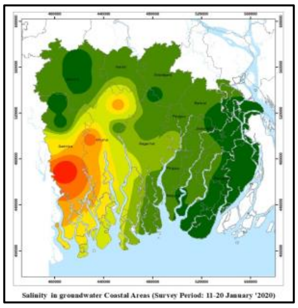
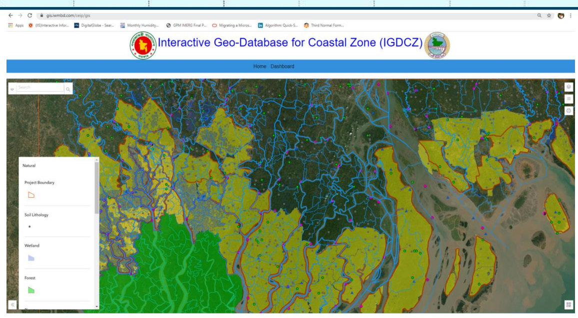
Ministry of Water Resources

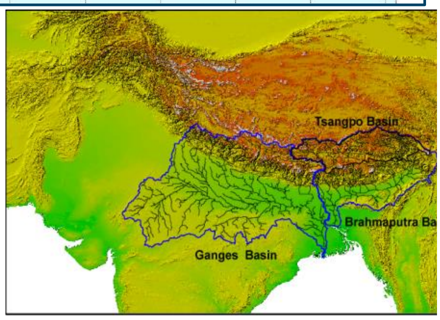
Bangladesh Water Development Board

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

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







QUARTERLY PROGRESS REPORT-5

February 2020

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)

QUARTERLY PROGRESS REPORT-5

February 2020

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

Memo No: CEIP/LTMRA/0320/59 Date: 02 March 2020

Project Management Unit
Coastal Embankment Improvement Project, Phase-I (CEIP-I)
House No.15, 4tn Floor, Road
No.24(CNW) Gulshan, Dhaka-1212

Att: Dr. Md Mizanur Rahman, Chief Engineer & Project Director

Dear Sir,

Submission of Fifth Quarterly Progress Report (first Submission)

The submission of the Fifth Quarterly Report was delayed by a few weeks until we concluded our discussions with the PMU and the World Bank regarding our maintaining reference to the original list of Project Deliverables as stated in the Terms of Reference. This includes some further amendments we have made to the list shown in the Fourth Quarterly Report. Each item on this list is also related to one or more activities described in the Progress Report.

Owing to the delay in finalising the Deliverables, we could not deliver QPR-5 as earlier promised. We apologise for the delay, but we hope the first submission (3 Copies) will help you to initiate the review of the report

Thank you,

Yours sincerely,

Dr Ranjit Galappatti
DHI Team Leader

Copies: Engineer A. M. Aminul Haque, Director General, BWDB
Engr. Md. Habibur Rahman, Additional Director General (Western Region), BWDB
Dr Kim Wium Olesen, Project Manager
Dr Alessio Giardino, Deltares Manager
Mr Zahirul Haque Khan, Deputy Team Leaders

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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

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

GNSS- Global Navigation Satellite System

GPS- Global Positioning 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

RCP- Representative Concentration Pathways

RSET-MH- Rod surface elevation table – marker horizon

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

ToR- Terms of Reference

WARPO- Water Resources Planning Organization L - Water Level

Executive Summary

ES-1 INTRODUCTION

After the feasibility study of the first phase CEIP-1, decided that certain gaps in our knowledge of the delta should be addressed by the research study which was to be known as the Long-Term Monitoring, Research and Analysis of Bangladesh Coastal Zone.

This study was initiated on 15 October 2018 and the Inception Phase was completed in January 2019. The Inception Report was treated as the first Quarterly Progress Report (QPR-1). The Second Quarterly Progress Report which was submitted in April 2019 covered the period 1 January 2019 to 31 March 2019. The Third Quarterly Progress Report (QPR-3) covers the period 1 April 2019 to 30 June 2019. The Fourth Quarterly Progress Report was submitted in November 2019. This is the Fifth Quarterly Progress Report describing the progress made between 1 October 2019 and 31 December 2019. .

The Work Plan proposed in the Inception Report has been amended slightly to respond to exigencies of carrying out the work with a very large team of experts, both local and foreign.

ES-2 DEVELOPMENT OF INPUT DATASETS FOR MODELLING PHYSICAL PROCESSES

The Data Collection programme is proceeding as planned, nearing completion in some areas. The field programmes conducted in collaboration with University of Colorado and Columbia University have proceeded as planned despite early setbacks. The large Surveys comprising several large field campaigns mounted by IWM are all on schedule.

