Ministry of Water Resources

Bangladesh Water Development Board

Coastal Embankment Improvement Project, Phase-I (CEIP-I)

Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics)

Lower Meghna - Tetulia River system morphological modelling study – Current situation



Joint Venture of DHI
The expert in WATER ENVIRONMENTS
& Deltares
Enabling Delta Life
in association with IWM, Bangladesh and University of Colorado, Boulder and Columbia University

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July 2020

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Columbia University, USA

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ACRONYMS AND ABBREVIATIONS

ADCP- Acoustic Doppler Current Profiler

BDP2100- Bangladesh Delta Plan 2100

BIWTA- Bangladesh Inland Water Transport Authority

BMD- Bangladesh Meteorological Department

BoB- Bay of Bengal

BTM- Bangladesh Transverse Mercator

BWDB- Bangladesh Water Development Board

CBA- Coast Benefit Analysis

CCP- Chittagong Coastal Plain

CDMP-Comprehensive Disaster Management Program

CDSP- Char Development Settlement Project

CEA- Cost Effectiveness Analysis

CEGIS- Centre for Environmental and Geographic Information Services

CEIP- Coastal Embankment Improvement Project

CEP- Coastal Embankment Project

CERP-Coastal Embankment Rehabilitation Project

CPA- Chittagong Port Authority

CPP-Cyclone Protection Project

CSPS-Cyclone Shelter Preparatory Study

DDM- Department of Disaster Management

DEM- Digital Elevation Model

DOE- Department of Environment

EDP- Estuary Development Program

FAP- Flood Action Plan

FM- Flexible Mesh

GBM- Ganges Brahmaputra Meghna

GCM- General Circulation Model

GIS- Geographical Information System

GTPE- Ganges Tidal Plain East

GTPW- Ganges Tidal Plain West

HD- Hydrodynamic

InSAR- Interferometric Synthetic Aperture Radar

IPCC- Intergovernmental Panel for Climate Change

IPSWAM- Integrated Planning for Sustainable Water Management

IWM- Institute of Water Modelling

LCC- Life Cycle Costs

LGED- Local Government Engineering Department

LGI- local Government Institute

LRP- Land Reclamation Project

MCA- Multi Criteria Analysis

MES- Meghna Estuary Study

MoWR- Ministry of Water Resources

MPA- Mongla Port Authority

NAM - Nedbor Afstromnings Model

PPMM- Participatory Polder Management Model

PSD- Particle Size Distribution

PWD- Public Works Datum

RCP- Representative Concentration Pathways

RTK- Real-Time Kinematic

SET-MH- Surface Elevation Tables – Marker Horizons

SLR- Sea Level Rise

SOB- Survey of Bangladesh

SSC- Suspended Sediment Concentration

SWRM- South West Region Model

TBM- Temporary Bench Mark

TRM- Tidal River Management

ToR- Terms of Reference

WARPO- Water Resources Planning Organization

WL - Water Level

1 Introduction

This report describes the development, calibration, validation and application of the meso-scale morphodynamic model covering the Lower Meghna - Tetulia river system.

Meso-scale model domains have been already selected based on available previous data, erosion history and the peripheral rivers around the polders that cover the whole coastal area. CEIP officials also agreed to the selected zones for this modelling. The selected meso-scale modelling groups are the following (Figure 1.1):

1. Pussur - Sibsa river system (Polder 32 & 33)
2. Baleswar - Bishkhali river system (Polder 35/1, 39/1, 39/2, 40/1, 40/2, 41 & 42)
3. **Lower Meghna - Tetulia river system (Polder 56/57,55/1,55/2, 55/3 & 59/2)**
4. Sangu river system (Polder 63/1a, 63/1b & 64/1b)

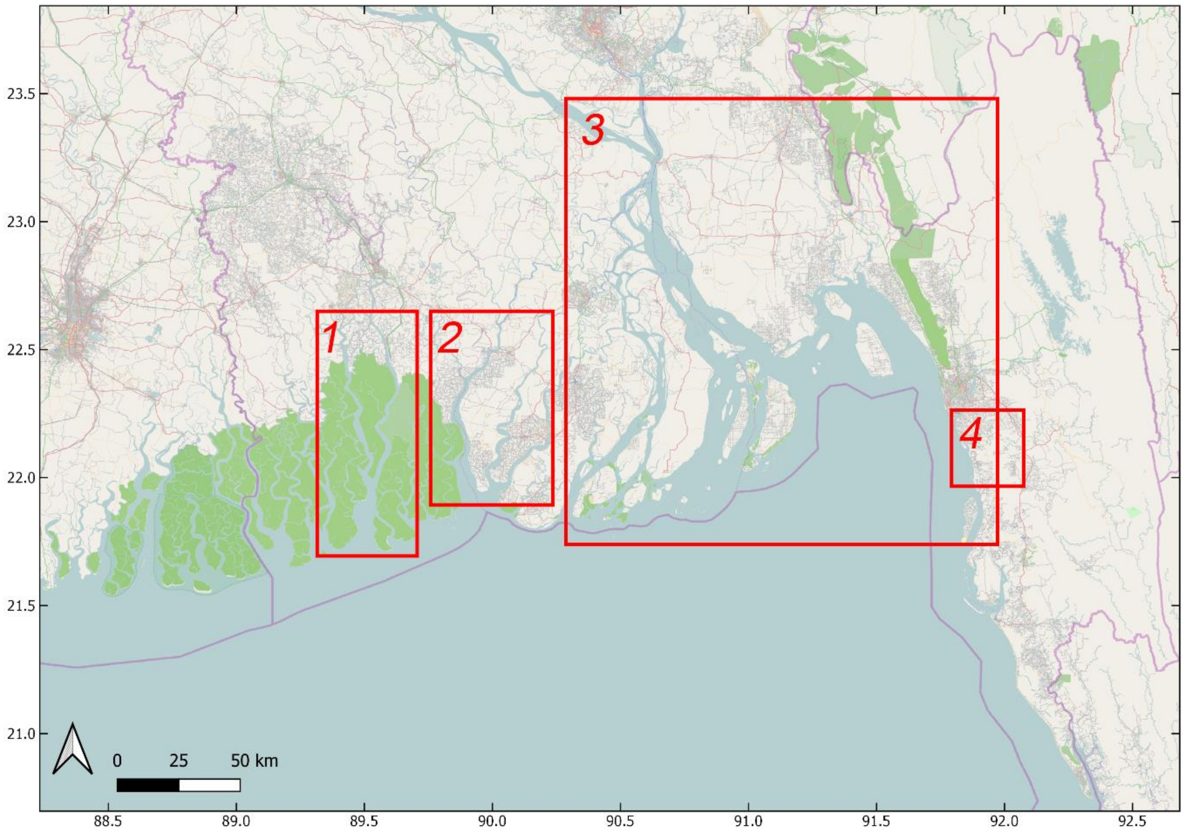

Figure 1.1 Map of meso-scale modelling groups for long-term morphology (1) Pussur-Sibsa; (2) Baleswar-Bishkhali; (3) Lower Meghna-Tetulia; (4) Sangu river

2 Objectives and Approach

The objectives of this model are:

- To hindcast and predict the morphological development of the Lower Meghna-Tetulia river system on decadal scales: can we understand the major morphological changes, what processes drives them and how will these change under future scenarios?
- To provide boundary conditions in terms of large-scale bed elevation change and sediment concentrations to micro-scale models.

The approach is as follows:

- Model grid - to construct an unstructured-grid model of the entire Lower Meghna - Tetulia river system, with rectangular grid cells except where areas of different resolution are connected by triangles (section 4.1).
- Setup and Calibration – setup, calibrate and validate the model with field measurements and remote sensing data (section 4.4, section 4.6.6).
- Morphological hindcast – reproduce the morphology from different previous periods.
- Scenario runs - study future changes in the morphodynamic processes based on possible scenarios.

  Two types of morphodynamic simulations are carried out (section 4.6.1):

  - Short-term (~ 1 year) runs with realistic time series boundaries;
  - Long-term (5-100 year) runs with schematized *representative* boundary conditions for the river discharges and simplified *representative* tidal components, combined with a *morphological factor* approach to accelerate the morphodynamic simulations.

Calibration of the sediment model on the shorter time scale is carried out using available sediment concentration measurements for selected periods where bathymetric, hydrodynamic and sediment concentration measurements are available.

Calibration of the decadal-scale morphological development is carried out using the accelerated approach (section 4.6.1), in order to have acceptable runtimes, as the available bathymetries to assess model skill are separated by 9 years, making brute-force simulations prohibitively long.

It must be noted that having a good calibration for sediment concentrations for the short-term runs is no guarantee that the same settings will lead to good morphological behaviour. This is in part because the longer-term evolution is influenced by parameters that have little influence on short time-scales, but also because there are different paths towards a reasonable concentration distribution that may result in quite different sedimentation/erosion patterns.

Therefore, the chosen approach for calibrating the sediment and morphology behaviour consists of trying to **reconcile** the settings for both types of simulations, rather than adopting the settings resulting from the short-term sediment calibration and assuming them to be equally valid for the morphological runs.

3 Data

In this section all used data for the model development will be documented and briefly described.

The projection is BTM (Bangladesh Transverse Mercator) and the vertical datum is m PWD (Public Works Datum).

3.1 Bathymetry

The river system has been surveyed in previous years, so suitable bathymetry information was readily available. Very detailed bathymetry surveys were conducted in 1997, 2000 and 2009/10 for the Meghna Estuary within the MES and EDP projects. A similar bathymetry survey was conducted for the present project. The available bathymetries from 1997-2019 are shown in the Figure 3.1 and summarised in Table 3.1 .

Table 3.1 Bathymetry data for Lower Meghna- Tetulia river system

Bathymetry data	**Source**	**Data Coverage**
1997 MES	MES1_1997	Meghna Estuary
2000 MES	MES2000	Meghna Estuary
2009-2010	EDP, IWM	Meghna Estuary
2011	IWM (Sustainable River Management, Ramgati Erosion Study)	Padma, Upper Meghna and Lower Meghna
2013	IWM	Upper Meghna and Lower Meghna
2015	IWM (Cymmit)	Ilisha-Tetulia (part)
2017	IWM	Tetulia
2017	IWM	Upper Meghna and Lower Meghna
2019	IWM (Present Project)	Lower Meghna

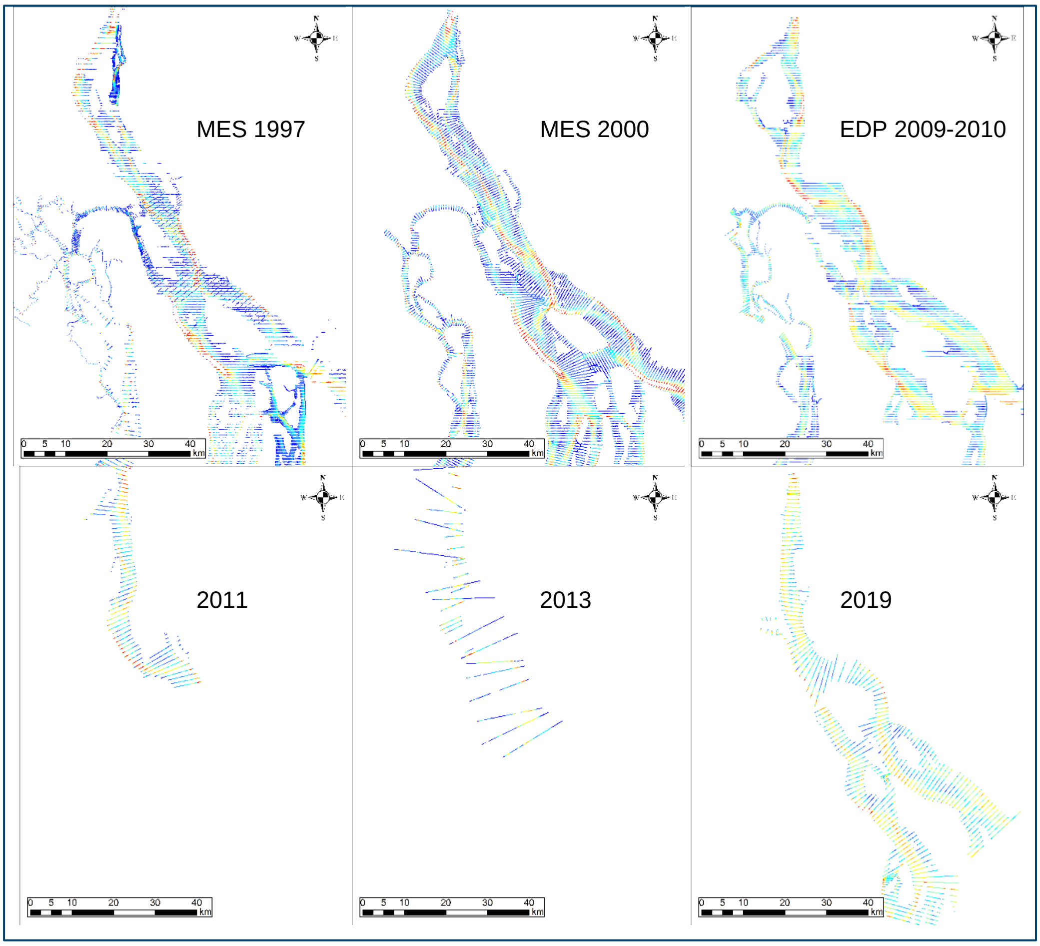

Figure 3.1 Bathymetry data from surveys carried out in 1997, 2000, 2009-2010, 2011, 2013 and 2019

3.2 Digital Elevation Model (DEM)

The bed level height of the dry land area is available through some RTK-GPS observations; however, these data are sparsely distributed in space and therefore not suitable as comprehensive input for the (terrestrial) elevation description in models. The use of satellite derived topography maps ensured full coverage of the coastal zone of Bangladesh. A digital elevation model (DEM) dataset was acquired by FINNMAP (a Finnish consultancy firm) in 1991 and updated by IWM in 2009 (IWM, 2009) using Google images from 2006-2007 to correct the data and to delineate the Sundarbans (Payo et al, 2016). After this update the dataset has been updated regularly by IWM with land surveys executed for different projects across the delta. The dataset available for this project provides topography information on a 30 m resolution grid of the Bangladesh coastal zone (Figure 3.2). As this dataset is acquired by remote sensing the accuracy of the data must be considered carefully. It is, for example, not known if the data provides the vertical level of the land or the top of the canopy in densely vegetated areas (e.g. the Sundarbans).

