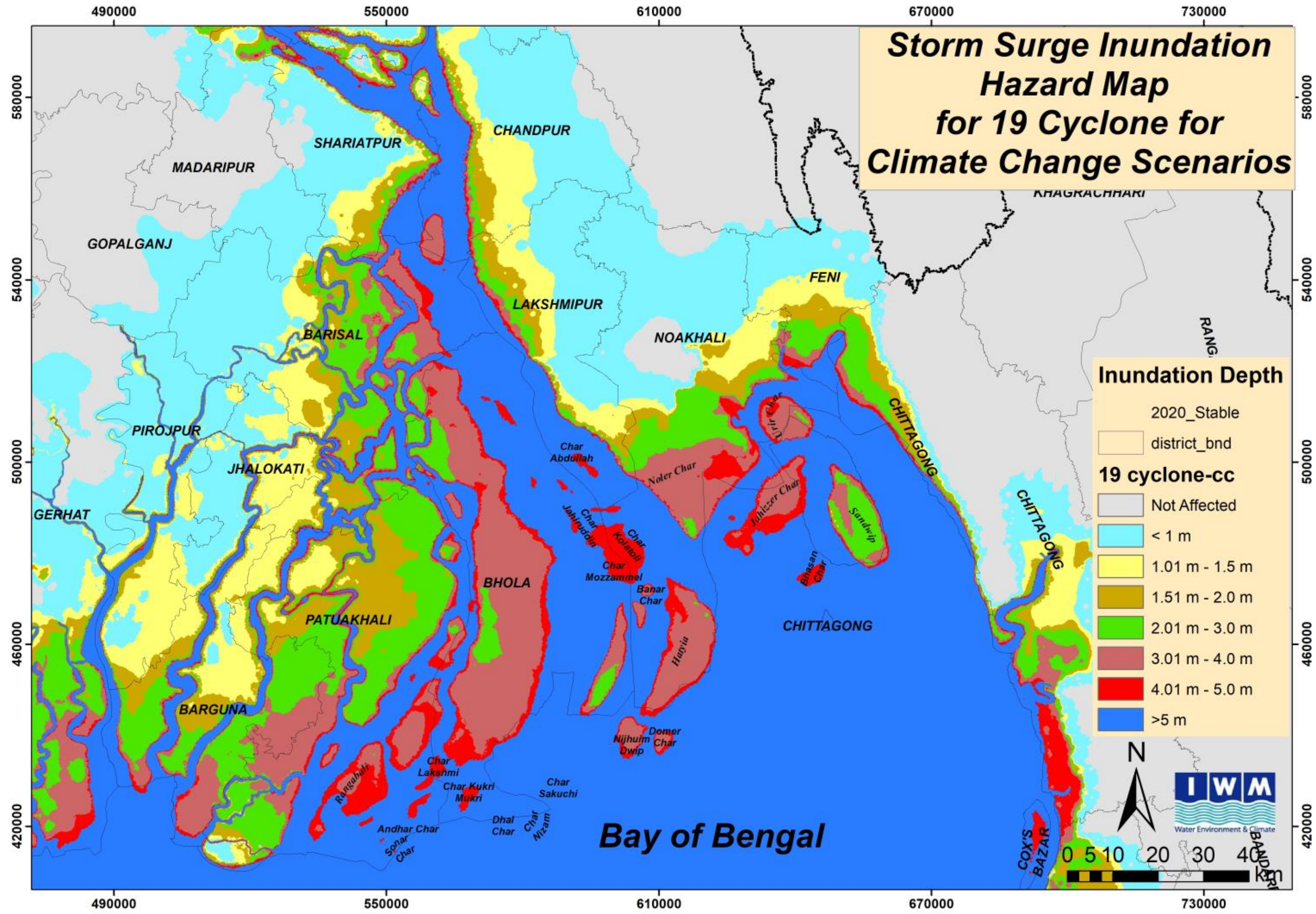


Figure 4.5: Storm surge induced inundation map from the cyclone events of 1960-2020(RCP 8.5-Extreme Event Conditions)

Global warming and climate change is taking place and it is very important to include the climate change scenario into the prediction of storm surge inundation. In this context, the RCP 8.5 scenario has been considered for simulation of the cyclonic events. According to 5th Assessment Report (AR5) of Intergovernmental Panel on Climate Change (IPCC), the global sea level rise will be 38cm and the change in extreme wind speed will be 8% increase from the present conditions. Hence, the cyclone model has been run for 8% increase in wind speed. The storm surge conditions have been simulated with a 47cm sea level rise considering 38cm global sea level rise and 4mm/year subsidence effect and 2mm/year sedimentation effect.

Storm surge level for different return period with and without climate change effect at CDSP IV char sites and proposed chars selected for future development locations in the Meghna Estuary are presented in the Table 4.2. Total sixteen storm surge extraction points are show in the Figure 4.6.

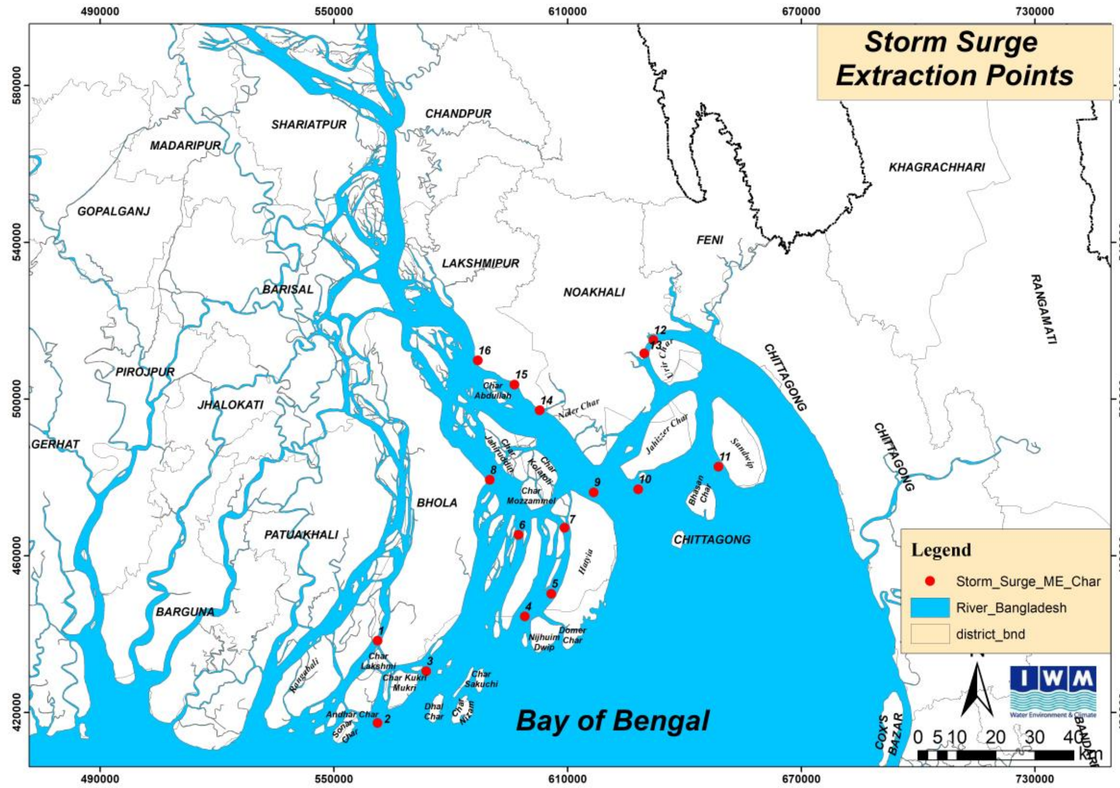


Figure 4.6: Locations for extraction of simulated storm surge levels

Storm surge level in different return period (years) without and with climate change conditions at different locations of Meghna Estaury are illustrated in Table 4.1.

Table 4.1: Storm surge level for different return periods with and without climate change condition

Location No.	Surge Level (mPWD) in different Return Period (Years) Without Climate Change					Surge Level (mPWD) in different Return Period (Years) with Climate Change (RCP 8.5)				Location Name/ Char Name
	1970	10	25	50	100	10	25	50	100	
1	5.70	2.70	3.77	4.57	5.36	3.28	4.54	5.47	6.40	Near Char Lakshmi
2	5.71	2.82	3.96	4.81	5.66	3.42	4.72	5.68	6.63	Near Andhar Char
3	5.63	2.89	4.06	4.93	5.80	3.30	4.50	5.39	6.27	Near Char Kukri Mukri
4	5.12	2.84	3.85	4.60	5.35	3.19	4.35	5.22	6.08	Near Nijhuim Dwip
5	5.03	2.87	3.89	4.65	5.40	3.20	4.33	5.17	6.00	Near Domer Char
6	5.71	2.93	3.95	4.71	5.47	3.26	4.46	5.36	6.25	Near Char Mozzammel
7	6.09	3.08	4.30	5.21	6.11	3.43	4.70	5.64	6.58	Near Banar Char
8	5.96	3.07	4.10	4.86	5.62	3.37	4.54	5.42	6.28	Near Char Jahiruddin
9	6.04	3.54	4.71	5.57	6.44	3.90	5.34	6.41	7.48	Near Char Kolatoli
10	6.07	3.67	4.91	5.82	6.73	4.06	5.58	6.70	7.82	Near Jahizzer Char
11	6.03	4.04	5.52	6.63	7.72	4.44	6.14	7.40	8.65	Near Bhasan Char
12	7.70	4.98	6.42	7.48	8.54	5.41	6.91	8.02	9.13	Near Urir Char
13	7.72	5.01	6.41	7.45	8.47	5.45	6.88	7.95	9.01	Near Char Maksumul Hakim
14	6.60	3.52	4.68	5.55	6.40	3.84	5.24	6.28	7.31	Near Char Jahiruddin
15	6.64	3.53	4.72	5.60	6.48	3.83	5.25	6.30	7.34	Near Char Abdullah
16	6.37	3.44	4.65	5.54	6.43	3.71	5.06	6.07	7.06	Ramgoti

From the above Table and Figure, it is found that East Shabazpur Channel at Lakkhipur and Noakhali, Ramgoti, Noler Char; Urir char at Noakhali side, Upstream of Char Jahiruddin,Char Abdullah, downstream of Shandwip, upstream of Hatia, eastern part of Bhola Island, Char Monpura, Dhal Char and Andhar Char were vulnerable both for erosion and storm surge . The storm surge level varies from 4.7 m PWD to 6.4 m PWD for existing condition and the extreme climate change conditions it is varies from 5.3 m PWD to 6.9 m PWD near Char Kolatoli, Jahizzer ,Bhasan Char, ,Urir Char , Char Maksumul Hakim for 1 in 25 years return period. Moreover, for 1 in 50-year return period the surge level is around 5.57 m PWD ~7.45m PWD without climate change (CC) conditions and it is around 6.41m PWD ~ 8.02 m PWD with CC conditions.

Therefore, most of the potential chars in the Lower Meghna estuary including CDSP IV areas are vulnerable to erosion and storm surge both existing and climate change conditions. Considering the satellite images analysis and hydro-morphological model result, the high , medium and low risk area are sumurrized below:

Table 4.2: High, Medium and Low Risk Area in Meghna Estuary

Sr.No	High Risk Area	Medium Risk Area	Low Risk Area
1	East Shabazpur Channel at Lakkhipur and Noakhali (194m/year)	Western Part of Bhola or Left bank of Tentulia River (13m~17m)/yr	Char Lakshmi (15m/yr)
2	Ramgoti (130m/yr)	Burir Char	Western part Char Shakuchi (28m/yr)
3	Noler Char (400m/yr)	Char Kukri Mukri (20m/yr)	Char Rangabali(15m/yr)
4	Urir char at Noakhali side (120m.yr)	Boyer char(49m/yr)	Andhar Char (5.46m/yr)
5	Northern portion of Char Jahiruddin (164m/yr)	Southern part of Nijhum dwip (22m/yr)	
6	Char Abdullah	Banar char (35m/yr)	
7	Southern part of Shandwip (73m/yr)		
8	Northern part of Hatia (95m/yr)		
9	Eastern part of Bhola Island		
10	Char Monpura(75m/yr)		
11	Dhal Char (136m/yr)		
12	Char Nangulia (175m/yr)		

5. EROSION MITIGATION MEASURES AND ITS EFFECTIVENESS

5.1 Potential Erosion Mitigations Options

One objective of this study is to make an assessment of the erosion processes along the shoreline of CDSP III and IV (Boyer char, Noler char, Char Nangulia) and on the options concerning how to develop sustainable infrastructure in these chars.

Over the last few years, the bank erosion problem has worsened in the chars under CDSP II, CDSPIII and in CDSP IV project areas. In those places, infrastructures like sluices and embankments either already damaged/eroded or are at increased risk. It is seen that the bankline of CDSP III and IV is eroding. Caring Char on the south corner of the CDSP IV land is completely washed away. Sluice DS2 in Char Nangulia had already gone by the end of 2016. It seems that the Sluices DS-1 in Caring Char, DS-3 in Noler char are also totally washed away. Two other sluices in Boyer Char (Tankir Sluice and Gabtoli Sluice) are still doing well, but the river is coming close to the structures. In Boyer Char between Tankir Sluice and Chatla Sluice the embankment is washed away over a length of about 1km. Recently a retired embankment was built by BWDB, but this has also broken away already. Therefore, there is an immense need to make an assessment of the erosion processes along the river banks of CDSP III and IV (Boyer char, Noler char and Char Nangulia) and stipulate options for development of sustainable infrastructure in these areas.

Considering the issues of development of sustainable infrastructure (embankment and regulators) of these CDSPIII and CDSP IV area, three potential improvement options have been devised for detailed investigations.

The Options have been developed based on the suggestions of local community and social workers, consultation with BWDB officials & TA Team and satellite images analysis, analysis of survey data, field visits and hydro morphological model results. Detailed descriptions of Option-1, Option-2, and Option -3 are shown in the Figure 5.1 to Figure 5.3 respectively.

Potential Erosion Mitigations Measures are presented in **Table 5.1**

Table 5.1: Option-wise List of Interventions for Potential Erosion Mitigations:

Sl No	Measures	Option-1	Option-2	Option-3
1	Re-alignment of embankment at stable Location	√	√	√
2	Selectin of regulators at stable locations	√	√	√
3	Protective Work at (Boyer Char to Char Nangulia , Total 27km)	√	√	√
4	Cross dam between Jahazer Char and Char Nangulia (Cross-Dam-2)	X	√	√
5	Cross-dam Between Urir Char and Noakhali (Cross-Dam-1)	X	X	√

Option-1: Re-alignment of Embankment and Regulators at Stable Locations

In this option there are no protective measures or cross dam, only realignment of embankment and regulators at stable locations. The realignment of embankment and regulators at a stable location are predicted considering expert judgement of BWDB officials, TA Team and stakeholder consultations, bank line shifting rate from satellite images analysis for the last 10 years as well as measured bathymetry data and thalweg line shifting and also from morphological model result. In Option-1 the proposed 5-year alignment is fixing considering the setback distance of 500 m at Boyer char, 1200m at Noler char and 900 m at char Nanglia where the average erosion rate is 50m/year, 400m/year and 175m/year respectively. The setback distance for 10-year proposed alignment is considered around 750 m for Boyer char, 2000m for Noler char and 1000m for char Nangulia. 15 years proposed alignment is also fixed considering this criterion. The realignment of proposed embankment of different years

(5year, 10 year and 15 year) is shown in **Figure 5.1**. The Component of Option-1 is as follows:

1. Re-alignment of embankment at stable Location for 5 year, 10 year and 15 year;
2. Selectin of 7 regulators (Two at Boyer Char, One at Noler char and Four at Char Nangulia) at safe locations;
3. 30 km Protective Work at (Boyer Char to Char Nangulia, Total 27km);

Realignment from Hydro- morphological model results:

The proposed alignment of 5 years, 10 years,15 years and 20 years have been predicted from morphological model result. **Figure 5.2**. shows the bankline shifting of 20 years starting from 2020. It is seen from **Figure 5.3**. that after 5 years, 10years, 15years and 20 years the maximum Bankline shifting is found at Noler char which is around 2 km, 4 km, 5.5 km 7.6 km respectively.

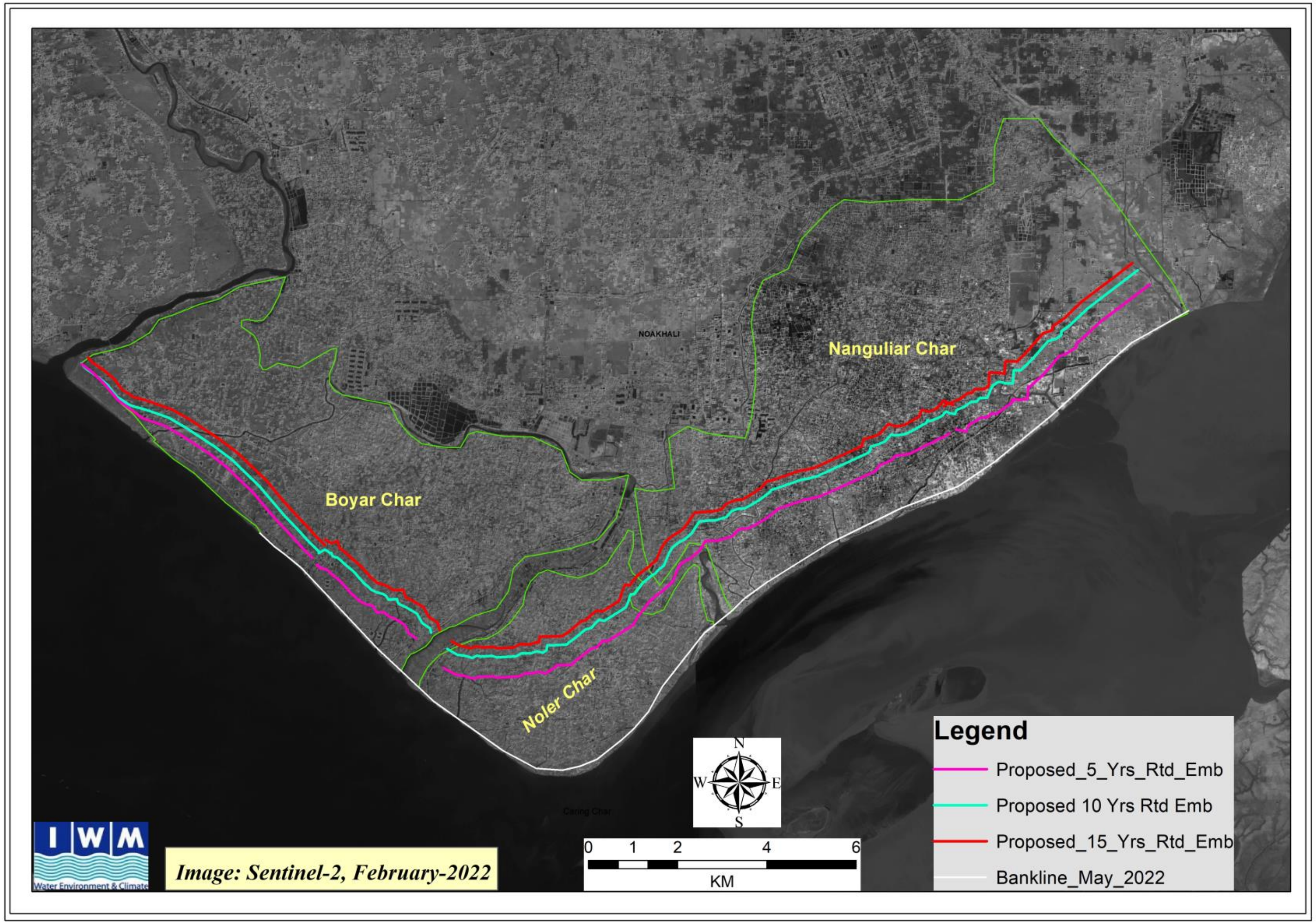


Figure 5.1: Re-alignment of Embankment and Regulators at Stable Locations for 5year,10years and 15 years

Option-2: Realignment of Embankment and Regulators at Stable Locations + 24 km Protective Work from Boyer Chat to Char Nangulia with One Cross Dam Between Jahazer Char and Char Nangulia

In Option-2, Re-alignment of embankment and regulators (Option-1) is considered. Additionally, a one cross dam at Jazhajer char to Char Nangulia is considered. Protective work and cross dam location is shown in **Figure 5.2.** The Component of Option-2 is as follows

1. Re-alignment of embankment at stable Location for 10 years;
2. Selectin of 8 regulators (Two at Boyer Char and Noler char and Four at Char Nangulia) at stable locations;
3. 30 km Protective Work at (Boyer Char to Char Nangulia, Total 30 km);
4. Cross dam between Jahazer Char and Char Nangulia (Cross Dam-2);

In this option cross dam is to be constructed first and then regulators may be constructed 2 to 3 years later observing the sedimentation patter and by identifying new drainage routes.

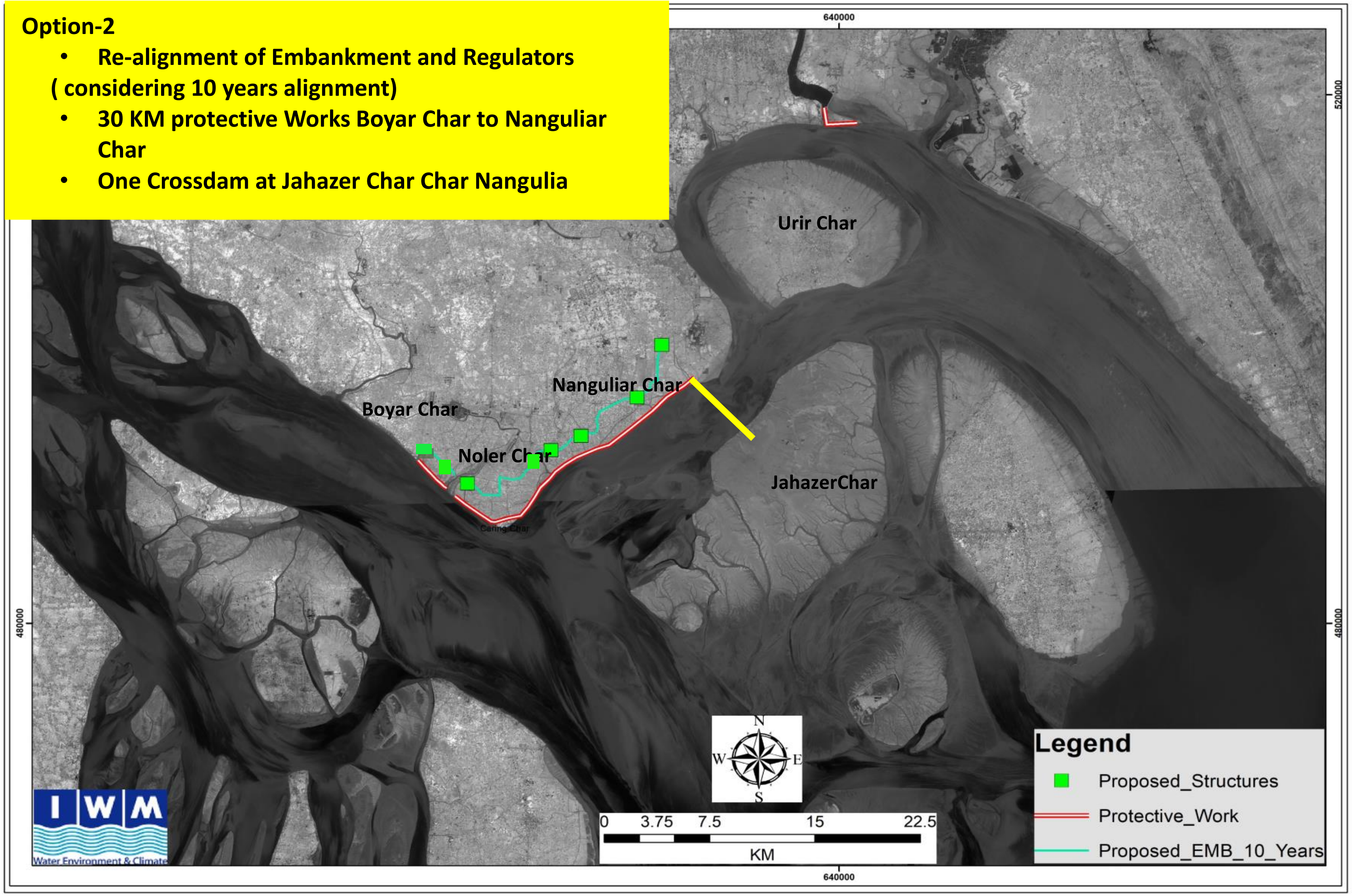


Figure 5.2: Protective Work from Boyer Chat to Char Nangulia with One Cross Dam

Option-3: Realignment of Embankment and Regulators at Stable Locations + 27 km Protective Work from Boyer Chat to Char Nangulia with Two Cross Dam

Otion-3 is same as Option-2 only difference is that it includes another cross dam at Urir char to Noakhali. There are 30 km protective work with two cross dams. One cross dam is at Jahazer char to Char Nangulia and another is at Urir char to Noakhali. Option -3 is shown in Figure 5.3. The Component of Option-3 is as follows:

1. Re-alignment of embankment at stable Location for 10 years;
2. Selectin of 8 regulators (Two at Boyer Char and Noler char and Four at Char Nangulia) at stable locations;
3. 30 km Protective Work at (Boyer Char to Char Nangulia, Total 30 km);
4. Cross dam between Jahazer Char and Char Nangulia (Cross Dam-2);
5. Cross-dam Between Urir Char and Noakhali (Cross Dam-1);

In this option cross dam is to be constructed first and then regulators may be constructed 2 to 3 years later observing the sedimentation patter and by identifying new drainage routes

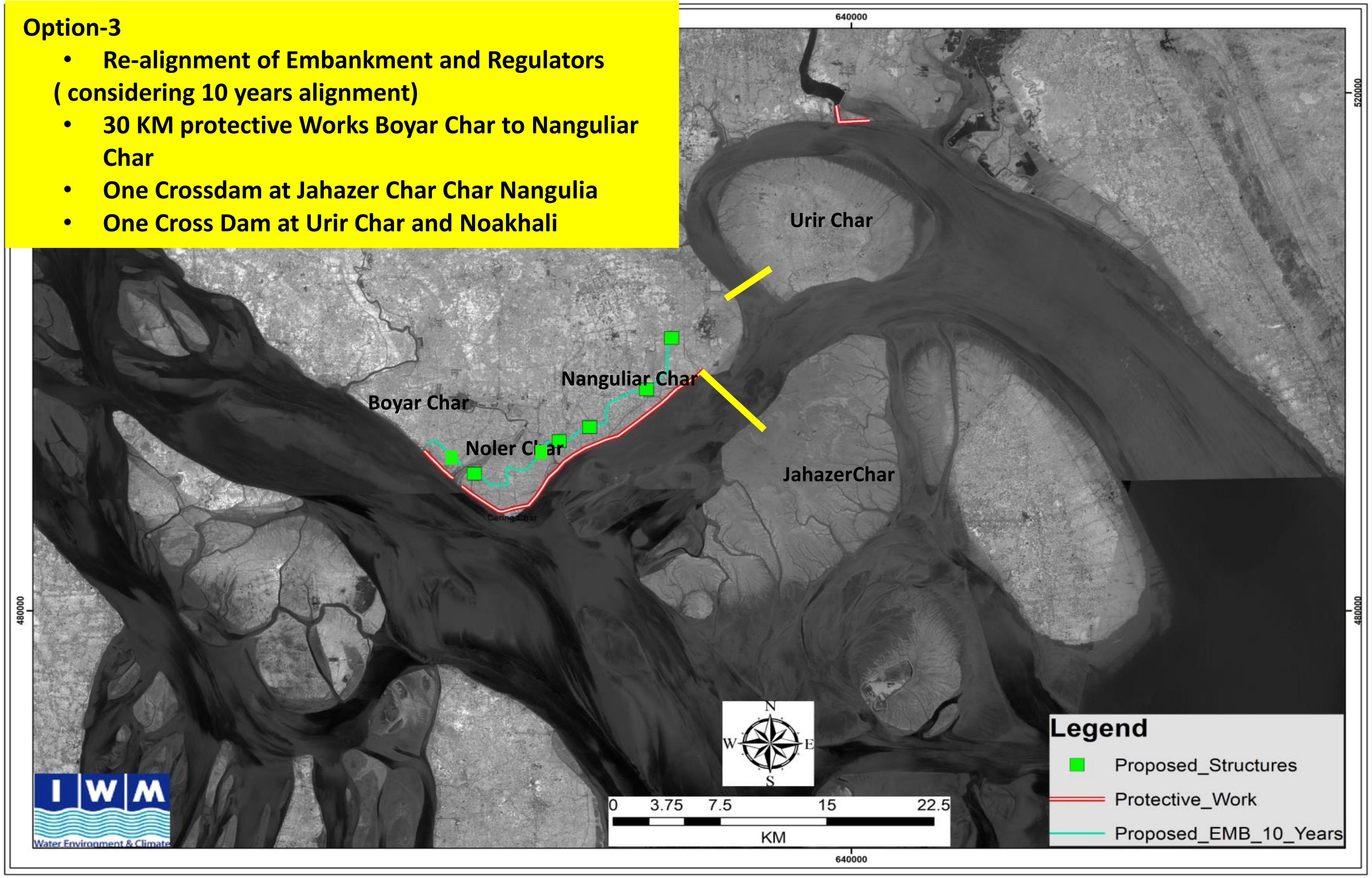


Figure 5.3: Protective Work from Boyer Chat to Char Nangulia with Two Cross Dam

5.2 Assessment of Current Speed, Water Level and Flow of Different Options

Before construction of the different options (cross-dams and protection works), their impact on the hydrodynamics and morphology of the Sandwip-Urirchar-Noakhali area as well as the whole Meghna estuary should be analyzed. The impacts of the cross-dams on the current speed, water levels, residual circulation, tidal volume, drainage congestions and erosion around the cross-dam have been investigated based on the two-dimensional mathematical model results.

5.2.1 Impact on Current Speed

The ebb tide velocity diagrams during wet seasons for base condition and different options are shown in Figure 5.4. The figures show that the velocity is decreased significantly in the channel between Swarnadwip and CDSP char area due to the construction of the cross-dam 2 between Jahazer Char and Char Nangulia. The maximum current speed maps plotted in Figure 5.5 and Figure 5.6 shows that the maximum velocity is significantly reduced by the construction of the cross-dams in the respective channels during monsoon and dry season. But there is no increase in the maximum velocity at the south-west side of the Sandwip Island or any other bank in the area.