The joint measurement programmes carried out with BWDB (Hydrology) at Bahadurabad has led to greater understanding and interaction regarding the interpretation of historical data and the sharing in of techniques and methodologies.

As per ToR the model input datasets (used in the many different models developed by the study), have been shared (in both soft and hard form) with the project office.

ES-3 DATABASE FOR THE COASTAL ZONE

The Database Design Report has been submitted. The Database itself is now active and receiving data. Protocols for updating and accessing the database have being discussed. Chapter 3.

ES-4 MODELLING LONG TERM PROCESSESS

Modelling is the largest component of this study and the variety and extents of modelling work undertaken can be seen in the table ES-1 below. All the models listed below are already under development. The hydrodynamic modelling stage is well advanced and the development of the morphological models has also been initiated in the models where the field sediment data have already been processed.

The modelling progress made so far is described in Chapter 4 of QPR-4.

Table ES-1: Models currently under development

	LIST OF MODELLING ACTIVITIES		
	Modelling Activity	Sub description	Scale
A	GBM Basin Model	Hydrotrend	Macro
B	Macro scale River Model	Delft3D Main River system (2D)	Macro
C	Macro scale River Model	Delft3D Main River system (1D)	Macro
D	Pussur Sibsa	Delft3D: Modelling of long term Morphology	Meso
E	Baleswar-Bishkhali Model	Delft3D: Modelling of long term Morphology	Meso
F	Lower Meghna	Delft3D: Modelling of long term Morphology	Meso
G	Sangu	Delft3D: Modelling of long term Morphology	Meso
H	Pussur Sibsa	MIKE21C: Modelling of bank erosion process	Meso
I	Baleswar-Bishkhali Model	MIKE21C: Modelling of bank erosion process	Meso
J	Lower Meghna	MIKE21C: Modelling of bank erosion process	Meso
K	Sangu	MIKE21C: Modelling of bank erosion process	Meso
M	Pussur-Sibsa fine sediment model- ext	Delft3D Fine Sediment (2D/3D)	Meso
N	Pilot TRM Model for Polder 24	MIKE11, MIKE21 AND MIKE FLOOD	Micro
O	Storm Surge Model	Generating Synthetic Storm Events	Bay of Bengal
P	Storm Surge Model	MIKE21FM & CYLONE MODEL	Bay of Bengal
Q	Salinity Model	Delft3D Salinity (2D/3D)	Total Coast

The models are all setup differently, on different computational grids and prepared to be run on their own time scales, related to the processes being modelled. This means that a very large number of models are developed and that each model would give rise to a model setup, calibration and verification process as well as a series of model applications, all reported separately..

ES-5 POLDER RECONSTRUCTION PROGRAMME

The model reconstruction programme is to eventually cover the entire coastal zone comprising 139 polders. In 2010 a multicriteria analysis (MCA) was used to evaluate the development needs and priorities for re-construction. 17 polders were identified for reconstruction in CEIP-1 and this resulted in detailed surveys and analyses being carried out to a greater level of accuracy than elsewhere. There was also a need to gather more detailed information on all the polders to repeat an improved MCA. The enhanced data collection programme was initiated during the 4th Quarter and extended into the 5th Quarter.

After the Selection of 5 Polders for Pilot Study have been approved by the PMU, the selected polders have been taken up for study. This has involved adjusting the extent of meso scale models simulating long term morphology to allow for testing drainage capacity during the design process.

A Strategic Approach towards devising a Polder Reconstruction Programme was decided and a Road Map was devised towards a reaching a viable Reconstruction Plan based on an extended multicriteria analysis.

ES-6 INVESTMENT PLAN FOR ENTIRE CEIP

Work on the investment plan will commence in 2020 after the MCA is finalized

ES-7 DESIGN PARAMETERS, CONSTRUCTION MANAGEMENT & MONITORING PLAN

The updated design parameters would depend on the following:

Embankment Design:

a) Embankment crest levels based on maximum storm surge level from increased modelling accuracy, a larger selection of storm events, wave propagation, incidence and overtopping

b) Ground subsidence: A more detailed knowledge of local subsidence levels are now known

c) Drainage Functionality: Impact of climate change on rainfall and cyclone intensity, More detailed drainage models and alternative drainage arrangements,

d) Impacts of sea level rise and *long-term* morphological impacts (peripheral river sedimentation impacts) on drainage efficiency

Polder Management Better knowledge of the need to relate the design to the effectiveness of polder operation and maintenance, and water management practices.