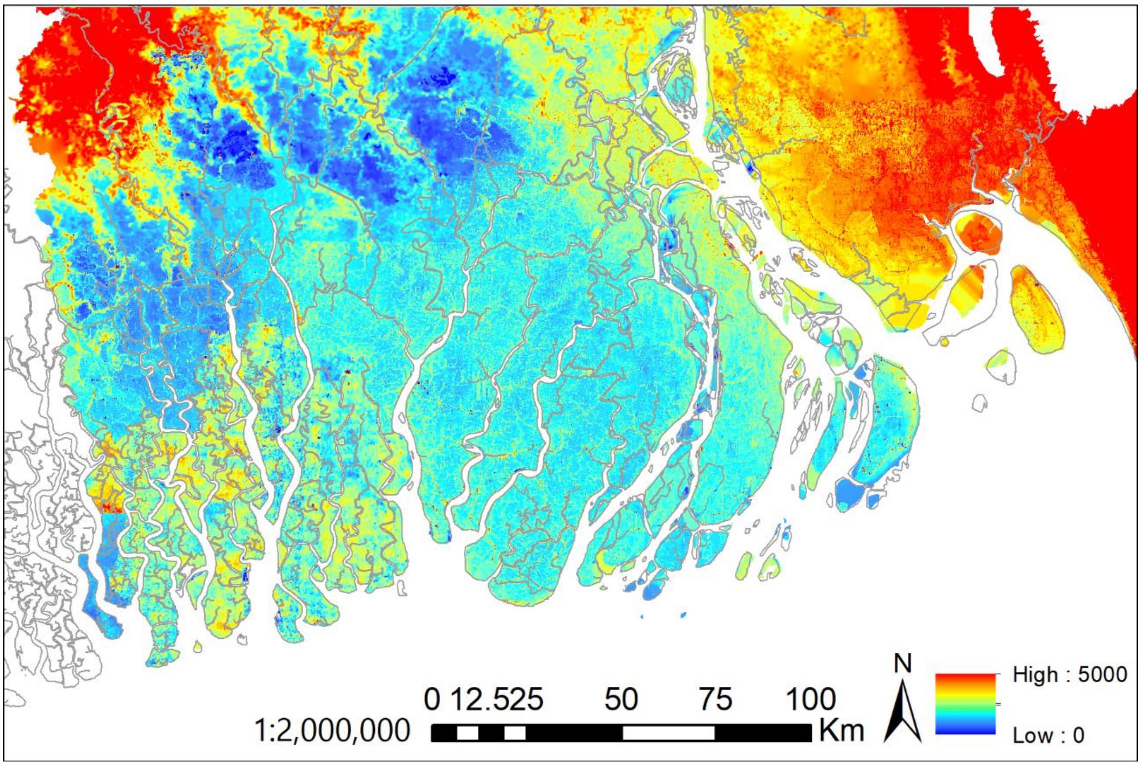

Figure 3.2 Satellite derived digital elevation model (DEM) for the Bangladesh coastal zone. Elevation shown in millimetres with respect to PWD.

3.3 Water level time-series

Observed water levels are available at several stations in the Lower Meghna - Tetulia river system. The data inventory is presented in Table 3.2. The locations of bathymetry, water level, discharge and sediment samples measurement under the present study are shown in Figure 3.4.

Table 3.2 Available water level observations from Lower Meghna- Tetulia river system

Sl. No.	Description of data	Period		Data Source
		From	To	
	Water Level			
1	Bathua-Bhola	04/07/2009	07/10/2009	BDWB (EDP)
2	Boyer Char (Chairman Ghat)	05/07/2009	07/10/2009	
3	Char Alexander	05/07/2009	07/10/2009	
4	Char Montaz (Launch Ghat)	03/07/2009	19/08/2009	
5	Char Langta (Guptachara Ghat)	18/08/2009	27/09/2009	
6	Char Changa	18/07/2009	19/10/2009	
7	Sandwip	18/07/2009	27/09/2009	
12	Char Clark	Feb-Mar 2010		
13	Char Laxmi			
14	Caring Char			
15	West Sandwip			
16	North Sandwip			
17	Chandpur	Monsoon 2011		IWM (SRM)
18	Eklaspur			
19	Mojuchowdhurir Hat			
20	Dasmina (Tetulia)	April 2019	Ongoing	IWM (Present Project)
21	Dhulashar (Rabnabad)	Feb 2019	Ongoing	

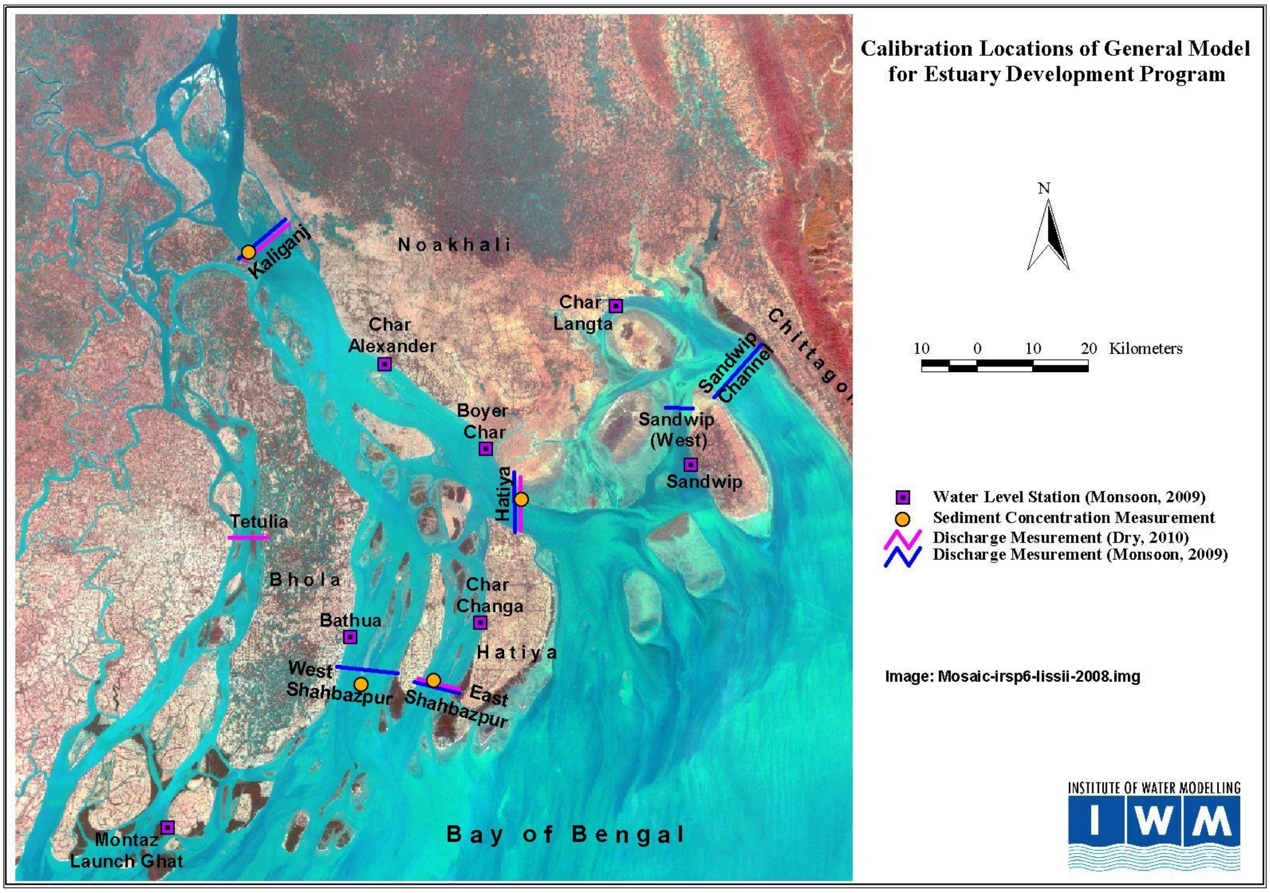

Figure 3.3 Field data collection map of the Estuary Development Program (Source: IWM, 2009-10)

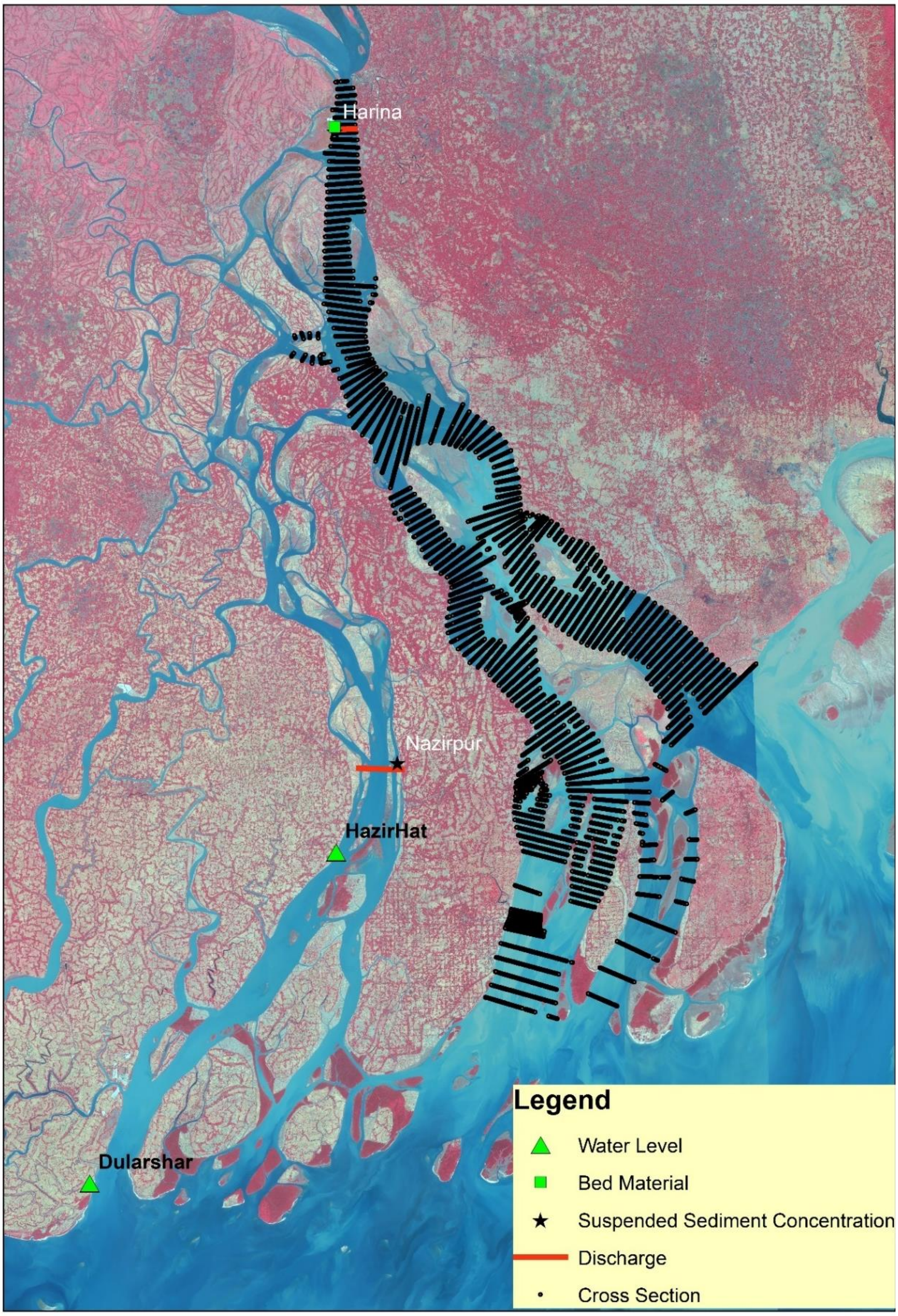

Figure 3.4 Field data collection map of the present study (Source: IWM, 2019)

3.4 Discharges time-series

The following discharge time series were available and have been used in the study. Table 3.3 summarises the datasets whereas the locations are given on the maps in Figure 3.3 and Figure 3.4.

Table 3.3 Available discharge observations from Lower Meghna - Tetulia river system

Sl. No.	Description of data	Period		Data Source
		From	To	
	Discharge	Monsoon	Dry	
1	Hatia North spring tide Hatia North neap tide	14/07/2009 24/07/2009	-	EDP-4
2	Hatia North	-	19/03/2010	EDP-9
3	Sandwip East	21/07/2009	-	EDP-4
4	Sandwip East	-	21/03/2010	EDP-9
5	Sandwip West	22/07/2009	-	EDP-4
6	Sandwip West	-	22/03/2010	EDP-9
7	Kaliganj spring tide Kaliganj neap tide	16/07/2009 26/07/2009	-	EDP-4
8	East-Shahbazpur Channel (Jahajmara)	5/8/2009	-	EDP-4
9	East-Shahbazpur Channel (Jahajmara)	-	3/3/2010	EDP-8
10	West-Shahbajpur Channel (Bhola-Monpura)	7/9/2009 12/9/2009	-	EDP-5
11	West-Shahbajpur Channel (Bhola-Monpura)	-	25/10/2009	EDP-6
12	West-Shahbajpur Channel (Bhola-Monpura)	-	1/2/2010	EDP-7
13	Tentulia spring tide Tentulia neap tide	-	5/10/2009 13/10/2009	EDP-6
20	Tentulia spring tide Tentulia neap tide	-	21/10/09 28/10/2009	Chevron
21	Urirchar-Char Laxmi spring tide Urirchar-Char Laxmi neap tide	-	5/3/2010 26/2/10	IWM-Survey (Sandwip-Urirchar-Noakhali)
22	Jahajer Char- Boyer Char spring tide Jahajer Char- Boyer Char neap tide	-	3/3/10, 24/2/10	
23	Sandwip-Jahajer Char	-	8/2/2010 14/2/10	
24	Sandwip- Urirchar	-	9/2/2010 16/2/10	
25	Chandpur	Dry and Monsoon 2011		IWM (SRM)
26	Eklaspur			
27	Mojuchowdhurir Hat			
28	Chandpur	Dry and Monsoon 2019		IWM (Present Project)
29	Dasmina (Tetulia)			

3.5 Sediment bed samples

In this section all readily available sediment bed samples for the Lower Meghna - Tetulia river system have been combined. Many samples have been collected for various projects, but no report compiling the available data into a comprehensive picture of the sediment bed could be identified. Table 3.4**Error! Reference source not found.** summarises the available data sets. The bed samples collected under different studies are shown in Figure 3.5.