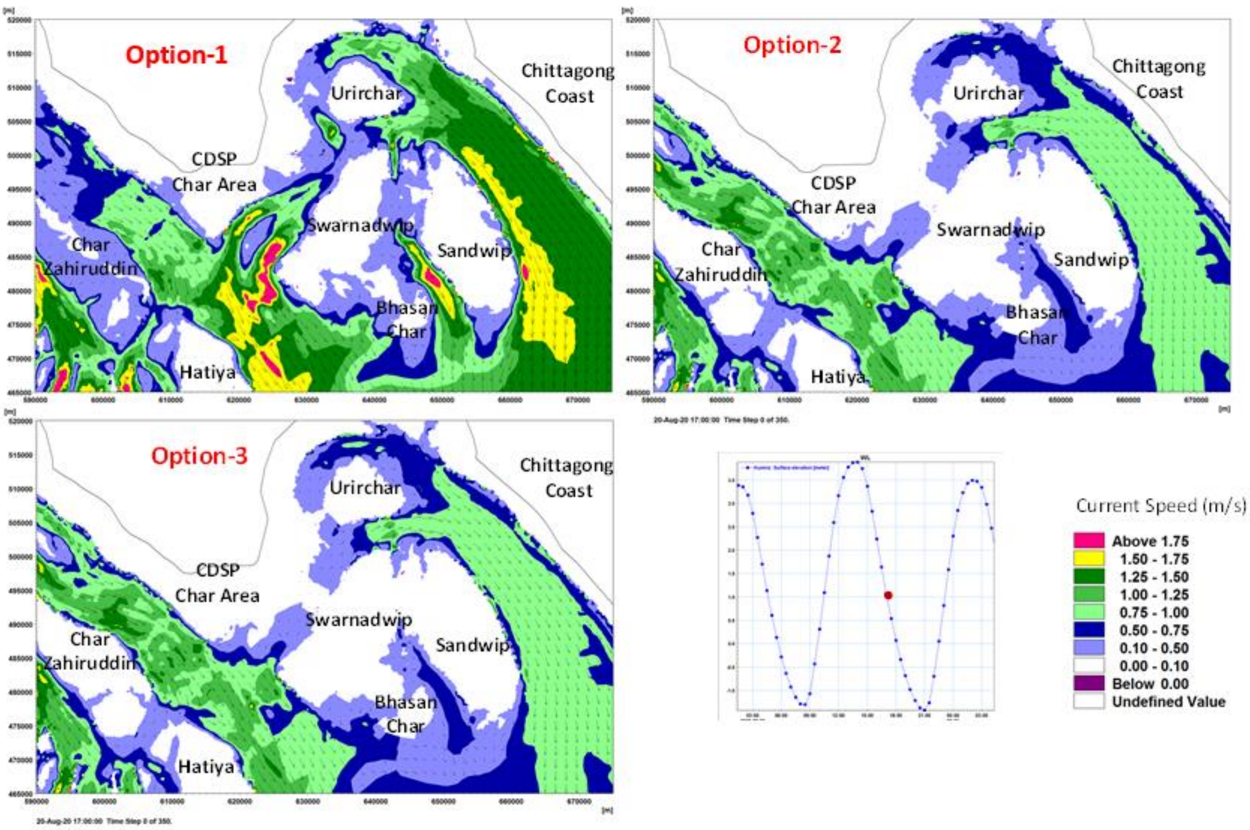


Figure 5.4: Velocity field during wet period ebb tide under different options

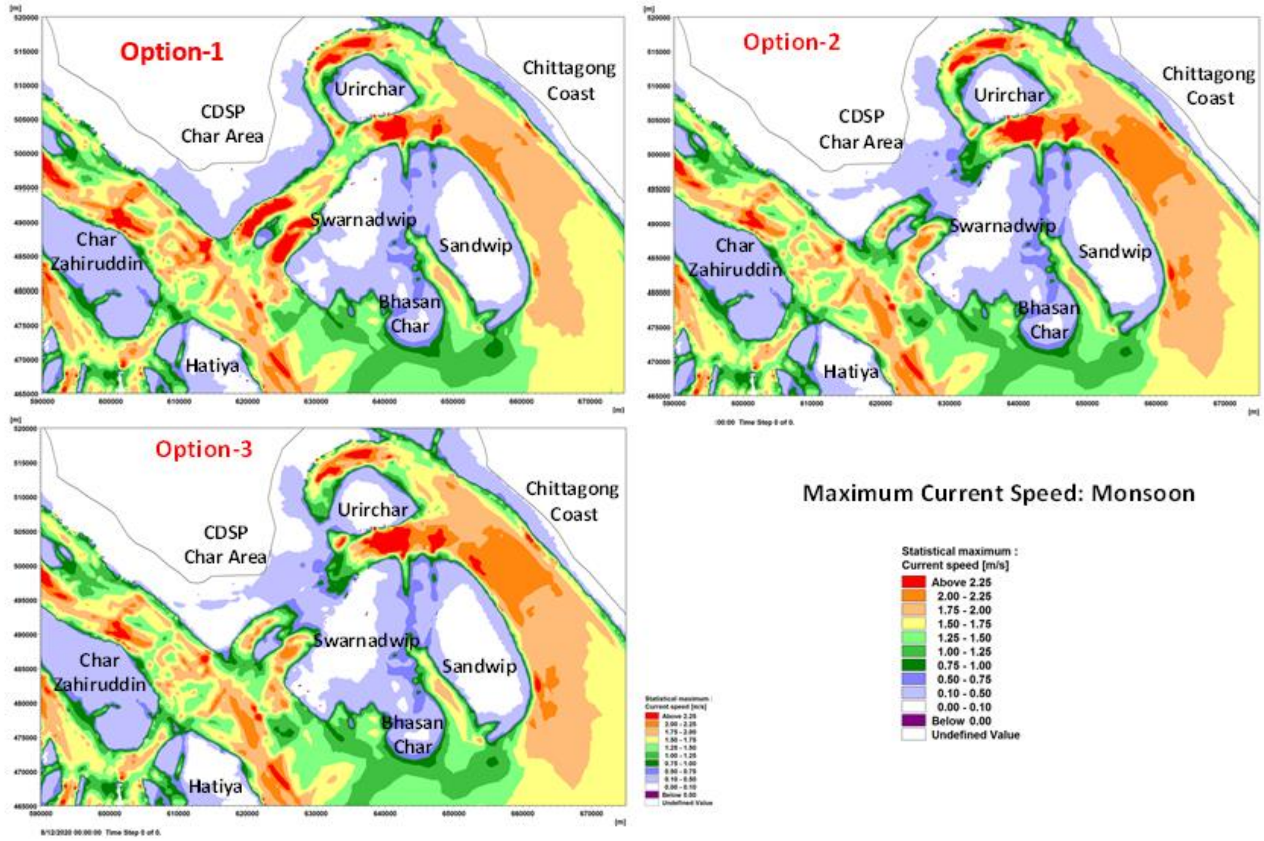


Figure 5.5: Maximum current speed map during monsoon period for different options

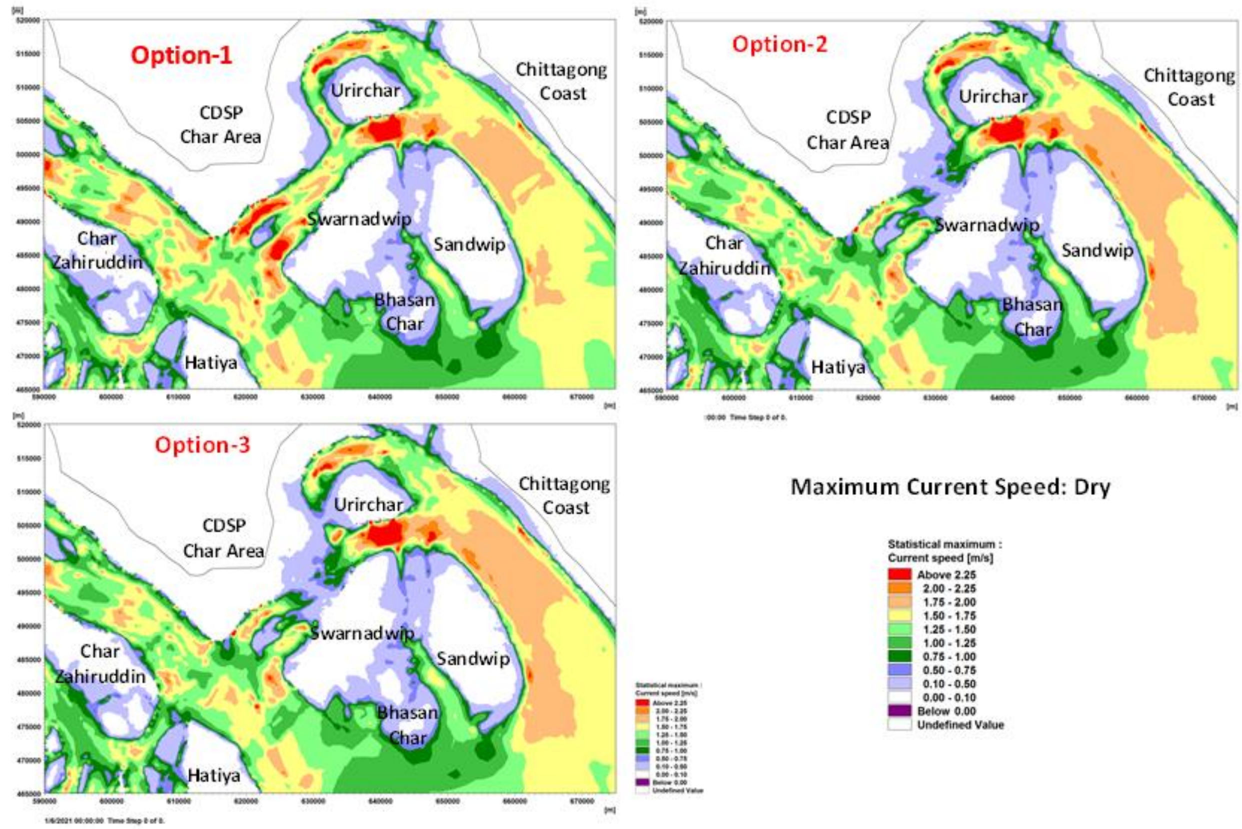


Figure 5.6: Maximum current speed map during dry period for different options

5.2.2 Impact on Water Level

The figure shows that all the options cause higher surface elevation at dam locations due to the obstruction of circulation of flow. Cross-dam causes maximum impact on surface elevation for both the seasons. It shows that the building of cross-dams increases the water level head at immediate upstream of the cross-dam and decrease water level at downstream. Here, upstream and downstream are considered with respect to the net flow distribution.

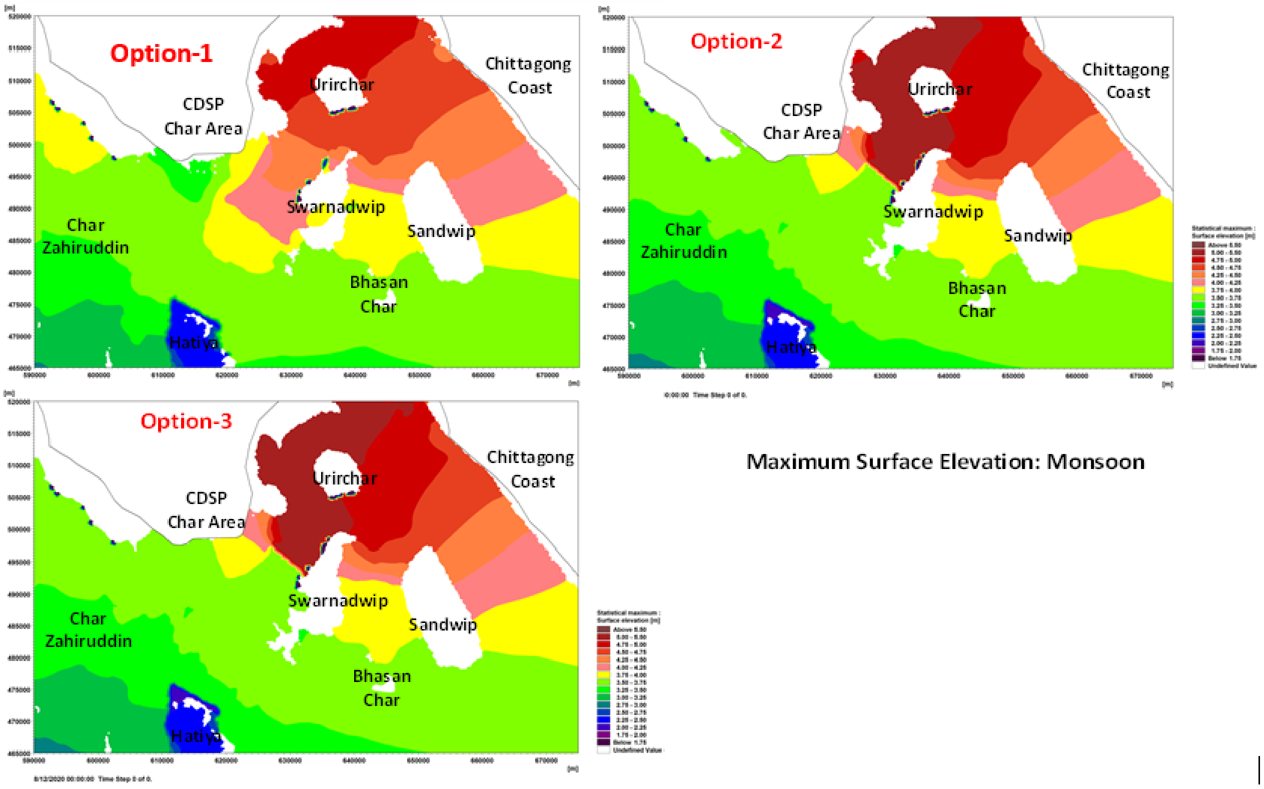


Figure 5.7: Maximum water level map during monsoon period for different options

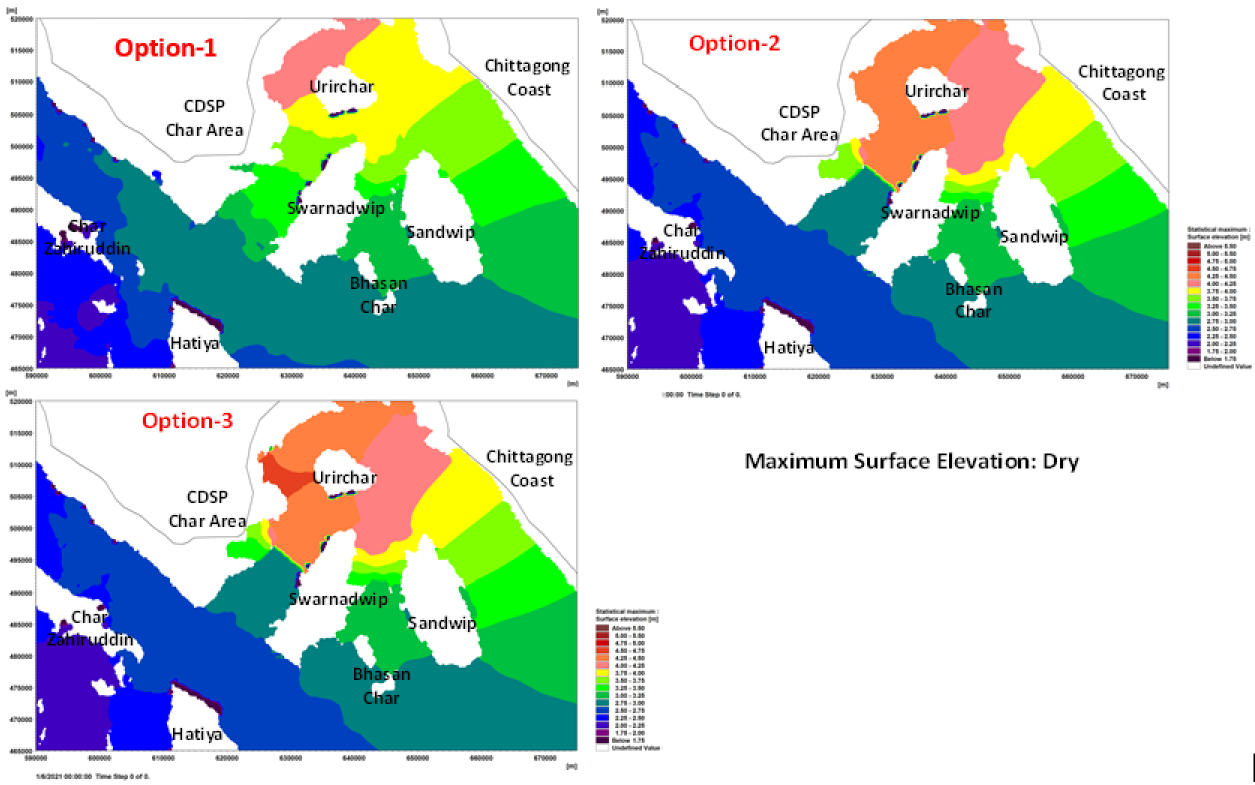


Figure 5.8: Maximum water level map during dry period for different options

5.2.3 Impact on Residual Flow

The residual flow (net flow) direction and mean current speed for dry and monsoon period for different options are shown in Figure 5.9 and Figure 5.10. From the analysis of the baseline conditions, it is evident that there is a prominent anti-clockwise residual flow in the study area and the downward residual flow in Hatiya channel is much greater in wet period than that in dry period. Construction of cross-dam 1 and cross-dam 2 restrict the flow around Urirchar and Jahazer Char respectively.

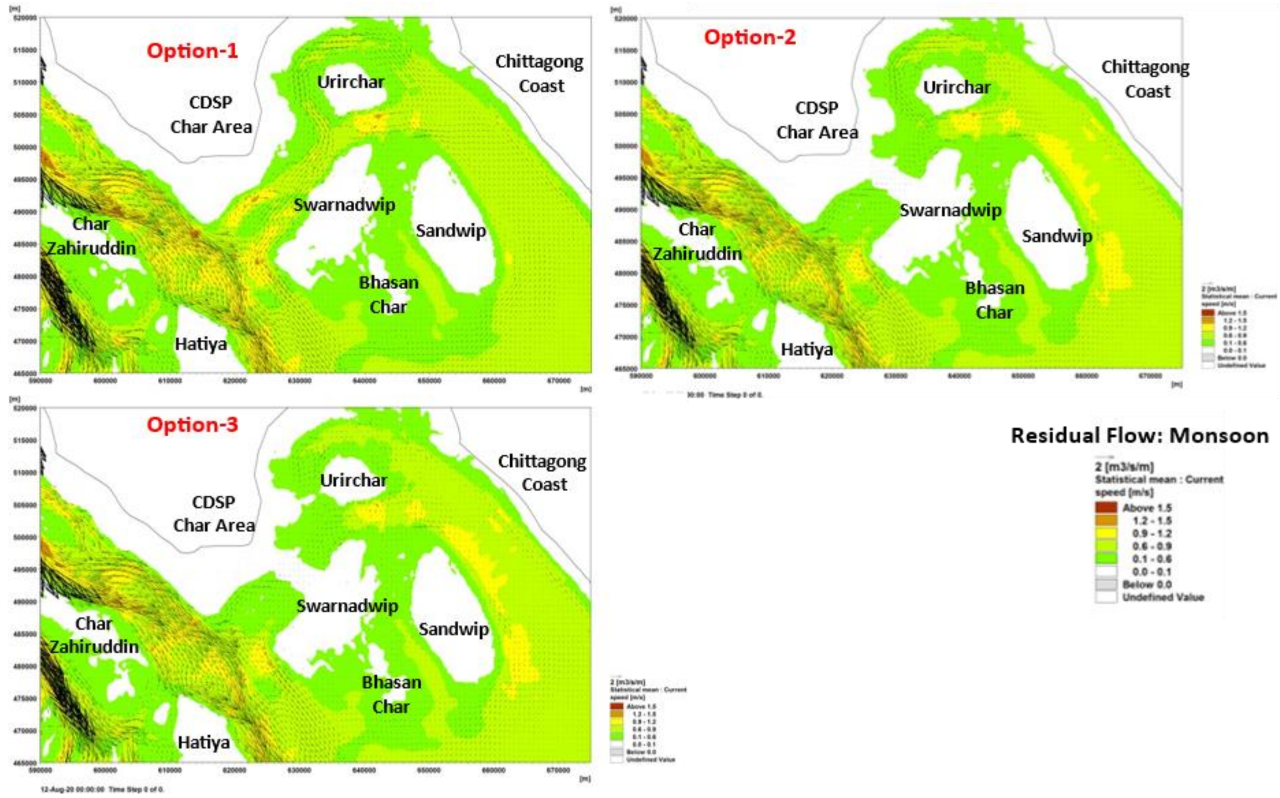


Figure 5.9: Residual flow and mean current speed during monsoon for different options (August, 2020)

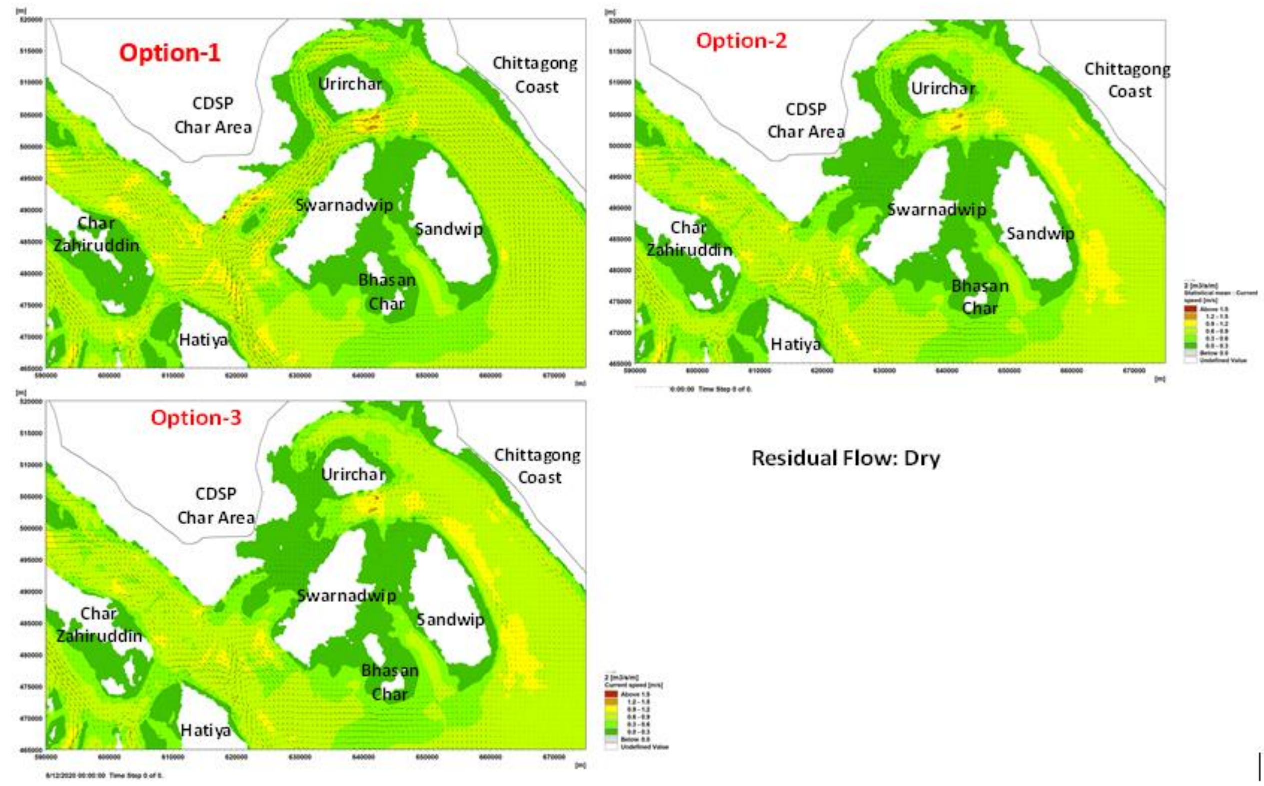


Figure 5.10: Residual flow and mean current speed during dry for different options (January, 2021)

5.2.4 Impact on Morphology

It was decided to apply the validated morpho-dynamic model to predict future morphological changes in the Lower Meghna Estuary. Figure 5.11 depicts the bed level after 20 years in the CDSP area for different options. With hard protection work (Option-1), erosion around the Noler Char area has been greatly minimized. Furthermore, erosion will occur in the Char Nagulia area due to the lack of protection works. The erosion will be stopped, however, if the cross-dam between Jahazer Char and the Noakhali mainland (Option-2) is built, as the current speed in this location will be much decreased, and silt will be deposited in the surrounding area. In addition, after 20 years, the Jahazer Char area will be merged into the CDSP area. The construction of a cross-dam between Urir Char and Noakhali in combination with the prior cross-dam (Option-3) will speed land reclamation in the Urir Char area, with minimal influence on the other parts of the CDSP area.

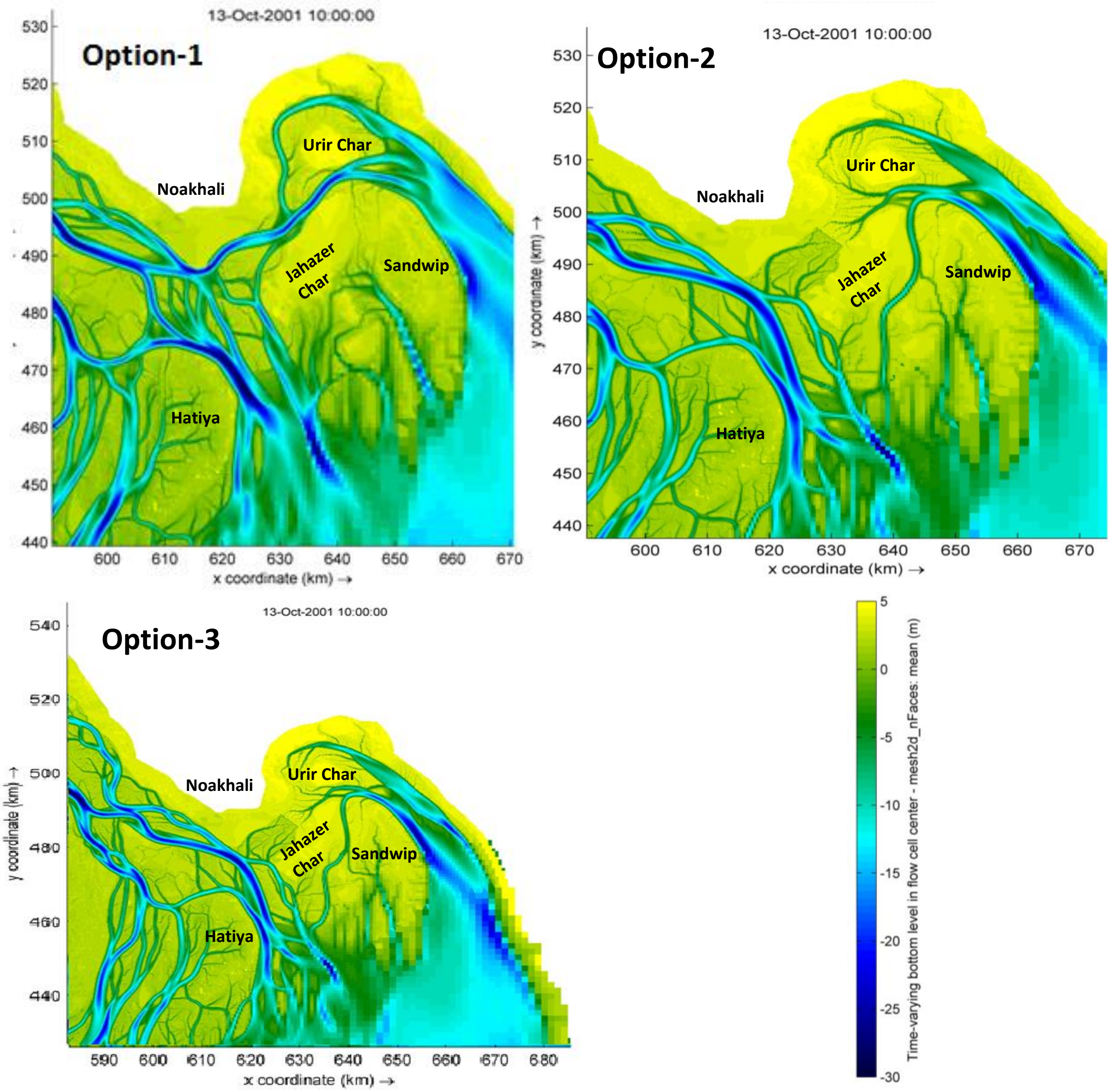


Figure 5.11: Morphological Changes after 20 years from present condition (2020) around the CDSP area for different options

Overall, based on the results of the hydro-morphodynamical model, it can be concluded that if no action is taken, the continuous erosion will continue to occur. The construction of a cross-dam between Jahazer Char and the Noakhali mainland (Option-2) will lessen erosion in this area while also speeding up land accretion in this location. However, the construction of this cross-dam will necessitate a significant investment as well as extensive investigation, which will be impossible to complete in a short period of time. As a result, option-1 is selected through agreement amongst CDSP, TA Team BWDB, Quality Control (SVASEK), and IFAD. A detailed description of prospective interventions in the CDSP area will be discussed further in the following chapter.

6. REALIGNMENT OF EMBANKMENT AND FIXING OF REGULATORS AT SAFE LOCATIONS

One objective of this study is to make an assessment of the erosion processes along the shoreline of CDSP III and IV (Boyer char, Noler char, Char Nangulia) concerning how to develop sustainable infrastructure in these chars.

Over the last few years, the bank erosion problem has worsened in the chars under CDSP II, CDSPIII and in CDSP IV project areas. In those places, infrastructures like sluices and embankments either already damaged/eroded or are at increased risk. It is seen that the bankline of CDSP III and IV is eroding. Caring Char on the south corner of the CDSP IV land is completely washed away. Sluice DS2 in Char Nangulia had already gone by the end of 2016. It seems that the Sluices DS-1 in Caring Char, DS-3 in Noler char are also totally washed away. At Boyer Char (Tankir Sluice and Gabtoli Sluice) are still doing well, but the river is coming close to the structures. In Boyer Char between Tankir Sluice and Chatla Sluice the embankment is washed away over a length of about 1.5 km. Recently a retired embankment was built by BWDB, but this has also broken away already. Therefore, there is an immense need to make an assessment of the erosion processes along the shoreline of CDSP III and IV (Boyer char, Noler char and Char Nangulia) and stipulate fixing alignment and regulators at stable locations for development of sustainable infrastructure and drainage system in these areas.

6.1 Realignment of Embankment Based on Satellite Images

The predicted shoreline is established considering satellite images analysis, morphological model results, data, thalweg line shifting, location of scour hole, near bank velocity expert judgement and stakeholder consultations. The proposed alignment of 5, 10, 15 years have been selected (red line) as shown in Fig.6.1

The realignment of embankment and regulators at a stable location are established based on time series satellite image analysis. The average erosion rate for the last ten years (2010 to 2020) is 50m/year at Boyer char, 400m/year at Noler char and 175 m/year at char Nangulia. Figure 4.1 shows the shoreline shifting from satellite image analysis.

Table 6.1: Erosion rate at Boyer Char, Noler Char and Char Nangulia for the last decades (2010~2020)

Item	Boyer Char	Noler Char	Char Nangulia
Average Erosion Rate(m/year)	50	400	175

6.2 Realignment from Hydro- morphological model results

The proposed alignment of 5 years, 10 years,15 years and 20 years have been predicted from morphological model result. **Figure 6.2** shows the shoreline shifting of 20 years starting from 2020. It is seen from **Figure 6.2** that after 5 years, 10years, 15years and 20 years the maximum shoreline shifting is found at Noler char which is around 2 km, 4 km, 5.5 km 7.6 km respectively.

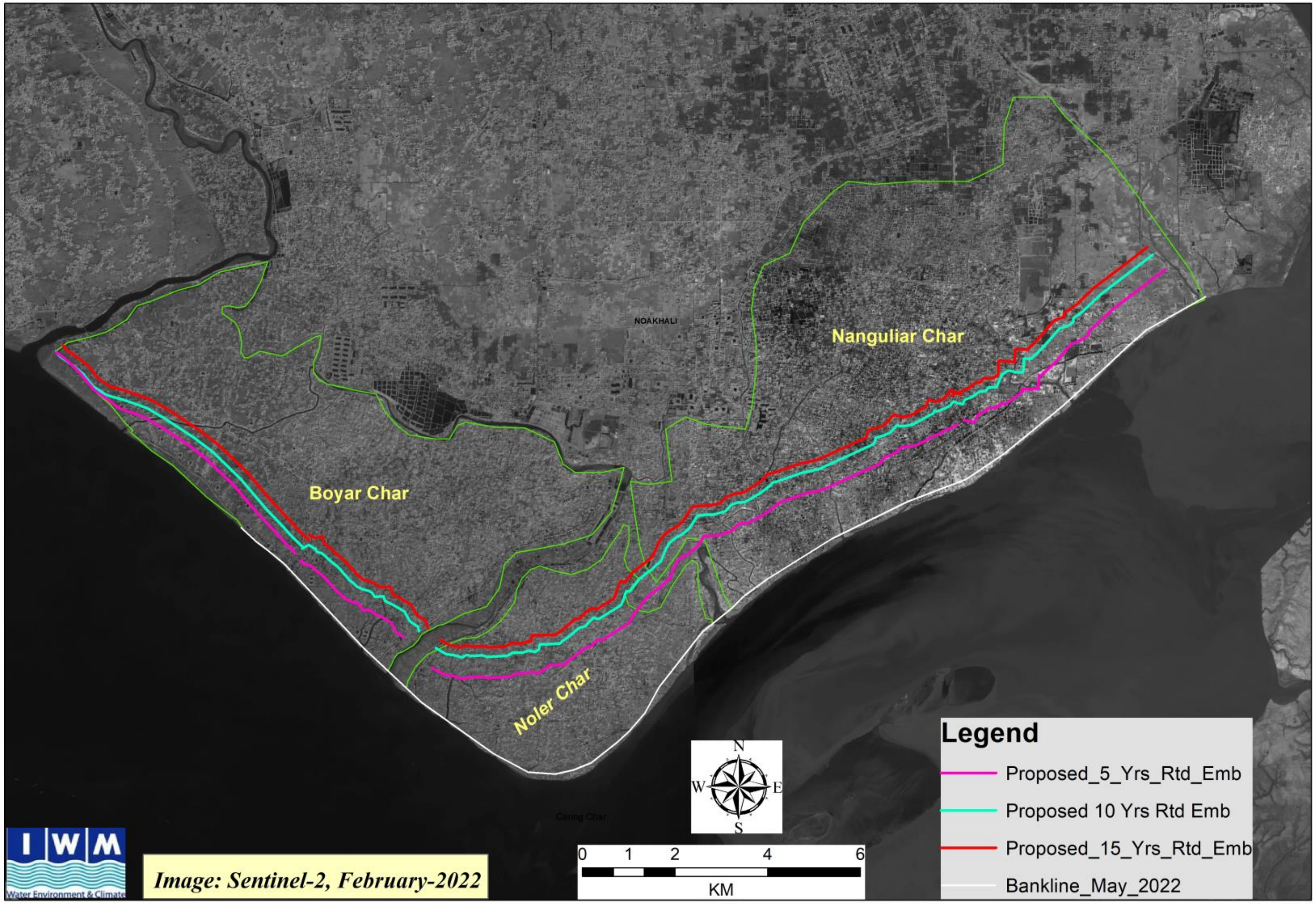


Figure 6.1 Shoreline Shifting from Satellite Image Analysis

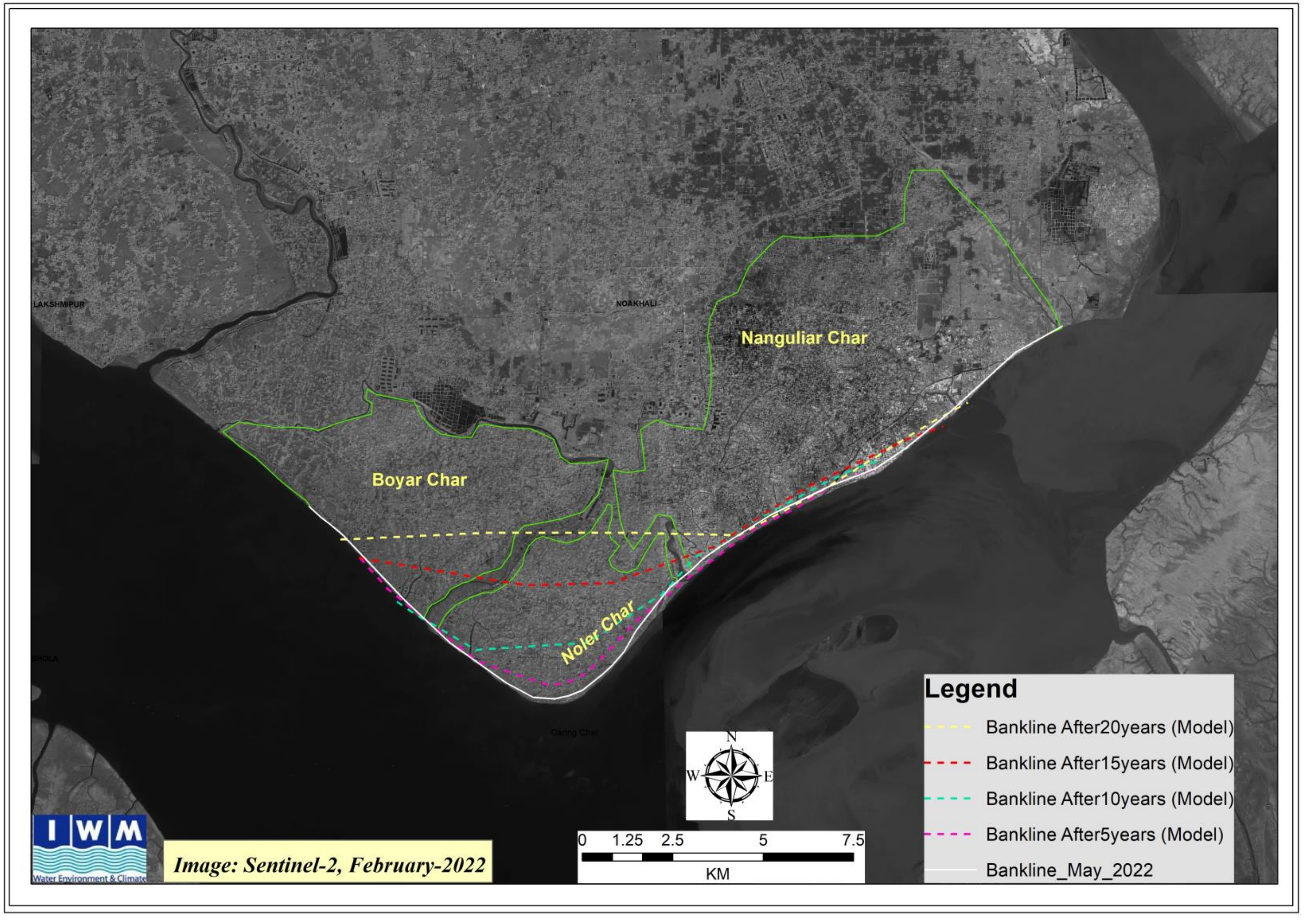


Figure 6.2: Shoreline Shifting from Model Result

6.3 Embankment Realignment from Satellite Images and Model result:

The predicted shoreline is established considering satellite images analysis, morphological model results, data, thalweg line shifting, location of scour hole, near bank velocity expert judgement and stakeholder consultations. The proposed alignment of 5, 10, 15 years have been selected (red line) as shown in **Figure 6.3 to Figure 6.5** respectively.