Design parameters will be derived from the modelling work This work will commence in mid-2020 when the design approach is finalized

ES-8 CAPACITY BUILDING

Training Courses and Study Tours have been undertaken and are described in Chapter 8. On-the-job training is ongoing. There is more formal participation of BWDB staff in these activities. Three BWDB engineers are enrolled on MSc courses at IHE, Delft.

The following Reports have been submitted by the project up to the end of the 5th Quarter

1. Inception Report, submitted on 20 January 2019

2. 2nd Quarterly Progress Report, submitted on 07 April 2019

3. 1st Interim Literature Review Report, submitted on 24 June 2019

4. 3rd Quarterly Progress Report, submitted on 06 August 2019

5. Database Design Report, submitted on 11 September 2019

6. Report on Regional Stakeholder's Consultation Workshop, Barisal (Both English and Bengali versions), submitted on 24 September 2019

7. Report on Regional Stakeholder's Consultation Workshop, Khulna (Both English and Bengali versions), submitted on 24 September 2019

8. Report on Boundary Data for Models at various scales, submitted on 25 September 2019

9. Report on GIS Database Maps, Submitted on 25 September 2019

10. Report on Data Reports, Inventory, Quality checks, Submitted on 29 September 2019.

11. 4th Quarterly Progress Report, submitted on 07 November 2019.

1 INTRODUCTION

The coastal zone of Bangladesh spans over 710 km of coastline and is subject to multiple threats. Sixty- two percent of the coastal land has an elevation less than 3 meters above mean see level. The coastal lands, being subject to regular flooding by saline water during high tides, could not be used for normal agricultural production in a country with a very high demand for land. The Coastal Embankment Project (CEP) was initiated in the 1950s and 1960s to build polders surrounded by embankments preventing the spilling of saline water onto the land at high tides. These embankments were built along the larger rivers and across the smaller rivers and creeks which then formed the drainage system within each polder and connected to the peripheral rivers via appropriately sized flap gate regulators, that open at low tide to let the drainage water out.

The Coastal Embankment Project made possible the reclamation of large tracts of land for agriculture from 1960 onwards. Polder building proceeded continuously until today. We now have 1.2 million hectares reclaimed in 139 active polders in the coastal zone of Bangladesh.

In over half century of its existence, a number of challenges have surfaced threatening the long-term safety and even the very existence of the polder system as a viable and sustainable resource. These are:

- The interference with natural tidal regime created severe siltation problems in some rivers resulting in severe drainage congestion in some polders.
- Sea level rise and changes in precipitation and water discharge due to climate change
- Threats of damming and diversion to the delivery of river sediments from upstream
- Subsidence of lands (except where it has been allowed to be rebuilt by tidal flooding) and structures founded on existing land
- Increasing vulnerability to cyclones and storm surges

The damage caused by Cyclones Sidr and Aila in 2007 and 2009 led to a major new investment of World Bank funds called the Coastal Embankment Improvement Project through which the coastal embankment system was to be improved and made much more climate resilient, over several phases of construction. After the feasibility study of the first phase CEIP-1, it was recommended that certain gaps in our knowledge of the delta should be addressed by the research study which was to be known as the **Long-Term Monitoring, Research and Analysis of Bangladesh Coastal Zone.**

After a very long gestation period, the study was initiated on 15 October 2018 and the Inception Phase was completed in January 2019. The Inception Report was treated as the first Quarterly Progress Report (QPR-1). The Second Quarterly Progress Report which was submitted in April 2019 covered the period 1 January 2019 to 31 March 2019. The Third Quarterly Progress Report (QPR-3) covers the period 1 April 2019 to 30 June 2019. QPR-4 covered the period from 1 July 2019 to 30 September 2019. This is the Fifth Quarterly Progress Report describing the progress made between 1 October 2019 and 31 December 2019.

1.1 Work Plan

The Inception Report (DHI, 2019) gave a detailed description of the work to be carried out by this project. Table 1.1 shows the full schedule of activities to be carried out during the 30 months of the project. This work plan in based on the plan shown in the Inception Report published in December 2018. This work plan is a more detailed version with some adjustments have that have had to be made due to contingencies and developments in the field. The updated work plan, which still includes the original deliverables as well as additional outputs, has been rescheduled as shown in Table 1.2. The modelling outputs are listed separately in Table 1.3. As far as this report is concerned the activities carried out during the 4th Quarter (1 July to 31 September) are described in detail.