Table 3.4 Available bed samples for Lower Meghna - Tetulia River system

Bed sample data collection year	Sources
2009-10	IWM (EDP Project)
2012	IWM (Protection of Ramgati and Kamal Nagar Upazilla of the Meghna River)
2014-2015	IWM (Integrated Development of Jahizzer Char)
2019-2020	IWM (Lower Meghna River along Bhola Island)
2019	Primary data (Present Project)

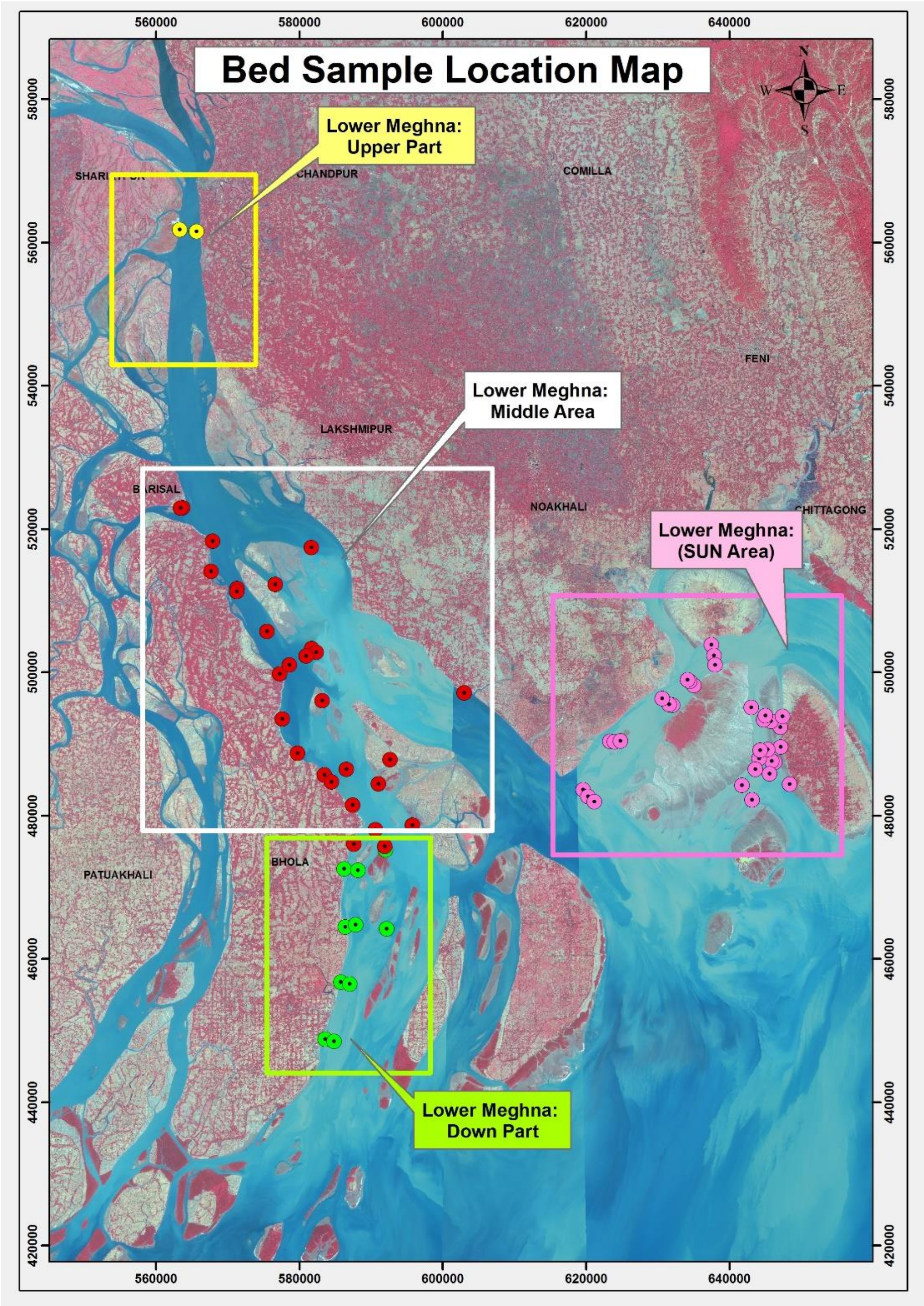

Figure 3.5 Map showing Bed sample Locations under different Studies

Error! Reference source not found. and **Error! Reference source not found.** show an example of a particle size distribution curve based on three samples taken at Harina station. The following can be noted:

- Very little cohesive sediment in the bed; cohesive sediment can be found along the channel edges and other relatively calm areas in the river.
- The d50 ranges between 0.122-0.160 mm in the three samples; representative d50=0.144 mm
- Standard deviation range 1.38-1.69, mean sample 1.54

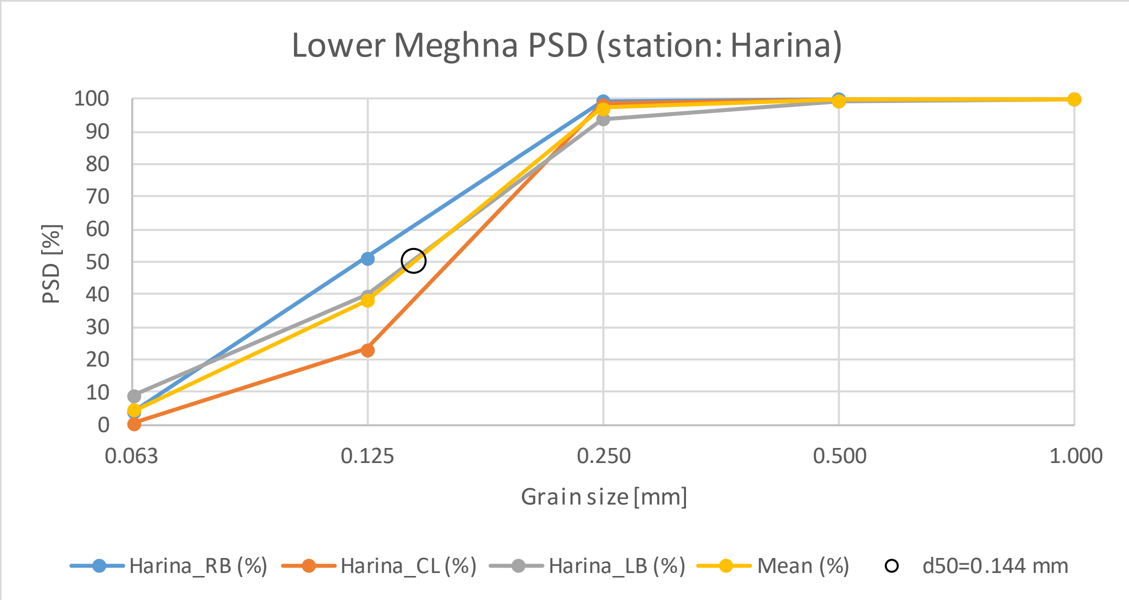

Figure 3.6 Particle size distribution for the Harina station Lower Meghna (near Chandpur)

Table 3.5 Processed bed samples at the Harina station in Lower Meghna

Station	Harina_RB	Harina_CL	Harina_LB	Mean
d_g [mm]	0.121	0.152	0.131	0.134
d_{50} [mm]	0.122	0.160	0.142	0.144
σ	0.58	0.46	0.75	0.63
σ_g	1.50	1.38	1.69	1.54

Central Part

The data shows that, the bed materials at the both bank of Ramgati have finer particle than the banks of Elishaghat. In both Ramgati and Elishaghat, the bed materials at left banks are finer than those of the right banks. It was also observed that, the bed materials near the chars are finer. Figure 3.7 shows the median values of the grain sizes at different locations of the study area.

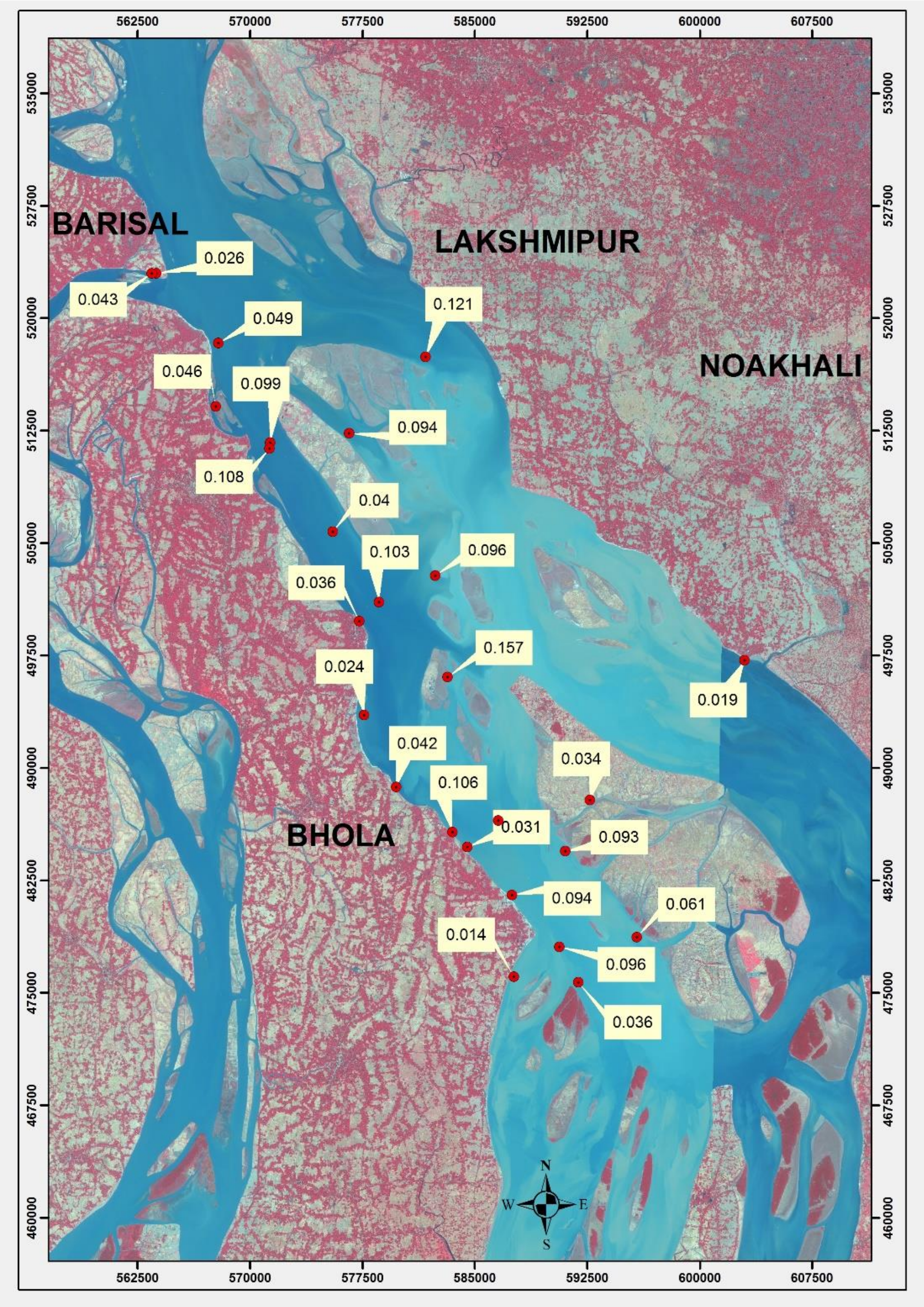

Figure 3.7: Median grain sizes at different locations from where samples were collected in the Ramgati Bank Erosion study (Year:2012)

Lower Part

The river bed material (Figure 3.8) was collected near Bhola Island. Bed sample was collected near the river bank and in the middle of the channel. In most of the cases, observed d50 value was below 63 microns. Moreover, in 7 locations the percentage of silt and clay is greater than 40%. In the main channel the river bed sediment characteristics is dominated by cohesive sediment.