<u>Setback distance establishment and intervention proposed:</u>

Considering the above criteria, it is found that after 5-year predicted alignment, the average setback distance is considered 500 m at Boyer char, 1200m at Noler char and 900 m at char Nanglia. The average setback distance for 10-year proposed alignment is identified and it is around 100 m for Boyer char, 2200 m for Noler char and 1600 m for char Nangulia. Proposed embankment alignment after 15 years is also fixed considering these criteria.
For 15-year proposed alignment the average setback distance is around 110 m for Boyer char, 3000 m for Noler char and 1700 m for char Nangulia.

Considering the 10-years and 15-years prediction of shoreline, total 5 number of regulators are suggested, one is at Noler Char and another four are at Char Nangulia. The details of embankment and regulators are given in Table 6.2. The Total length of embankment for 10 years and 15 years are 27 km and 24.92 km respectively.

Table 6.2: Proposed alignment of embankment and regulators for 10 and 15 years

Name of Char	For 10 Years				For 15Years	
	Embankment Length (km)	**Khal Name**	**Khal Width (m)**	**Proposed Regulators size (m x m)**	**Embankment Length (km)**	**Proposed Regulators size (m x m))**
Noler Char	5.80	Milon Khal	30	4 vent -1.5x 1.8	5.00	2 vent -1.5x 1.8
Nangulia Char	14.50	Mamur Khal	30	2 vent -1.5x 1.8	12.00	4 vent -1.5x 1.8
		Nangulia Khal	25	3 vent -1.5x 1.8		1 vent -1.5x 1.8
		Bhuiyar Khal	25	6 vent - 1.5x 1.8		3 vent - 1.5x 1.8
		Katakhali Khal-2	40	9 vent- 1.5x 1.8		4 vent- 1.5x 1.8
		Borrowpit Khal	20	3 vent -1.5x 1.8		1 vent -1.5x 1.8
Boyer Char	9.70	Chatla Khal	20	3 vent -1.5x1.8	9.00	2 vent -1.5x1.8
		Gabtoli Khal	40	9 vent- 1.5x 1.8		6 vent- 1.5x 1.8
Total	**30**			**8 Regulators and vent size (1.5x 1.8)**	**26.00**	**8 Regulators and vent size (1.5x 1.8)**

For 10 years proposed alignment total **30** km embankment and 8 regulators, one (1) at Noler Char, five (5) at Char Nangulia and another two (2) at Boyer Char are suggested. The gross protected area is going to be 90.00 Km^2 which will be 73% of total area of Boyer Char, Noler

Char and Char Nangulia. Total 26.00 km embankment and 8 regulators will be required for 15 years proposed alignment. If the embankment alignment and structures will be considered based on 5-year set back distance, the lifetime is very short, and it is not economically viable. Also, it will take considerable time to implement the project. As a result, the project lifetime is less than 5 years. For 15 years proposed embankment alignment location the gross protected area would be of 40 % of the productive land of Boyer Char, Noler Char and Char Nangulia. Therefore, 10 years embankment alignment and structure location are suggested for the social and economic point of view. Moreover, as the erosion rate is high at Noler char and the morphological process of the whole area is so dynamic, from the technical point of view it is safe to fixing alignment for 15 years. The quality control team Svask suggested for 15 years alignment considering high erosion rate. The maximum erosion rate 756m/year at Noler char. Considering this erosion rate the full Noler Char is totally out of the project area after 20years prediction and nearly 10% productive land of Char Nangulia will be remain within the embankment. In this context, the project benefited area will be very less.

Finally, considering the social and technical and economic point of view the 10 years alignment is recommended.
DPP for construction of Urir Char-Noakhali Cross-Dam is at the final stage of approval by ECNEC. This may be implemented during 2022.23. Hopefully this will not conflict with implementation of Option I of CDSP-B (AF)

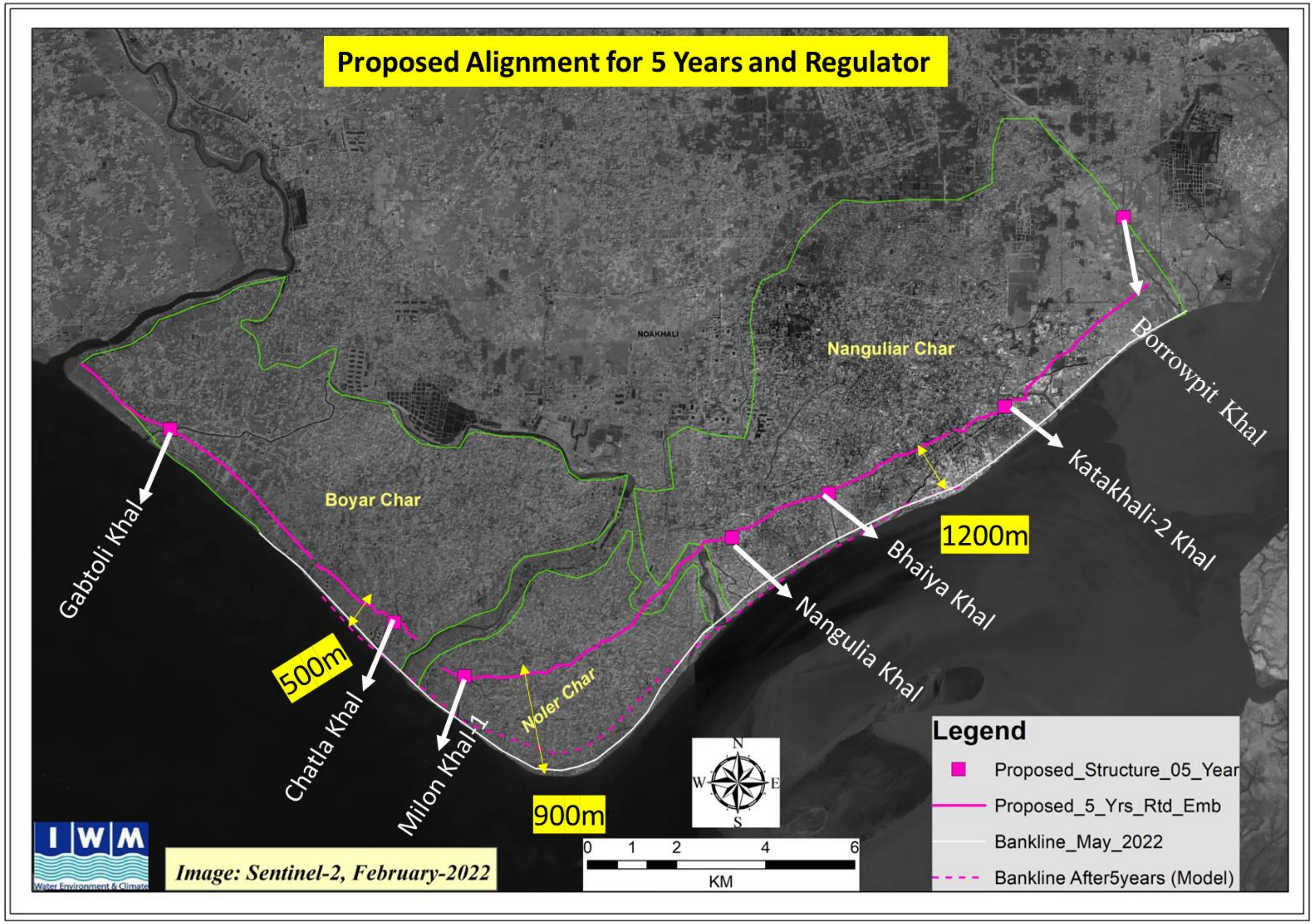


Figure 6.3: Proposed Alignment of embankment and regulators for 5 years

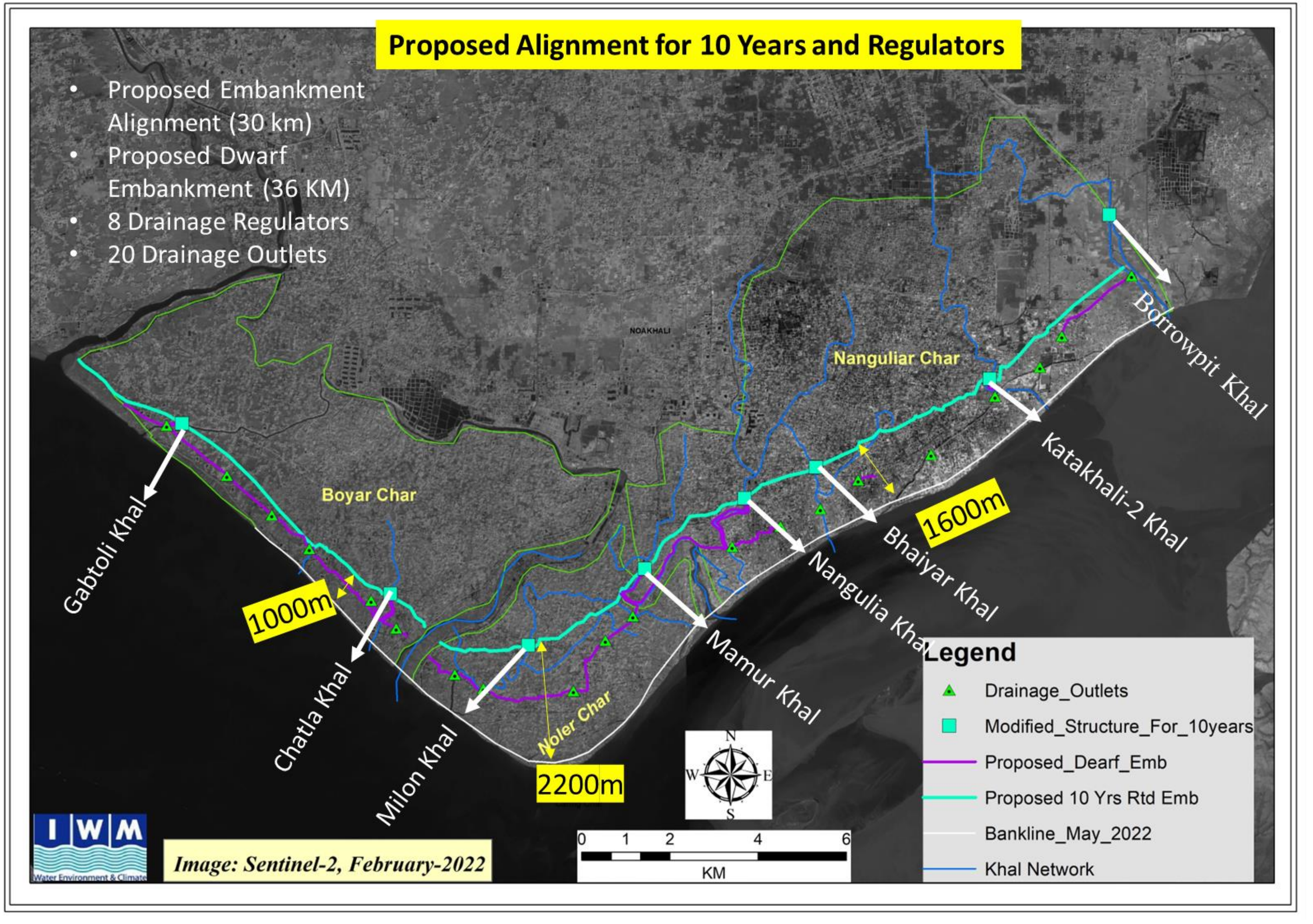


Figure 6.4: Proposed Alignment of embankment and regulators for 10 years

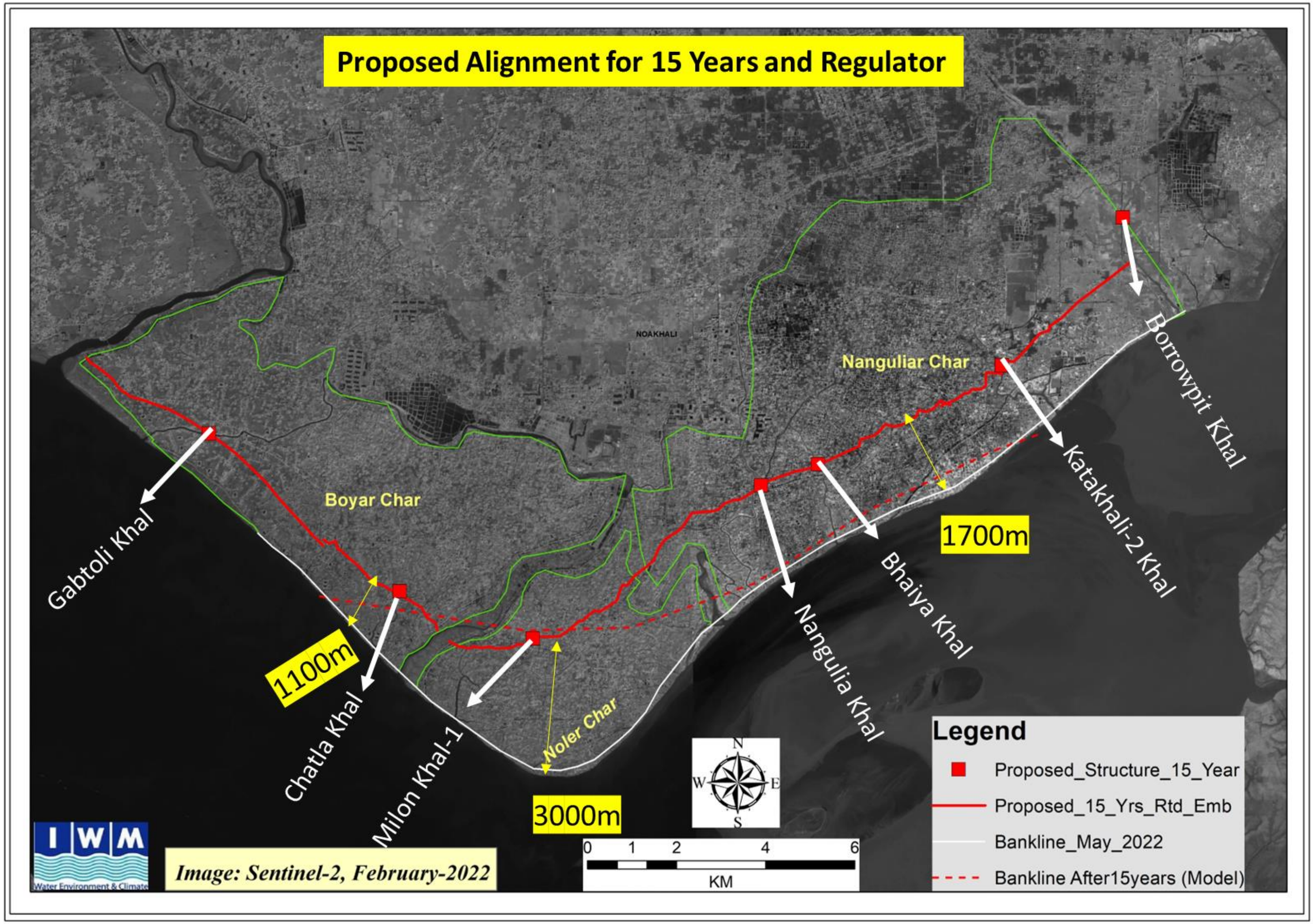


Figure 6.5: Proposed Alignment of embankment and regulators for 15 years

6.4 Alignment for Dwarf Embankment

The proposed Embankment alignment is considered for 10 and 15years shows that a huge amount of CDSP area in Noler Char and Boyar char will be unprotected and will be affected by even in high spring flood damaging crop fields, infrastructure and daily livelihood of the people residing outside the embankment protection area. Considering this problem, a dwarf embankment may be proposed as a temporary solution in order to protect the area outside the proposed embankment. Figure 6.4 shows the proposed Dwarf Embankment alignment which is considered with a setback distance of 520m near Boyar char and 1300m in Noler Char and Char Nanguliar. The length of the proposed Dwarf Embankment is 27 Km for 10 years. There are some existing Roads which are used as a Dwarf Embankment, but some improvement or re-sectioning is required. Therefore total 14.57 km re-sectioning is required. Table 6.3 shows the detail of proposed dwarf embankment for 10 years proposed embankment alignment.

Table 6.3 Proposed Alignment of Dwarf Embankment

Name of the Char	Dwarf Embankment Length (Km)	Re-sectioning of Embankment
Noler Char	16.9	14.57
Nangulia Char	3.4	
Boyer Char	6.7	
Total	**27.00**	**14.57**

- **Drainage outlet:** Dwarf embankment will be constructed as secondary protection to safe agricultural land from regular tidal inundation. Due to continuous dwarf embankment there will be drainage congestion in the agricultural land in monsoon and require proper drainage outlet which marked 20.

Location	Total (Nos)
Boyerchar	7
Noler Char	5
Nangulia Char	8
Grand Total:	**20**

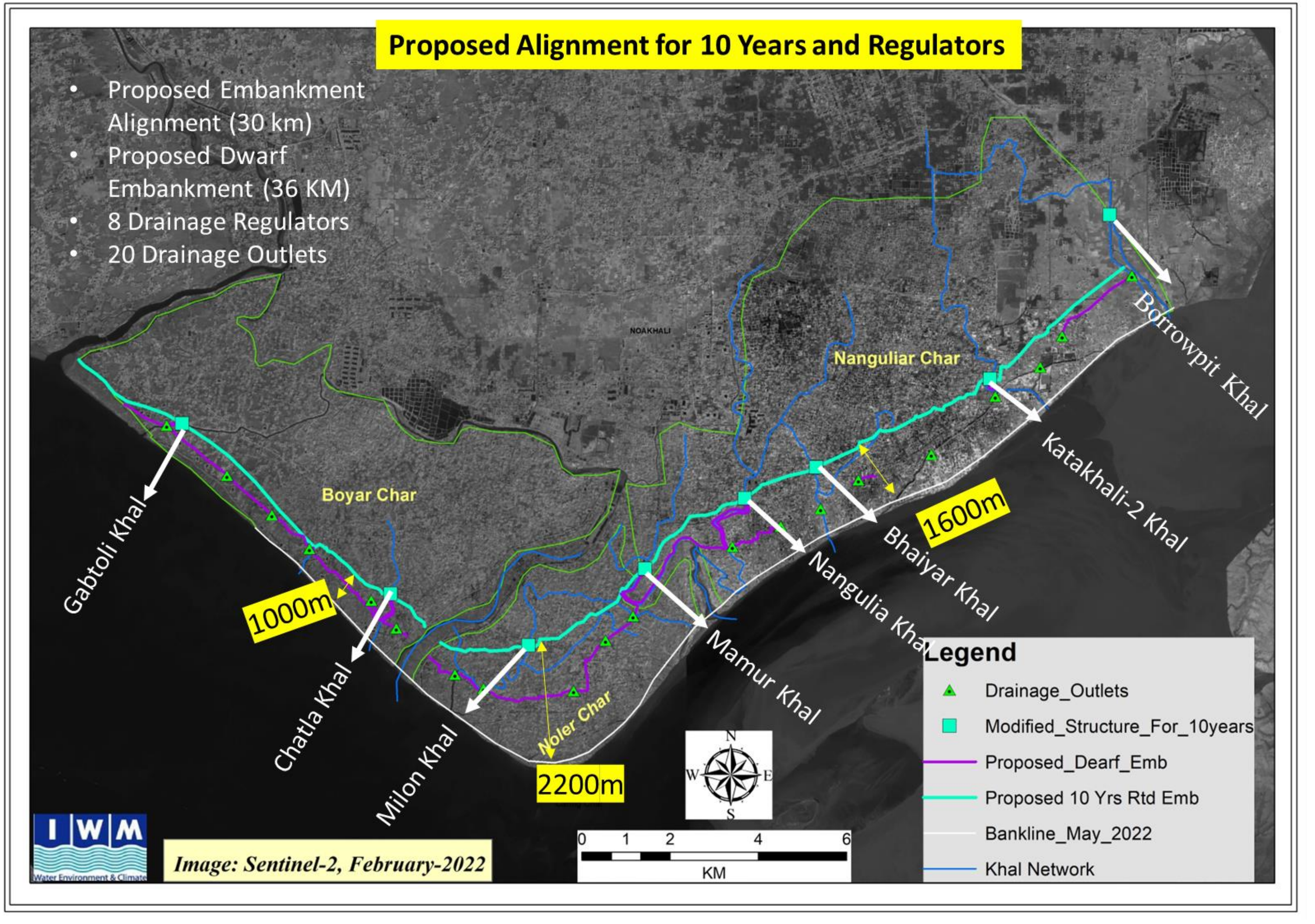


Figure 6.6 Proposed 10 years Alignment of Dwarf Embankment

6.5 Proposed Shore Protection Work

Morphological model result shows that after 5 years, l0 years, 15 years and 20 years, the maximum bank line shifting at Noler Char is found about 2 km, 4 km, 5.5 km and 7.6 km respectively. It is observed a huge productive land as well as important infrastructure, road network developed under CDSP project will be lost in future if any protection measures is not taken up. Under CDSP-IV project, around 254 km road network, 203 nos Bridge/Culvert, 36 Cyclone Shelter cum School and many others infrastructure were constructed which are under threat due to the severe erosion. As erosion rate is very high (756m/year) at Noler Char area as shown in Figure 6.7, an immediate protection measure is considered for the 5 km reach along the shore line of Noler char. Protection measure for Boyer Char and Char Nagulia can be taken in later stage. A detailed feasibility study is required for planning and design of erosion mitigation measures along the shoreline of Boyer char and Char Nangulia.

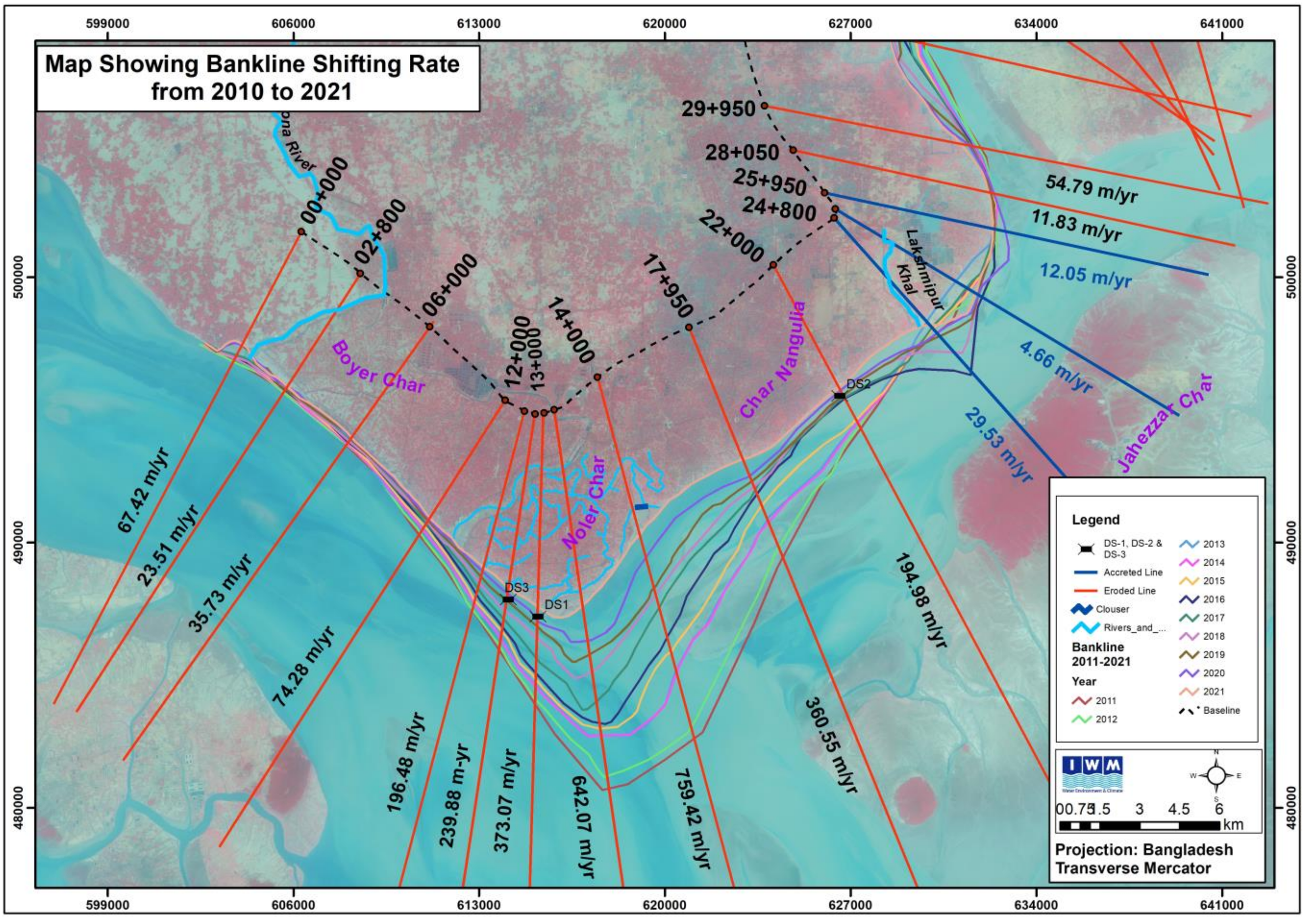


Figure 6.7 Map showing the Average Shoreline Shifting Rate at CDSP area from 2011 to 2021

7. PLANNING AND DESIGN OF EMBANKMENT AND REGULATORS & COSTING

7.1 Design consideration for Structure

Total 08 (eight) drainage structures have been proposed considering 10 years proposed embankment alignment from which 02(Two) in Boyer Char, 01 (one) in Noler Char and 05 (five) in Char Nangulia. Following design considerations are for Hydraulic design for the 08 (eight) proposed drainage structure.

- Drainage structure should be adequate for passage of flood discharge of 10-year return period with 5 days cumulative rainfall.
- Adequate depth of water should prevail during dry season;
- Hydraulic design of these 05 (Five) drainages structures have been fixed in a way that improvement of drainage recession and irrigation purpose have to be well addressed. Flash water from the upstream will act as a protector to the sediment including salinity intrusion;
- The adequate number of gate have been derived by using hydrodynamic modelling.

Preliminary design involves the following process.

7.1.1 Catchment Delineation

Drainage catchment has been delineated considering the reduced area after 10 years due to embankment construction on the basis of existing land level of the polder area, alignment of existing khals, hydraulic structures, and other topographical features including road networks, satellite Images and field investigation and consultation with the local people.

7.1.2 Selection of Design Flood Event

The study area is influenced by the rainfall stations namely Noakhali, Hatiya and Feni. Rainfall station Hatiya has the highest weight for Noler Char, Boyar Char and Char Nangulia. Thus, Hatiya station has been selected for frequency analysis of rainfall. Historical rainfall data from 1967 to 2015 has been collected for all the stations **Figure 7.1**. Yearly maximum 5-days cumulative rainfall has been calculated from the daily rainfall data. Then these 5-days cumulative rainfall is used for frequency analysis using Gumbel, Log Normal and Log Pearson Type-III distribution methods. Usually 5-days 10-yr rainfall event is considered for water management projects of BWDB. Analysis shows that rainfall of 2008 is the 5-days 10-yr rainfall event for Hatiya station. Thus, rainfall of 2011 has been selected as design rainfall event to simulate the rainfall run-off model.

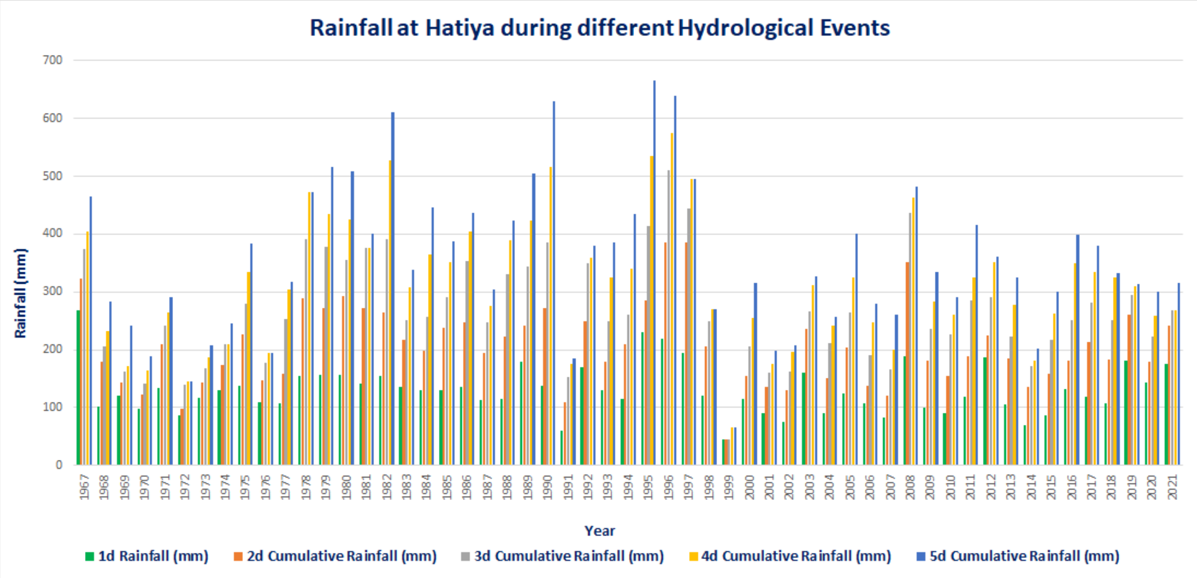


Figure 7.1 Rainfall Analysis for Hatiya Rainfall Station from 1967-2021

7.1.3 Assessment of Rainfall Run-Off and Preliminary Design Parameter of the Structure

Rainfall run-off model (NAM) is applied to estimate Runoff of each catchment. Information of drainage catchment and rainfall data for the design rainfall event are used as input data to simulate the rainfall run-off model (NAM). The mean areal rainfall runoff for each river catchment is assessed from the simulation result.

Table 7.1 : Preliminary Design parameter for Structure

Area Name	Khal Name	Easting (BTM_X)	Northing (BTM_Y)	Khal width, m	Area (sqkm)	Discharge at Outfall (m^3/s)	Number of Vent
Noler char	Milon Khal	614991.82	490556.38	30	7.95	21.75	4
Nanguliar char -1	Mamur Khal	617683.60	492497.22	30	4.10	11.22	2
Nanguliar char -2	Nangulia Khal	619948.36	494093.57	25	7.3	19.97	3
Nanguliar char -3	Bhuiyar Khal	621566.81	494713.05	25	13.5	36.94	6
Nanguliar char -4	Katakhali Khal-2	625503.73	496798.10	40	22.5	61.56	9
Nanguliar char -5	Borrowpit Khal	628217.78	500520.65	20	7.35	20.11	3
Boyer Char	Chatla Khal	611914.69	491926.46	20	9.89	27.06	3
Boyer Char	Gabtoli Khal	607188.28	495787.15	40	16.00	55.2	9

All this design parameters are from preliminary analysis thus a detailed feasibility study is recommended during implementation.

7.2 Costing of proposed Embankment and Structures

A tentative cost for proposed interventions is given in Table 7.2. It is mentioned that the costing may vary with actual design and foundation treatment.

Table 7.2 Costing for Proposed Structures

SL.	Structure Type	Khal Name	Unit	Size	Unit Cost (Crore Taka)	Costing (Crore Taka)
1	Proposed Embankment for 10 years alignment		Km	**30**	1.75	52.5
2	Proposed Dwarf Embankment		Km	27	0.66	17.82
3	Re-sectioning of Existing Road		Km	14.57	0.4	5.828
4	4-Vent Regulator at Noler Char	Milon khal	No. of Vents	4		5.83
5	2-Vent Regulator at Char Nangulia	Mamur Khal	No. of Vents	2		4.00
6	3-Vent Regulator at Char Nangulia	Nangulia Khal	No. of Vents	3		4.84
7	6-Vent Regulator at Char Nangulia	Bhuiyar Khal	No. of Vents	6		8.00
8	9-Vent Regulator at Char Nangulia	Katakhali Khal -2	No. of Vents	9		12.58
9	3-Vent Regulator at Char Nangulia	Borrowpit Khal	No. of Vents	3		4.84
10	3-Vent Regulator at Boyer Char	Chatla Khal	No. of Vents	3		4.84
11	9-Vent Regulator at Boyer Char	Gabtoli Khal	No. of Vents	9		12.58
12	Drainage Outlets (pipe sluice: 1- vent, dia 1.20m)		No. of Vents	20	0.43	8.60
	Total Cost					**142.258**

8. SELECTION OF CHARS FOR FUTURE DEVELOPMENT

8.1 Potential chars for development

The Meghna Estuary is morphologically very dynamic and changes its planform in every year. The estuary is being shaped by interactions between tide, upstream water flow, sediment transport, wind and waves. The formation of Chars in the tide dominating delta is a complex system. Several million people live in these chars which are exposed to natural hazards like cyclone, erosion, flood, drainage congestion etc. However, climate change worsens these vulnerabilities. In the Meghna Estuary two types of chars are found. Some chars emerge during low tide which are called submergible chars and some chars do not emerge during the high tide is called visible/stable chars. Initially, the process of land/char's formation becomes visible when a char emerges during low tide. Gradually the elevation of the chars increases and becomes higher than the average low tide. Over the time elevation increases and the coverage of the char surfaces changes. It is first colonized by Uri-grass (Portaresia coarctata). (CEGIS). In most of the cases, Bangladesh forest department then transplants mangrove for the quick development of this chars. After rise a certain level, very close to the average high tide mangrove forest dominate the land surface and people starts settle there. The elevation of the chars depends upon the tidal range of the surrounding area. Chars' maturity depends on availability of sediment and favourable environment for sedimentation. The time required for the development of land from its first emergence above low tide level to being fully covered by mangrove forests or the initiation of settlements, varies from place to place. The fastest land development as observed from time-series satellite imagery is 8 years within the Shahbajpur Channel. (CEGIS).