Table 1.1: Activity Schedule Page 1

Overview of Deliverables (Effective Date of commencement is 15 October 2018)																																		
No	TOR Reference/ Deliverables Code	**TOR Deliverables**	15-Oct-18	15-Nov-18	15-Dec-18	15-Jan-19	15-Feb-19	15-Mar-19	15-Apr-19	15-May-19	15-Jun-19	15-Jul-19	15-Aug-19	15-Sep-19	15-Oct-19	15-Nov-19	15-Dec-19	15-Jan-20	15-Feb-20	15-Mar-20	15-Apr-20	15-May-20	15-Jun-20	15-Jul-20	15-Aug-20	15-Sep-20	15-Oct-20	15-Nov-20	15-Dec-20	15-Jan-21	15-Feb-21	15-Mar-21	15-Apr-21
			0	1	2	3	4	5	6	7	8	9	#	11	#	#	#	#	#	#	18	#	#	21	#	23	24	25	26	27	28	29	30
D-1	D-1	Inception Workshop																															
		Inception Report (Workplan etc																															
D-2	D-2	**Literature Review & Lessons Learnt**																															
		Literature Inventory & Interim Review 1																															
		Literature Inventory & Interim Review 2																															
		Literature Review & Lessons Learnt																															
D-3		**Development of Input datasets for modelling the physical processes**																															
	D-3:1,2	1) Soft and hard copies of map of the location of all the current field measurement stations, by tape, stored in Database of BWDB, Map showing the location of primary BM with values																															
	D-3:1,2	2) Raw datasets of all type of data. Including meta-data. Stored in Database of BWDB																															
	D-3.3	Completed and validated dataset including meta-data, stored in Database of BWDB																															
	D-3:4	GIS based National Coastal Polder Database/ Management Information System/ Database																															
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	D-3:5	Boundary conditions and data for calibration and validation of models																															
	D-3:6	Monitoring results on sedimentation rate in rivers and floodplain																															
	D-3:7	Annual and seasonal sediment load of major rivers and to Bay of Bengal																															
	D-3:8	Technical memorandum describing the validation and completion procedures that have been udes by the consultant for all type of data; for reproducibility purposes and to be stored in Database of BWDB																															
	D-3:9	Memorandum with recommendations to improve the data collection, processing, validation and dissemination within the GoB																															
D-4		**Modelling of the long-term physical processes**																															
D-4A-1		**Morphology on a macro scale**																															
	D-4A-1:1	The software newly developed under this project with all source code and accompanying technical document with detailed explanation of the methodology and assumptions																															
	D-4A-1:2																																
		Geospatial datasets of main sources and deposits of sediment at present, including full meta-data a restored and archived in Database of BWDB;																															
		Geospatial datasets of main sources and deposits of sediment for 100 years from present, including full meta-data are published and archived in Database of BWDB.																															
	D-4A-1:3,4	Geospatial datasets of main sources and deposits of sediment for 100 years from present, including full meta-data are published and archived in Database of BWDB.																															
		Technical reports																															

Table 1.1 (contd.) Activity Schedule Page 2

D-4A-2		**Morphology on a meso scale**
	D-4A-2:1,2	Report on upgrade and update of present meso scale model including detailed explanation of the methodology and assumptions. Geospatial datasets of erosion and sedimentation in the coastal zone at present for various seasons and circumstances in relevant. These geospatial datasets should include full meta-data and be stored and archived in Database of BWDB
	D-4A-2:3	Geospatial datasets of erosion and sedimentation in the coastal zone for possible scenarios 25, 50 and 100 years from now, for various reasons and circumstances if relevant. These geosparial datasets should incldue full meta-data and be stored and archived in Database of BWDB
	D-4A-2:4	Technical report (one report for 4A-1 and 4A-2)
D-4A-2		
	D-4A-2:1,2	Report on upgrade and update of present meso scale model including detailed explanation of the methodology and assumptions. Geospatial datasets of erosion and sedimentation in the coastal zone at present for various seasons and circumstances in relevant. These geospatial datasets should include full meta-data and be stored and archived in Database of BWDB
	D-4A-2:3	Geospatial datasets of erosion and sedimentation in the coastal zone for possible scenarios 25, 50 and 100 years from now, for various reasons and circumstances if relevant. These geosparial datasets should incldue full meta-data and be stored and archived in Database of BWDB
	D-4A-2:4	Technical report (one report for 4A-1 and 4A-2)
D-4D-3		Geospatial datasets of High Water, Low Water and maximum salt intrusion in all river branches for average tide in the wet and dry season at present and at 25, 50 and 100 years from now, including full meta-data stored and archived in database of BWDB.
	D-4D-3:1,2,3,4,5	Geospatial datasets of groundwater salinity at 3 relevant levels (in the upper shallow, lower shallow and deeper aquifers, to be deignated by BWDB) at present and at 25, 50 and 100 years from now, including full metadata and stored and archived in Database of BWDB. Tidal and salinity curves for key locations in the coastal zone (about 20, to be designated by BWDB) in the wet and dry season at present, and at 25, 50 and 100 years from now. Exceedance frequency curves for water levels in the same 20 stations at present, and at 25, 50 and 100 years from now. Define extreme water levels in the polder of coastal zone at 25, 50 and 100 years from now, due to cyclonic storm surges