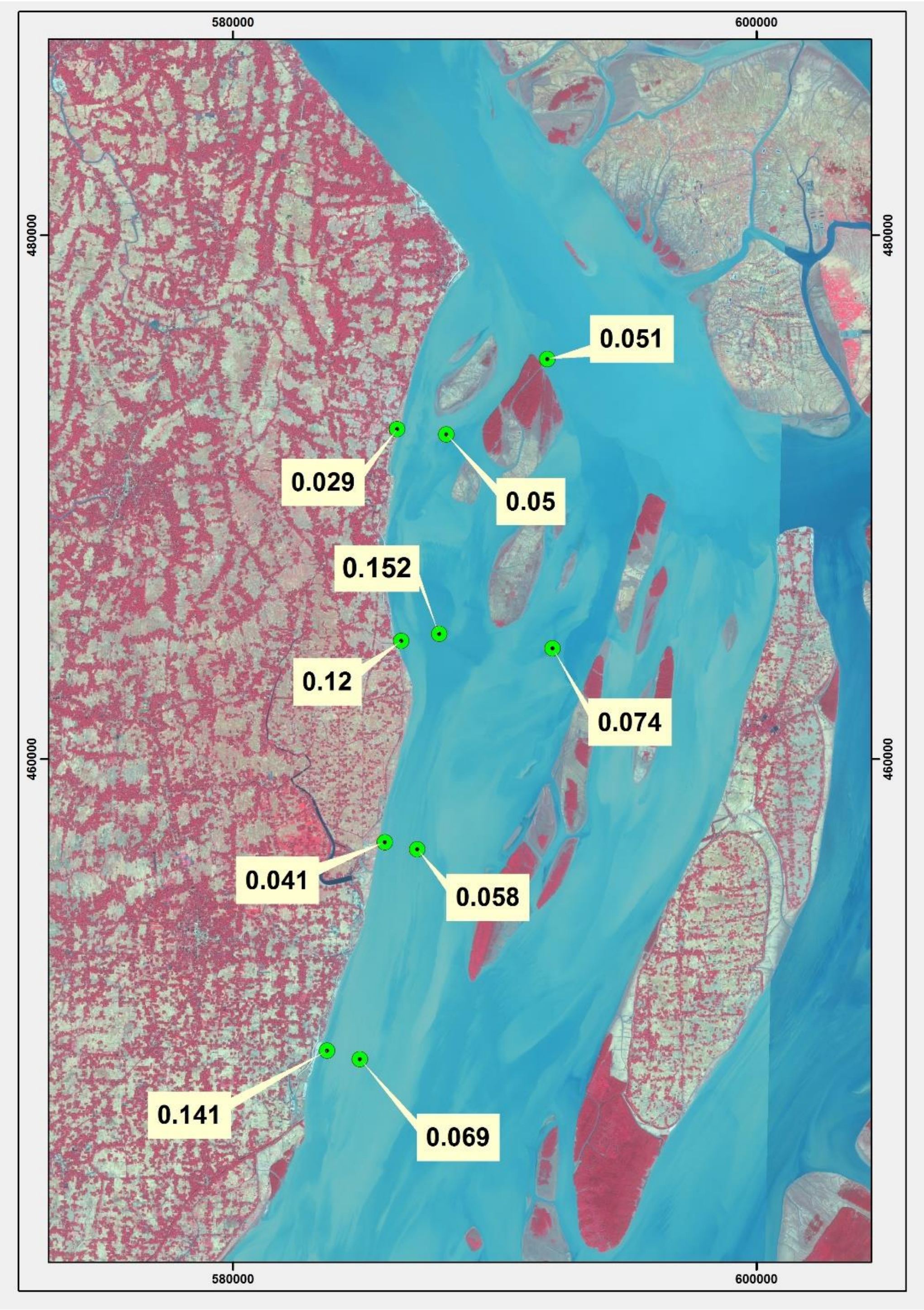

Figure 3.8: Median grain sizes at different locations from where samples were collected in the Bhola Bank Erosion study (Year:2019)

Sandwip-Urirchar-Noakhali (SUN) Area

The river bed material (Figure 3.9) was collected near Sandwip-Urirchar-Noakhali area. The d-50 Value gives the indication of cohesive sediment river bed around the SUN area.

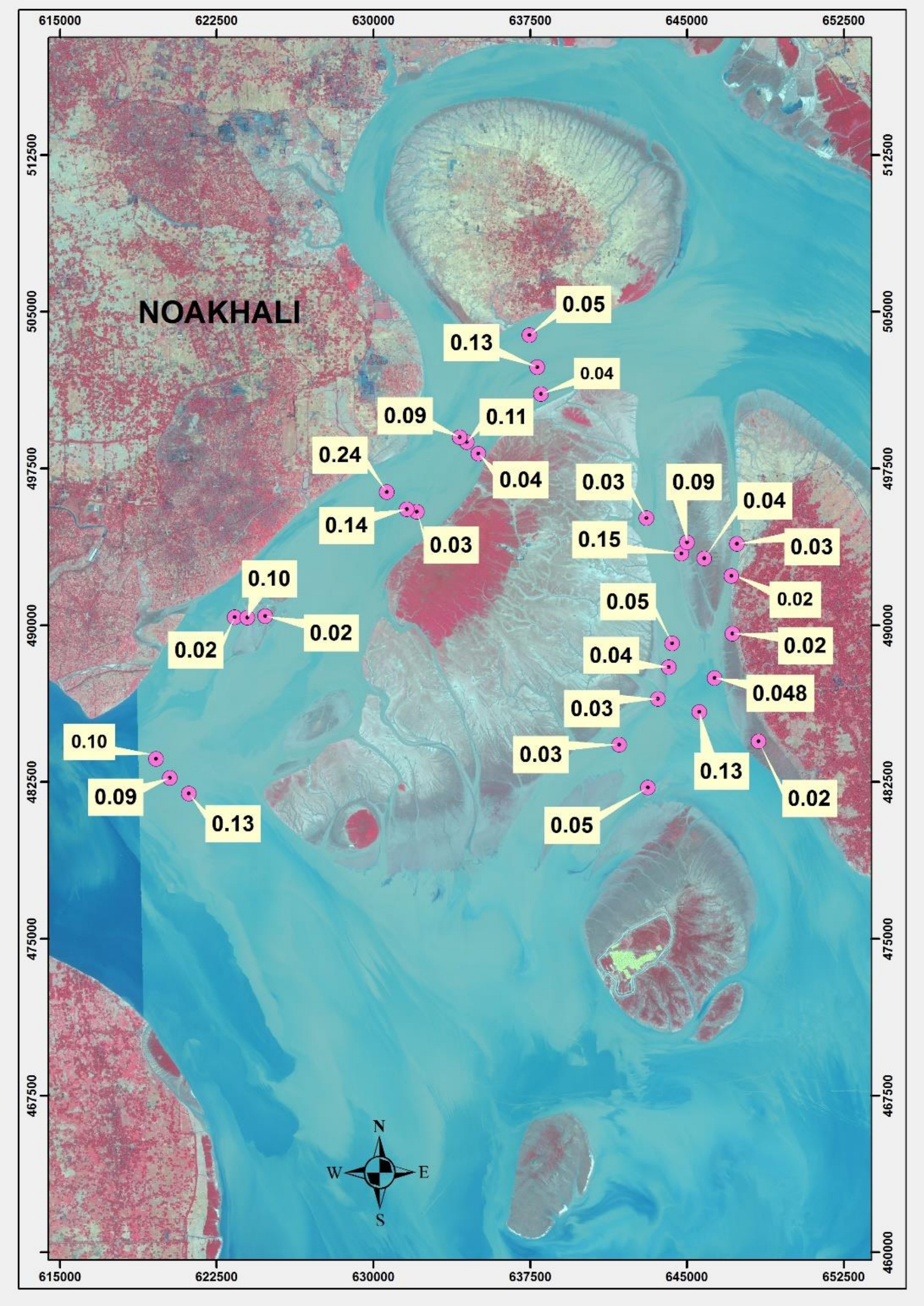

Figure 3.9: Median grain sizes at different locations from where samples were collected in the Jahizzer Char (Swarna Dwip) study (Year:2014)

3.6 Suspended sediment data

For the purpose of the present project, samples were collected in the Meghna area by IWM in February and May 2019 in 2 locations: Harina and Bhairab (Table 3.6). No wet season samples are available because of the prohibitively high flow velocities during those months. The data was processed by taking the average value from the three sample depths (0.2, 0.6, 0.8 times local depth). Some samples also included a measurement of 0.5 m above the bed, however these were not used in the averages (Figure 3.10, Figure 3.11).

Table 3.6 Details sample campaign for suspended sediment concentrations in Meghna area

Station	Easting (m UTM)	Northing (m UTM)	Date
Bhairab Bazar	295782	2660686	15/02/2019
Harina	255795	2563930	30/03/2019
Harina	255795	2563930	05/04/2019

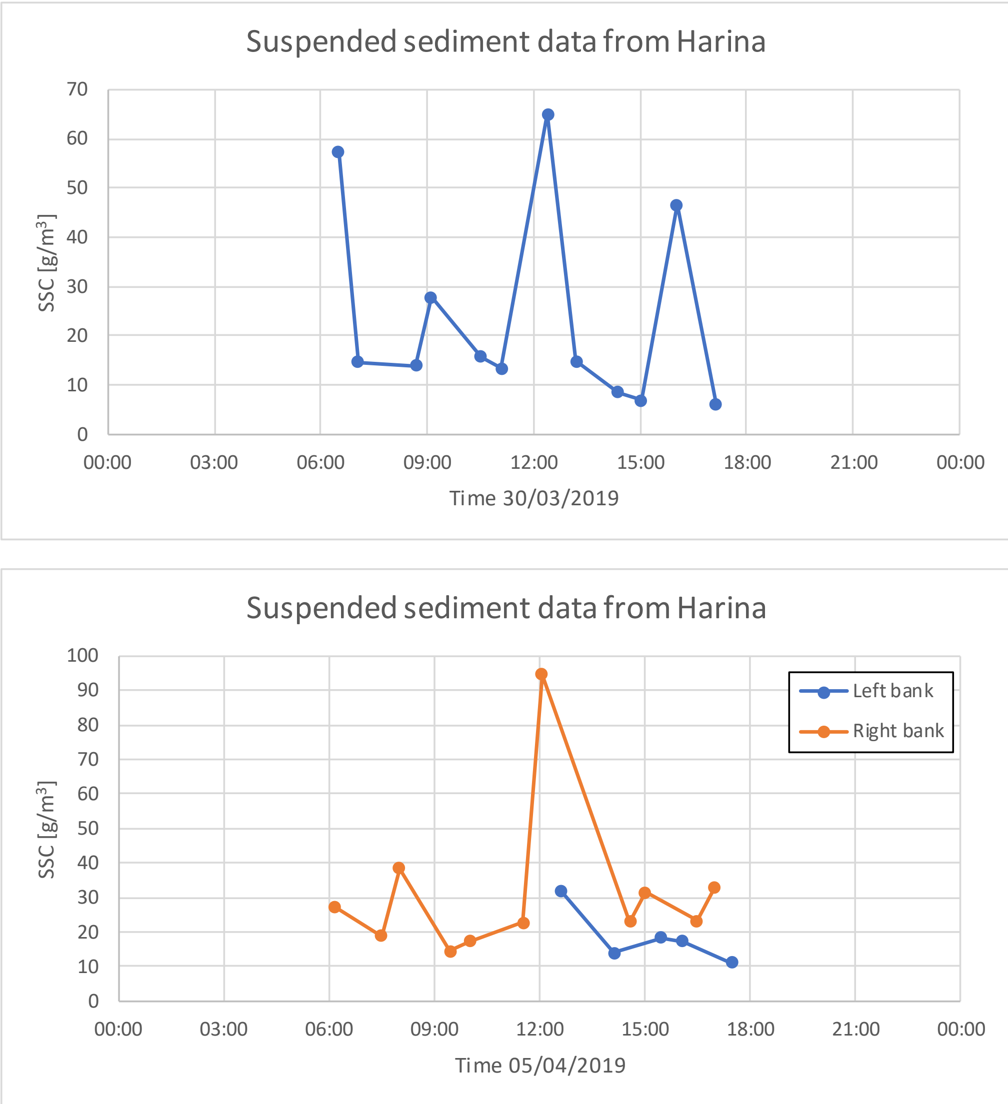

Figure 3.10 Dry season suspended sediment concentration from Harina collected by IWM (2019).

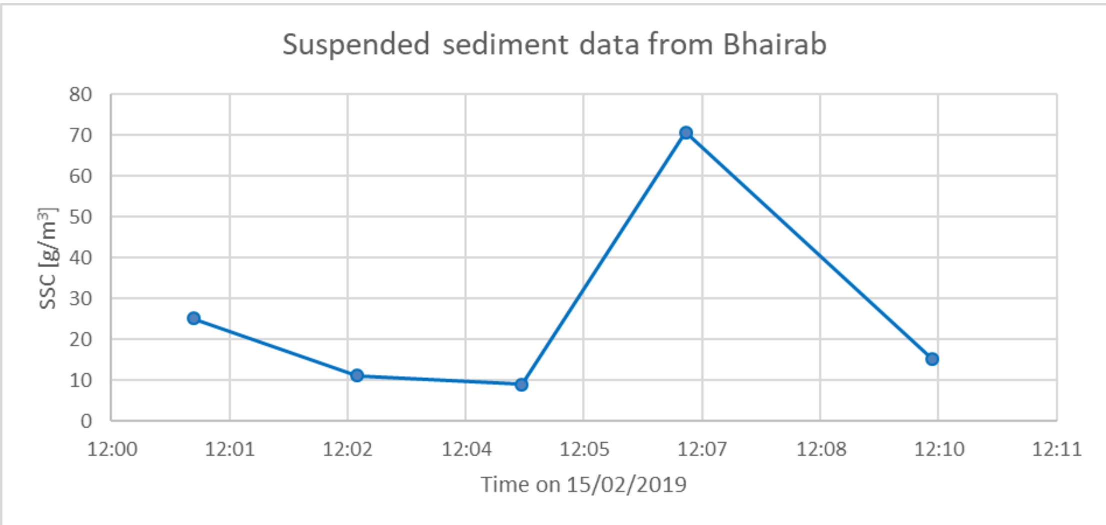

Figure 3.11 Dry season suspended sediment concentration from Bhairab Bazar collected by IWM (2019).

3.7 Historical bank lines from satellite imagery

In the study area, nine cloud-free scenes of Landsat imagery were acquired for the period of 1988–2019 from the Earth Explorer database of the U.S. Geological Survey, which covers the meso-scale modelling river system considered in the project. Suitable images were mainly available during the dry season from November to February as there were hardly any cloud-free images during other seasons. All the extracted riverbank lines are presented in Figure 3.12 for the Lower Meghna – Tetulia river system. The model extent for all runs has been finalised and incorporated in the model domain based on the maximum spatial extent of the collection of historical bank lines.