In this study, potential/stable chars for future development are identified from review of previous study, satellite images analysis, morphological model prediction and stakeholder consultation. The stable chars that are selected for future development considering the following criteria:

- Erosion Vulnerability from satellite images analysis and model prediction.
- Maturity of Char (15~20 years)
- Accessibility to the char and its location
- Population Density
- Land Level (major area above or close to High-High WL)
- Water Level
- Tide
- Salinity or Water Quality
- Bio Diversity or Ecological Critical Zone

Considering these criteria, Total eighteen (18) chars are selected which are stable as shown in Table 8.1 and Figure 8.1. At the eastern part of Meghna Estuary two chars (2) named Bhasan char and Char Moksumul Hakim are found stable. At the middle part of MES area total eight chars (8) are stable named: Banar Char, Char Abdullah, Char Jahiruddin, Char Kolatoli, Char

Mozzammel, Dhal Char (CDSP-V), Domer Char and Andhar Char. In the western part of Meghna Estuary Char Kukri Mukri, Char Lakshmi/ Char Bangla, Char Nizam/ Puber char, Char Sakuchi/ Char Kalkini, Dhal Char, Sonar Char e.t.c are found stable for future development.

IWM has been working on water field for a long time. For satellite images analysis IWM used Landsat satellite Image (30x30m resolution) for year 2000 to 2014 and Sentinal-2 Satellite Image (10x10m regulation) for the year 2015 to 2020. As it is mentioned earlier that the study area is very much dynamic due to its' geographical location and accretion and erosion is very common process in the study area. The historical image analysis shows the level of accretion and erosion pattern. There is a limitation in this analysis such as the bank line of corresponding images doesn't mention the time whether it is in low tide or high tide which may affect most. Because the chars of the study area are being inundated during high tide. So, the bank line which has been considered as the only demarcation from year to year may have erroneous information due to phase lack. All the images were taken in same phase and results has shown accordingly. Although the clusters of chars are very adjacent to each other but the accretion and erosion patterns are different from char to char due to the influence of Hatiya Channel, Shahbazpur Channel and Manpura-Hatiya Channel as per its vicinity.

Table 8.1: List of Potential Chars in Meghna Estuary for future development

Zone	SL No.	Char_Name	2020 (Area_sqkm)	Year of Existence	Remarks
East Part	1	Bhasan Char	63.32	2005-2020	
	2	Char Moksumul Hakim	36.67	2000-2020	CDSP-V
	3	Urir Char	124.5	1984-2020	CDSP-IV
Middle Part	4	Banar Char	20.89	2005-2020	
	5	Char Abdullah	11.75	2010-2020	
	6	Char Jahiruddin	114.25	2005-2020	
	7	Char Kolatoli	26.56	2005-2020	CDSP-V
	8	Char Mozzammel	36.68	2005-2020	CDSP-V
	9	Dhal Char (CDSP-V)	19.55	2005-2020	CDSP-V
	10	Domer Char	19.11	2005-2020	
	11	Nijhuim Dwip	46.29	2005-2020	
West Part	12	Andhar Char	7.65	2005-2020	
	13	Char Kukri Mukri	51.72	2005-2020	
	14	Char Lakshmi/ Char Bangla	19.05	2005-2020	
	15	Char Nizam/ Puber Char	21.92	2005-2020	
	16	Char Sakuchi/ Char Kalkini	11.37	2005-2020	
	17	Dhal Char	13.72	2005-2020	
	18	Sonar Char	21.85	2005-2020	

Analysis for Andhar Char:

According to the Satellite image of 2000, Andhar Char was occupied only about 5.6 sqkm of land which is mostly the center portion of today's total area. But it is seen that in between 2000 to 2005 there was accretion which was about 0.56 sqkm of land mostly from north-eastern part which was about 300 m from the previous bank line. Afterward up to 2005 there was the erosion pattern observed which was about 0.01 sqkm of land which was mostly the south-eastern part of the char, and the bank line shifting was about 850m from the previous bank line. However, in between 2010 to 2020 there was accretion which was about 1.50 sqkm of land mostly from south-eastern corner of the car which was about 1.4 km from the previous bank line. Since the char is situated at the dynamic zone of Shahbazpur Channels then it is hard to say the stability of this char.
But after analyzing these images, experience of field visits and opinion of local stakeholders indicates that the char is stable and naturally it may accrete more land to its surrounding areas. The figure is representing the bar chart of net area of on successive 5 years' time interval and Figure is representing the bank line of Andhar Char from 2000 to 2020. The the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.2: Trend of Erosion-Accretion pattern of Andhar char from 2000~2020

Andhar Char		
Year	Area (sqkm)	Remarks
2000	5.60	
2005	6.16	0.56 sqkm accretion in between 2000 to 2005
2010	6.15	-0.01 sqkm erosion in between 2005 to 2010
2015	7.44	1.29 sqkm accretion in between 2010 to 2015
2020	7.65	0.21 sqkm accretion in between 2015 to 2020

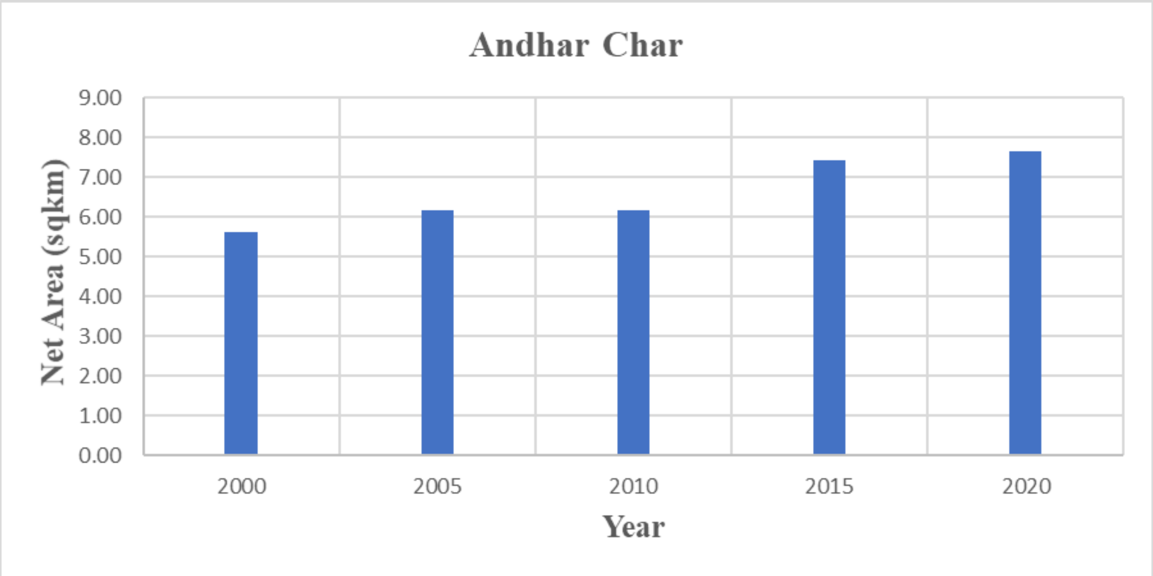


Figure 8.1: Graphical representation of accretion and erosion of Andhar Char

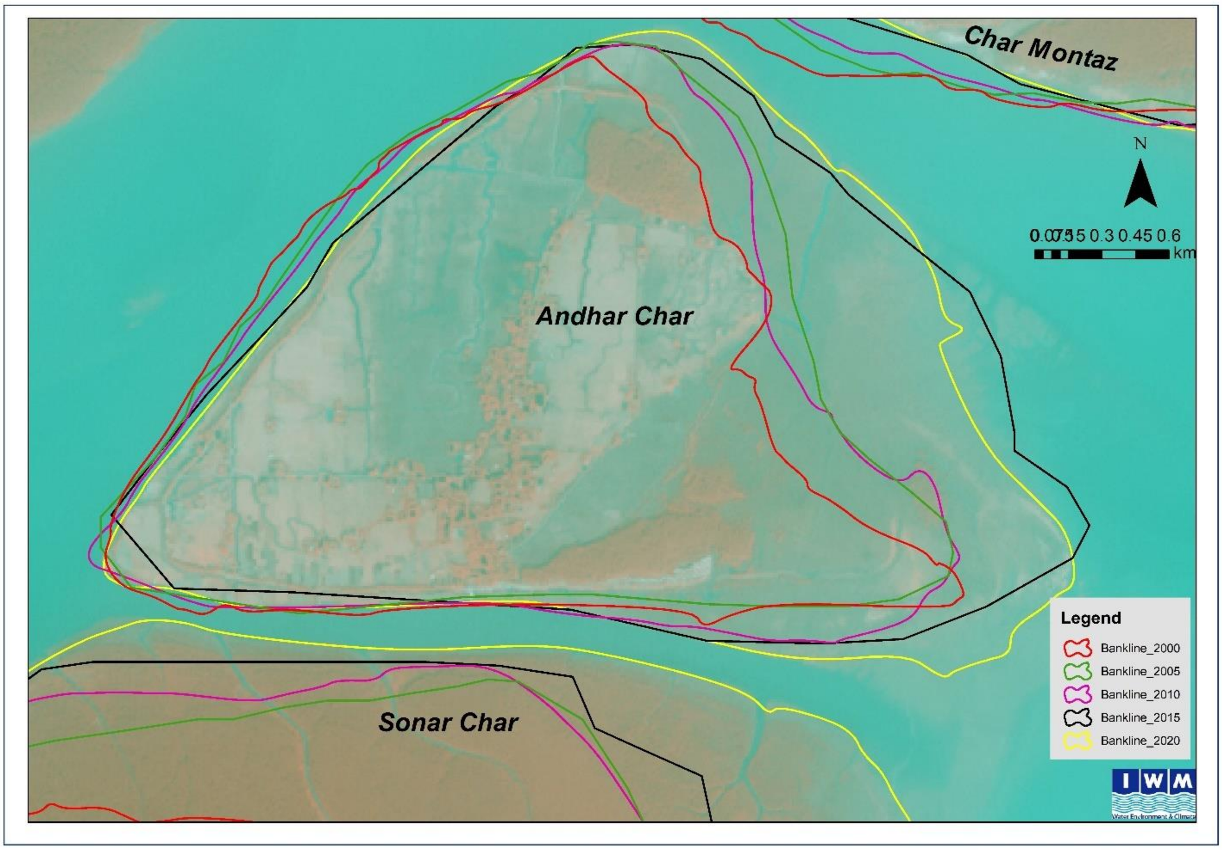


Figure 8.2: Bankline Change of Andhar Char

Water level during high spring tide is 1.92m and 3.12m during dry and monsoon period respectively. The government settled some 240 households in 2015-2016 and 245 household in 2019-2020 under Abashon/Asrayan Project. Tidal water inundated on the crop land during high tide time in monsoon and they lost standing crops. The study area is hydraulically very dynamic in nature, and it is hard to make any concrete prediction of riverbank erosion in near future along the boundary. The trend of the sedimentation and erosion pattern has been assessed through analyzing the above satellite images. ***But it is better to have another separate monitoring study on erosion vulnerability in the study area just before the implementation of the project.***

Analysis for Banar Char

According to the Satellite image of 2000, Banar Char was occupied only about 11.63 sqkm of land which is mostly the center portion of today's total area. But it is seen that in between 2000 to 2020 there was erosion which was about 2.36 sqkm of land mostly from western part which was around 350 m . For the last 20 years accretion tendency was found at the eastern side of the Banar char and it was around 11.62 sqkm. Since the char is situated at the dynamic zone of Shahbazpur and Manpura-Hatiya Channels then it is hard to say the stability of this char. **But after analyzing these images, experience of field visits and opinion of local stakeholders indicates that the char is stable and naturally it may accrete more land to its surrounding areas**. The Figure 8.3 is representing the bar chart of net area of on successive 5 years' time interval and Figure 8.4 is representing the bank line of Banar Char from 2000 to 2020. The Table 8.3 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.3: Trend of Erosion-Accretion pattern of Banar char from 2000~2020

Banar Char

Year	Area (sqkm)	Remarks
2000	11.63	
2005	10.08	-1.55 sqkm erosion in between 2000 to 2005
2010	9.27	-0.81 sqkm erosion in between 2005 to 2010
2015	16.32	7.05 sqkm accretion in between 2010 to 2015
2020	20.89	4.58 sqkm accretion in between 2015 to 2020

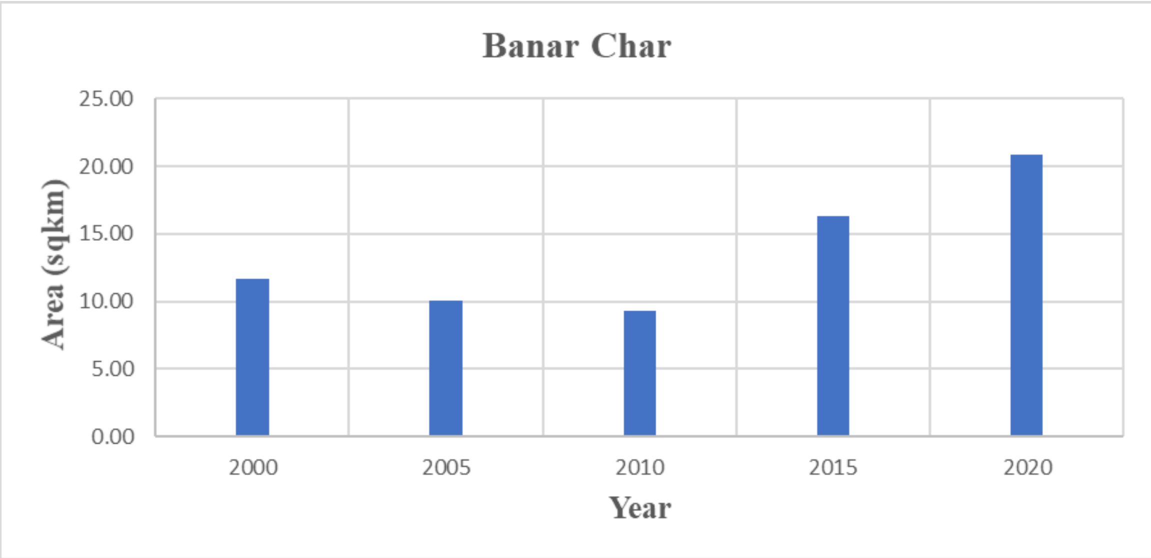


Figure 8.3: Graphical representation of accretion and erosion of Banar Char

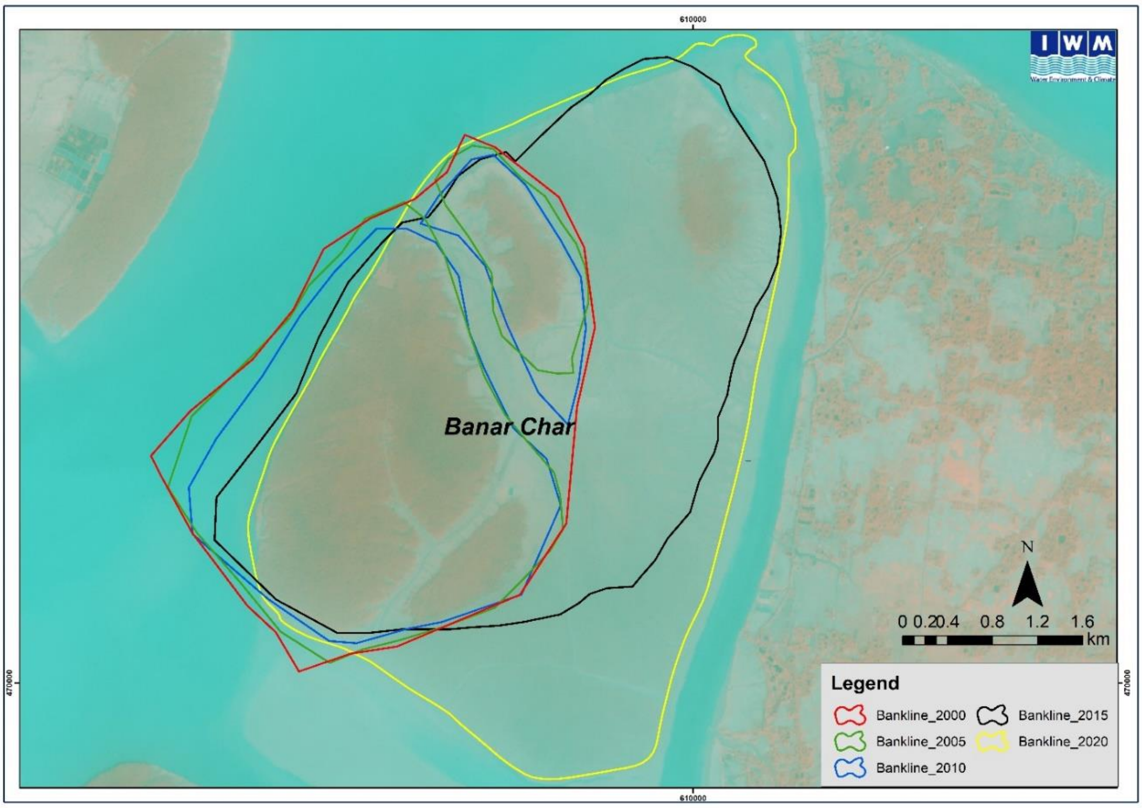


Figure 8.4:Bankline Change of Banar Char

Satellite Image Analysis for Bhasan Char

According to the Satellite image of 2005, Bhasan Char occupied only about 16.10 sqkm of land which is mostly the center portion of today's total area. But it is seen that in between 2000 to 2020 there was accretion which was about 63.32 sqkm of land mostly at the north part in between Jahizzer char and Sandwip. The Figure 8.5 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.6 is representing the bank line of Bhasan Char from 2000 to 2020. The Table 8.4 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020. This char is extended its area for the last 15 years and under the development of Bangladesh Army.

Table 8.4: Trend of Erosion-Accretion pattern of Bhasan char from 2000~2020

Bhasan Char		
Year	Area (sqkm)	Remarks
2000	0.00	
2005	16.10	16.10 sqkm accretion in between 2000 to 2005
2010	26.09	9.99 sqkm accretion in between 2005 to 2010
2015	53.86	27.77 sqkm accretion in between 2010 to 2015
2020	63.32	9.45 sqkm accretion in between 2015 to 2020

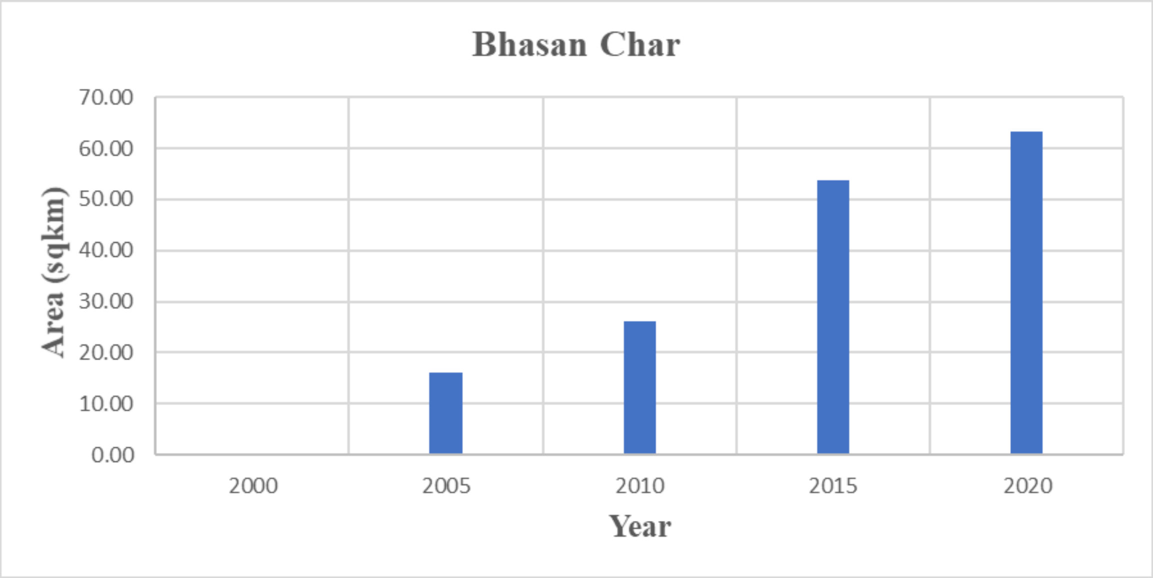


Figure 8.5: Graphical representation of accretion and erosion of Bhasan Char

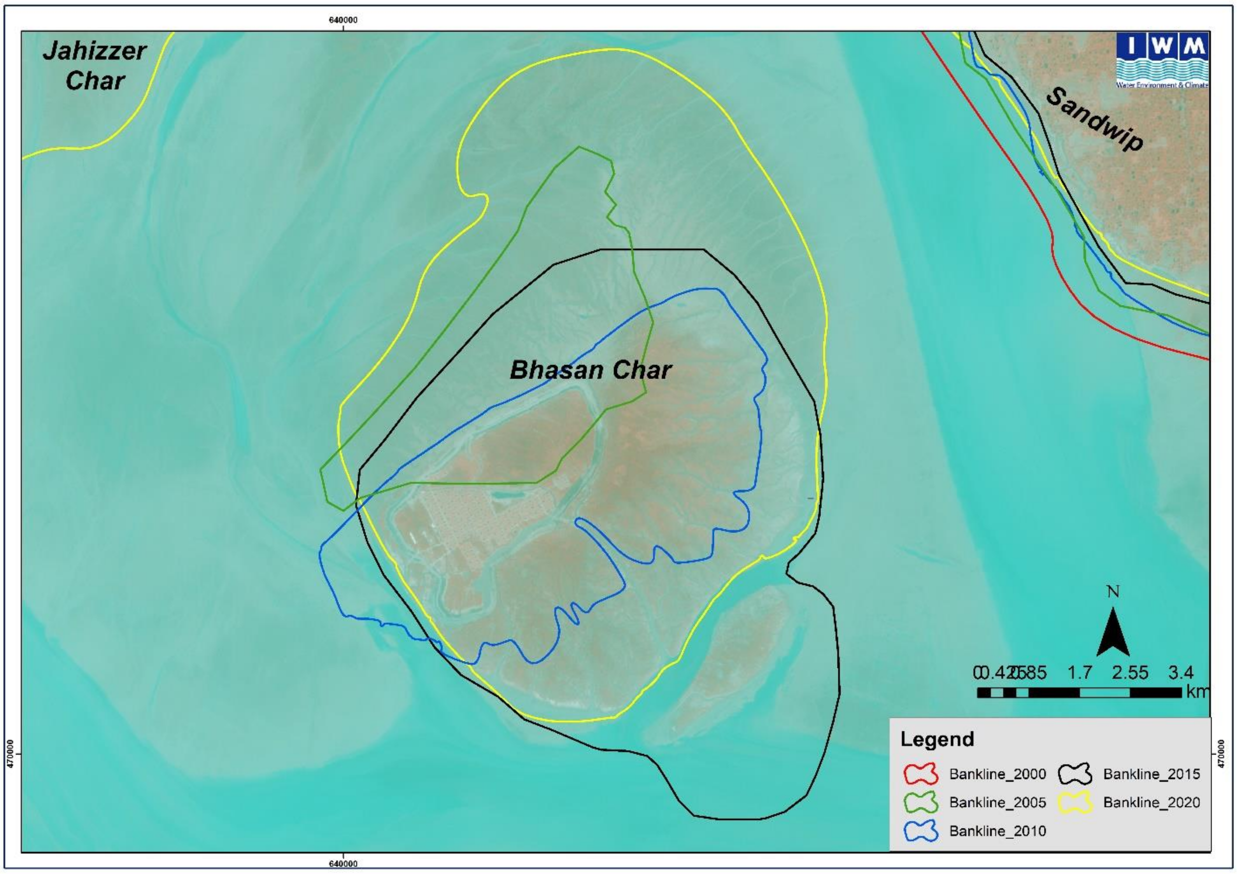


Figure 8.6: Bankline Change of Bhasan Char

Satellite Image Analysis for Char Abdullah

Char Abdullah was basically developed around 2010. According to the Satellite image of 2010, Char Abdullah was occupied only about 9.27 sqkm of land which is mostly the center portion of today's total area. But it is seen that in between 2010 to 2015 there was erosion which was about 3.90 sqkm of land mostly at the north part (Head erosion) of the char. But between 2015 to 2020 there was accretion which was about 6.38 sqkm of land mostly at the north part of the char and there was some tail erosion at the south side of the char and there is another smaller char developing at the east side of the char. The Figure 8.7 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.8 is representing the bank line of Char Abdullah from 2000 to 2020. The Table 8.5 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020. During 2010 to 2015 huge erosion was occurred. ***Therefore, this char is excluded from the list of stable chars***

Table 8.5: Trend of Erosion-Accretion pattern of Abdullah char from 2000~2020

Char Abdullah		
Year	Area (sqkm)	Remarks
2000	0.00	
2005	0.00	0.00 Char did not Exist
2010	9.27	9.27 sqkm accretion in between 2005 to 2010
2015	5.37	-3.90 sqkm erosion in between 2010 to 2015
2020	11.75	6.38 sqkm accretion in between 2015 to 2020

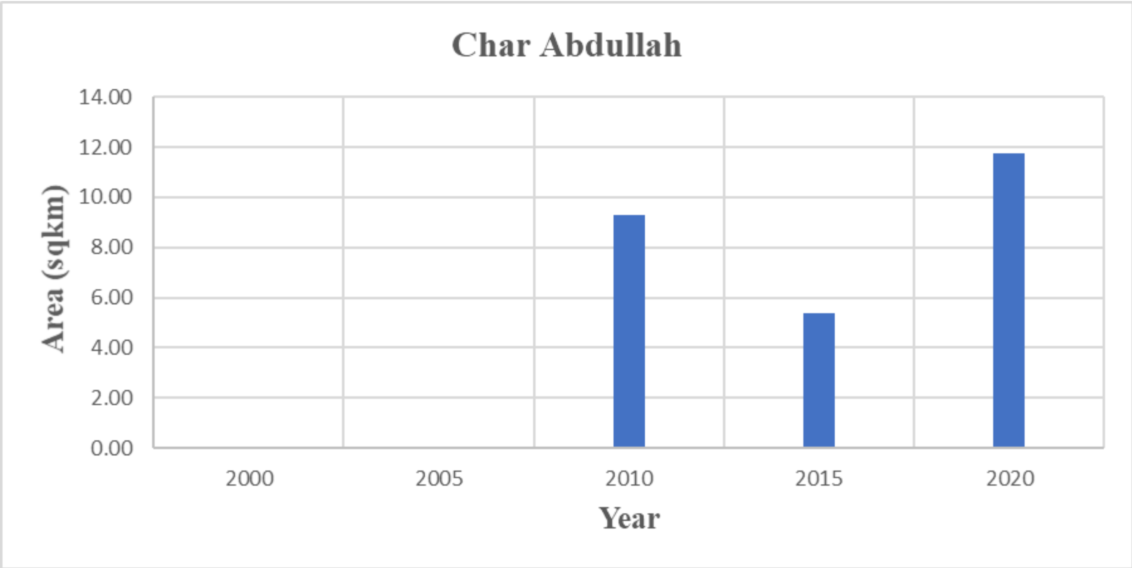


Figure 8.7: Graphical representation of accretion and erosion of Char Abdullah

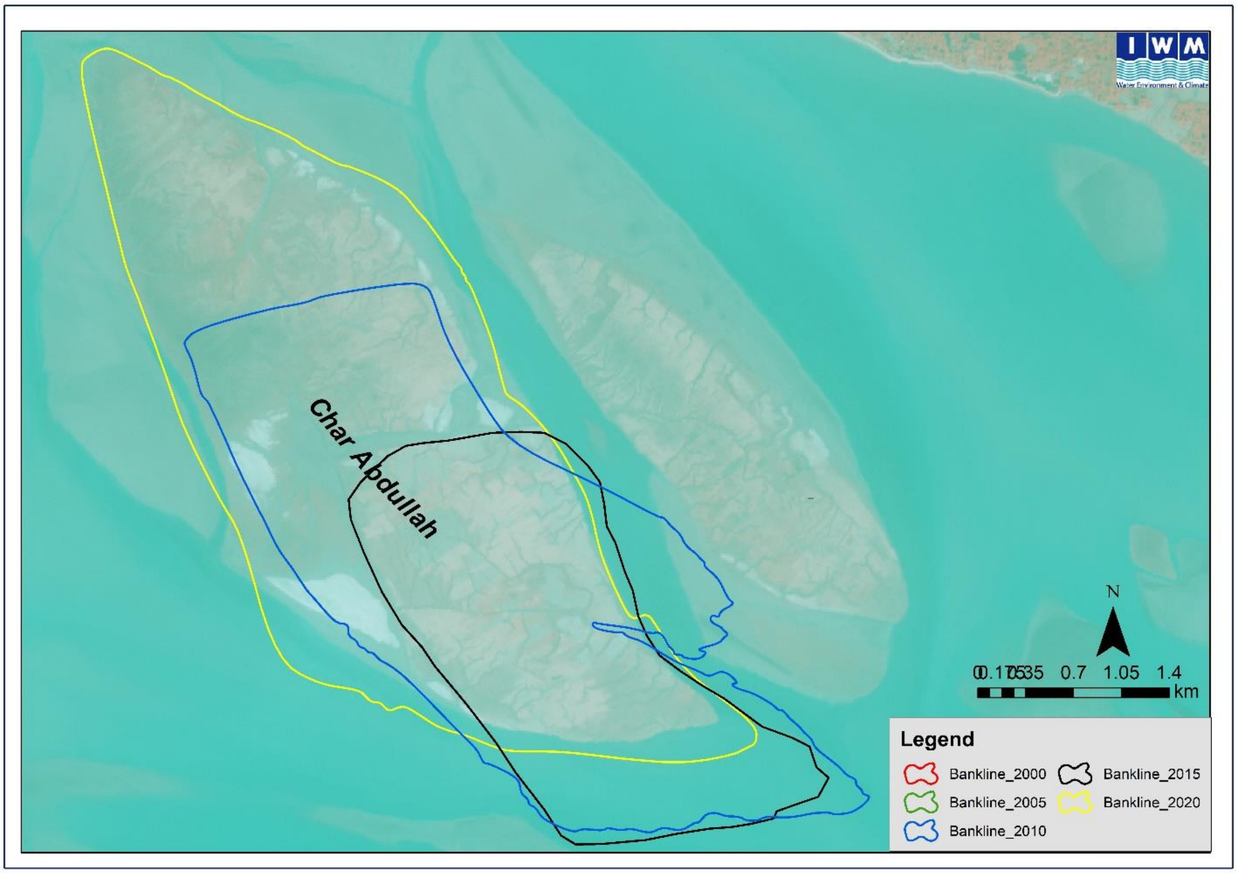


Figure 8.8: Bankline Change of Char Abdullah

Satellite Image Analysis for Char Jahiruddin

According to the Satellite image of 2000, Char Jahiruddin occupied only about 80.86 sq km of land which is mostly the northern portion of today's total area. But it is seen that in between 2000 to 2020 there was net accretion which was about 33.65 sqkm of land mostly at the southern part of the char. But in the meantime, there was erosion occurred at the northern part of the char mainly the head erosion along East Shabazpur Channel. The Figure 8.9 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.10 is representing the bank line of Char Jahiruddin from 2000 to 2020. The Table 8.6 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020. ***Enormous erosion is occurring at the upstream of char Jaziruddin that's why this char is also excluded from the list of Stable Char.***.