Table 1.1 (contd.) Activity Schedule Page 3

D-4A-3	**D-4A-3:1,2,3**	The model setup developed will be updated under this project with all accompanying technical document with detailed explanation of the methodology and assumptions. A report that describes the pros and cons of the different methodologies to prevent water-logging within the polder and sedimentation of tidal river system including polder-subsidence. The report will include meta-data on the models used and measurements, recommendations for polder design including drainage and long term management plan, and recommendations for pilot area/ polder to implement the ideas, such as but not limited to location, methods and measurements. Recommended plan to manage sediment at the downstream stretch of the tidal river and in the polder.
D-4B	**D-4B:1,2,3**	**Subsidence** Geospatial datasets of total subsidence at present and for 25, 50 and 100 years from now, including full metadata and stored in Database of BWDB and Estimate the annual rate of subsidence. Detailed Technical Report with description and explanation of geospatial analysis of the total subsidence in the four regions of the polder area of the coastal zone at present and for 25, 50 and 100 years from present, including description of the causes of subsidence, full metadata and stored in Databse of BWDB. Report on the total subsidence in specific polders (designated by BWDB) in 25, 50 and 100 years from now when no sediment is supplied to the polder, including the amount of
D-4C	**D-4C:1,2**	**Meteorology** Technical Report describing current trends and future scenarios in rainfall in the polder area of coastal zone for four coastal regions (including estimation of rainfall distribution over the year) and cyclone frequency and intensity for the next 25, 50 amd 100 years from now, including meta-data of the datasets used for the trend analyses and store and archived in Database of BWDB. The Research Team shall include a description of the statistical and downscaling methods used for reproducibility reasons. Geospatial Dataset and archived in Database of BWDB.
D-4D	**D-4D:1,2,3**	**Climate Change Effects** Geospatial datasets of High Water, Low Water and maximum salt intrusion in all river branches for average tide in the wet and dry season at present and at 25, 50 and 100 years from now, including full meta-data stored and archived in database of BWDB. Geospatial datasets of groundwater salinity at 3 relevant levels (in the upper shallow, lower shallow and deeper aquifers, to be deignated by BWDB) at present and at 25, 50 and 100 years from now, including full metadata and stored and archived in Database of BWDB. Tidal and salinity curves for key locations in the coastal zone (about 20, to be designated by BWDB) in the wet and dry season at present, and at 25, 50 and 100 years from now.
	D-4D:4,5	Exceedance frequency curves for water levels in the same 20 stations at present, and at 25, 50 and 100 years from now. Define extreme water levels in the polder of coastal zone at 25, 50 and 100 years from now, due to cyclonic storm surges.
	D-4D:6	Technical Report with description and explanation of the geospatial datasets of surface and ground water salinity, and the tidal salinity and water level curves, including description of relevant seasonal variations, used models, indication of more and less likely scenarios and full metadata. The Research Team shall also discuss the effect of at least two relevant options of redistribution of river water in the South West delta on salt intrusion.