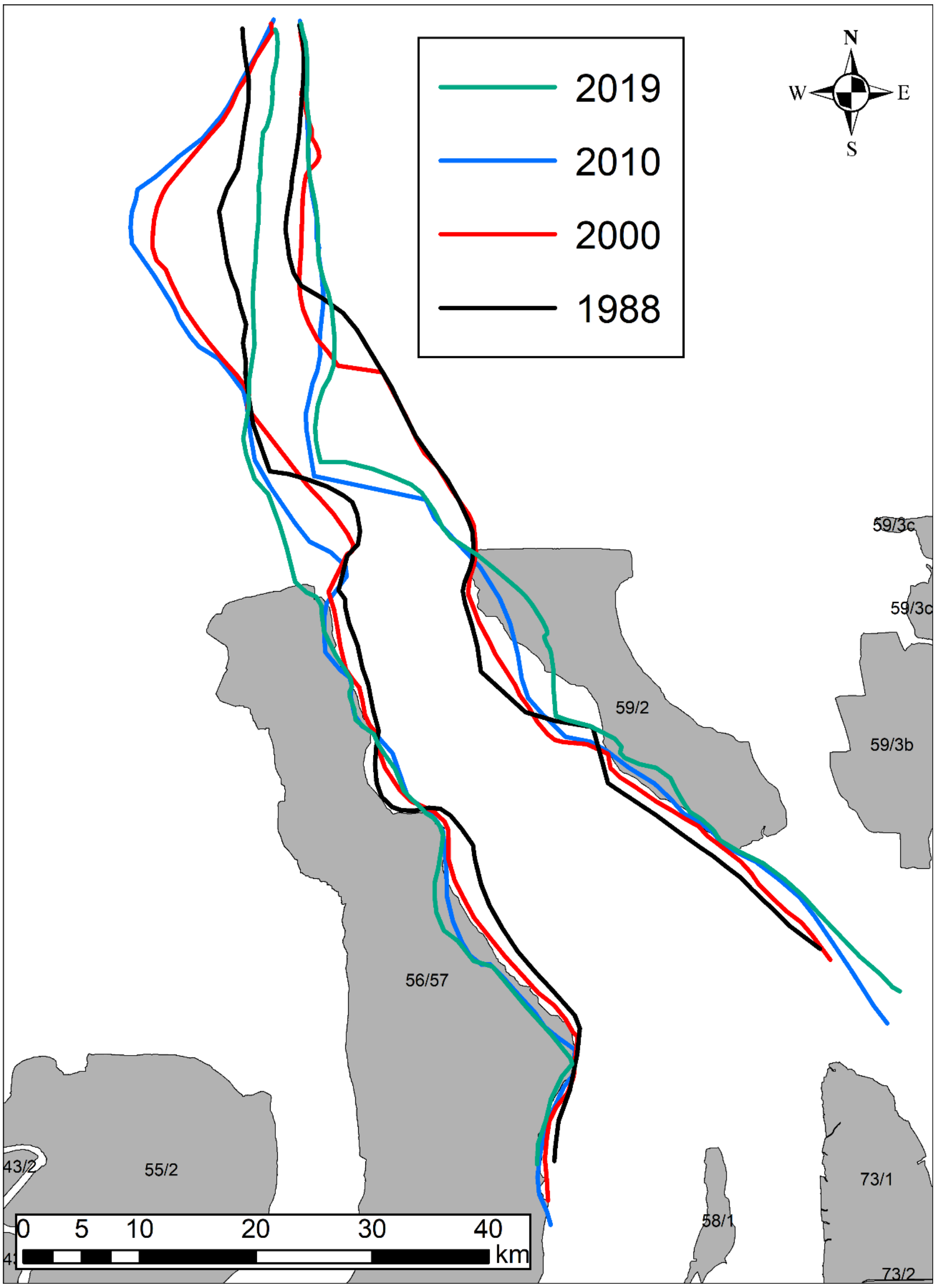

Figure 3.12 Bank lines from 1988 to 2019 for Lower-Meghna

4 Model development

4.1 Grid and bathymetry

The long term meso scale model for the Lower Meghna - Tentulia river system was developed using the Delft3D FM modelling system. The Lower Meghna - Tetulia river system is modelled in one numerical grid, combining both Lower Meghna and Tetulia systems in a single model. The available 2000 and 2009 bathymetry data for the main river channel was interpolated on the unstructured curvilinear grid system. The grid size varies between 1600 m and 200 m. Figure 4.1 shows the grid and bathymetry of the Lower Meghna - Tentulia river system for 2009. The bathymetry of the model is currently further updated with the 2019 survey data and will be incorporated during the next quarter.

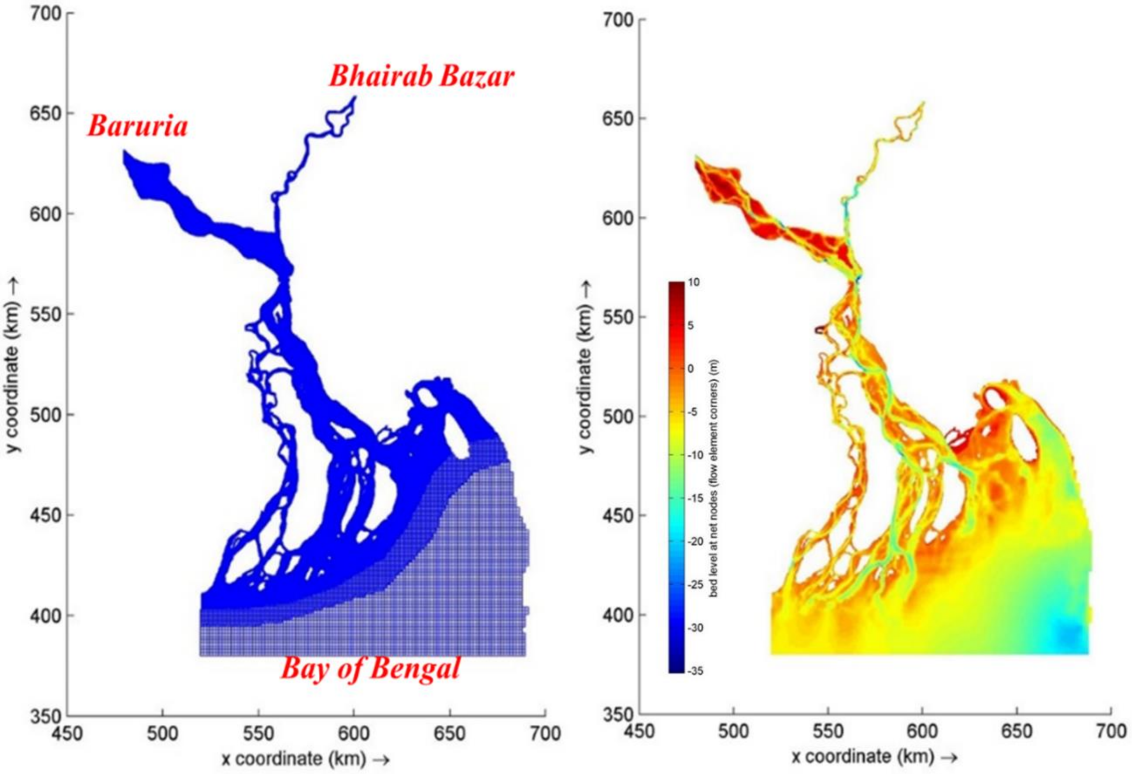

Figure 4.1 Computational mesh and interpolated bathymetry for the Lower Meghna - Tentulia river system. Bed level is with respect to PWD

4.2 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 (21.030' north latitude). 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 2009. The southern boundary has been extracted from the existing Bay of Bengal Model (Figure 4.3). Figure 4.1 (left) shows all boundary locations. Time series for the boundaries at Bhairab

Bazar and at Baruria are presented in Figure 4.2. Selected time series along the Bay of Bengal boundary are shown in Figure 4.3.

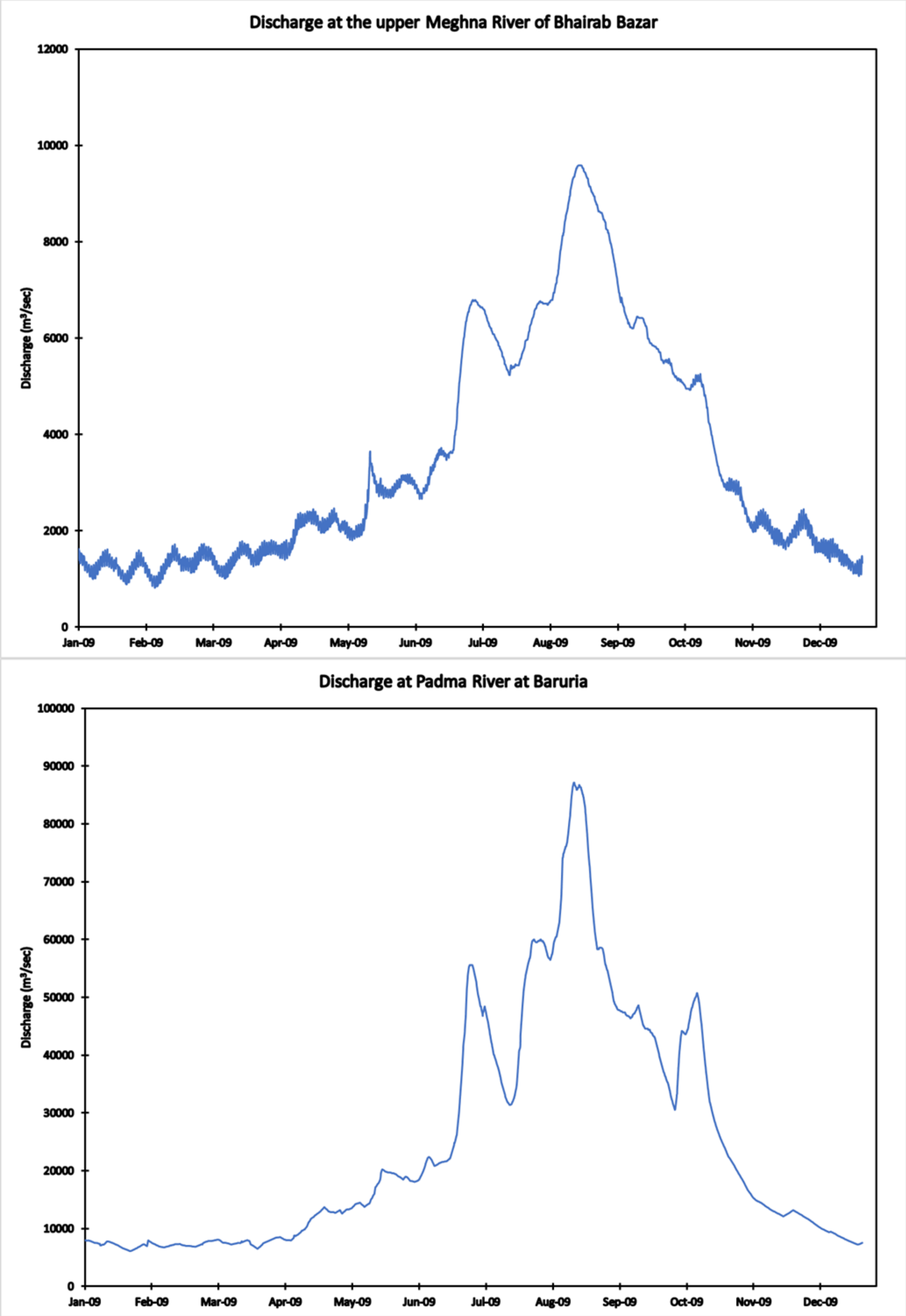

Figure 4.2 Discharge boundary at Bhairab Bazar of Upper Meghna river (upper panel) and discharge boundary at Baruria of Padma River (bottom panel)

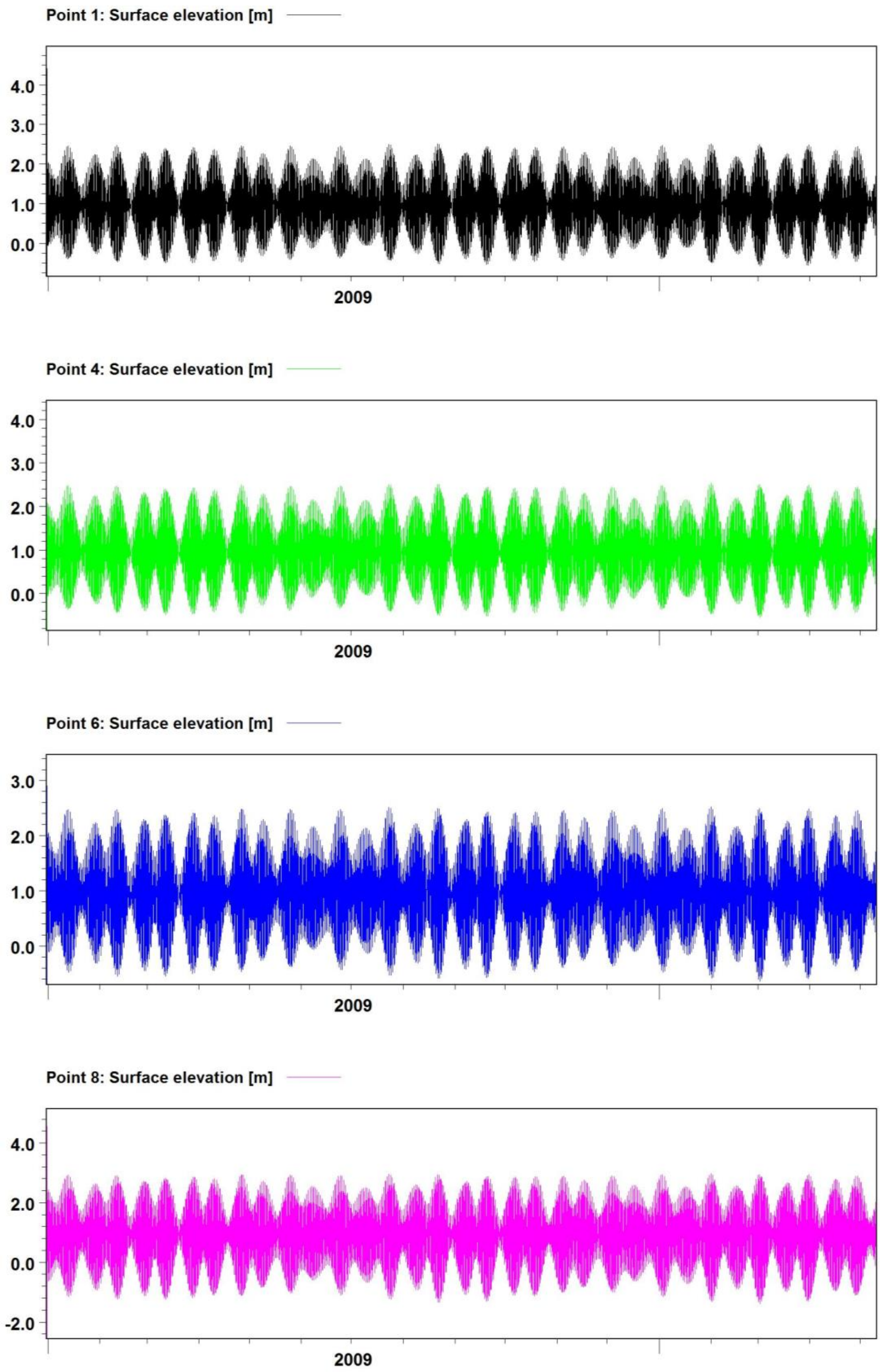

Figure 4.3 Time series of water level (west to east) along the southern boundary from Bay of Bengal Model (MIKE 21 FM), with PWD reference.