Table 8.6: Trend of Erosion-Accretion pattern of Char Jahoruddin from 2000~2020

Char Jahiruddin		
Year	Area (sqkm)	Remarks
2000	80.86	
2005	91.26	10.40 sqkm accretion in between 2000 to 2005
2010	92.94	1.68 sqkm accretion in between 2005 to 2010
2015	99.11	6.17 sqkm accretion in between 2010 to 2015
2020	114.51	15.40 sqkm accretion in between 2015 to 2020

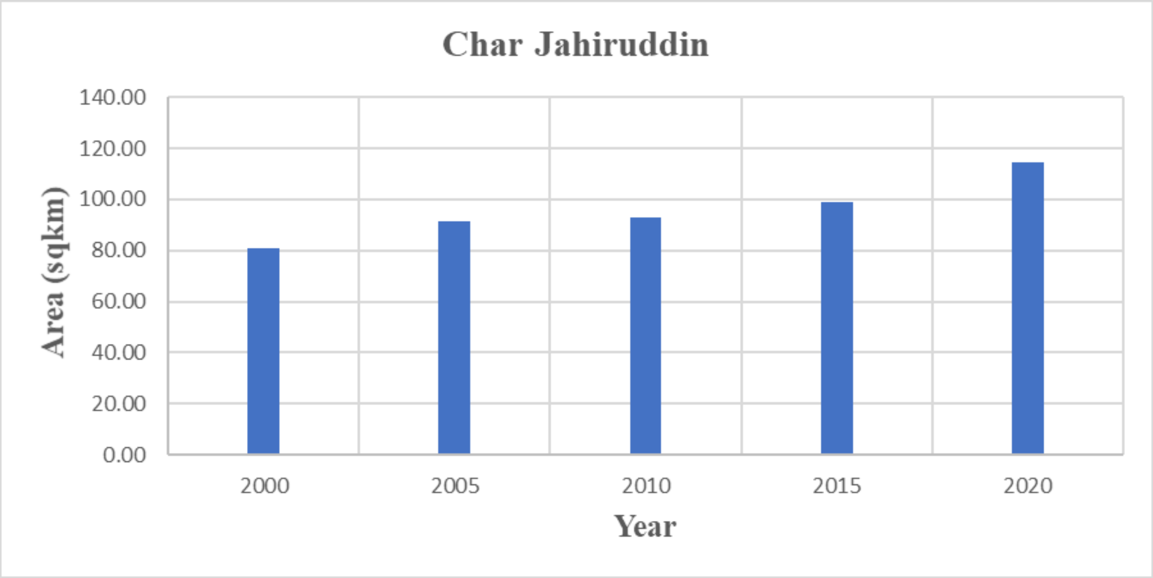


Figure 8.9: Graphical representation of accretion and erosion of Char Jahiruddin

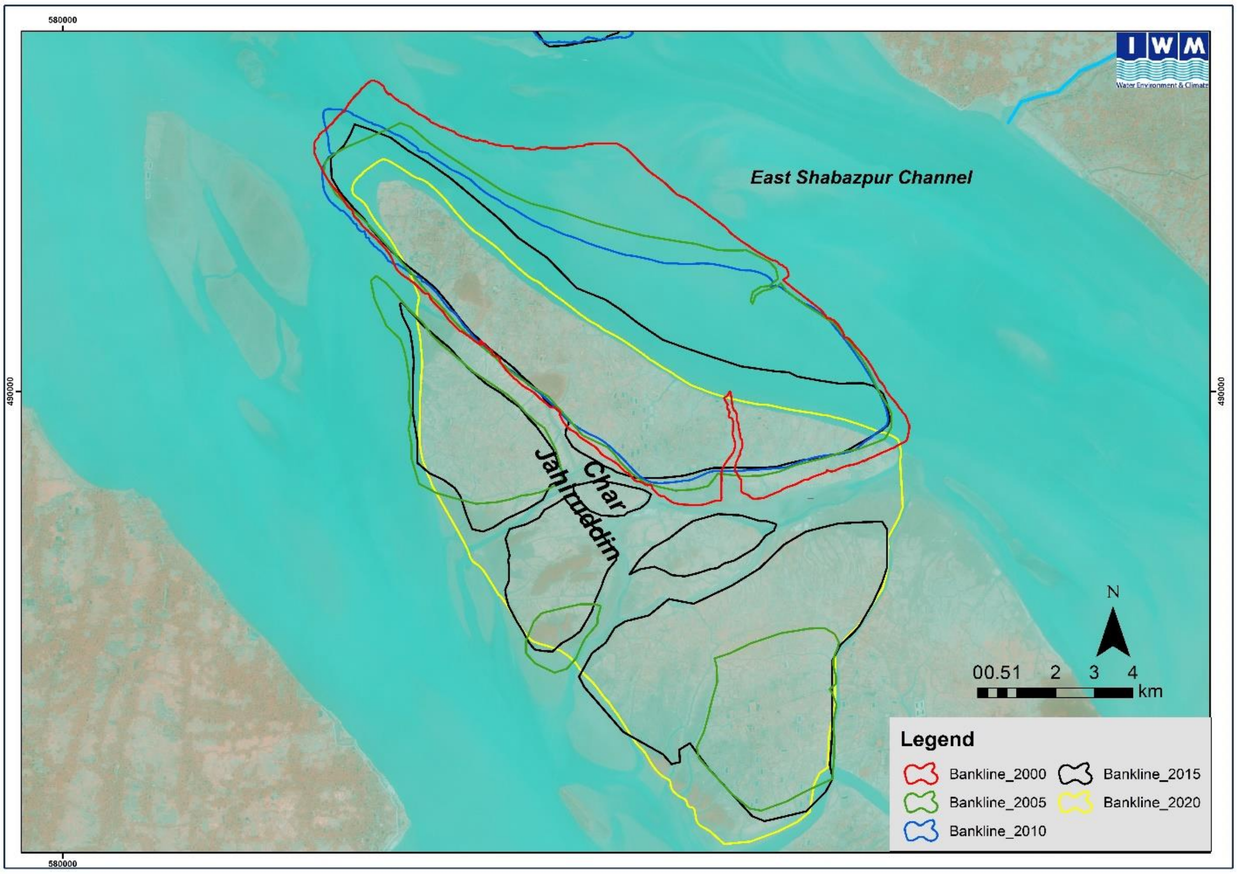


Figure 8.10: Bankline Change of Char Jahiruddin

Satellite Image Analysis for Char Mozammel

According to the Satellite image of 2000, Char Mozammel was occupied only about 22.31 sqkm of land which is mostly the southern portion of today's total area. But it is seen that in between 2000 to 2005 there was net erosion which was about 0.14 sqkm of land mostly at the southern part of the char along the East Shabazpur Channel. Afterward in between 2005 to 2020 there was net accretion which was about 14.37 sqkm of land mostly at the north-western part of the char. During this accretion period the north western part of the char was developed which is about 2.3 km from 2005 bankline. But in the meantime, there was also some erosion occurred at the southern part of the char mainly the tail erosion along East Shabazpur Channel which is about 0.6 km. Since the char is situated at the dynamic zone of Shahbazpur and Manpura-Hatiya Channels then it is hard to say the stability of this char. But after analyzing these images, experience of field visits and opinion of local stakeholders indicates that the char is stable and naturally it may accrete more land to its surrounding areas. The Figure 8.11 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.12 is representing the bank line of Char Mozammel from 2000 to 2020. Water level during high spring tide is 2.4m and 3.7m during dry and monsoon period respectively. The Table 8.7 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020. ***Continuous accretion process was occurred in this char so this is found to be stable.***

Table 8.7: Trend of Erosion-Accretion pattern of Mozammel char from 2000~2020

Char Mozammel		
Year	Area (sqkm)	Remarks
2000	22.31	
2005	22.18	-0.14 sqkm erosion in between 2000 to 2005
2010	31.13	8.96 sqkm accretion in between 2005 to 2010
2015	36.00	4.87 sqkm accretion in between 2010 to 2015
2020	36.55	0.55 sqkm accretion in between 2015 to 2020

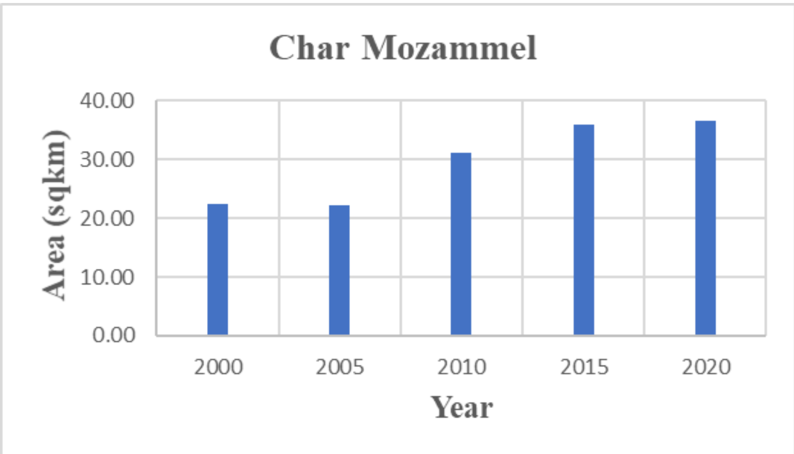


Figure 8.11: Graphical representation of accretion and erosion of Char Mozammel

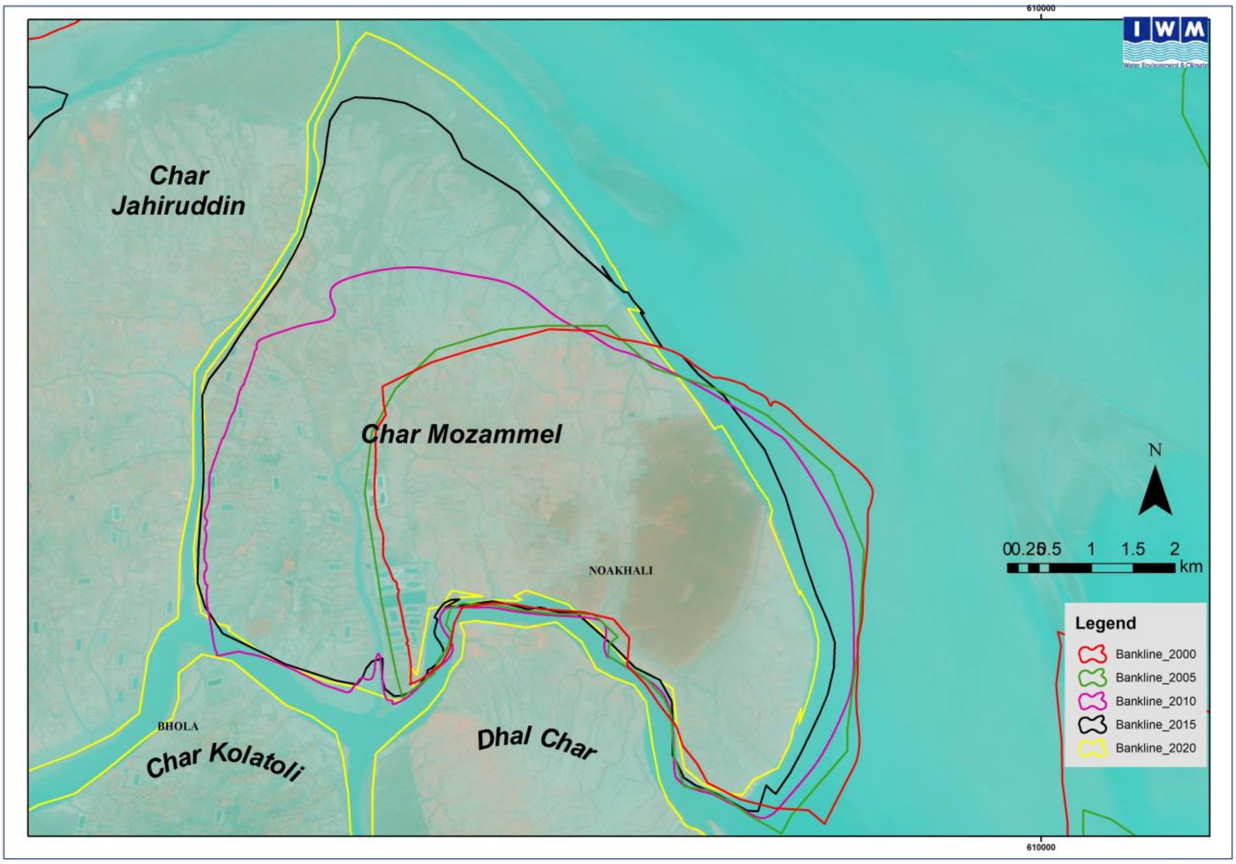


Figure 8.12: Bankline Change of Char Mozammel

Satellite Image Analysis for Char Kukri Mukri

Maximum water level during high spring tide in monsoon season is around 2.8m and during dry period it is around 1.6 m . According to the Satellite image of 2000, Char Kukri Mukri was occupied only about 39.48 sqkm of land which is mostly the center portion of today's total area. But it is seen that in between 2000 to 2020 there was net accretion which was about 12.24 sqkm of land mostly at north-western part which was about 2.00 km from the previous bank line. However, in between 2000 to 2020 there was some erosion along the east part of the char***. Since the char is situated at the dynamic zone of Shahbazpur Channels then it is hard to say the stability of this char. But after analyzing these images, experience of field visits and opinion of local stakeholders indicates that the char is stable and naturally it may accrete more land to its surrounding areas.*** The Figure 8.13 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.14 is representing the bank line of Char Kukri Mukri from 2000 to 2020. The Table 8.8 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.8: Trend of Erosion-Accretion pattern of char Kukri Mukri from 2000~2020

Char Kukri Mukri		
Year	Area (sqkm)	Remarks
2000	39.48	
2005	46.60	7.12 sqkm accretion in between 2000 to 2005
2010	49.28	2.68 sqkm accretion in between 2005 to 2010
2015	50.10	0.82 sqkm accretion in between 2010 to 2015
2020	51.72	1.62 sqkm accretion in between 2015 to 2020

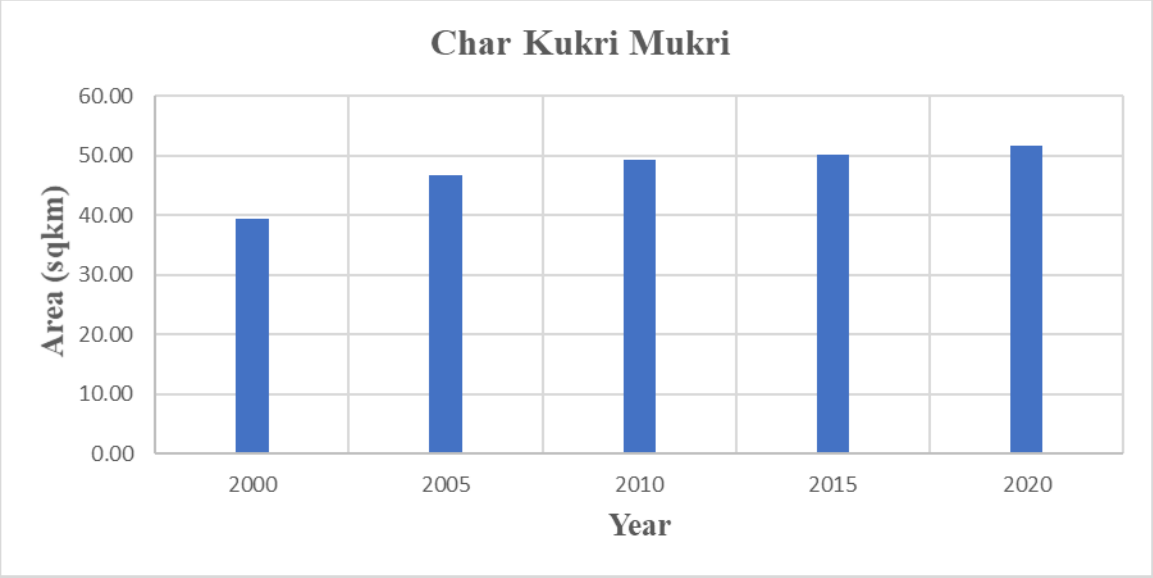


Figure 8.13: Graphical representation of accretion and erosion of Char Kukri Mukri

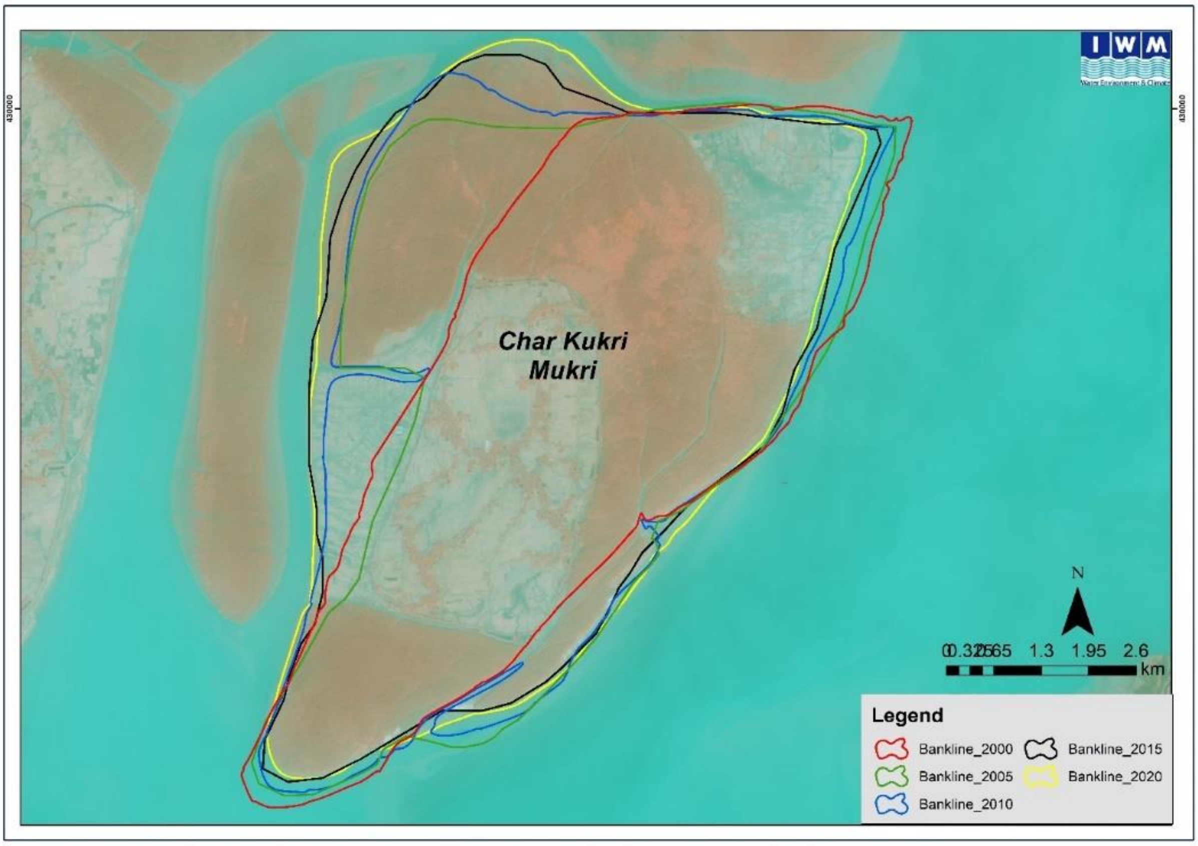


Figure 8.14: Bankline Change of Char Kukri Mukri

Satellite Image Analysis for Char Lakshmi

Maximum water level during high spring tide in monsoon season is around 3.2 m and during dry period it is around 1.6 m According to the Satellite image of 2000, Char Lakshmi was occupied only about 17.53 sqkm of land which is mostly the center portion of today's total area. But it is seen that in between 2000 to 2020 there was net accretion which was about 1.52 sqkm of land all along the char which is about 400 m from year 2000 bankliine. Since the char is situated at the dynamic zone of Shahbazpur Channels then it is hard to say the stability of this char. **But after analyzing these images, experience of field visits and opinion of local stakeholders indicates that the char is stable and naturally it may accrete more land to its surrounding areas.** The Figure 8.15 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.16 is representing the bank line of Char Lakshmi from 2000 to 2020. The Table 8.9 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.9: Trend of Erosion-Accretion pattern of char Lakshmi from 2000~2020

Char Lakshmi/ Char Bangla		
Year	Area (sqkm)	Remarks
2000	17.53	
2005	18.33	0.80 sqkm accretion in between 2000 to 2005
2010	18.64	0.31 sqkm accretion in between 2005 to 2010
2015	18.98	0.34 sqkm accretion in between 2010 to 2015
2020	19.05	0.07 sqkm accretion in between 2015 to 2020

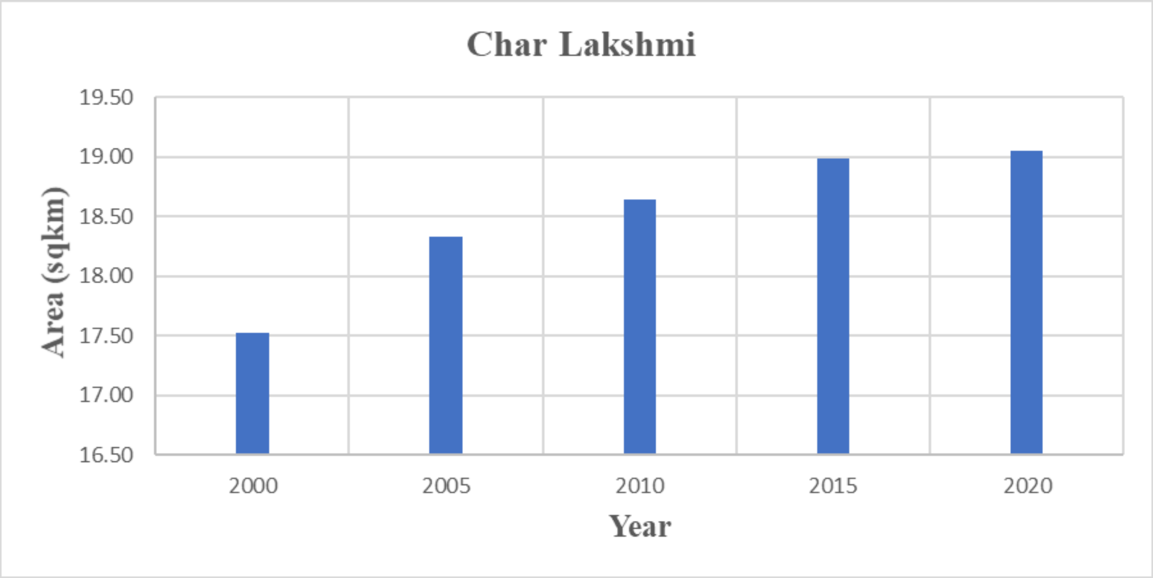


Figure 8.15: Graphical representation of accretion and erosion of Char Lakshmi/ Char Bangla

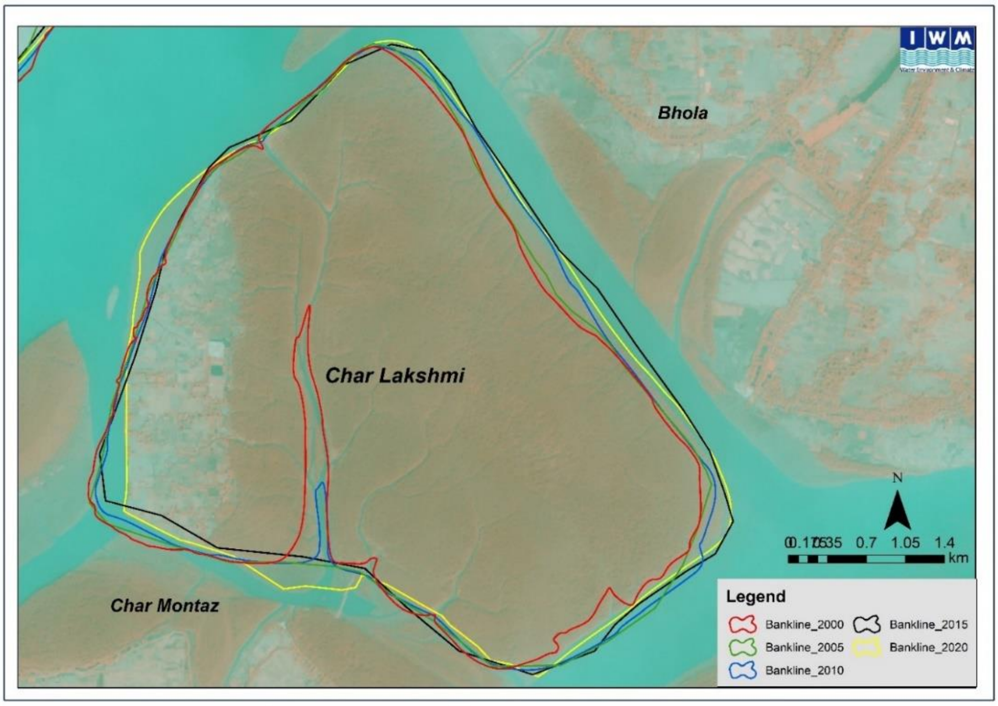


Figure 8.16: Bankline Change of Char Lakshmi/ Char Bangla

Satellite Image Analysis for Char Moksumul Hakim

Maximum water level during high spring tide in monsoon season is around 4.3m and during dry period it is around 3.8 m According to the Satellite image of 2000, Char Moksumul Hakim was occupied about 57.96 sqkm of land which is mostly the landward side of today's total area. But it is seen that in between 2000 to 2020 there was net erosion which was about 29.29 sqkm of land along the Urir char-Moksumul Hakim Channel. The Figure 8.17 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.18 is representing the bank line of Char Maksumul Hakim from 2000 to 2020. The Table 8.10 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.10: Trend of Erosion-Accretion pattern of char Moksumul Hakim from 2000~2020

Char Moksumul Hakim		
Year	Area (sqkm)	Remarks
2000	57.96	
2005	39.53	-18.43 sqkm erossion in between 2000 to 2005
2010	39.68	0.15 sqkm accretion in between 2005 to 2010
2015	37.15	-2.53 sqkm erossion in between 2010 to 2015
2020	36.67	-0.48 sqkm erossion in between 2015 to 2020

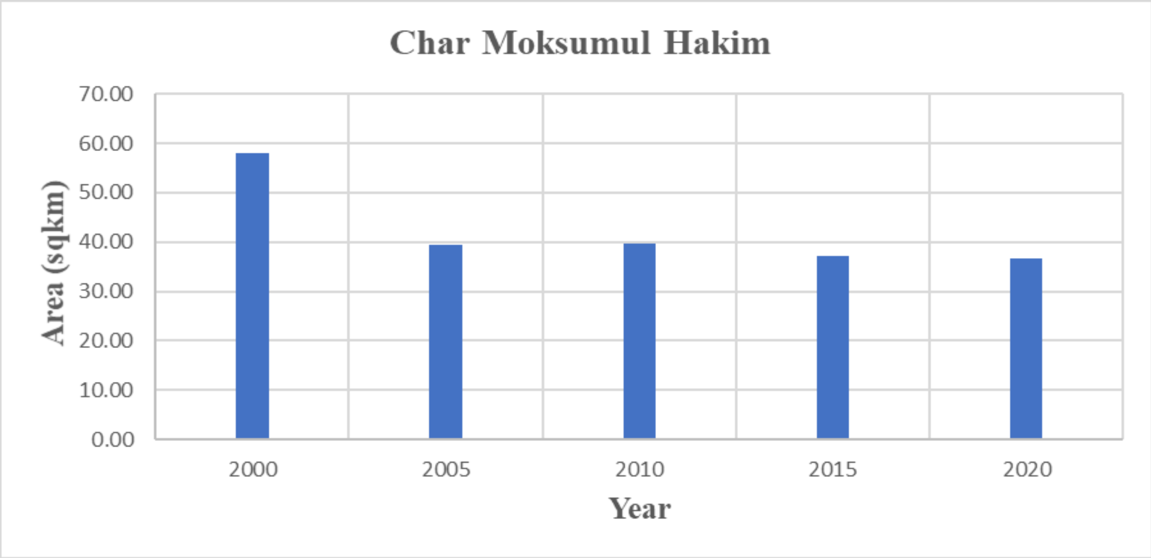


Figure 8.17: Graphical representation of accretion and erosion of Char Moksumul Hakim

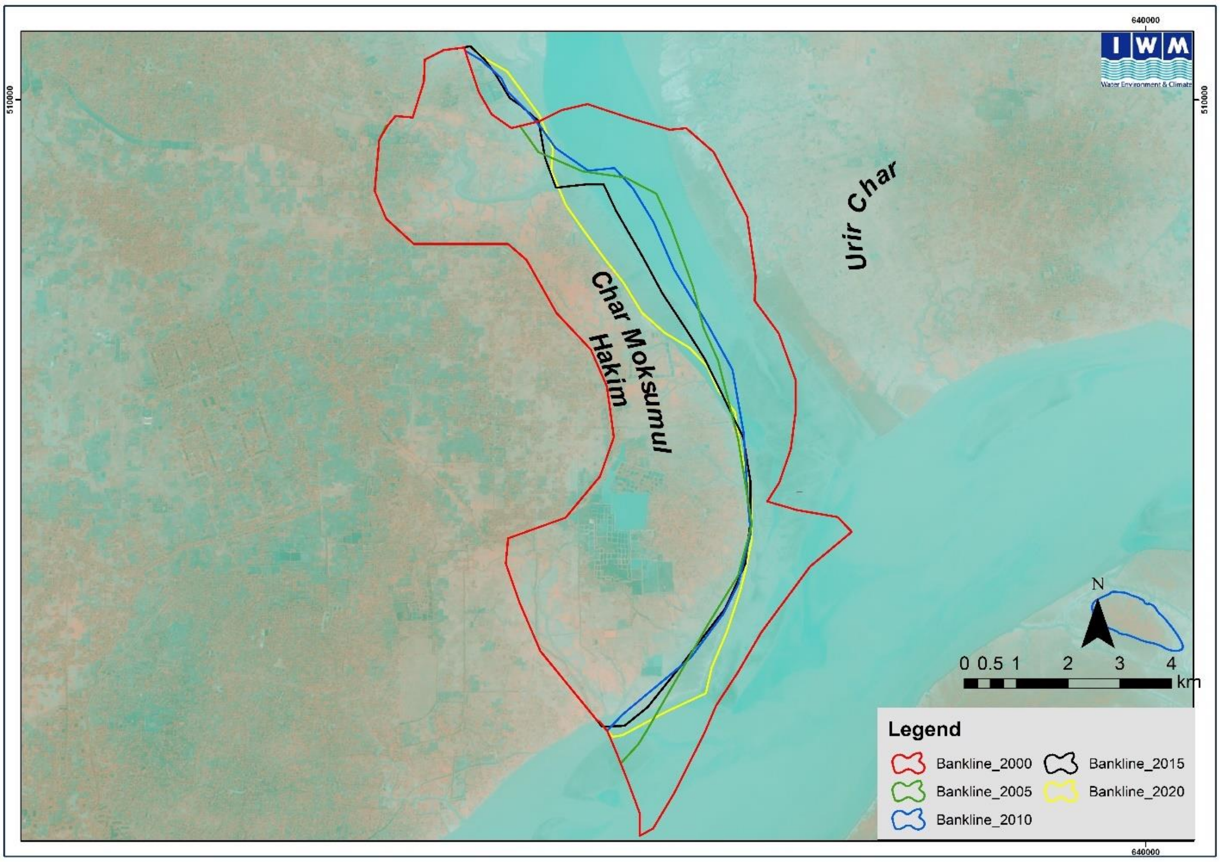


Figure 8.18: Bankline Change of Char Moksumul Hakim

Satellite Image Analysis for Char Kolatoli

Maximum water level during high spring tide in monsoon season is around 4.3m and during dry period it is around 1.83 m. According to the Satellite image of 2000, Char Kolatoli was occupied about 14.05 sqkm of land which is mostly the central part of today's total area. But it is seen that in between 2000 to 2010 there was net accretion which was about 8.09 sqkm of land along the Dhal Char-Hatyia channel. Afterward between 2010 to 2015 there was net erosion which was about 0.32 sqkm. Again in between 2015 to 2020 there was net accretion which is about 2.73 sqkm of land which is mainly along the west Shabazpur Channel. The Figure 8.19 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.20 is representing the bank line of Char Kolatoli from 2000 to 2020. The Table 8.11 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.11: Trend of Erosion-Accretion pattern of Jahoruddin char from 2000~2020

Char Kolatoli		
Year	Area (sqkm)	Remarks
2000	14.05	
2005	16.93	2.88 sqkm accretion in between 2000 to 2005
2010	22.14	5.21 sqkm accretion in between 2005 to 2010
2015	21.82	-0.32 sqkm erossion in between 2010 to 2015
2020	24.55	2.73 sqkm accretion in between 2015 to 2020

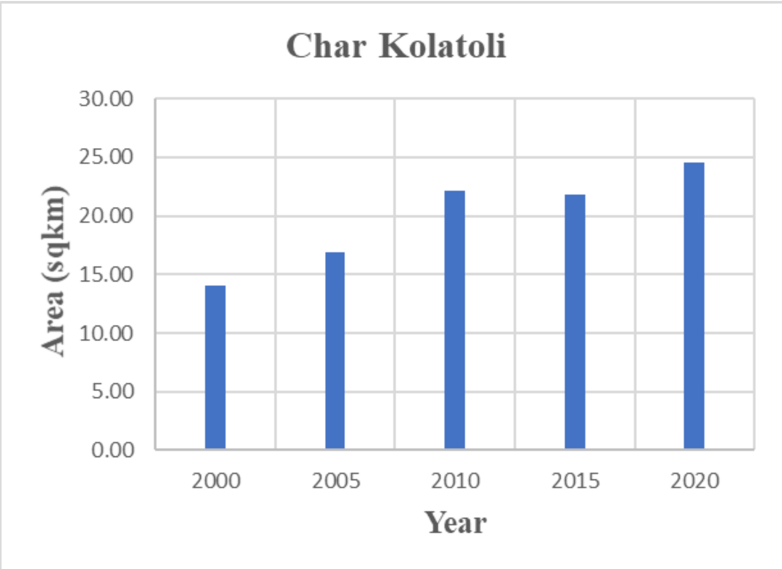


Figure 8.19: Graphical representation of accretion and erosion of Char Kolatoli

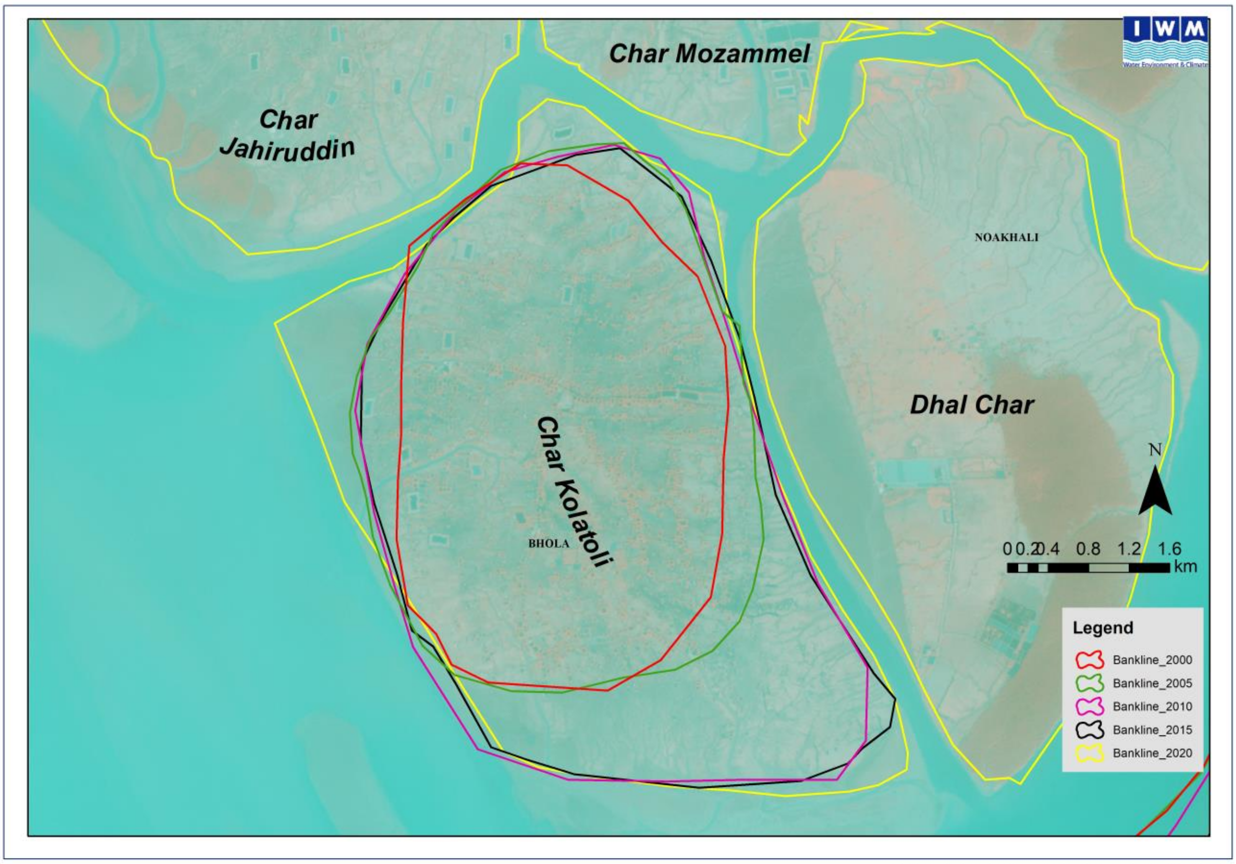


Figure 8.20: Bankline Change of Char Kolatoli

Satellite Image Analysis for Char Nizam/ Puber Char

Maximum water level during high spring tide in monsoon season is around 3.3m and during dry period it is around 1.64 m . According to the Satellite image of 2000, Char Nizam was occupied about 5.08 sqkm of land which is mostly the western part of today's total area. But it is seen that in between 2000 to 2010 there was net accretion which was about 16.58 sqkm of land along the south-eastern corner of the char. Afterward between 2010 to 2015 there was net erosion which was about 2.92 sqkm of land which occurred mainly at the north-eastern part of the char. Again in between 2015 to 2020 there was net accretion which is about 3.18 sqkm of land which is mainly at the south part of the char. The Figure 8.21 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.22 is representing the bank line of Char Nizam from 2000 to 2020. The Table 8.12 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.12: Trend of Erosion-Accretion pattern of Nizam char from 2000~2020