Table 1.1 (contd.) Activity Schedule Page 4

D-5		
	D-5A:1	Technical Report on Long Term Polder Improvement measures and Polder Development Plan
	D-5A:1	
	D-5A:2	Design of polder improvement measures of 17 polders under CEIP-I with consideration of existing improvements.
		Draft report focusing on initial 4 Polders to be optimised.
		Final report, 17 polders
	D-5A:3	Report for each of the 3-5 polders with a description of ; Present situation, boundary conditions (scenarios), Matching with polder options, Including management plan,
		Draft report focusing on initial 4 Polders to be optimised. Final Report, 17 Polders.
D-5B		Report describing the Interdependencies and relations between the processes and parameters, consequences for the boundary conditions and recommendations for future action plan/ research
D-6		**Updating of design paramerters and specificaitons for construction works and management paractices**
	D-6.1	Report with updated set of design parameters and specifications for construction/ reconstruction of the polders as well as associated appurtenant structures.
		Detailed delivery plan to be developed druing the inception phase.
D-6.2	D-6.2	
		Report on Management plans for the polders
		Detailed delivery plan to be developed during the inception phase
D-6.3	D-6.3	
		Report on participatory monitoring mechanism with goals and targets
		Detailed delivery plan to be developed during the inception phase
D-7		**Investment Plan for Entire CEIP**
	D-7:1	An investment plan describing a phaased polder improvement roadmap and required budget
	D-7:2	An investment plan for long term management of the polders, including the expansion of monitoring
	D-7:3	An execution plan including financing and fundraising strategies and plan and technical collaboration plan
D-8		**Action Plan for Capacity Building**
		On the job technical training in country
		Report on: results of the on the job training, list of participants
		International Workshop
		Teach the teacher, Teaching at the universities
D-9.1		**Outreach Program**
	D-9.1:1	Workshops
	D-9.1:2	Workshop Report
D-9.2		**Communication Strategy**
		Storage of all datasets of BWDB and Communication materials