4.3 Bed resistance

The bed sediment samples presented in this report suggest that the inland portion of the model domain will be sandy whereas mud may be found close to river banks and more towards the mouth. Mud will be transported as wash load that only settles in sheltered environments and near turbidity maxima. Muddier environments will lead to a smoother bed and lower resistance. Based on numerous hydrodynamic calibration runs, 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.

4.4 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 2009 measurement campaign, both for dry and monsoon season. The locations of the field data sampling points are shown in Figure 3.3.

4.4.1 Calibration for water levels during 2009

The hydrodynamic model of Meghna Estuary Model was calibrated with the field data collected in 2009 (Figure 3.3) during both dry and monsoon season to achieve satisfactory model performance. The water level calibration at Char Alexander, Boyar Char, Char Langta and Sandwip West are illustrated in Figure 4.4. The water level shows good correlation with measured and simulated water level data, especially with respect to the tidal phasing. Char Alexander and Sandwip West seems to overestimate the observed water levels, whereas Boyar Char and Char Langta underestimate observed water levels. It is not very straightforward to improve the model results because of this contrasting model performance. Also, it is possible that the bathymetry close to the observation stations is not up to date.

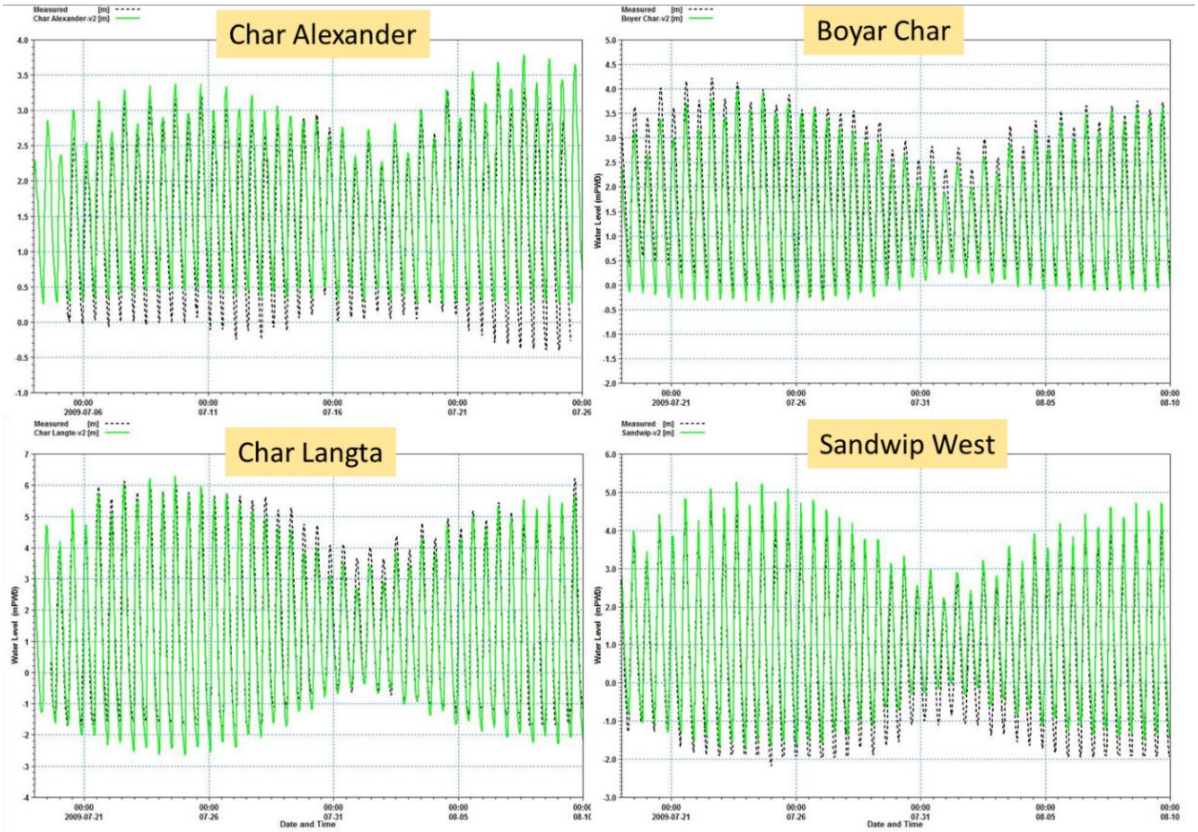

Figure 4.4 Comparison between observed and computed water level at Lower Meghna Estuary during monsoon season with respect to PWD

4.4.2 Calibration for discharge during 2009

The discharge calibration at Monpura-Jahajmara in the East-Shahbazpur Channel and Bhola-Monpura in the West-Shahbazpur Channel during monsoon season are illustrated in Figure 4.5. The discharge calibration shows good correlation with measured and simulated discharge data with the applied roughness fields.

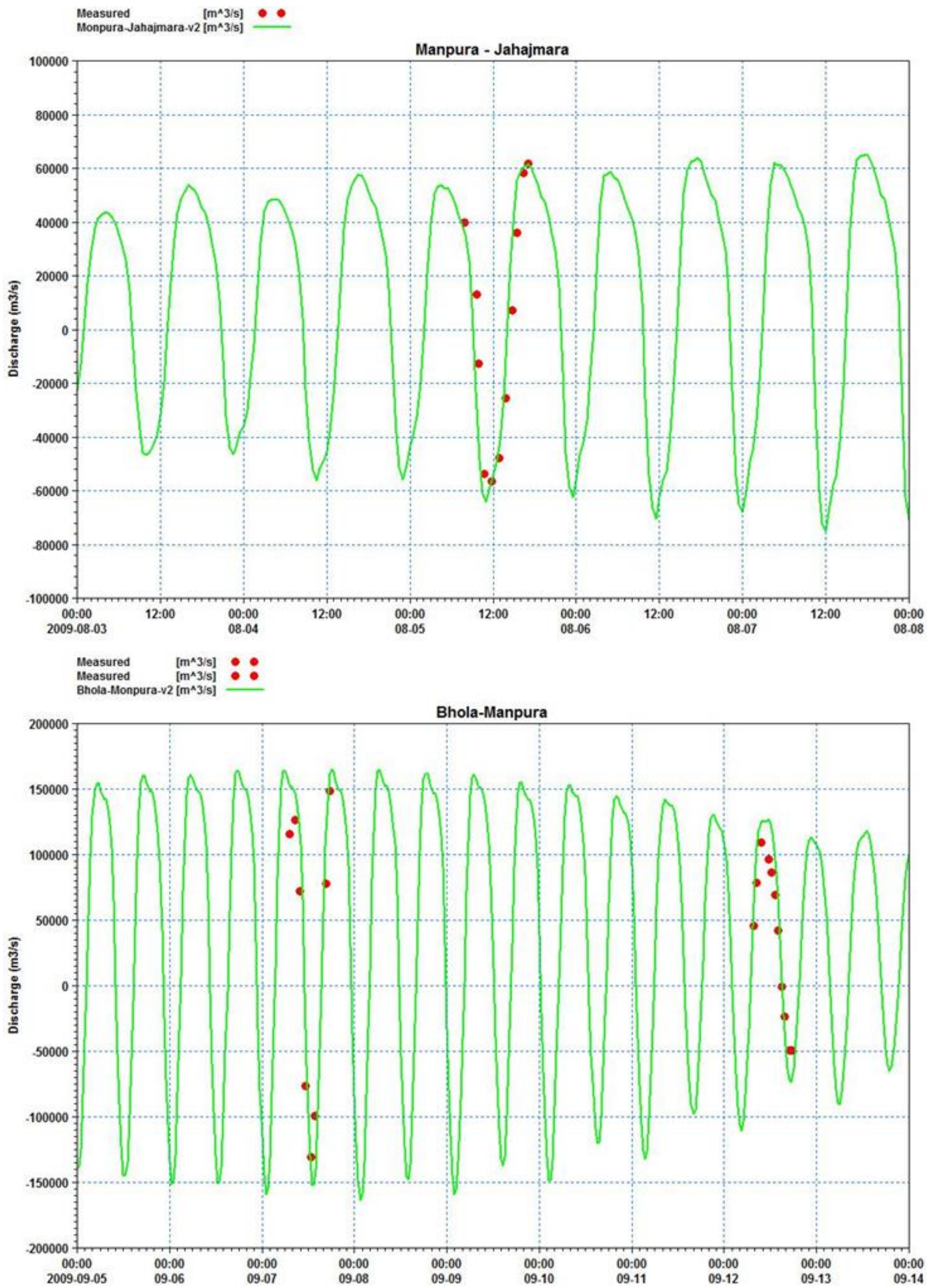

Figure 4.5 Comparison between observed and computed Discharge at Lower Meghna Estuary during Monsoon

4.5 Sediment transport boundary conditions

The first attempts at modelling observed suspended concentrations were done using constant concentration boundary conditions with mud concentrations as shown in Table 4.1. Following the macro scale model settings (DHI and Deltares, 2020), for the Padma river at Baruria a constant concentration of 0.9 kg/m3 was assumed, well within the reported range of 0.75-1.25 kg/m3; for the Meghna at Bhairab Bazar we applied a much lower value of 0.1 kg/m3. For the sand transport equilibrium conditions were assumed. The total suspended load transport imposed on the upstream boundaries amounts to about 913 Mt/yr, which is well within the range of estimates. The open sea (south) boundaries SSC values were set to 0.20 (kg/m^3).

Table 4.1 Sediment concentration boundaries for the morphological model

Boundary	Mud (kg/m^3)
Bhairab Bazar (upper Meghna)	0.10
Baruria (Padma)	0.90
South Boundaries	0.00

4.6 Morphodynamic model

4.6.1 Method

The method applied for the long-term simulations is the same as applied in the macro-scale model, as described in section 6.8.1 of the report on the current situation (DHI and Deltares, 2020). Here the procedure is repeated for readability. 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 is thus equivalent to 26 years of morphological change. Comparison with a run applying a MorFac of 1 and a one year hydrograph showed similar results as a run with a MorFac of 26 and a hydrograph of two weeks. Increasing the MorFac to more than 26 did not seem to be logical since a hydrograph shorter than two weeks would harm the sediment throughput time, i.e the time required for a sediment particle to travel through the model domain during high river flow.

4.6.2 Domain and initial bathymetry

The domain and grid for the morphodynamic model are described in Section 4.1. 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 set to a reasonable value of +3m, allowing it to be eroded in principle. Other areas not covered by the 2000 campaign were supplemented with data from the model set up for the hydrodynamic calibration, mainly from around 2009.

4.6.3 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 4.6: 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.

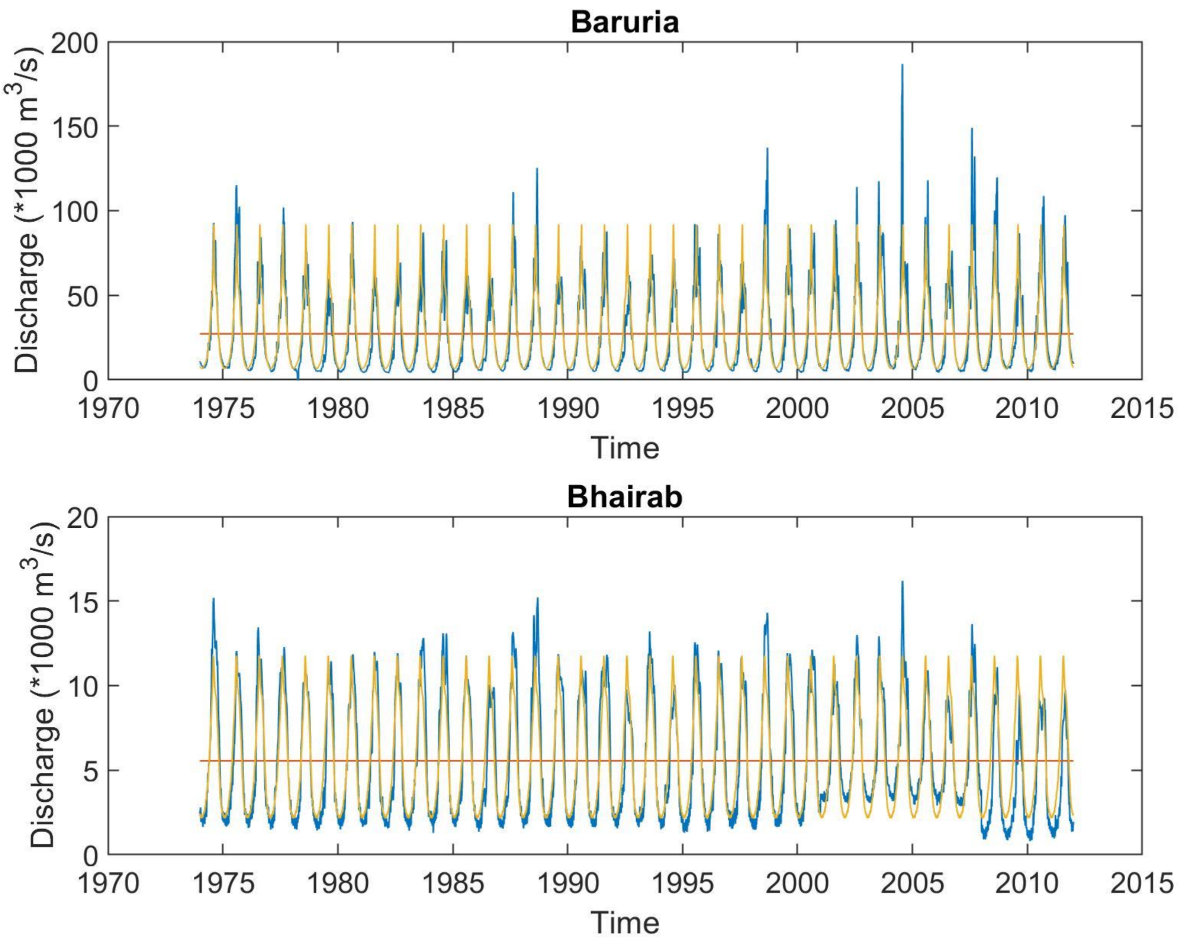

Figure 4.6 Morphodynamics Discharge boundaries of Bhairab Bazar and Baruria (Mean (orange) and seasonally varying (yellow) vs measured (blue))

For the seaward boundaries, output points were generated in the 2D macro model (DHI and Deltares, 2020) and representative tidal components were generated based on the time series extracted from a month-long run. 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, 248.4 and 186.2 minutes, respectively. M2 amplitudes ranged from 1.22 m to 0.90 m and C1 amplitudes from 0.13 m to 0.15 m; M4 was of the order of 0.009 m and the higher order M6 and M8 were negligible.