Char Nizam		
Year	Area (sqkm)	Remarks
2000	5.08	
2005	21.27	16.19 sqkm accretion in between 2000 to 2005
2010	21.66	0.39 sqkm accretion in between 2005 to 2010
2015	18.73	-2.92 sqkm erosion in between 2010 to 2015
2020	21.92	3.18 sqkm accretion in between 2015 to 2020

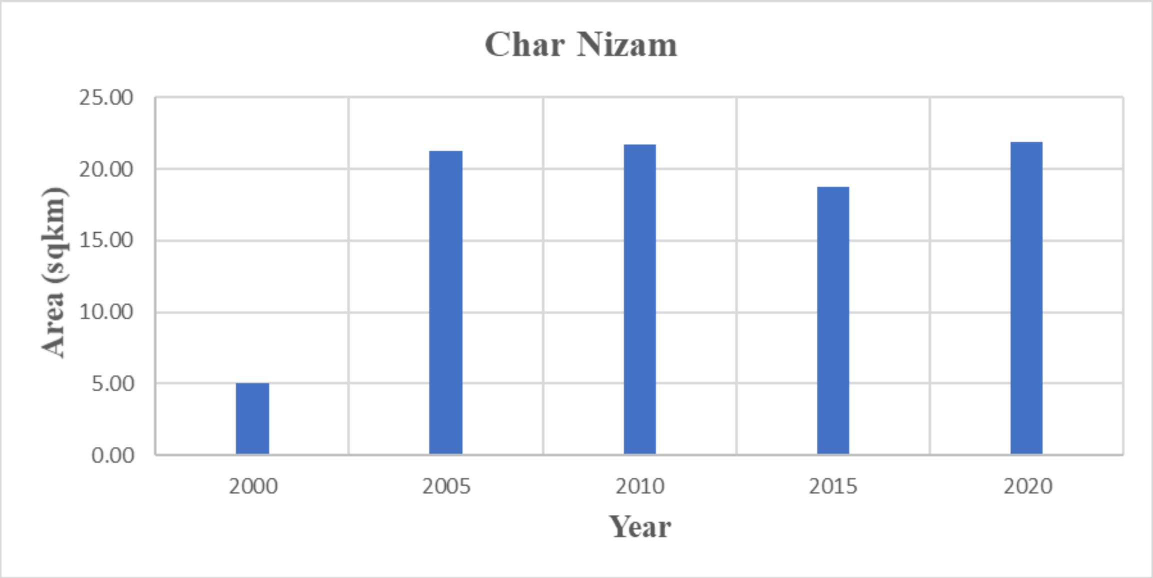


Figure 8.21: Graphical representation of accretion and erosion of Char Nizam/ Puber Char

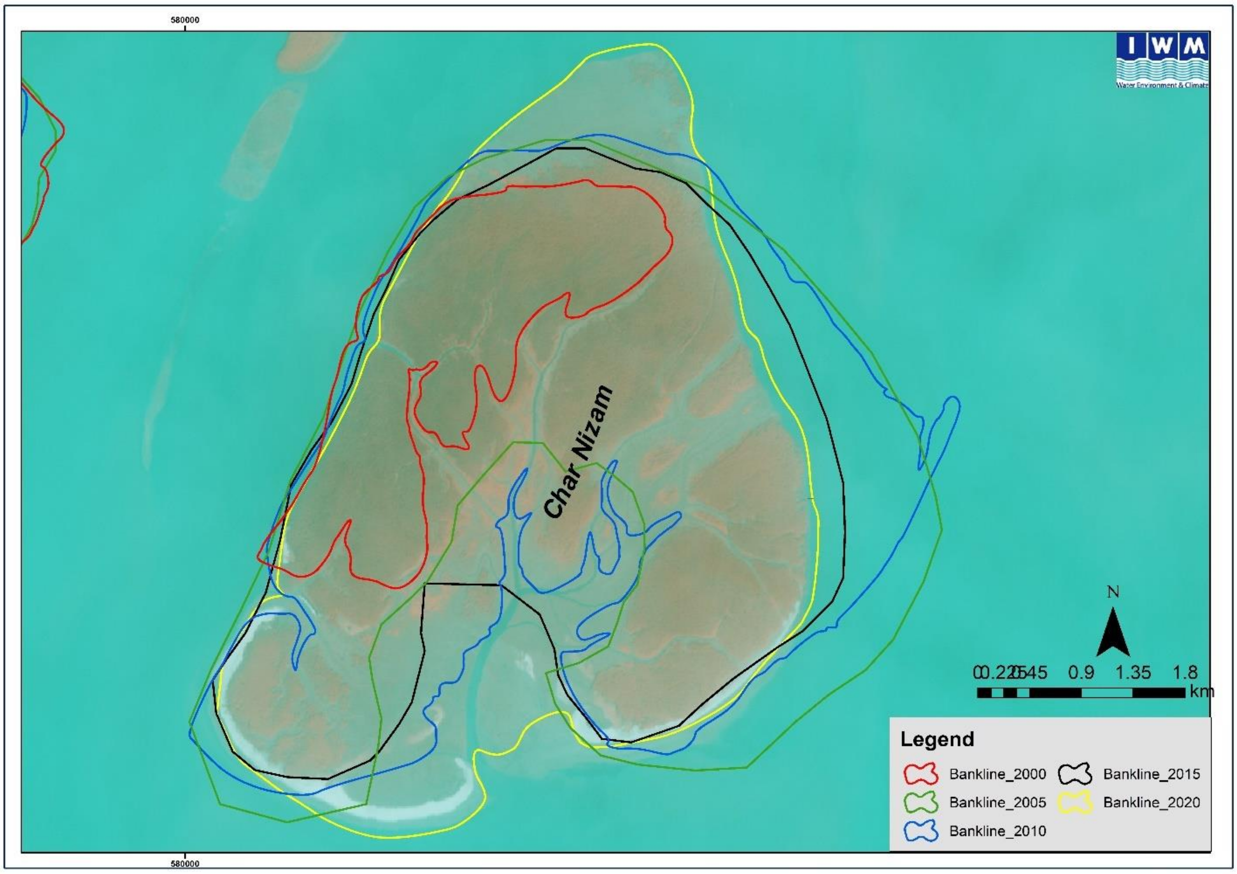


Figure 8.22: Bankline Change of Char Nizam/ Puber Char

Satellite Image Analysis for Char Sakuchi/ Char Kalkini

Maximum water level during high spring tide in monsoon season is around 3.14m and during dry period it is around 1.72 m. According to the Satellite image of 2000, Char Sakuchi was occupied about 3.12 sqkm of land which is mostly the central part of today's total area. But it is seen that in between 2000 to 2015 there was net accretion which was about 10.42 sqkm of land all along the char which is about 1.8 km at north part of the cahr. Afterward in between 2015 to 2020 there was net erosion which is about 2.17 sqkm of land which occurred mainly along the southern and eastern part of the char. During that period about 1.8 km of land accretion occurred at the south side of the char and 0.9 km accretion occurred at the east part of the char. Since the char is situated at the dynamic zone of Shahbazpur Channels then it is hard to say the stability of this char. ***But after analyzing these images, experience of field visits and opinion of local stakeholders indicates that the char is stable and naturally it may accrete more land to its surrounding areas.*** The Figure 8.23 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.24 is representing the bank line of Char Sakuchi from 2000 to 2020. The Table 8.13 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.13: Trend of Erosion-Accretion pattern of Sakuchi char from 2000~2020

Char Sakuchi		
Year	Area (sqkm)	Remarks
2000	3.12	
2005	6.25	3.13 sqkm accretion in between 2000 to 2005
2010	9.82	3.57 sqkm accretion in between 2005 to 2010
2015	13.54	3.72 sqkm accretion in between 2010 to 2015
2020	11.37	-2.17 sqkm eroded in between 2015 to 2020

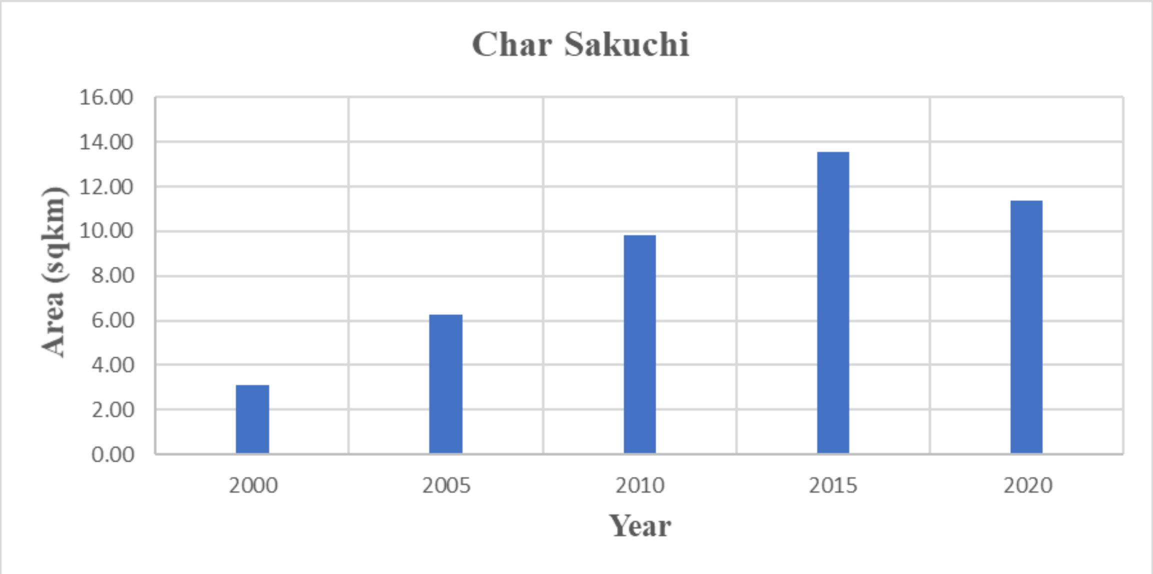


Figure 8.23: Graphical representation of accretion and erosion of Char Sakuchi/ Char Kalkini

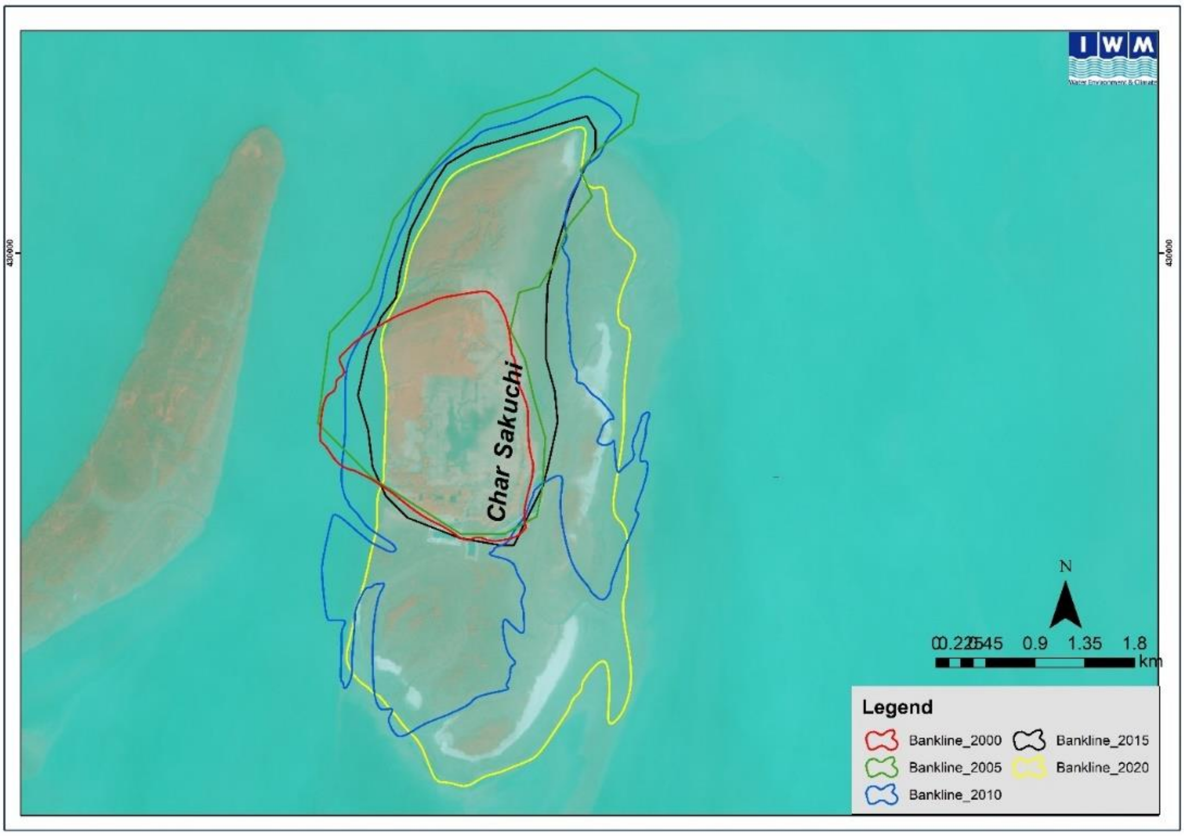


Figure 8.24: Bankline Change of Char Sakuchi/ Char Kalkini

Satellite Image Analysis for Dhal Char (CDSP-V)

Maximum water level during high spring tide in monsoon season is around 3.3 m and during dry period it is around 2.6 m. According to the Satellite image of 2000, Dhal Char was occupied about 22.25 sqkm of land which is mostly the central part of today's total area. But it is seen that in between 2000 to 2010 there was net erosion which was about 2.21 sq km of land all along the Hatyia-manpura Channel. Afterward between 2010 to 2015 there was net accretion which was about 0.09 sq km of land which occurred mainly at the western part of the char beside the char Mozammel. Again in between 2015 to 2020 there was net erosion which is about 0.79 sq km of land which occurred mainly along Hatyia-Manpura Channel. The Figure 8.25 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.26 is representing the bank line of Dhal Char from 2000 to 2020. The Table 8.14 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.14: Trend of Erosion-Accretion pattern of Dhal char (CDSP V) from 2000~2020

Dhal Char (CDSP-V)		
Year	Area (sqkm)	Remarks
2000	22.25	
2005	21.45	-0.80 sqkm erosion in between 2000 to 2005
2010	20.04	-1.41 sqkm erosion in between 2005 to 2010
2015	20.13	0.09 sqkm accretion in between 2010 to 2015
2020	19.34	-0.79 sqkm erosion in between 2015 to 2020

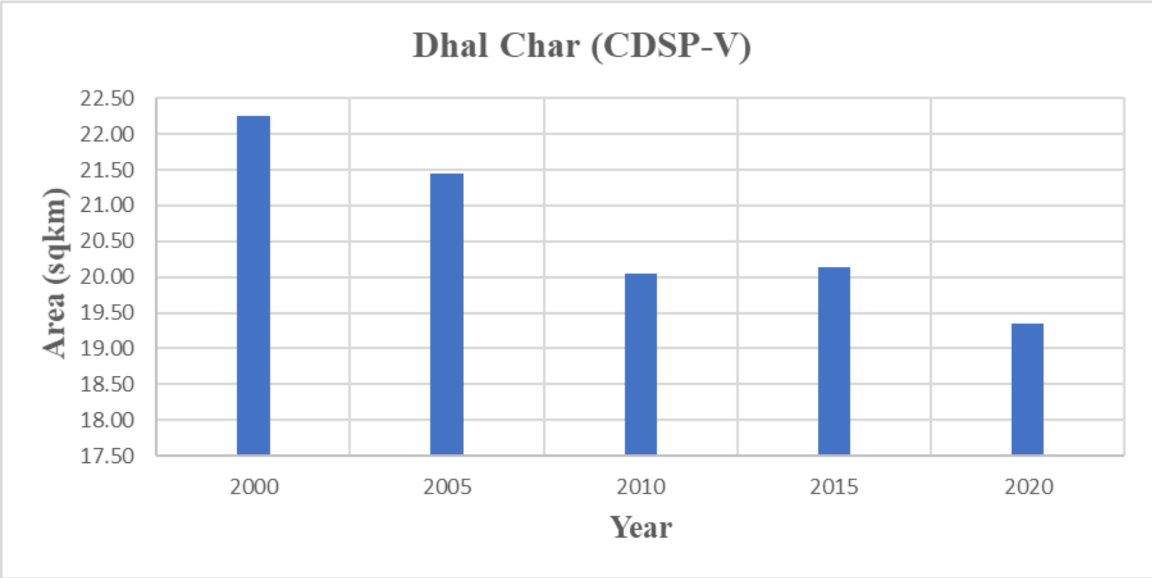


Figure 8.25: Graphical representation of accretion and erosion of Dhal Char

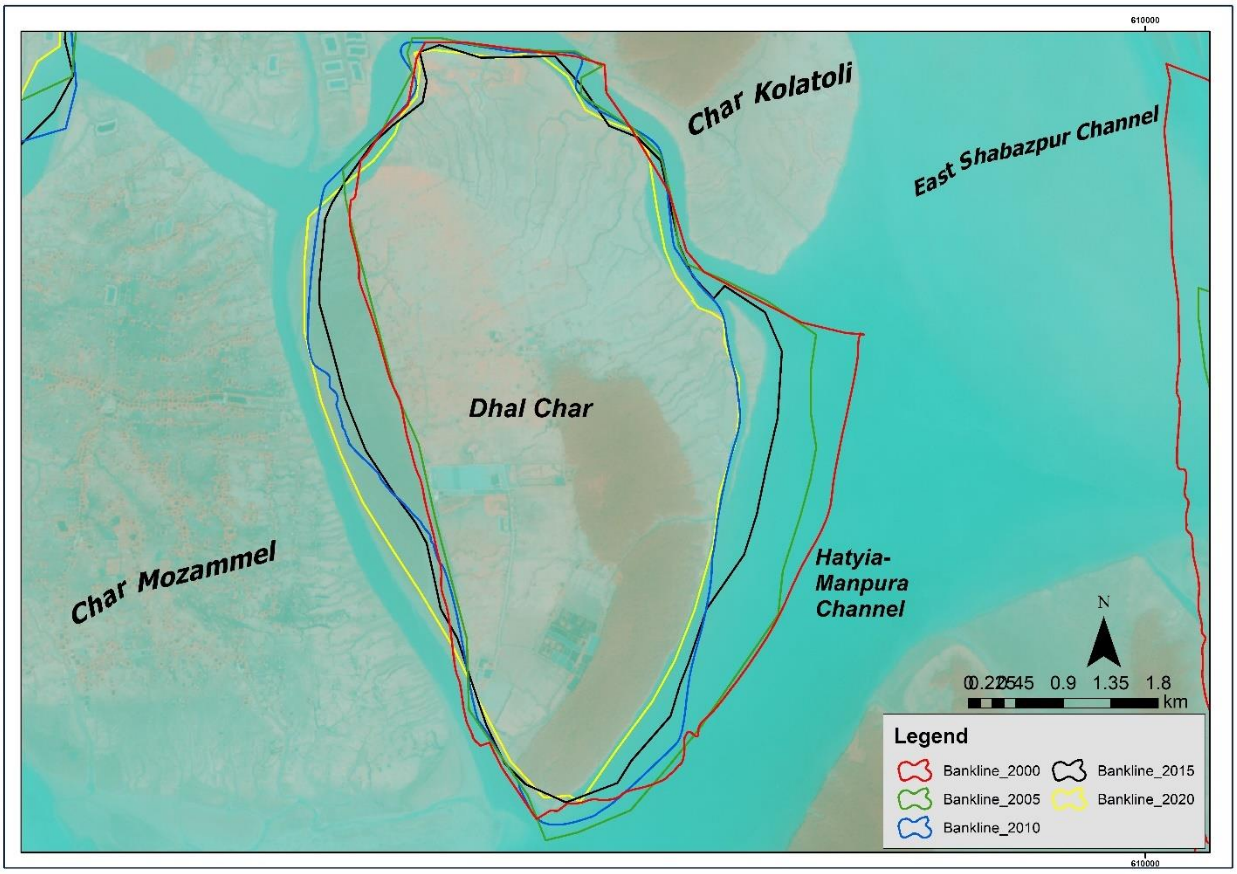


Figure 8.26: Bankline Change of Dhal Char (CDSP V)

Satellite Image Analysis for Dhal Char

Maximum water level during high spring tide in monsoon season is around 3.2m and during dry period it is around 1.77 m . According to the Satellite image of 2000, Dhal Char was occupied about 18.30 sqkm of land which is mostly the whole char and 1.5 km northern part of today's existing char. But it is seen that in between 2000 to 2005 there was net erosion which was about 0.40 sqkm of land. Afterward between 2005 to 2010 there was net accretion which was about 1.80 sqkm of land which occurred mainly at the western part of the char. Again in between 2010 to 2020 there was net erosion which is about 5.98 sqkm of land which occurred mainly at the northern part of the char as a head erosion which is about 1 km. Since the char is situated at the dynamic zone of Shahbazpur Channels then it is hard to say the stability of this char. But after analyzing these images, experience of field visits and opinion of local stakeholders indicates that the char is stable and naturally it may accrete more land to its surrounding areas. The Figure 8.27 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.28 is representing the bank line of Dhal Char from 2000 to 2020. The Table 8.15 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.15: Trend of Erosion-Accretion pattern of Dhal char from 2000~2020

Dhal Char		
Year	Area (sqkm)	Remarks
2000	18.30	
2005	17.90	-0.40 sqkm erosion in between 2000 to 2005
2010	19.70	1.80 sqkm accretion in between 2005 to 2010
2015	14.56	-5.14 sqkm erosion in between 2010 to 2015
2020	13.72	-0.84 sqkm erosion in between 2015 to 2020

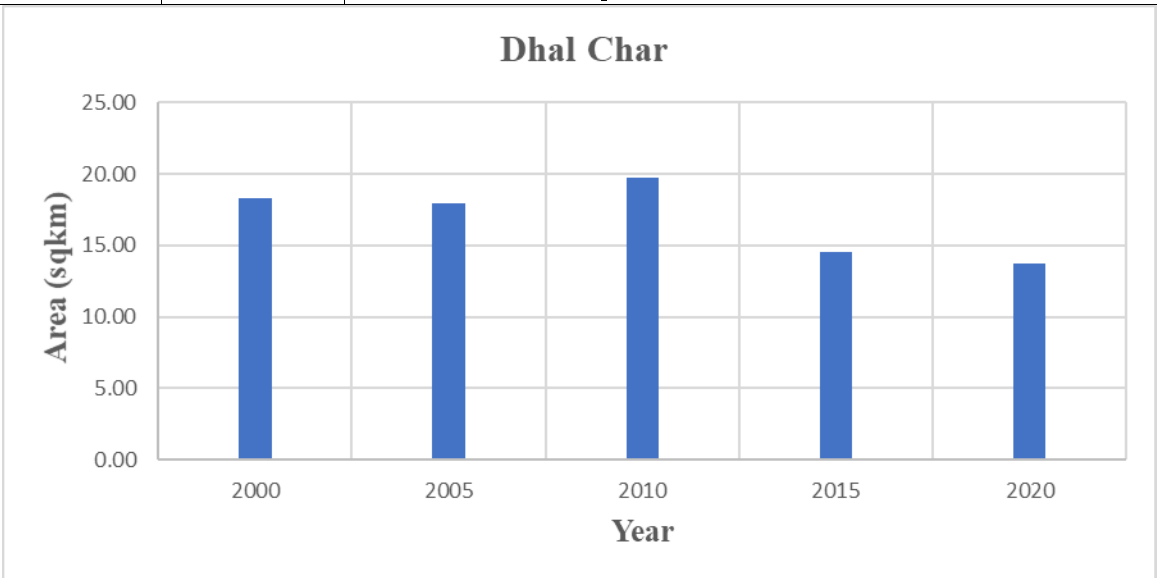


Figure 8.27: Graphical representation of accretion and erosion of Dhal Char

Figure 8.28: Bankline Change of Dhal Char

Satellite Image Analysis for Domer Char

Maximum water level during high spring tide in monsoon season is around 3.6 and during dry period it is around 1.8 m . According to the Satellite image of 2000, Domer Char was occupied about 1.37 sqkm of land which is mostly the central part of today's total area. But it is seen that in between 2000 to 2010 there was net accretion which was about 20.91 sqkm of land all along the char. Afterward between 2010 to 2015 there was net erosion which was about 3.63 sqkm of land which occurred mainly at the southern and eastern part of the char. Again in between 2015 to 2020 there was net accretion which is about 0.46 sqkm of land. The Figure 8.29 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.30 is representing the bank line of Domer Char from 2000 to 2020. The Table 8.16 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.16: Trend of Erosion-Accretion pattern of Domer char from 2000~2020

Domer Char		
Year	Area (sqkm)	Remarks
2000	1.37	
2005	6.28	4.91 sqkm accretion in between 2000 to 2005
2010	22.27	16.00 sqkm accretion in between 2005 to 2010
2015	18.65	-3.63 sqkm erosion in between 2010 to 2015
2020	19.11	0.46 sqkm accretion in between 2015 to 2020

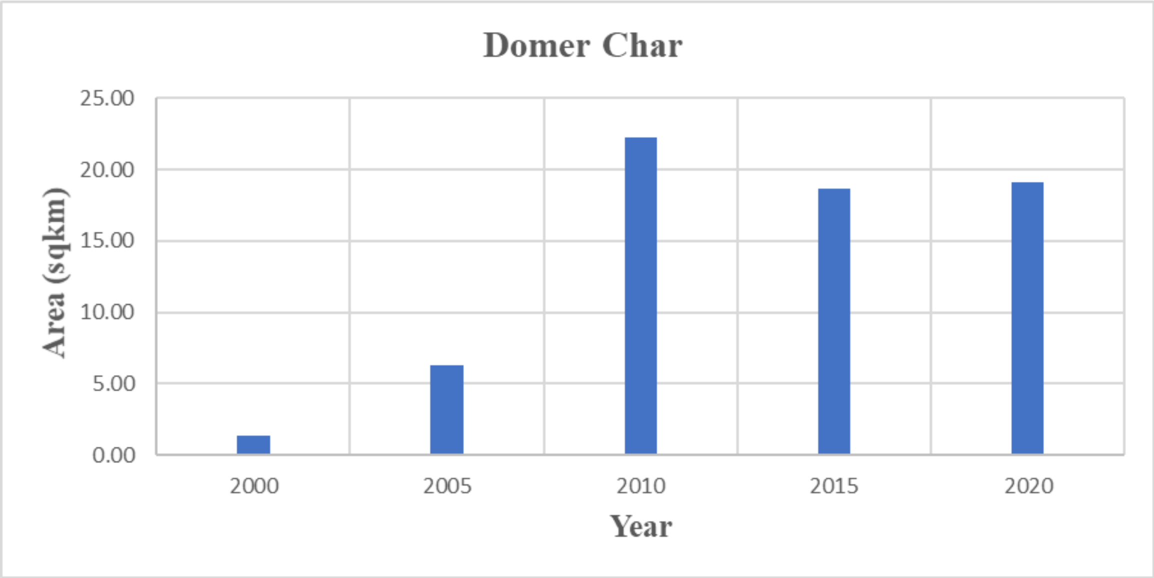


Figure 8.29: Graphical representation of accretion and erosion of Domer Char

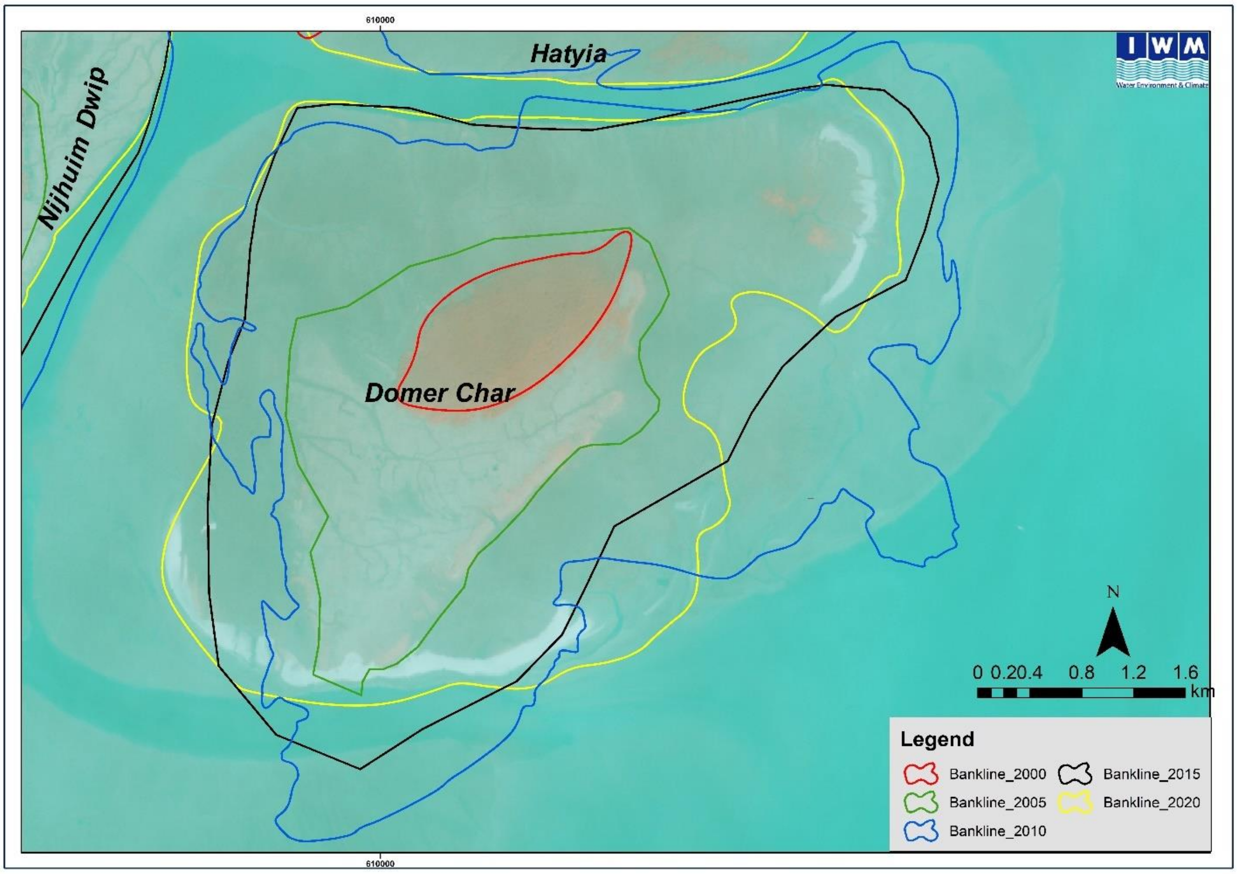


Figure 8.30: Bankline Change of Domer Char

Satellite Image Analysis for Nijhuim Dwip

Maximum water level during high spring tide in monsoon season is around 3.0m and during dry period it is around 1.9 m. According to the Satellite image of 2000, Nijhuim Dwip occupied about 30.41 sq km of land which is mostly the central part of today's total area. But it is seen that in between 2000 to 2010 net accretion was about 16.29 sq km of land all along the char. Afterward between 2010 to 2015 there was net erosion which was about 5.72 sq km of land which occurred mainly along the Manpura-Hatyia Channel. Again in between 2015 to 2020 there was net accretion which is about 5.31 sq km of land along the Manpura-Hatyia Channel. The Figure 8.31 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.32 is representing the bank line of Nijhuim Dwip from 2000 to 2020. The Table 8.17 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020.