1.2 List of Non-Modelling Milestones and Deliverables (pl see Chapter 4 for Modelling Deliverables)

Table 1.2: List of non-modelling milestones and deliverables

Output No	TOR Reference	TOR Deliverables	Description	Programme Item (s)	Schedule in Inception Report	Adjusted delivery date (if any)	Deliverable Status	Comment
D-1	D-1	Inception Workshop	Inception	Inception Workshop	0-3		√	Delivered
		Inception Report (Workplan etc		Inception Report (Workplan etc			√	
D-2	D-2	Literature Inventory & Interim Review 1	Literature	Literature Inventory & Interim Review 1	0-6		√	Delivered
		Literature Inventory & Interim Review 2		Literature Inventory & Interim Review 2	7-24			Due Dec 2019 rec. contributions
		Literature Review & Lessons Learnt		Literature Review & Lessons Learnt	12	24		Due in 9th Qtr end
D-3	D-3: 1, 2	1) Soft and hard copies of map of the location of all the current field measurement stations, by tape, stored in Database of BWDB, Map showing the location of primary BM with values 2) Raw datasets of all type of data. Including meta-data. Stored in Database of BWDB	Data Collection, Analysis and Documentation in GIS Database	Data Report, Inventory & Quality Checks (Includes field Data collection and monitoring programmes)	3-9		√	This item refers to progress on field activities up to August 2019
	D-3: 3	Completed and validated dataset including meta-data, stored in Database of BWDB		Databased Design Report	3-9		√	Delivered Month 11
	D-3: 4	GIS based National Coastal Polder Database/ Management Information System/ Database		GIS Based Maps	3-9		√	Delivered Data Report & CD
	D-3: 4	GIS based National Coastal Polder Database/ Management Information System/ Database		GIS Based Database/ MIS system/ Sharepoint	3-9	24		Data entry in progress
	D-3: 5	Boundary conditions and data for calibration and validation of models		Supply of Model Boundary Data	3-9		√	continuing to end of 5th Quarter
	D-3: 6	Monitoring results on sedimentation rate in rivers and floodplain		Monitoring Results on Sedimentation rate in rivers		24		
	D-3: 7	Annual and seasonal sediment load of major rivers and to Bay of Bengal		Annual & Seasonal Sediment load of Major rivers & to Bay of Bengal		24		
	D-3: 8	Technical memorandum describing the validation and completion procedures that have been udes by the consultant for all type of data; for reproducibility purposes and to be stored in Database of BWDB		Technical Report of Data analysis & Validation	10-12	24		Under processing by Survey & Modelling Teams
	D-3: 9	Memorandum with recommendations to improve the data collection, processing, validation and dissemination within the GoB		technical Report on improving Data collection	10-12			Awaitng completiong of consultation with BWDB
D-4			Mathematical Modelling	Complex programme of modelling, is dealt with in a separate Table				
D-5	D-5A:1	Technical Report on Long Term Polder Improvement measures and Polder Development Plan	Polder Development Plan	Polder Development Plan I	30	24		Update Polder Inventory, Characterisitcs, (incl land use, population, economic activity, … Problems requiring solutions Ongoing (include 17 Polders)
	D-5A: 1			Polder Development Plan II	30	18-28		Completion of new MCA, Identifaction of interventions etc Analysis and more consultations
	D-5A: 1			Polder Development Plan III	30	20-30		Preparation of Development plan
	D-5A:2	Design of polder improvement measures of 17 polders under CEIP-I with consideration of existing improvements. Draft report focusing on initial 4 Polders to be optimised. Final report, 17 polders		(incl) Improvements to 17 Polders	21-30	24		Included in above plan
D-5	D-5A: 3	Report for each of the 3-5 polders with a description of ; Present situation, boundary conditions (scenarios), Matching with polder options, Establish design, Including management plan, Costs and benefits. Draft report focusing on initial 4 Polders to be optimised. Final Report, 17 Polders.		Feasibility Report on each of 3-5 Polders	10 to 14	18		Study has commenced
				Final Report on 17 polders	4-21	21		Awaiting study results
	D-5B	Report describing the Interdependencies and relations between the processes and parameters, consequences for the boundary conditions and recommendations for future action plan/ research		Coherence with respect to Overall Delta	24	28		Awaiting results of other studies
				Environmental Assessment of Proposed Interventions	new item	20-26		Environmental Assessment of Proposed Interventions
D-6.1	D-6.1	Report with updated set of design parameters and specifications for construction/ reconstruction of the polders as well as associated appurtenant structures	Updated Parameters	Updated Design Parameters & Specifications	30			rescheduled
		Detailed delivery plan to be developed during the inception phase		Detailed Delivery Plan	6	18		
D-6.2	D-6.2	Report on Management plans for the polders	Polder Management	Polder Management Plan	30	26		
		Detailed delivery plan to be developed during the inception phase		Detailed Delivery Plan	6	18		
D-6.3	D-6.3	Report on participatory monitoring mechanism with goals and targets		Performance Monitoring Mechanisms	24-30			
		Detailed delivery plan to be developed during the inception phase		Detailed Delivery Plan	30	18		
D-7	D-7	An investment plan describing a phaased polder improvement roadmap and required budget	Investment Plan ar Fund Raising	Investment Plan fo Enitire CEIP	24-30			Awaiting initiation
					none			On going
		An investment plan for long term management of the polders, including the expansion of monitoring						
		An execution plan including financing and fundraising strategies and plan and technical collaboration plan			6			Under preparation
D-8	D-8	On the job technical training in country	Capacity Building	In-country on-the- job Training	0 - 24	3-27		Requires more BWDB participstion
		Report on: results of the on the job training, list of participants		Training Report with list of trainees	27			
		International Workshop		International Worlshop	27			
		Teach the teacher, Teaching at the universities		Cirriculum Development		24-27		Appoint Curriculum Development Committee
D-9.1	D-9.1	Workshops Workshop Report	Outreach programme	Workshops Workshops Report	12,16,24,27		√ (3, 6, 7) √ (4, 11, 11)	3 workshops to date; Reports submitted