4.6.4 Sediment settings

A large number of simulations were carried out as part of the calibration. Here the focus will be on two distinct settings for the relative sediment thickness of the sand and mud layer, the critical shear stress for erosion, and the erosion parameter. In Table 4.2 both settings are indicated. In the macro-scale 2D model (DHI and Deltares, 2020), the second set of parameters produced much better behaviour for the model in general and for the sedimentation, erosion and net volume changes in the Meghna Estuary. In the discussion of the results these settings will be referred to as '*settings 1*' and '*settings 2*'. Settings1 applies a slightly higher bed friction with less mud in the bed with lower critical erosion shear stress (tau_{ce}) but also a lower erosion factor (M).

Table 4.2 Overview of sediment parameters of the current model with 2 settings

Variable	Description	Current setting 1	Current setting 2
D50	Sand median diameter (mm)	0.15	0.15
IniSedThick sand	Initial thickness of sand layer (m)	30	15
Cref, sand	Bed concentration sand (kg/m^3)	2650	2650
IniSedThick mud	Initial thickness of mud layer (m)	0.5	15
frac	Availability of mud fraction	Depending on bed composition sand/mud, variable.	
M	Erosion parameter (kg/s/m^2)	0.0001	0.001
w_s	Fall velocity (m/s)	0.001	
tau_{ce}	Critical shear stress for erosion (N/m^2)	0.15	0.30

tau_{cd}	Critical shear stress for deposition (N/m^2)	1000	1000
C	Chezy value (m^1/2 /s) around mouth and coast	100	120
Cref, mud	Bed concentration (kg/m^3)	700	700

4.6.5 Morphological settings

In Table 4.3 the morphology model settings are summarized. Most parameters are set to default or have already been discussed, such as the MorFac and spin up interval MorStt; noteworthy are AlfaBn, a transverse bed slope gradient term that works only on the bedload part of the transport of the sand fraction. Since this is only a small part of the total sediment transport it needs to be set to relatively high values to have any effect and results in smoothing the bed evolution to a reasonable extent. Using the Wetslope keyword avalanching is activated when slopes get too high. As the grid is generally very coarse (200 m square cells in most cases) it is noted that a 1:50 slope still allows bed level differences of 4 m between neighbouring cells.

Unfortunately, the Wetslope parameter does not apply to the transition between dry and wet cells. A ‘dry cell erosion’ mechanism is available, under keyword Thetsd, which translates erosion of a wet cell to that of an adjacent dry cell; however, this process induced instabilities in unexpected areas and had to be shut off for most of the runs reported here. The cause of these instabilities was found, after a protracted search process, to be a software bug which was removed days before production of this report. Therefore, only (promising) partial results can be shown here. It will be applied in future simulations in order to properly represent large-scale bank erosion.

As was discussed before, the underlayer model is essential to create a realistic spatial distribution of the sediment fractions in the top layer, which in turn greatly influences the sediment concentrations.

Table 4.3 Overview of morphological parameters current model

[Morphology]			
MorFac	26	[-]	Morphological scale factor
MorStt	172800	[s]	Spin-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
RWave	2	[-]	Wave related roughness = RWAVE * estimated ripple height.
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	0	[-]	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

4.6.6 Calibration

The observed and computed sedimentation-erosion patterns are shown in Figure 4.7 and Figure 4.8. A number of observations can be made:

- 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, with both settings.
- The area around Sandwip Island is strongly accretive in both observations and model.
- The erosion of land areas is not taking place in the model, due to the issue with the dry cell erosion, although in many cases there is an observed erosive trend next to such areas due to an encroaching channel, e.g in the north of Hatiya island.
- The sediment and roughness settings have a profound effect on the sedimentation-erosion pattern and the overall balance of the area. With settings 2 a somewhat better sediment balance is found in the downstream area, consistent with the results of the macro-scale 2D model (DHI and Deltares, 2020). The large accretion around Sandwip is represented better, as well as the accretion in the Tetulia river. The modelled accretion in the Meghna river is too high for settings 1 but generally well described in settings 2.

- Settings 2 initially has more mud in the bed that erodes more easily than sand. This leads to less accretion in the Meghna and deeper main channels. The mud released from the bed settles in sheltered areas like the Sandwip area.

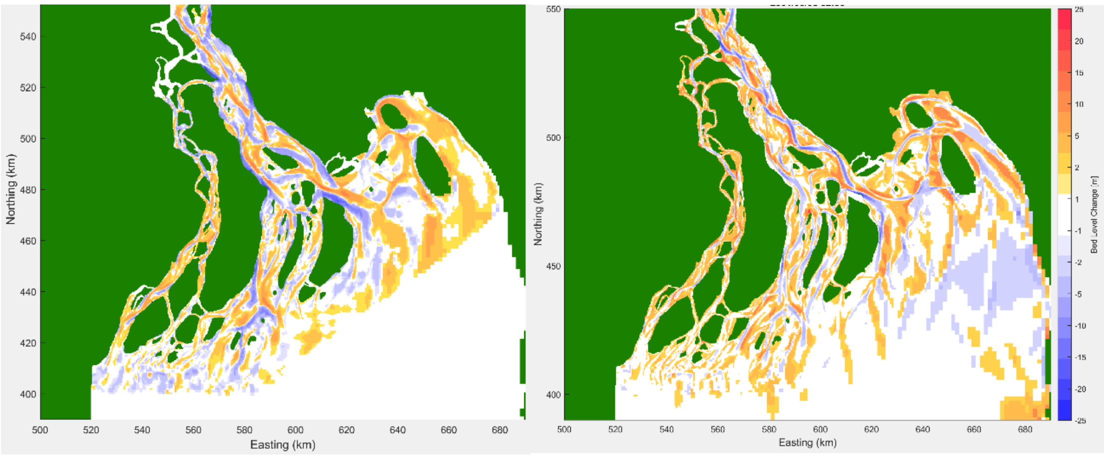

Figure 4.7 Observed (left panel) and simulated (right panel) bed level changes, 2000-2009, settings 1.

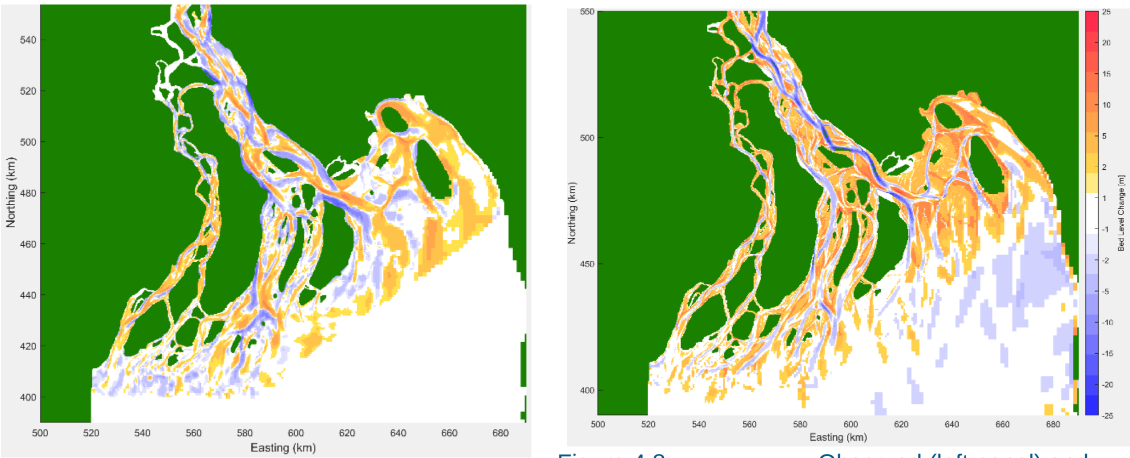

Figure 4.8 Observed (left panel) and simulated (right panel) bed level changes, 2000-2009, settings 2.

The same volumetric analysis as for the macro-scale 2D model (DHI and Deltares, 2020) was applied, based on observed differences between the 2000 and 2009 bathymetries. In the following figures, the results for settings 1 are shown on the left; for the settings 2 on the right.

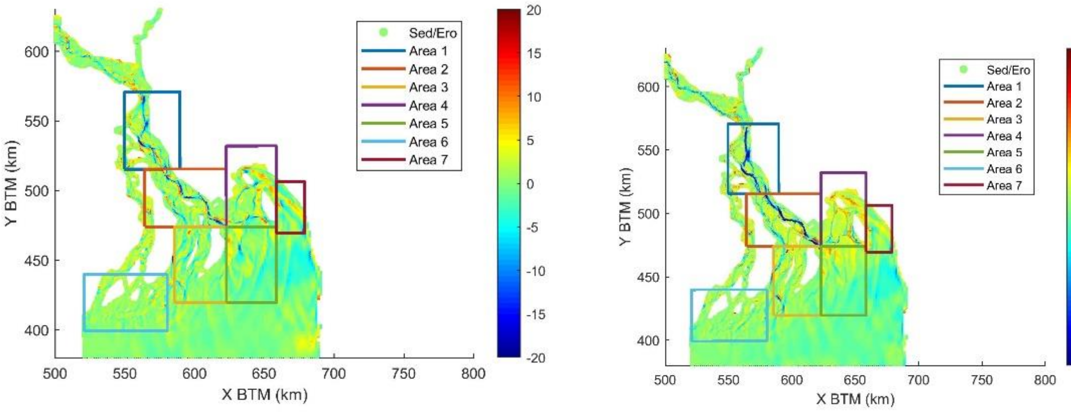

Figure 4.9 Sedimentation/erosion pattern over period 2000-2009 in lower Meghna area, and volume balance areas applied in EDP study (2009). Left panel: settings 1; right panel: settings 2.

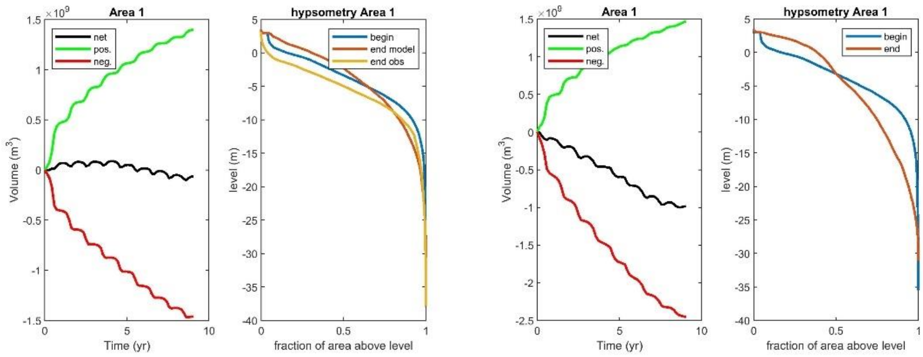

Figure 4.10 Volume and hypsometry change 2000- 2009; left: settings 1 and right: settings 2; Area 1.

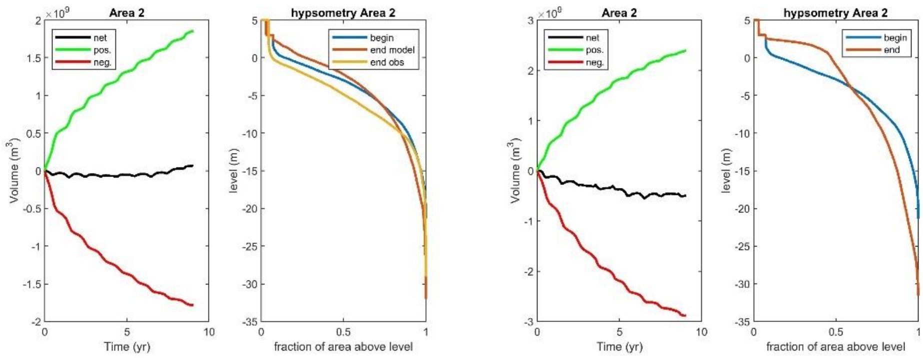

Figure 4.11 Volume and hypsometry change 2000- 2009; left: settings 1 and right: settings 2; Area 2.

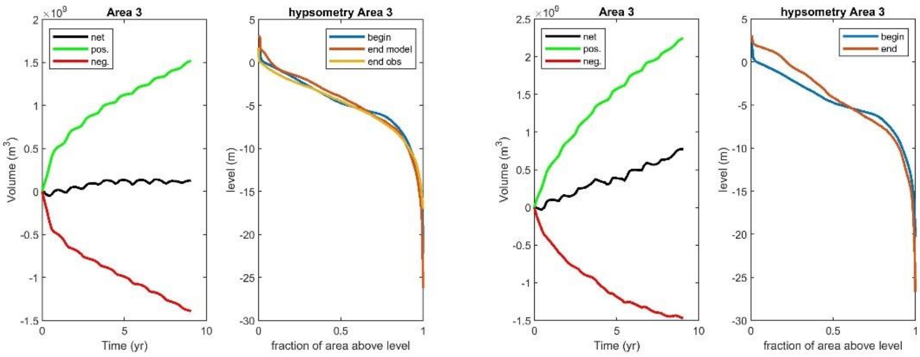

Figure 4.12 Volume and hypsometry change 2000- 2009; left: settings 1 and right: settings 2; Area 3.