Table 8.17: Trend of Erosion-Accretion pattern of Nijhuim Dwip from 2000~2020

Nijhuim Dwip		
Year	Area (sq km)	Remarks
2000	30.41	
2005	35.14	4.73 sq km accretion in between 2000 to 2005
2010	46.69	11.55 sq km accretion in between 2005 to 2010
2015	40.98	-5.72 sq km erosion in between 2010 to 2015
2020	46.29	5.31 sq km accretion in between 2015 to 2020

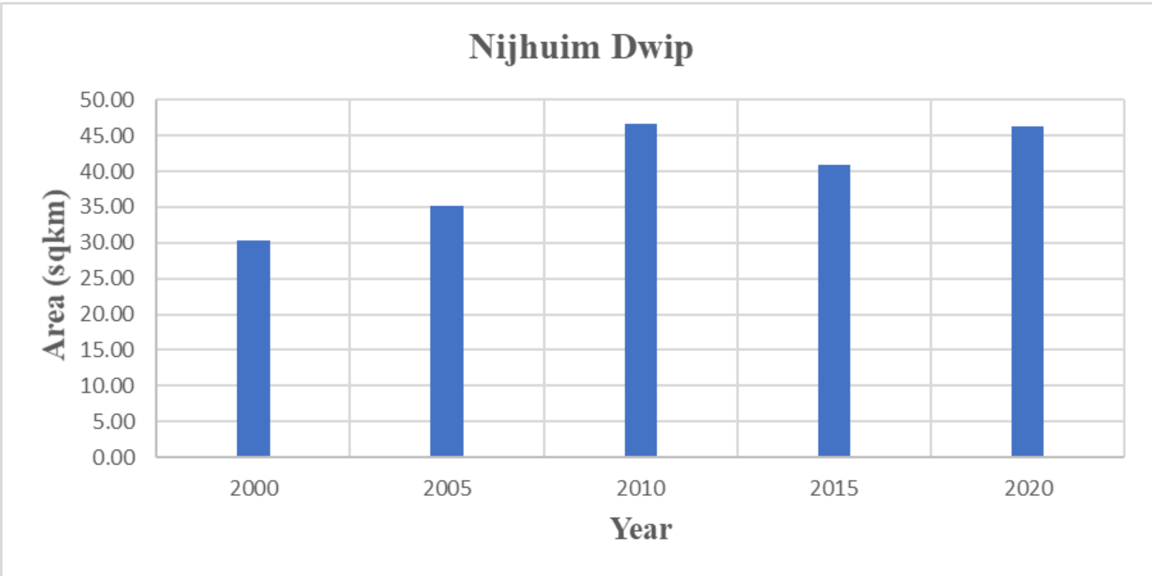


Figure 8.31: Graphical representation of accretion and erosion of Nijhuim Dwip

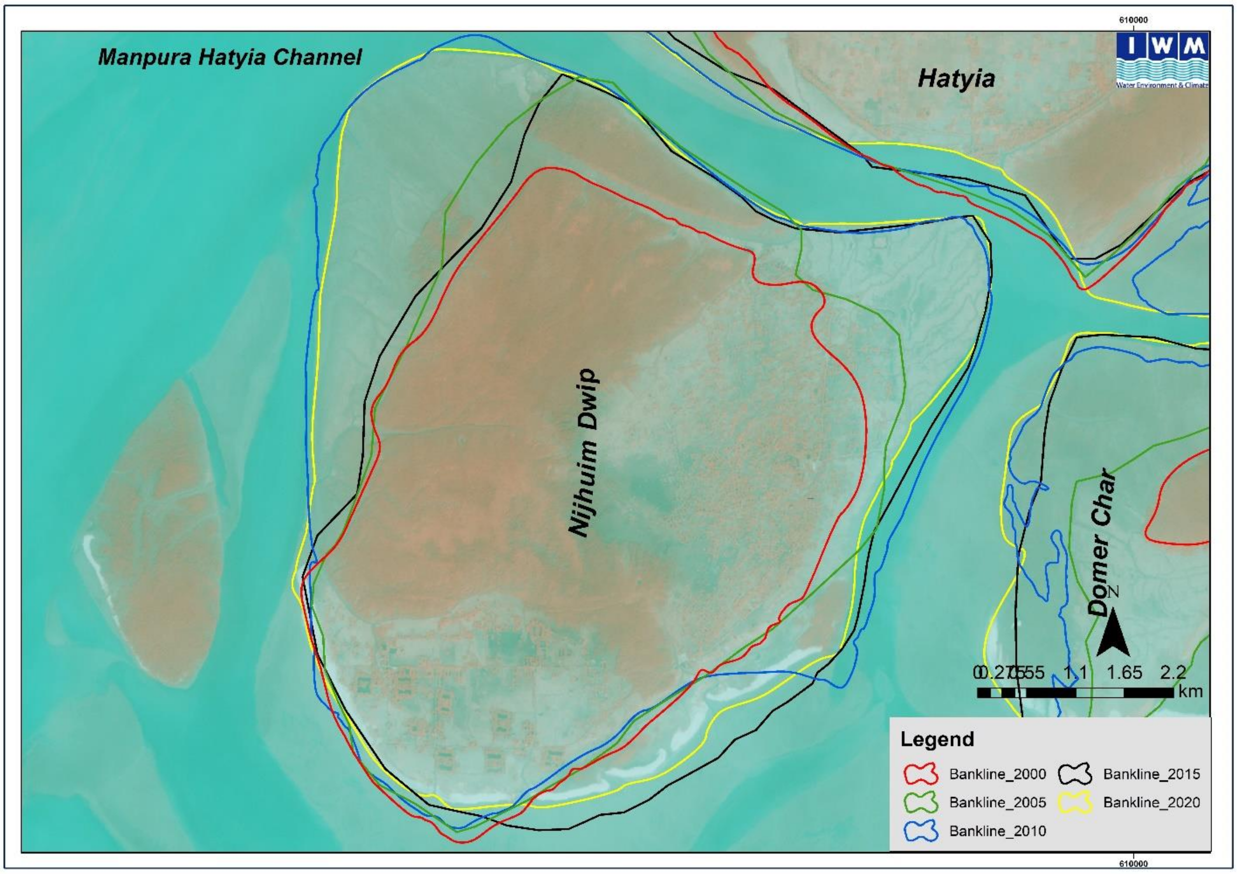


Figure 8.32: Bankline Change of Nijhuim Dwip

Satellite Image Analysis for Sonar Char

According to the Satellite image of 2000, Sonar Char was occupied about 14.88 sqkm of land which is mostly the central part of today's total area. But it is seen that in between 2000 to 2010 there was net accretion which was about 4.35 sqkm of land which was mostly at the north-east side of the char. Afterward between 2010 to 2015 there was net erosion which was about 0.94 sqkm of land which occurred mainly at the south-west corner of the char. Again in between 2015 to 2020 there was net accretion which is about 5.57 sqkm of land along the Sonar char Andhar Char channel. The Figure 8.33 is representing the bar chart of net area on successive 5 years' time interval and Figure 8.34 is representing the bank line of Sonar Char from 2000 to 2020. The Table 8.18 shows the accretion and erosion of char from year 2000 to 5 years' time interval till 2020. However, this char is stable, but char is under ecological critical zone. ***Therefore, this char is not suitable for future potential development*** in the near future.

Table 8.18: Trend of Erosion-Accretion pattern of Sonar Char from 2000~2020

Sonar Char		
Year	Area (sqkm)	Remarks
2000	14.88	
2005	18.61	3.73 sqkm accretion in between 2000 to 2005
2010	19.23	0.62 sqkm accretion in between 2005 to 2010
2015	18.29	-0.94 sqkm erosion in between 2010 to 2015
2020	21.85	3.57 sqkm accretion in between 2015 to 2020

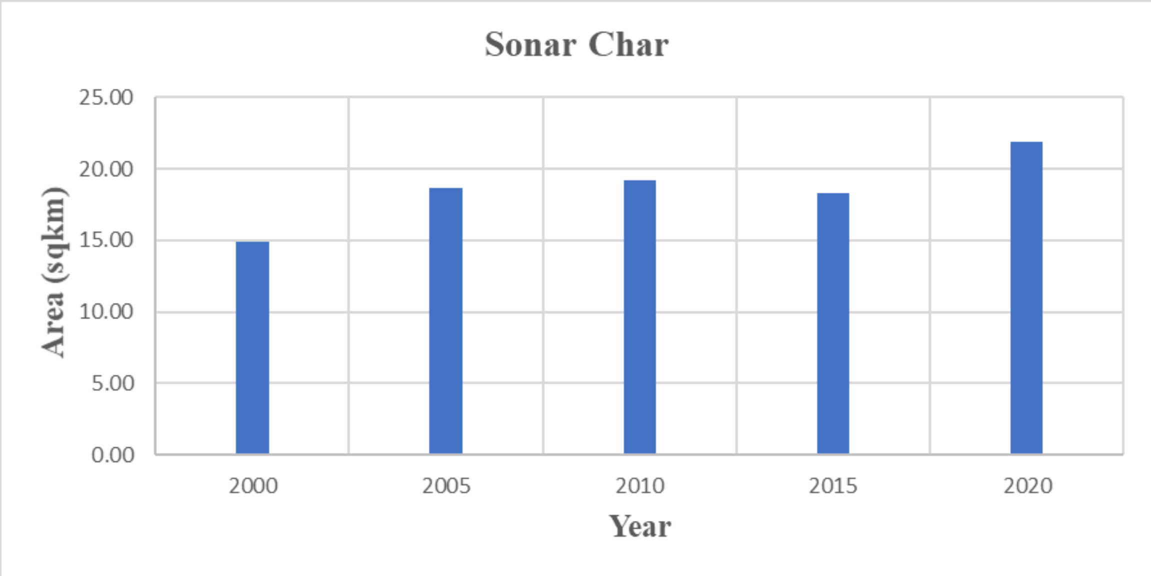


Figure 8.33: Graphical representation of accretion and erosion of Sonar Char

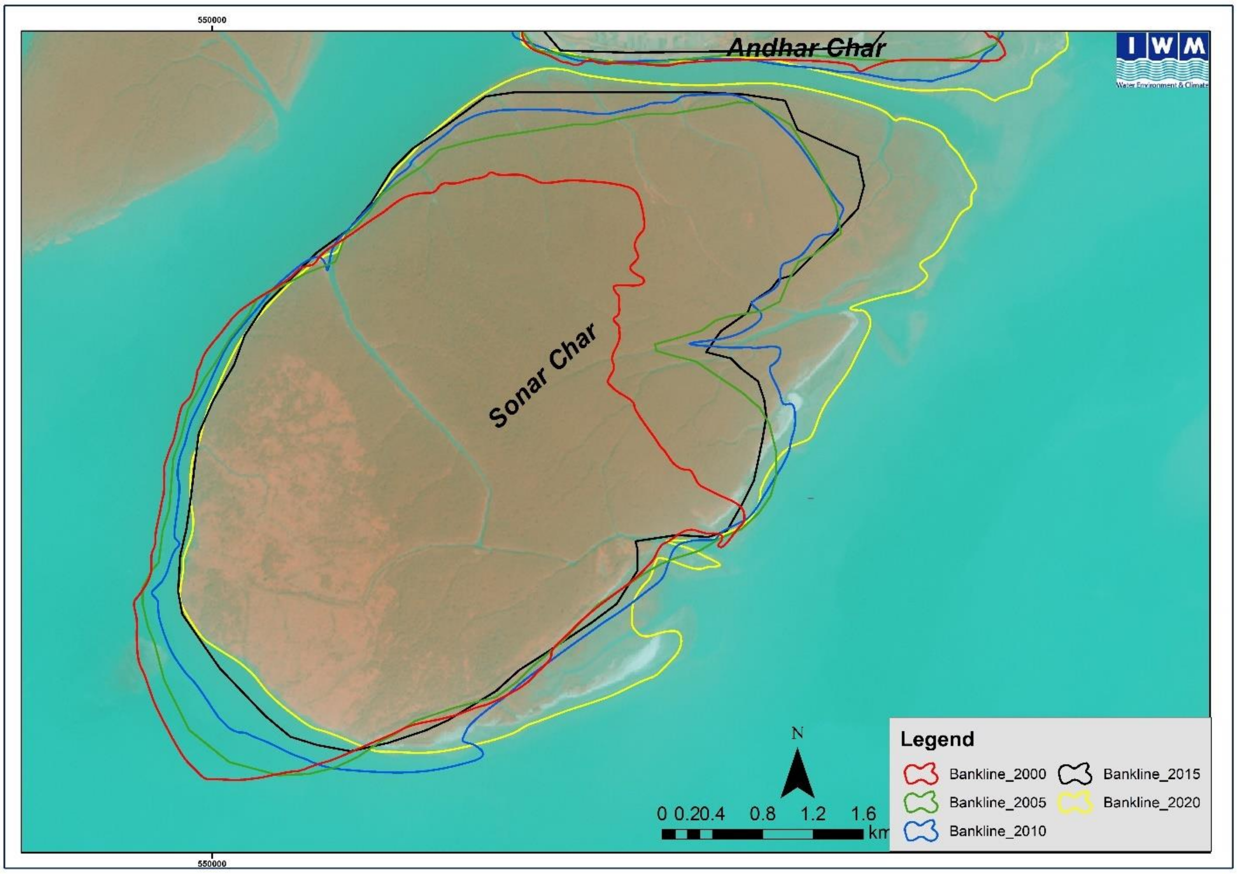


Figure 8.34: Bankline Change of Sonar Char

The study area is hydraulically very dynamic in nature, and it is hard to make any concrete prediction of riverbank erosion in near future along the proposed alignment of embankment. The trend of the sedimentation and erosion pattern has been assessed through analyzing the satellite images. ***But it is better to have another separate monitoring study on erosion vulnerability in the study area just before the implementation of the project.***

8.2 Selection of Potential Char for Future Development

Selection of suitable or potential chars for future development depends on morphological behavior, maturity of Char (15~20 years), storm surge level, population density, existing land level, tidal condition, salinity, bio diversity, environmental and social consideration. Based on these criteria total twelve chars are selected from seventeen chars. Although Basan char is potential but it is under the development of army. Sonar char area is situated in the ecological critical zone. It is found from above analysis that Char Abdullah is not matured and char Jahiruddin shape is changing with time and upstream side is eroding. In addition, Urir Char is quite stable, settlements are old enough, agriculture practice is common for long time. Only problem was land demarcation between two Districts which is solved recently. Impoldering of this Char has no other obstruction as feasibility study has been done under CDSP-IV. Based on these criteria along with the intensive analysis in Article 8.1 with deep observation of erosion/accretion process, trends, prevailing situation around and total twelve chars in Meghna estuary are selected for future development out of seventeen chars studied.

List of Chars in Meghna Estuary for future development are illustrated in Table 8.19

Table 8.19: List of Chars in Meghna Estuary for future development

SL No.	Char_Name	2020 (Area_sq km)	Year of Existence	Remarks
1	Char Moksumul Hakim	36.67	2000-2020	CDSP-V
2	Char Kolatoli	26.56	2005-2020	CDSP-V
3	Char Mozzammel	36.68	2005-2020	CDSP-V
4	Dhal Char (CDSP-V)	19.55	2005-2020	CDSP-V
5	Domer Char	19.11	2005-2020	
6	Nijhuim Dwip	46.29	2005-2020	
7	Andhar Char	7.65	2005-2020	
8	Char Kukri Mukri	51.72	2005-2020	
9	Char Lakshmi/ Char Bangla	19.05	2005-2020	
10	Char Nizam/ Puber char	21.92	2005-2020	
11	Char Sakuchi/ Char Kalkini	11.37	2005-2020	
12	Dhal Char	13.72	2005-2020	

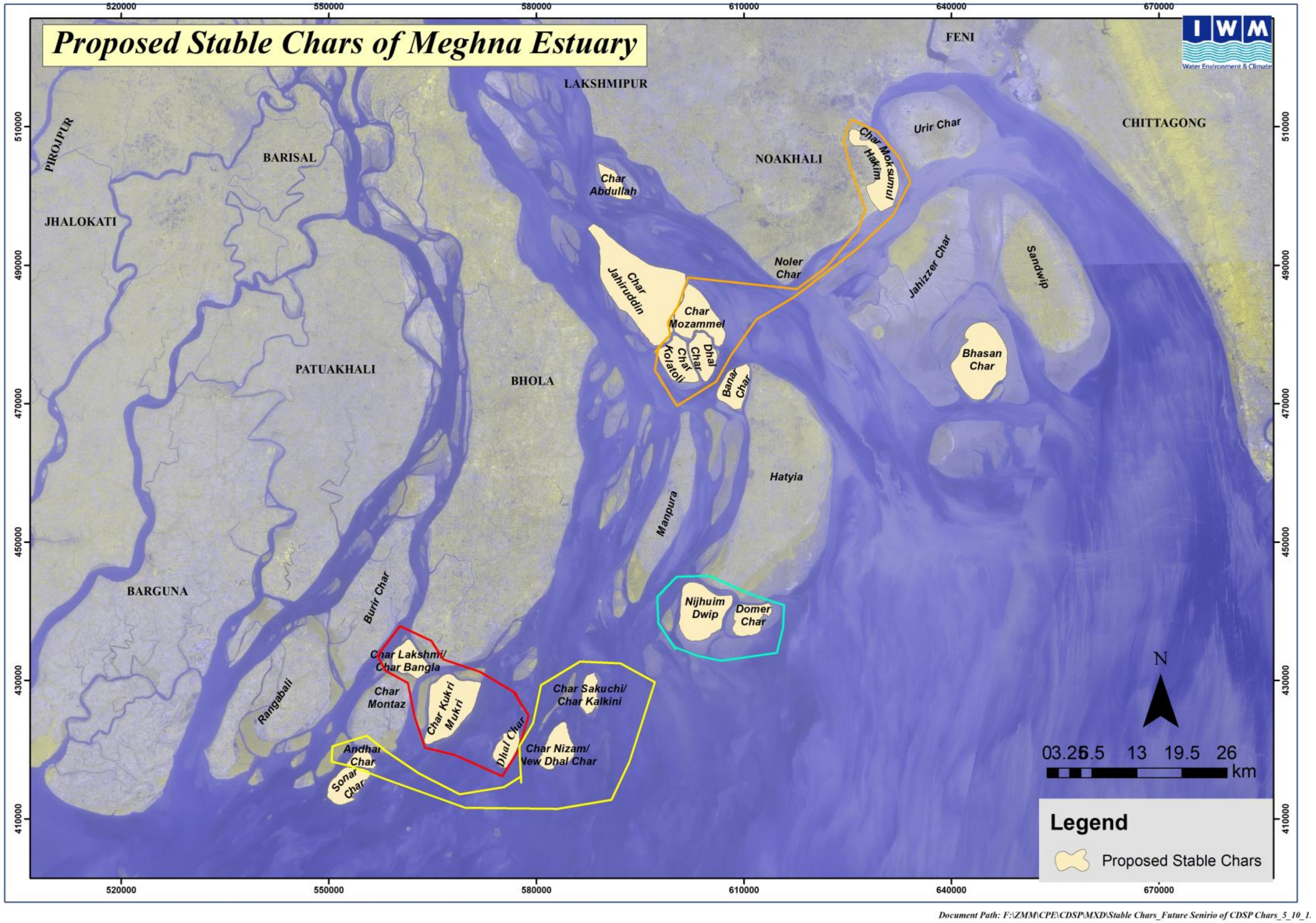


Figure 8.35: Potential/ Stable char for Future Development.

A total of eleven projects have been formulated and fact sheets have been prepared for all these projects which are given in Strategic Planning Report (Volume II). Among these projects, four projects are based on twelve chars for future development are illustrated below.

1. Integrated Development and Disaster Management of Nijhum Dwip and Damar Char;
2. Stabilization, Disaster Risk Reduction of Char Lakshmi, Char Kukri-Mukri and Dhal Char;
3. Study for Char Development, Stabilization, Land Reclamation, and Afforestation of Andar Char, Char Nizam and Char Sukuchi ;
4. Improved Planning and Design for the Development of Char Kolatoli, Char Muzzamal, Dhal Char & Char Muksumul Hakim;

During CDSP IV, feasibility studies have been done on several chars such as Char Kolatoli, Dhal Cahr, Char Mozammel and Char Muksumul Hakim. Therefore, these areas may be included for a review instead of a completely new study, such study can be done during the next phase of CDSP-V or during extended period of Bridging (if so happen).

These projects may be selected as provisional. Based on more detail hydro-morphological study, environmental study and detail design a priority ranking may be done for future development. These projects may be taken up under CDSP or GoB funding or other development partner funding.

8.3 Community development plan of Stable Chars:

The community development plan has been designated followed by adaptive Delta Management Approach. It will include different components of households and socio-economic development issues of the people of Chars. At first, it is tried to identify the prevailing vulnerabilities of the community in future. The islands of Meghna Estuary heckle island-specific venerability with some common vulnerabilities. The social team has tried to identify the vulnerabilities of households as well as socio-economic obstacles of the area. The followings vulnerabilities describe through community consultation, field visit and discussion with local government representatives of chars.

a. Prevailing Vulnerabilities of Char Nizam

Issues	Brief
Land Erosion	During Population Census Year (2011 to 2021), more than 50 hectares human habitat and agriculture land has been lost in the sea/channel; Only 30 hectares land exist for human habitat and crop land. The river erosion has been damaging the human habitat, crop land, asset and livelihood means. The government did not give permission to resettle households at the blank/forest area with titled land after Ershad regime.
Cyclone/Surges	In catastrophic cyclone of 1970, only 12 people was alive in the island. 36 people dead, lost livestock and asset in 1991. All cyclones happened in the past hit on the island as well as human habitat and people lost crops, culture fish, assets and livestock.

Issues	Brief
Tide	Tidal water inundated on the crop land during high tide time in monsoon and they lost standing crops.
Soil & Water Salinity	Due to soil and water salinity, the people do not cultivate land during Boro/Robi crops season; The rice production is less than other area of the country due to soil salinity.
Lack of Drinking Water	The people of the area drink tube-well water. There are only 5 to 6 tube-well within human habitat area but it is less than demand. The people are not habituating to drink rain water and pond water.
Climate Change	The vulnerability of life and livelihood has been increased due to climate change. There is only one cyclone shelter for saving life during natural disaster period and it is too much less than demand. There is no Killa for saving livestock and other assets during disaster.
Population Growth	There were some 296 households and 1468 population according to population census 2011, BBS. The FGD participants said, there are some 800 households. Many of Households shifted here from Dhalchar (due to losing homes and land by river erosion); The government settled some 240 households in 2015-2016 and 245 household in 2019-2020 under Abashon/Asrayan Project.
Embankment	Never ever the embankment built in the char which can save people's lives and assets;
Scarcity/Loss of Income Generating Activities	Most of the working force- people and children (95%) are involved in fishing and related activities. There is huge scarcity of income generating activities in the area. The people are usually engaged in fishing and Amon rice product once in a year. The working force migrates temporarily to Dhaka, Chittagong and other area of the country for earning, when fishing stopped and lean season of fishing.
Education	There is a Primary School (cum cyclone shelter) and a Madrasha. The majority of the students are dropped-out before/after primary school and they join households' income earning activities. The literacy rate is 16.7% according to population census 2011, BBS.
Health & Hygiene	There is no clinic/hospital. 44.8% residence structures are Kutcha and 55.2% Jhupri. 47.9% households have no own toilet facilities followed by 43.5% non-sanity latrine and 8.6% no water seal sanitary latrine.

b. Prevailing Vulnerabilities of Dhalchar

Land Erosion	Between Population Census of 2011 and 2021 (ten years), more than 550 hectares human habitat and agricultural land has been lost in the Bay of Bengal/channel; Only 60 hectares land exist for human habitat and crop land. The river erosion has been damaging the human habitat. Erosion happens in both North and South side of the island. Erosion continued since 15 years and it is increased too much in recent time. The government did not give permission to resettle households at the adjacent forest and blank area yet. The age of the forest area is about 60 years.
Cyclone/Surges	During catastrophic cyclone of 1970, only 36 households' members were alive and rest of people dead. 103 people dead during 1991. In the past, all cyclones hit on the island and people lost crops, livestock, house structures and livestock.

Tide	Tidal water inundates on the crop land during high tide time in monsoon. It damaged the standing crops. All canals are opened, so that tidal water comes on agricultural land easily.
Soil & Water Salinity	Due to water salinity, the people do not cultivate land during Boro/Robi crops season; The rice production is less than other area of the country due to soil salinity.
Lack of Drinking Water	The people of the area drink tube-well water. The numbers of tube-well have been damaged due to erosion of human habitat.
Climate Change	The vulnerability of life and livelihood has been increased due to climate change. There were 13 cyclone shelters cum primary school but now only one exist for saving life during natural disaster period. There is one Killa exists for saving livestock and other assets during disaster
Population Growth	The human habitat started from 1945 to 1950. Only 34 households were there. Further in-migration started from 1968. In 1990, there was 388 households in Dhalchar. There were some 1438 households and 7436 population according to Population Census 2011, BBS. Now 4000 households with 20,684 population in Dhalchar (of them a portion has been migrating Char Nizam and other surrounding chars. At before, 1200 acres of land was distributed for human settlement and now only 300-acre land exist of its. The people have been migrating/resettling majorly at Char Nizam/Kalkini and Tarua Beach area of Dhalchar. 7 wards of Dhalchar Union have already been eroded. Some 200 households resettled at Tarua Beach Area (at the southern part of Dhalchar) and Another 2000 households is ready to come here but yet did not get permission from Forest Department; The government settled some 38 households under Abashon/Asrayan Project.
Embankment	There is no embankment surrounding human habitat and crop land at main Dhalchar and also Tarua area, where people have been starting to resettle. No sluice-gate on the canals which influence to inundated crop land during high tide time especially in monsoon.
Scarcity/Loss of Income Generating Activities	The most of the working people and children (90%) are involved in fishing profession. Once many households were dependent on agriculture, when they had crop land. But due to river erosion, they lost their crop land and it hampers their livelihood means. Huge scarcity of income generating activities. The people migrated temporarily to Dhaka, Chittagong and other area of the country for earning. Even some family permanently migrated to major urban area of the country.
Education	There were 13 primary schools in Dhalchar. Now only 4 schools temporarily built teen shed to continue education. One high school has been broken due to river erosion. The education rate is 44.8% in 2011. Due to lack of school and migration of households, many students of both primary and secondary level are dropped out and they have to be bound to join in household income earning activities.
Health & Hygiene	The union health complex has been lost by river erosion. There were 81.8% residence structure is Kutcha followed by 17.4%- Jhupri, and one percent semi-pucca and pucca. 66.5% households have non-sanitary latrine followed by 8% sanitary no water seal, 4% sanitary with water seal and 2% has no own toilet facilities at all.

c. Prevailing Vulnerabilities of Notun Dhalchar/Puber Char

Land Erosion	No land erosion found.
Cyclone/Surges	There was no human habitat one year ago.
Tide	Tidal water inundated on the crop land during high tide time in monsoon. All canals are opened, so that tidal water comes on the land easily.
Soil & Water Salinity	The land is not yet cultivated. So that it is not clear about soil salinity. Saline water comes through the canals with tide but not inundate the land except monsoon.
Lack of Drinking Water	There are two tube-wells installed for drinking water.
Climate Change	The vulnerability of life and livelihood would be in future increased due to climate change. There is no cyclone shelter and Killa built yet.
Population Growth	One household built a residence house in the island. Furthermore, many households who lost their houses by erosion at Dhalchar, are ready to resettle here; if the government give permission under settlement program.
Embankment	There is no Embankment;
Scarcity/Loss of Income Generating Activities	One residence lives here. There is a fish landing and fish trading centre at Khaleker Tek. During hilsha fishing season more than 200 people work here for fish trading and related activities. If people of Dhalchar resettle here, then income generating activities will be increased. Thousands of hectares cultivable land will be under cultivation.
Education	No school has been built here yet.
Health & Hygiene	No facilities for health and hygiene
Market Place	There is a fish trading centre as well as fish landing centre is operated mainly in fishing pick season from Baishakh to Aswin months.
Fish Processing Industry	Found fish dried in the island.
Tourism	There is an attractive beach area at the south-eastern site of the island and forest area. The tourist can come here if the different facilities e.g. residence, foods, tourist water boat are available. Transport from the main land of Bhola is not smooth for tourists at Puber Char Beach area.

d. Prevailing Vulnerabilities of Andar Char

Land Erosion	Erosion found at some half kilometre area at the north-western side and it is happened due to rising a new char in the Tutulia River.
Cyclone/Surges	All natural disasters hit here from the catastrophic cyclone of 1970.
Tide	Tidal water inundated on the crop land during high tide time in monsoon. The embankment washed out that is why it is happened.
Soil & Water Salinity	Due to soil salinity, the rice production is less than other area of the country. Water salinity happened especially during dry season.
Lack of Drinking Water	There are two tube-wells installed for drinking water.
Climate Change	The people would face the impact of cyclone and surge in future. The cyclone shelter is less than population of the char.
Population	The human habitat established before 50 years back. There were 466

Growth	households with 2173 household according to Population Census 2011, BBS; Now it is more than 500 households and approximate 2400 population according to local sources;
Embankment	An embankment built in 2013 and within one year of building, it has been washed out approximate more than 4 kilometres out of 12 kilometres due to wave action at the east side; The embankment erosion happened at North-west side due to rising a char at Tetulia River;
Scarcity/Loss of Income Generating Activities	There is scarcity of diversified income generation activities. The majority households are engaged in agriculture and fishing. Inadequate irrigation facilities during dry season are the great obstacle to increase income from crop cultivation.
Education	There is one Primary School. The literacy rate of the island is about 55.2 according to community series of population census 2011 of BBS.
Health & Hygiene	There are no health facilities within the island area.
Market Place	There is a market named ‘Sagorpar Bazar’
Fish Processing Industry	Some people dry fish within the island area.
Tourism	Adjacent Sonar char area is tourist attractive place. Many tourists go Sonarchar.

e. Prevailing Vulnerabilities of Char Bangla/ Char Lakshmi

Land Erosion	River erosion found at the south-west site, where is human habitat; Approximate 50 households shifted to Majher Char after damaging residence here.
Cyclone/Surges	Maximum cyclone/surges hit here and people lost assets and crops.
Tide	Tidal water inundated the crop land during high tide time in monsoon. There is about 8 khals entered into the jangle, all khal are open. So, that tidal water enters into the land area easily.
Soil & Water Salinity	Due saline water intrusion, many people culture Bagda (shrimp). Due to soil salinity, Amon production is not much.
Lack of Drinking Water	There are two tube-wells installed for drinking water.
Climate Change	People face problems during cyclone. One cyclone shelter and it is old.
Population Growth	***The establishment of human habitat happened in the last 27 years.***
Embankment	There is no embankment to save human habitat and crop land.
Scarcity/Loss of Income Generating Activities	There is scarcity of diversified income generation activities. The majority households are engaged in agriculture and fishing. Due to lack of irrigation facilities, the people could not cultivate land during dry season.
Education	There is one Primary School. The literacy of the island is about 22% according to community series of population census 2011 of BBS.
Health & Hygiene	There are no health facilities within the island area.

Market Place	There is a market named 'Bangla Bazar'
Fish Processing Industry	Some people dry fish within the island area.
Tourism	Not found.

f. Prevailing Vulnerabilities of Char Kukri Mukri

Land Erosion	There was land erosion at Char Patila area before 6 to 7 years.
Cyclone/Surges	Some people died in 1970 and 1991. After that, the people face losses of assets and crops during cyclone and storm surges.
Tide	Every year fish and crops washed by the high tide period more or less. There was no sluice gate on the canals that is why it was happened. Now the work of building sluice-gate and closure is going one. It is found water logged, where Bagda cultivated. It was not in before. At the first time, one people started Bagda cultivation in Kukri area.
Soil & Water Salinity	The saline water enteres in to the polder area and the only culture Bagda fish. Due to soil salinity, the rice production is less than other area.
Lack of Drinking Water	The people of the polder area drink tube-well water. The number of tube well is inadequate.
Climate Change	The water level increase. The polder is comparably less impacted due to climate change. The mangrove forest area exist in almost all corner of the polder that is why, the effect of cyclone and storm surge is less than other char area.
Population Growth	There are 1727 households with 8362 population in 2 mouzas according to Population Census 2011, BBS. The present households' number is 2717 and population is about 14000.
Embankment	The first Ring-Beri was built before 15 years back an NGO named COAST. After that BWDB has been built the embankment in 2018 is about 10 kilometers. Some 4 kilometers of crop land is outside of the embankment at west side of Kukri Mukri where government built 3 Guchchagram for landless people; There is no embankment in Char Patila.
Scarcity/Loss of Income Generating Activities	There are 55% land people live in the island. The poverty rate is around 60% in the project area. The majority household are engaged in agriculture and fishing. Due to lack of irrigation facilities, the people could not cultivate land during dry season.
Education	There are 6 Primary schools cum cyclone shelter, one high school, and Dakhil Madrasha.
Health & Hygiene	There is one union health centre in Kukri. No health facilities in Char Patila.
Market Place	There are 4 market places named Kukri Mukri Bazar, Munira Bazar, Dakatia Bazar and char Patila Bazar.
Fish Processing Industry	There are many places of the island, found fish drying facilities.
Tourism	Many tourists come here round the year but facilities for tourists is inadequat. There is no tourist facilities as yet.

g. Prevailing Vulnerabilities of Char Kola Toli

Settlement	The settlers are residing on khas lands without valid legal title.
Intrusion of saline water	Intrusion of saline water from sea increases salinity level in soil and pond water. The salinity level reaches critical level in the lean period covering the months, December to March. Cultivation of Rabi crops is restricted. Both people and livestock suffer from shortage of good drinking water
Cyclone/Surges	The area is not protected against tidal floods and cyclone storm surges. Cyclone storm surges wash away crops in the field and cause heavy damages to dwelling houses, livestock and other properties.
Soil & Water Salinity	The saline water entered in to the polder area. Due to soil salinity, the rice production is less than other area.
Scarcity of Drinking Water	At present, 30 tube wells are the source of clean drinking water for the entire population of the island.
Education	The existing schools and madrasas are adequate in number, but not fully equipped to provide education to all children of school-going age. There are three primary schools in operating condition and three madrasas for the entire island
Health & Hygiene	Sanitation facilities in the char are poor. Most of the people excrete in the open fields. Recently Red Crescent, a NGO has started distribution of pit slabs to households for sanitary latrine. Health care facilities for the char population are below the minimum. Recently a sub health center has been established in Kola Toli. Most of the people cannot afford to visit Upazila Health Center at Monpura.
Inadequate road communication	The existing road communication facilities in the char are inadequate for the population. There are six earthen narrow roads in the island linking the bazaars with different points and the boat landing ghats.
	There are two cyclone shelters in Char Kolatoli
	Safe-keeping of livestock during the high floods/storm surge is also a serious problem for the settlers.
Drainage Congestion	Some drainage canals have silted up. As a result, some parts of the char land remain water logged for considerable period.

h. Prevailing Vulnerabilities of Dhal Char

Land Use/Settlement	About 800 households of Hatiya, who are victims of river erosion, have been allotted land in Dhal char. They are still living on embankment slopes and other places in Hatiya, and would come here, if the island is protected by embankment
Intrusion of saline water	Intrusion of saline water from sea increases salinity level in soil and pond water. The salinity level reaches critical level in the lean period covering the months, December to March. Cultivation of Rabi crops is mostly impossible Both people and livestock suffer from shortage of good drinking water
Cyclone/Surges	The settlers of the island are not effectively covered by cyclone warning system. The settlers do not receive any assistance during the disasters. Recently a committee of 10 persons has been formed for the purpose.
Tide	Area is un- protected against tidal floods & cyclonic storm surges During the monsoon, all agricultural lands are flooded. During high tidal floods, 90% of the homesteads are inundated. Cyclonic storm surges wash away

	crops in the field and cause heavy damages to dwelling houses, livestock and other properties.
Soil & Water Salinity	The saline water enteres in to the polder area. Due to soil salinity, the rice production is less than other areas.
Scarcity of Drinking Water	At present, deep tube wells are the source of clean drinking water for the entire population of the char. During the dry months, pond water turns very saline, not suitable for drinking by human and livestock
Climate Change	The water level increase.
Scarcity/Loss of Income Generating Activities	Problem of safe- keeping livestock Safe- keeping of live stock during the high floods/storm surge is a serious problem for the settlers. In the absence of cyclone shelter/killa in the char, settlers try to save their livestock population by keeping them on the raised platform of the homesteads during high floods/ storm surges.
Education	There is no primary school or madrasha in the char
Health & Hygiene	There is no public health care centre for the settlers of the island and no medicine shop. The settlers collect some general medicine through the milk men coming from Hatiya to collect milk from the char settlers
Market Place	There are 4 market places named Kukri Mukri Bazar, Munira Bazar, Dakatia Bazar and char Patila Bazar.
Fish Processing Industry	There are many fish drying places in the island.
Tourism	Many tourists come here round the year.but facilities for tourists is inadequate.
Inadequate road communication	The existing road communication facilities in the char are very poor. There are only two narrow earthen roads, linking the Mosjid market and the boat landing ghat.
	Safe-keeping of livestock during the high floods/storm surge is also a serious problem for the settlers.
Social Security	Some participants reported theft of livestock. Taking advantage of scattered location of homesteads in the char, organized gangs took away forcibly cattle of several families in night time, during the last few years.

i. Prevailing Vulnerabilities of Char Mozammel

Land Use/Settlement	Erosion-affected people mostly from Tazumuddin Upazila are living in the char on khas land without valid title document. The participants pleaded for immediate land settlement, as done in CDSP project areas.
Intrusion of saline water	Intrusion of saline water from sea increases salinity level in soil and pond water. The salinity level reaches critical level in the lean period covering the months, December to March. Cultivation of Rabi crops is restricted. Both people and livestock suffer from shortage of good drinking water
Cyclone/Surges	There is no cyclone shelter or killa in the island. Cyclone 2010 caused damages to houses and properties in the island. During 2010 Cyclone, most of the families in the island were evacuated to safer places in Abasan Project Area. Safe- keeping of livestock during the high floods/storm surge is a serious problem for the settlers. In the absence of cyclone shelter /killa in the char, settlers try to save their livestock population by keeping them on the raised platform of the homesteads.

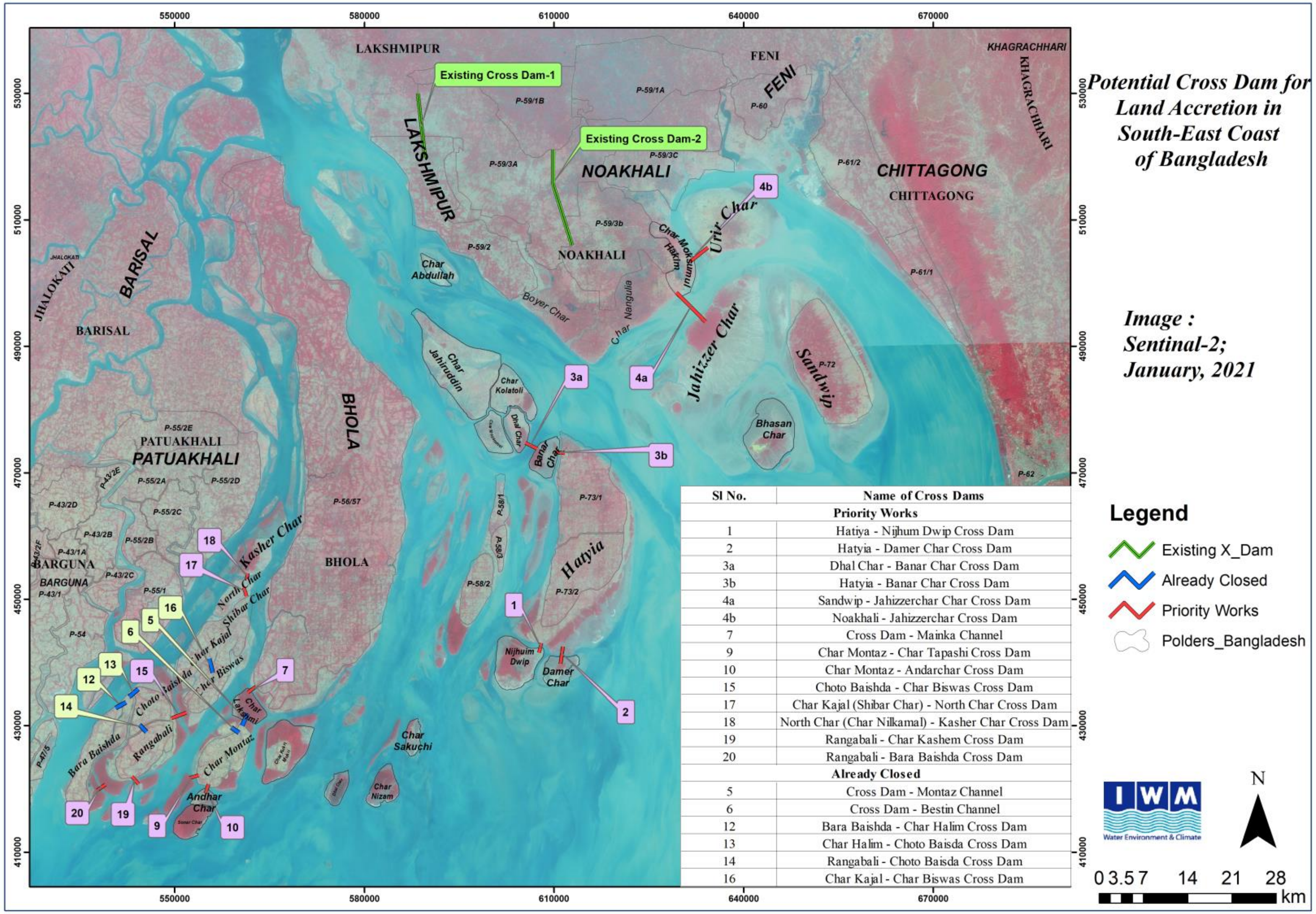
Tide	3) Area is un- protected against tidal floods & cyclonic storm surges During the monsoon, all agricultural lands are flooded. Flood water inundates most of the homesteads. Cyclonic storm surges wash away crops in the field and cause heavy damages to dwelling houses, livestock and other properties. The settlers try to remain in their houses unless great danger signal No.10 is announced. There is no organizational arrangement for alerting the settlers in case of big disasters. Local leaders use mosque loud speakers to warn islanders in times of disasters
Soil & Water Salinity	Intrusion of saline water from sea increases salinity level in soil and pond water. The salinity level reaches critical level in the lean period covering the months December to March. Cultivation of Rabi crops is restricted. Both people and livestock suffer from shortage of good drinking water.
Scarcity of Drinking Water	At present, 18 deep tube wells in the island are the source of clean drinking water for the entire population of the char. Average distance between two DTWs is about 2-3 km. However, there are 20 DTWs in four blocks of Abasan project area. During the dry months, pond water turns very saline, not suitable for drinking by the people and livestock.
Scarcity/Loss of Income Generating Activities	Problem of safe- keeping livestock Safe- keeping of livestock during the high floods/storm surge is a serious problem for the settlers. In the absence of cyclone shelter/killa in the char, settlers try to save their livestock population by keeping them on the raised platform of the homesteads during high floods/ storm surges.
Education	Educational facilities for the children of school- going age in the island is poor. There are four Ananda schools and one madrasa functioning in the island. Ananda schools are operated under donor-funded Government educational program to provide basic education to children over 8 years of age who had no scope to attend formal school.
Health & Hygiene	Sanitation facilities in Char Mozammel are very poor. Most of the people excrete in the open field. At present, there is no program in operation in the char for improving sanitary situation. There is no public health care centre for the population of the island. A few medicine shops in the bazaar help people with medicine and advice in case of illness
Inadequate road communication	The existing road communication facilities in the char are quite inadequate for the population. There are five narrow earthen roads, built by Muslim Aid, an NGO linking bazaars to boat landing ghats and important points in the island. Another 3 km long earthen road from Muktijodha Bazaar towards the north has been built by Union Parishad.
	There are two cyclone shelters in Char Kolatoli
	Safe-keeping of livestock during the high floods/storm surge is also a serious problem for the settlers.
Drainage Congestion	Some drainage canals have silted up. As a result, some parts of the char land remain water logged for considerable period.
Social Security	Some participants reported theft of livestock. Taking advantage of scattered location of homesteads in the char, organized gangs took away forcibly cattle of several families in night time, during the last few years.

9. SELETION OF POTENTIAL AREAS FOR LAND RECLAMATION

9.1 Selection of potential areas for land Reclamation

Enormous volume of sediment is transported to the Bay of Bengal through the Lower Meghna River and give rise to natural accretion in the shallow water area of the Meghna Estuary. However, it is seen that physical interventions are needed in order to accelerate the rate and area for this land hungry country. With intent of reclaiming land in 1977 the Governments of Bangladesh undertook Land Reclamation Project (LRP) with assistance from the Netherlands which continued until 1991. It focused on reclamation and development of newly formed land. Two phases of Meghna Estuary Study (MES) carried out extensive bathymetric surveys as well as implementation of several erosion control and land reclamation measures in pilot basis. Later, a Task Force of BWDB identified 19 potential cross-dams to accelerate the natural land formation process in the Meghna Estuary on the basis of the findings and observations of MES and MES-II.

In this study, the updated MES model is applied for simulating different scenarios to identify the potential locations for future land reclamation by cross-dams or any other suitable interventions and quantify the probable reclaimed land in this area. Huge benefit comes from these reclaimed land. The reclaimed land can be used for turism, industrial hub and various purpose. It is also assessing the probable impact on surrounding area by the proposed cross-dam construction or other intervention. BWDB identified 19 potential cross-dams to accelerate the natural land formation process in the Meghna Estuary on the basis of the findings and observations of MES and MES-II. However, some of them were already implemented and some of are naturaly closed. Preset study identified fifteen (15) potential cross dam based on recent time series analysis, field visit and local stakeholder consultations. A detailed feasibility study is required for selection of suitable locations of cross dam which will be socially acceptable and environmentally sound. The potential cross dam locations is shown in Figure 9.1



Sl No.	Name of Cross Dams
	Priority Works
1	Hatiya - Nijhum Dwip Cross Dam
2	Hatyia - Damer Char Cross Dam
3a	Dhal Char - Banar Char Cross Dam
3b	Hatyia - Banar Char Cross Dam
4a	Sandwip - Jahizzerchar Char Cross Dam
4b	Noakhali - Jahizzerchar Cross Dam
7	Cross Dam - Mainka Channel
9	Char Montaz - Char Tapashi Cross Dam
10	Char Montaz - Andarchar Cross Dam
15	Choto Baishda - Char Biswas Cross Dam
17	Char Kajal (Shibar Char) - North Char Cross Dam
18	North Char (Char Nilkamal) - Kasher Char Cross Dam
19	Rangabali - Char Kashem Cross Dam
20	Rangabali - Bara Baishda Cross Dam
	Already Closed
5	Cross Dam - Montaz Channel
6	Cross Dam - Bestin Channel
12	Bara Baishda - Char Halim Cross Dam
13	Char Halim - Choto Baisda Cross Dam
14	Rangabali - Choto Baisda Cross Dam
16	Char Kajal - Char Biswas Cross Dam

Figure 9.1: Potential Cross Dams for land accretion as recommended in this study

10. CONCLUSIONS & RECOMMENDATIONS

The Meghna estuary is a disaster-prone area. Cyclones, storm surges, bank erosion, droughts, floods, water-logging and salinity intrusion have a huge impact on people and their livelihood. The entire Meghna Estuary specially CDSP areas are highly vulnerable to erosion. Many embankments, sluices and entire Caring Char had already been washed away. Noler Char, Boyar Char and Char Nangulia are under threat of erosion and in near future most of the areas of these Chars will disappear. Other islands in the Meghan Estuary such as Hatiya, NIjhum Dwip, Bhola , Dhal char, Char Muzammel, Char Maksumul Hakim, Char Nizam and Andhar Char are also vulnerable to erosion and storm surge inundation. The Meghna Estuary in Bangladesh is also very heterogeneous and has a tremendous potential to create opportunities of national importance.

A comprehensive study has been carried out to identify the prevailing problems and find long-term solution considering technical and social aspects. Under this study, primary and secondary data, updated models, previous report and experience are analysed for assessing present problems, predicting the hydro-morphology and a continuing hydro-morphological monitoring system which is a very important aspect of water resources planning, development and management.

The Meghna estuary is highly dynamic and changes its planform continuously as found from the analysis of satellite imageries, bathymetric surveys and the hydro morphological model result. Satellite image analysis shows that the Meghna Estuary has huge erosion over the last twenty years. It is found that at the left bank of Lower Meghna like Ramgati, Caring char, char Elahi etc. have the erosion tendency and same tendency was found at the right bank of Lower Meghna such as Char Illisha, Bara Manik. Moreover, at Urir char, Sharnadwip, Vasanchar net accretion were occurred during this period.

Over the last few years, especially the bank erosion problem has worsened in the chars under CDSP II and CDSP IV project areas. Caring Char on the south corner of the CDSP land has completely washed away. Sluice DS2 in Char Nangulia had engulfed into the bay by the end of 2016. It was observed that the Sluices DS-1 in Caring Char, DS-3 in Noler char were totally washed away in 2020. From Bathymetric chart surveyed in 2009 and 2020, it is found that the thalweg line shifted to the left bank of the Lower Meghna River near Char Munshi and Noler char. At Char Munshi thalweg line shifted around 4.5 km and at Noler Char it is around 7 km and the scour hole depth is almost 11m to 17 m in this area. Same tendency was found from the model result.

From satellite images analysis, it is seen that the average rate of erosion is 50 m/year, 400 m/year and 175 m/year in Boyar Char, Noler char and Nanguliar char respectively which is also supported morphological model result. But some places in Noler char maximum erosion rate of 930 m/year is observed. Analysis from both model and satellite image shows that Noler char area is the most vulnerable due to erosion and may be diminished within next 20 years period without any intervention.

20-year morphological model simulation results with 26 morfac , focused on the whole estuary as well as near the CDSP area. A dominant channel has been formed along the south of Noler Char and Char Nagulia. This area will experience huge erosion problem and after 20 year, Noler Char will be totally vanished if no measures is taken. In real situation, this area experienced huge erosion problem for last decade and rate of erosion is very high (756m/year) which is very much similar to the model result. Model analysis shows north Hatiya channel is also gaining. Also from different measurement it has been found the depth of North Hatiya channel has been increased day by day. The bed level evolution has also located the deposition prone area.

Sedimentation mainly occurs at north- east side of Meghna Estuary, Sandwip-UrirChar-Jahazer Char area. Around Jahazer Char, sedimentation is more. Also a channel has been developed along the west side of Jahazer Char. Shandwip Channel experiences some erosion. At the north of Sandwip and Jahazer Char, where tidal meeting point exists, sedimentation occurs and the continuity of the channel along the west side of Sandwip Island disrupts. Two Islands are being developed at the south-west side of Sandwip Island.

East Shabazpur Channel at Lakkhipur and Noakhali, Ramgoti, Noler Char;Urir char at Noakhali side,Upstream of Char Jahiruddin, Char Abdullah, downstream of Shandwip, upstream of Hatia, eastern part of Bhola Island, Char Monpura,Dhal Char and Andhar Char were vulnerable for erosion and storm surge . The storm surge level varies from 4.7 mPWD to 6.4 m PWD for existing condition and the extreme climate change conditions it is varies from 5.3 m PWD to 6.9 m PWD near Char Kolatoli, Jahazer ,Bhasan Char, ,Urir Char , Char Maksumul Hakim for 1 in 25 years return period,. Therefore, most of the chars in the Lower Meghna estuary is vulnerable to erosion and storm surge both existing and climate change conditions.

Three Potential Options for Erosion Mitigations and their effectiveness are assessed.

Option-1, Only Re-alignment of embankment and regulators at stable location and 30 km protective works from Boyer char to Char Nangulia location for proposed 10 year life time. Both satellite images analysis and morphological model results shows that after 5 years, 10years, 15years and 20 years the maximum bank line shifting is found at Noler char which is around 2 km, 3.5 km, 5.5 km 7.6 km respectively if any km slope protection work will not be constructed.

In Option-2, Re-alignment of embankment and regulators (Option-1) is considered. Additionally, one cross dam at Jahazzir char to Char Nangulia is considered. Option-2 show that the velocity is decreased significantly in the chanpnel between Jahazzir char and CDSP char area due to the construction of the cross-dam during monsoon and dry season. But there is no increase in the maximum velocity at the south-west side of the Sandwip Island or any other bank in the area.

Otion-3 is same as Option-2 only difference is that it includes another cross dam (cross-dam-1) at Urir char to Noakhali. Construction of cross-dam 1 and cross-dam 2 restrict the flow around Urirchar and Jahazer Char respectively. Cross-Dam 1 will speed land reclamation in the Urir Char area, with minimal influence on the other parts of the CDSP. *Construction of Urir char to Noakhali Cross-dam is being taken up under a different entity by Noakhali O & M Division, the DPP is at the finishing stage of approval by competent Authority. Hopefully its implementation will start immediately after approval of DPP. This may not conflict implementation of option 1.*

Based on the results of the hydro-morphodynamical model, it can be concluded that if no action is taken, the continuous erosion will continue to occur. The construction of a cross-dam between Jahazer Char and the Noakhali mainland (Option-2) will lessen erosion in this area while also speeding up land accretion in this location. However, the construction of this cross-dam will necessitate a significant investment as well as extensive investigation, which will be a great challange to complete in a short period of time. As a result, option-1 is selected through agreement amongst CDSP, BWDB, Quality Control (SVASEK), and IFAD.

Regarding option 1, we propose 5, 10, and 15-year alignments based on satellite image analysis, model results, and expert judgment. However, as 5 years proposed alignment for embankment and structure locations are very short in considering construction period and with 15 years proposed location protection of only 30% of the productive land, therefore 10 years embankment alignment and structure location is recommended covering 73% of the productive land.

Selection of suitable or stable chars for future development is depends on morphological behaviour, maturity of Char (15~20 years), storm surge level, population density, existing land level, tidal condition, salinity, bio diversity, environmental and social consideration. Based on these criteria 12 chars are selected out of 17 chars. The potentials chars are Char Moksumul Hakim, Char Kolatoli,,Char Mozzammel, Dhal Char (CDSP-V, the next Phase), Domer Char, Nijhuim Dwip, Andhar Char ,Char Kukri Mukri ,Char Lakshmi, Char Nizam, Char Sakuchi and Dhal Char.(may be CDSP-VI, the next but one Phase)

BWDB identified 19 potential cross-dams to accelerate the natural land formation process in the Meghna Estuary on the basis of the findings and observations of MES I and MES-II. However, some of them were already implemented and some of are naturaly closed. Preset study identified fifteen (15) potential cross dam based on recent time series satellite images analysis, field visit and local stakeholder consultations. A detailed feasibility study is required for selection of suitable locations of cross dam which will be socially acceptable and environmentally sound.

Recommendations

The following interventions are proposed for protecting the CDSP-III and CDSP-IV, mainly areas of Boyar Char, Noler Char and Nangliar Char

I. It is suggested to follow the 10 years proposed embankment alignment for the implementation of erosion protection of Noler char, Boyer char and Char Nangulia. There shall be a provision of Hydro-Morphological monitoring program (a) Hydro-morphological survey of the whole Estuary at alternate years & (b) Hydro-Morphological Model study after each three sets of Survey: for monitoring the erosion& accretion rate, water level water flow and performance of new interventions and future projections in line with recommendations of BDP2100.

The suggested interventions are;

- Re-alignment of proposed embankment for 10 years, Total **30** km as shown in Table 10.1 and Figure 10.1;
- Total 8 drainage regulators required; Two are (3-vent) at Chatla khal and (9-vent) Gabtoli Khal in Boyer char , one is (4-vent) at Milon khal in Noler char and others five are at Char Nangulia in (2-vent) Mamur Khal , Nangulia Khal (3 Vent), Bhuiyar Khal (6 Vent), Katakhali Khal-2 (9 Vent) and Borrowpit Khal (3 Vent);
- Setback distance is suggested considering the erosion rate of this area based on model results, data analysis, past experience and judgement and stakeholder consultations. For 10-year proposed alignment the average setback distance is around 1000 m for Boyer char, 2200 m for Noler char and 1600 m for char Nangulia. The proposed setback distance of Noler char shall be updated considering the future morphological

Table 10.1 List of proposed embankment length and regulators for 10 years are as follows:

Name of Char	Area Existing (km^2)	Area After 10 Years (km^2)	For 10 Years					
			Embankment Length (km)	Khal Name	Khal Width (m)	Khal's Position		Proposed Regulators size (m x m)
						Easting (BTM_X)	Northing (BTM_Y)	
Noler Char	18.15	4.72	8.90	Milon Khal	30	614991.82	490556.38	4 vent – 1.5x 1.8
Nangulia Char	63.40	46.72	11.30	Mamur Khal	30	617683.60	492497.22	2 vent – 1.5x 1.8
				Nangulia Khal	25	619948.36	494093.57	3 vent – 1.5x 1.8
				Bhaiyar Khal	25	621566.81	494713.05	6 vent – 1.5x 1.8
				Katakhali Khal-2	40	625503.73	496798.10	9 vent- 1.5x 1.8
				Borrowpit Khal	20	628217.78	500520.65	3 vent – 1.5x 1.8
Boyer Char	43.67	38.56	9.70	Chatla Khal	20	611914.69	491926.46	3 vent – 1.5x 1.8
				Gabtoli Khal	40	607188.28	495787.15	9 vent- 1.5x 1.8
Total	**125.22**	**90.00**	**30.00**					**8 Regulators and vent size (1.5x 1.8)**

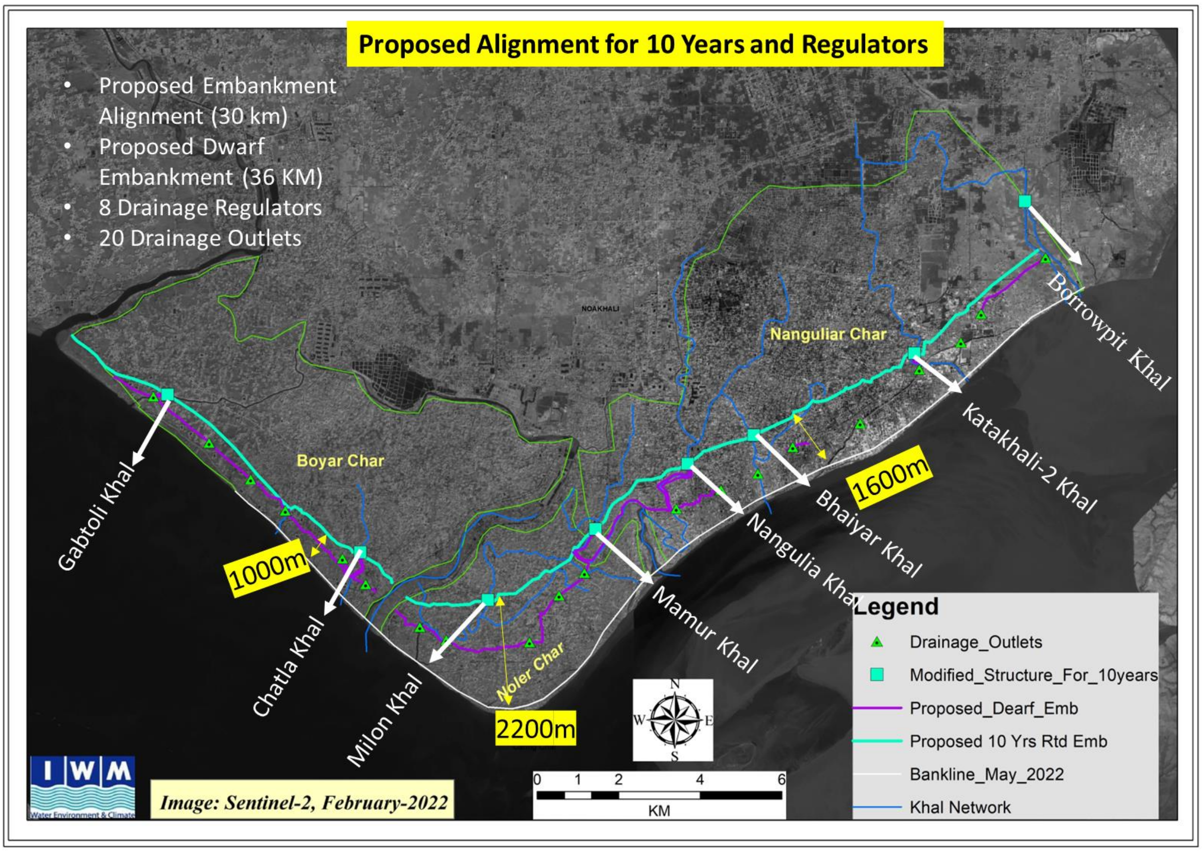


Figure 10.1: Re-alignment of Embankment and Regulators at Stable Locations for 10 years Proposed Alignment

- The proposed Embankment alignment of 10 years life time shows that a huge amount of CDSP area in Noler Char, Boyar char and Nanguliar char will be unprotected and will be affected by high spring tide, damage of crop, infrastructures and daily livelihood of the people residing outside the embankment. Considering social demand, a dwarf embankment of **27** Km is proposed and re-sectioning of existing road is 14.57 km as a temporary solution in order to protect the area outside the proposed embankment;

- A total 30 km bank protection measure may be recommended for Boyar char, Noler Char and Nanguliar char (Table E-2). As erosion rate is very high (756m/year) at Noler char area, *an immediate protection measure is considered for the 5 km reach along the shore line of Noler char*. Protection measure for Boyer Char and Char Nagulia can be taken at a later stage. A detailed feasibility study is required for planning and design of erosion mitigation measures along the shoreline of Boyer char and Char Nangulia;

II. Total Twelve potential chars are selected for future development. Detailed strategic Planning of these 12 chars is already discussed in the separate Volume II. A detailed feasibility study is required for planning and design of erosion mitigation measures of these potential chars. The potential chars for future development are shown in Figure 10.2.

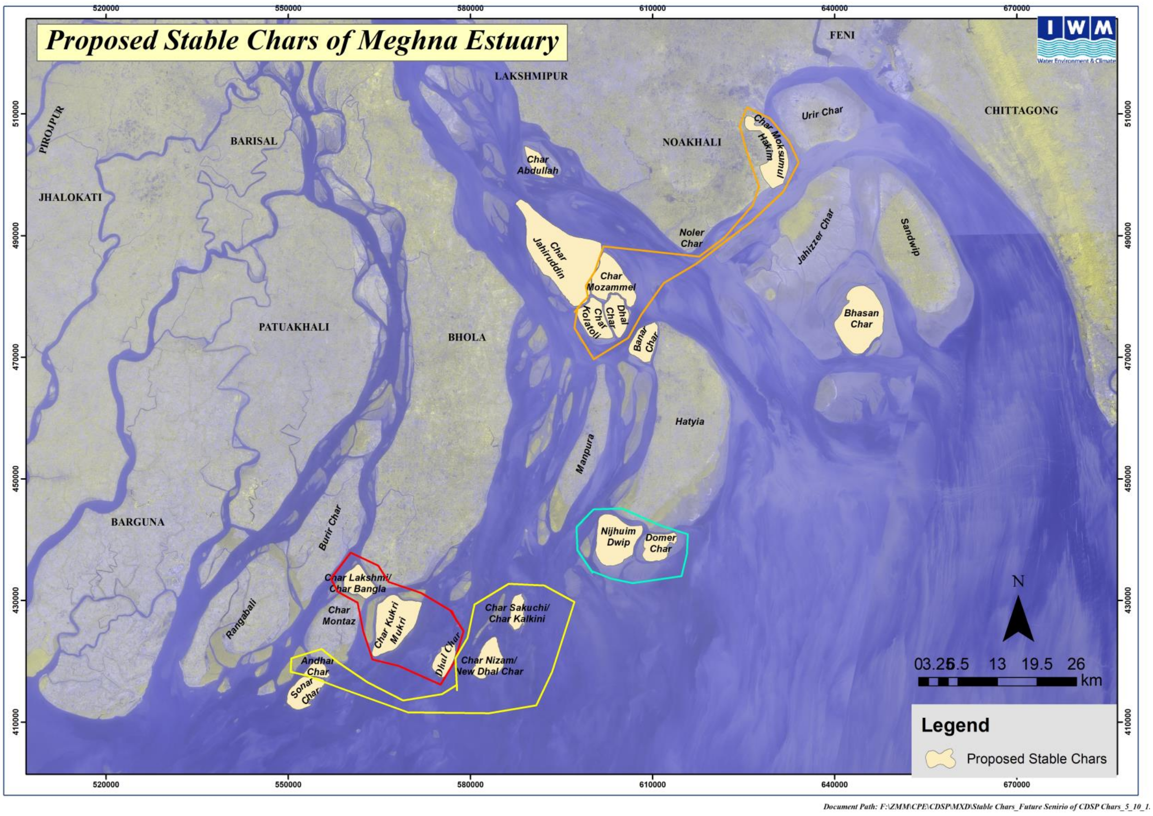


Figure 10.2: Potential/ Stable char for Future Development.

III. BWDB identified 19 potential cross-dams to accelerate the natural land formation process in the Meghna Estuary on the basis of the findings and observations of MES I and MES-II. However, some of them were already implemented and some of are naturaly closed. Preset study identified fifteen (15) potential cross dam based on recent time series satellite images analysis, field visit and local stakeholder consultations. **A detailed feasibility study is required for selection of suitable locations of cross dam which will be socially acceptable and environmentally sound.** The potential cross dam locations is shown in Figure 10.3.

IV. Physical, environmental, social and economic benefit monitoring is recommended to carry out before, during and after completion of the project.

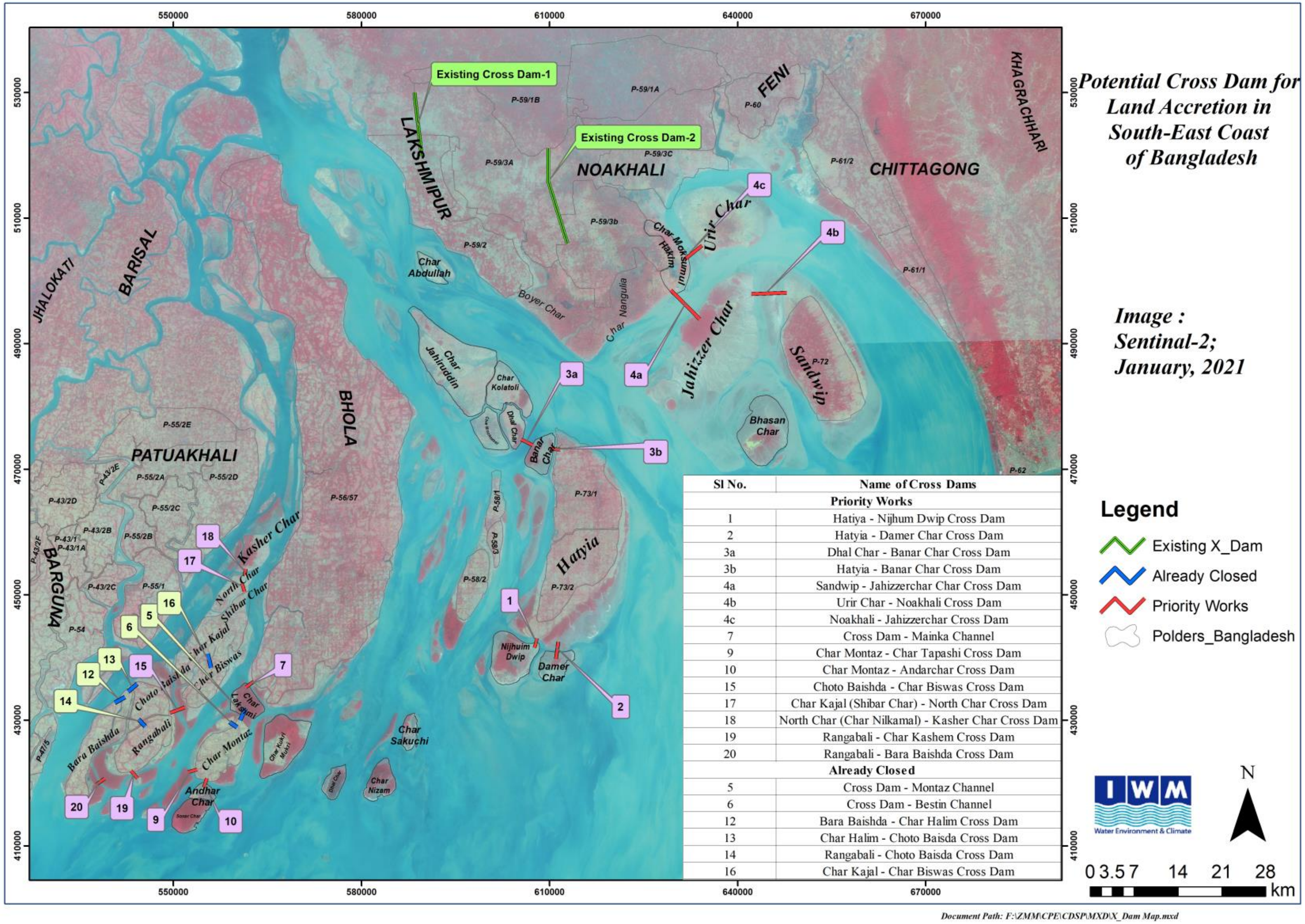


Figure 10.3: Potential Cross Dams for land accretion as recommended in this study

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