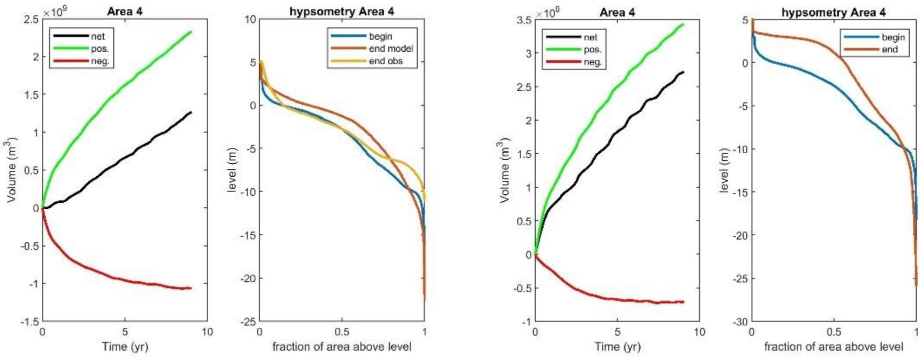

Figure 4.13 Volume and hypsometry change 2000- 2009; left: settings 1 and right: settings 2; Area 4.

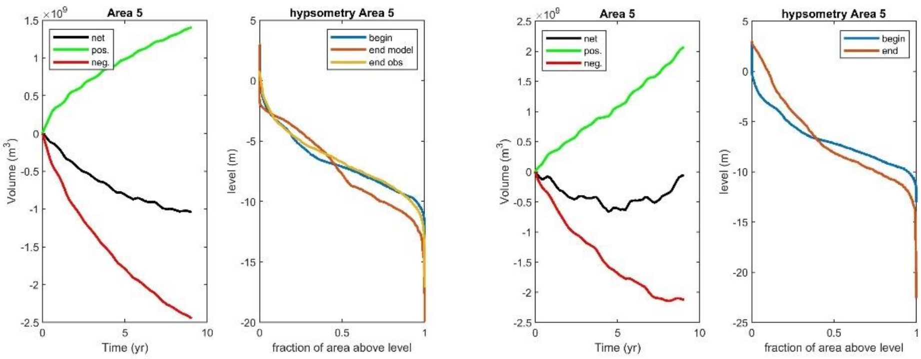

Figure 4.14 Volume and hypsometry change 2000- 2009; left: settings 1 and right: settings 2; Area 5.

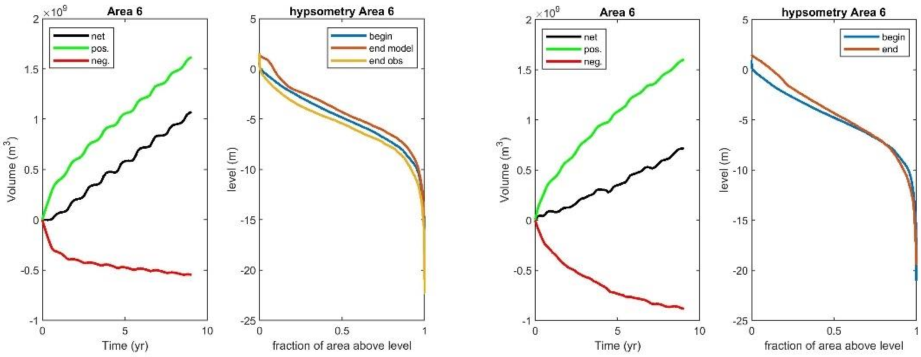

Figure 4.15 Volume and hypsometry change 2000- 2009; left: settings 1 and right: settings 2; Area 6.

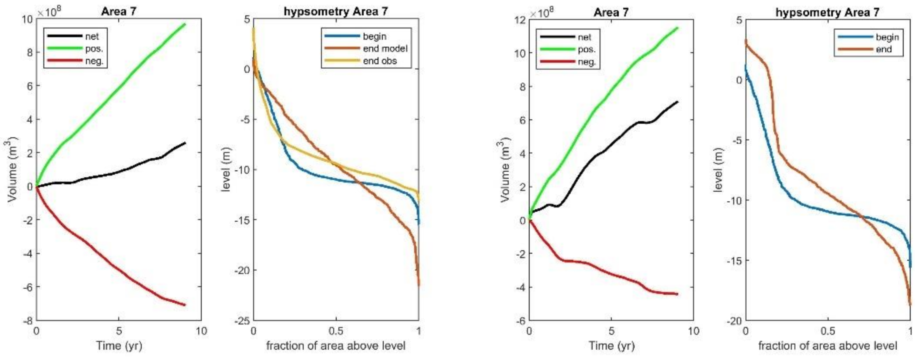

Figure 4.16 Volume and hypsometry change 2000- 2009; left: settings 1 and right: settings 2; Area 7.

Using settings 2, the model predicts a much larger accretion (magnitude and trend) in all volume analysis zones. This accretion mainly happens in shallower parts for all subareas of the model domain. The lower Meghna river and the Meghna mouth (area 2+3) change from an erosive to a stable/accretionary volume change trend. The area around Sandwip island (area 4+7) is now dominated by strong accretion. The area around the mouth of the Tetulia river (area 6) shows a more accretionary trend using settings 2, as compared to the stable volume trend using settings 1.

Apart from area 3, the model does not convincingly reproduce development towards 2009 observed hypsometries. In some areas the shape of the hypsometry is nicely reproduced albeit that the modelled hypsometry increases despite the observed decrease (areas 1, 2 and 6). Sometimes, the 2009 modelled hypsometries are steeper than the 2009 observed hypsometries (area 5 and 7). Except for area 6, settings 1 seems to perform better than settings 2. Adding waves, improved initial sediment composition and applying space varying roughness values (e.g. higher roughness in deeper channels) are possible techniques to improve the model performance.

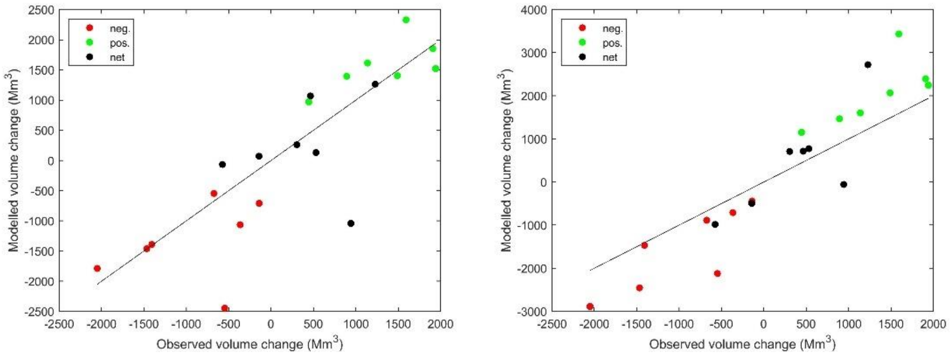

Figure 4.17 Computed vs. observed erosion (red), sedimentation (green) and net volume change (black), 2000-2009.

With the settings 1, as shown in Figure 4.17, left panel, there is a reasonable agreement in the gross sedimentation and erosion volumes, with area 5 as an outlier, which especially impacts the net balance and generally tilts the results towards erosion instead of the observed net accretion. Using settings 2 (Figure 4.17, right panel), the erosive and net volumes are simulated more reliably (

Table 4.6, Table 4.7), albeit that the accretionary, erosive and nett trends by themselves are overpredicted. This reflected in the values of the RMSE, bias and MAE as well (Table 4.7).

Overall, the trends using settings 2 are quite acceptable, with a correlation of 0.81 and a slope of 1.2 for the net sedimentation, which is a much better result than for the macro-scale model (DHI and Deltares, 2020), thanks probably to the 2.5 times higher resolution (200m instead of 500m as minimum grid size). The gross volume changes are both highly correlated as well, though the rate of change is overestimated by a factor of around 1.7, which is well within the usual range for morphological models.

Table 4.4 Observed and modelled volumetric changes, settings 1.

	Observed volume change (Mm3)			**Modelled volume change (Mm3)**		
	Neg.	**Pos.**	**Net**	**Neg.**	**Pos.**	**Net**
1	-1467	892	-574	-1461	1398	-63
2	-2050	1908	-142	-1787	1855	69
3	-1408	1941	533	-1391	1521	130
4	-366	1594	1228	-1063	2330	1267
5	-547	1492	944	-2446	1404	-1042
6	-672	1138	465	-546	1617	1071
7	-139	444	305	-710	970	260
Total	-6649	9409	2759	-9404	11095	1691

Table 4.5 Error metrics for modelled volumetric changes, settings 1

Parameter	**Neg.**	**Pos.**	**Net**
RMSE	755	425	878
BIAS	-394	241	-153
MAE	511	401	543
SLOPE	1.41	1.18	0.61
CORR	0.38	0.65	0.21

Table 4.6 Observed and modelled volumetric changes, settings 2.

Zone	Observed volume change (Mm3)			Modelled volume change (Mm3)		
	Neg.	Pos.	Net	Neg.	Pos.	Net
1	-1467	892	-574	-2453	1469	-984
2	-2050	1908	-142	-2885	2393	-493
3	-1408	1941	533	-1470	2245	775
4	-366	1594	1228	-712	3434	2722
5	-547	1492	944	-2124	2070	-54
6	-672	1138	465	-884	1602	718
7	-139	444	305	-442	1153	711
Total	-6649	9409	2759	-10971	14365	3394

Table 4.7 Error metrics for modelled volumetric changes, settings 2.

Parameter	Neg.	Pos	Net
RMSE	540	514	790
BIAS	-617	708	91
MAE	617	708	593
SLOPE	1.65	1.53	1.23
CORR	0.82	0.73	0.81

4.6.7 Preliminary test of bank erosion

The process of large-scale bank erosion resulting from the migration of channels can be approximated by a relatively simple algorithm, which has long been used in the curvilinear Delft3D. It has also been implemented in Delft3D-FM but did not function well in this complex model with a combination of sandy and muddy sediment, due to a bug that was only found after an extensive search and with the help of a dedicated small test model.

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 behaviour of shallow shoals and channels, but also allows for retreat of banks.

Some initial tests with the Lower Meghna model produce very promising results. Here some initial results after a morphological simulation time of approximately 2 years are shown in Figure 4.18. The north of Hatiya (green area in the centre) is clearly shrinking, in line with observations of strong retreat. Also, the bank on the top left of the Figure is seen to erode.

Further calibration of the bank erosion mechanism is needed and will be reported in subsequent reports.

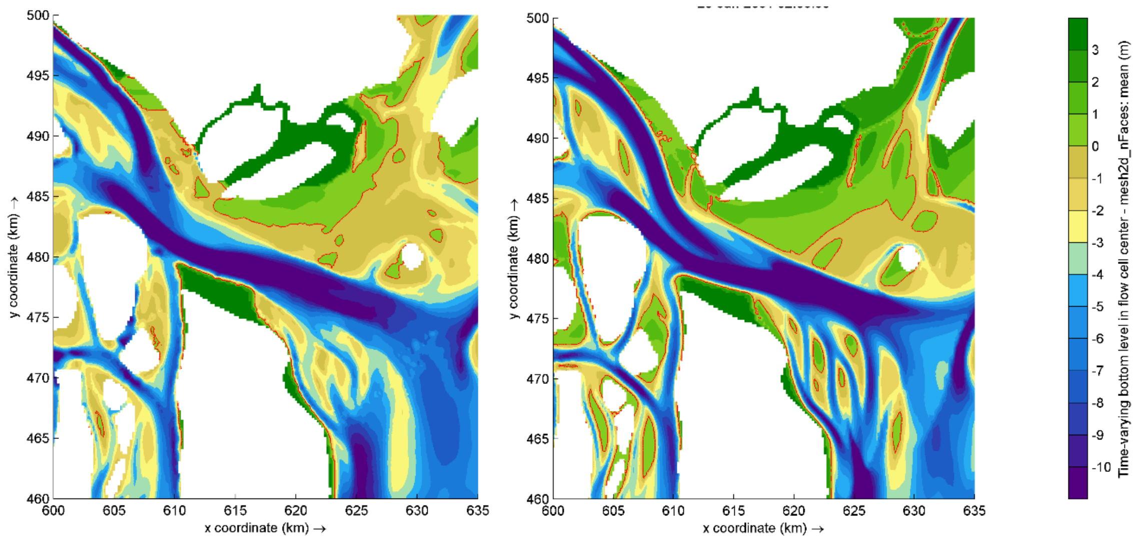

Figure 4.18 Initial (left panel) bathymetry and bathymetry after approx. 2 morphological years (right panel), including ‘dry cell erosion’ mechanism to simulate bank erosion.

5 Model applications

The model in its present form can be applied to assess the effects of sea level rise, wind and wave climate change and upstream changes in river flows and sediment loads on the sedimentation and erosion and may give an indication how certain areas may be prone to bank erosion due to encroaching channels. The effects of polder creation or cross dams can be assessed, and large-scale dredging operations can be simulated and their effects on the overall morphological development and water levels can be estimated.

Unlike the meso-scale models of the Pussur-Sibsa and Baleshwar-Bishkali the seaward and landward boundaries of the model are relatively well-known (upstream) or far enough away (sea) not to induce large uncertainties.

In the current version of the model the shifting of bank lines due to encroaching channels could not be directly modelled due to a problem in the implementation of the algorithm. However, this issue was resolved and preliminary results show promising behaviour.

A more elaborate bank erosion algorithm will be developed and tested as part of the MSc research by Ms Marzia Israt and Mr Oli Chowdhury, both from BWDB, and may be applicable within the framework of this project.

6 Conclusions and recommendations

The focus of the current study has been to assess the value of a morphological hindcast. Without this validation, other scenarios and sensitivity analyses would have limited value. The model has been sufficiently calibrated and validated hydrodynamically and has been shown to represent time series of water levels and cross-sectional discharges accurately.

The morphological development has been tested for the period 2000-2009 and has shown a quite acceptable reproduction of sedimentation – erosion patterns and gross and net volume changes, with sediment settings similar to those of the macro-scale 2D model.

Therefore, the model is a useful tool to study general trends of erosion and sedimentation patterns and effects of possible management scenarios in terms of years to decades. Next steps should/could include an exploration on the effect of past human interventions like the cross-dams, Feni river closure, variations in sediment supply due to the Assam earthquake or Ganges damming and sea level rise. The upcoming work will include these sensitivity analyses which add more explicit insight into the systems behaviour.

In the current version, the shifting of bank lines due to encroaching channels can now be simulated but this will still need more calibration and validation to resolve them with reasonably good performance in the model. It is recommended to elaborate on the efforts in subsequent reports also including the development and test of a new algorithm based on a coupling with the ShorelineS model (Roelvink et al, 2020) that may offer the desirable improvement.

7 References

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