Table 1.3: Deliverable related to Modelling activities

TOR Reference	TOR Deliverables	Scale	Model	Description each			Delivery Dates
D-4A-1: 1	The software newly developed under this project with all source code and accompanying technical document with detailed explanation of the methodology and assumptions		Instead of Source Code the Consultant will deliver the following for every model set up and run under this project: a) The Model Set up files and related report b) Input data files and related results files c) Related software licences transferred to BWDB				
D-4A-1: 2	Geospatial datasets of main sources and deposits of sediment at present, including full meta-data a restored and archived in Database of BWDB Geospatial datasets of main sources and deposits of sediment for 100 years from present, including full meta-data are published and archived in Database of BWDB.	**Macro**	GBM Basin Model	Model Set up Calibration & Validation	**a**	D4A-1 Describes all these activities . Deliverable between Aug 19 and Oct 20	Mar-20
		Macro	Macro scale River Model	Model Set up Calibration & Validation	**a**		Mar-20
		Macro	Macro scale River Model	Model Set up Calibration & Validation	**a**		Mar-20
		Macro	GBM Basin Model Applications	Climate Change Simulations	**b**		7th Quarter
		Macro	Macro scale River Model Applications	Climate Change Simulations	**b**		7th Quarter
		Macro	Macro scale River Model Applications	Climate Change Simulations	**b**		7th Quarter
		Macro	Sediment Budget Analyses	Long Term Sediment Balances in Delta			Apr-20
D-4A-1: 3, 4	Geospatial datasets of main sources and deposits of sediment for 100 years from present, including full meta-data are published and archived in Database of BWDB. Technical reports		**FINAL REPORT ON MORPHOLOGICAL TRENDS**		**A**		Oct-20
			SPECIAL REPORT ON SEDIMENT RECIRCULATION IN THE DELTA		**B**		Oct-20
			Long Term Morphology Modelling				
D-4A-2: 1, 2	Report on upgrade and update of present meso scale model including detailed explanation of the methodology and assumptions. Geospatial datasets of erosion and sedimentation in the coastal zone at present for various seasons and circumstances in relevant. These geospatial datasets should include full meta-data and be stored and archived in Database of BWDB	**Meso**	Pussur Sibsa	Model Set up Calibration & Validation	**a**		Mar-20
		Meso	Baleswar-Bishkhali Model	Model Set up Calibration & Validation	**a**		Mar-20
		Meso	Lower Meghna	Model Set up Calibration & Validation	**a**		Mar-20
		Meso	Sangu	Model Set up Calibration & Validation	**a**		Mar-20
D-4A-2: 3	Geospatial datasets of erosion and sedimentation in the coastal zone for possible scenarios 25, 50 and 100 years from now, for various reasons and circumstances if relevant. These geosparial datasets should incldue full meta-data and be stored and archived in Database of BWDB	**Meso**	Pussur Sibsa	Long Term Morphology Applications	**b**		7th Quarter
		Meso	Baleswar-Bishkhali Model	Long Term Morphology Applications	**b**		7th Quarter
		Meso	Lower Meghna	Long Term Morphology Applications	**b**		7th Quarter
		Meso	Sangu	Long Term Morphology Applications	**b**		7th Quarter
D-4A-2: 4	Technical report (one report for 4A-1 and 4A-2)		**FINAL REPORT ON ESTUARINE MORPHOLOGY**		**C**		Nov-20
			Bank Erosion on Meso Scale				
D-4A-2: 1, 2	Report on upgrade and update of present meso scale model including detailed explanation of the methodology and assumptions. Geospatial datasets of erosion and sedimentation in the coastal zone at present for various seasons and circumstances in relevant. These geospatial datasets should include full meta-data and be stored and archived in Database of BWDB	**Meso**	Pussur	Model Set up Calibration & Validation	**a**		Apr-20
		Meso	Sibsa	Model Set up Calibration & Validation	**a**		Apr-20
		Meso	Baleswar	Model Set up Calibration & Validation	**a**		Apr-20
		Meso	Bishkali	Model Set up Calibration & Validation	**a**		Apr-20
		Meso	Lower Meghna	Model Set up Calibration & Validation	**a**		Apr-20
		Meso	Sangu	Model Set up Calibration & Validation	**a**		Apr-20
D-4A-2: 3	Geospatial datasets of erosion and sedimentation in the coastal zone for possible scenarios 25, 50 and 100 years from now, for various reasons and circumstances if relevant. These geosparial datasets should incldue full meta-data and be stored and archived in Database of BWDB	**Meso**	Pussur	Erosion Prediction Report	**b**		Dec-20
		Meso	Sibsa	Erosion Prediction Report	**b**		Dec-20
		Meso	Baleswar	Erosion Prediction Report	**b**		Dec-20
		Meso	Bishkali	Erosion Prediction Report	**b**		Dec-20
		Meso	Lower Meghna	Erosion Prediction Report	**b**		Dec-20
		Meso	Sangu	Erosion Prediction Report	**b**		Dec-20
D-4A-2: 4	Technical report (one report for 4A-1 and 4A-2)	**Meso**	**FINAL REPORT ON BANK EROSION MODELLING**		**D**		Jan-21
			Other special purpose models				
		Meso	Pussur-Sibsa fine sediment model- ext	Pussur Sibsa Fine Sediment Model	**E**		Jan-20
D-4D-3: 1, 2, 3, 4, 5	Geospatial datasets of High Water, Low Water and maximum salt intrusion in all river branches for average tide in the wet and dry season at present and at 25, 50 and 100 years from now, including full meta-data stored and archived in database of BWDB. Geospatial datasets of groundwater salinity at 3 relevant levels (in the upper shallow, lower shallow and deeper aquifers, to be deignated by BWDB) at present and at 25, 50 and 100 years from now, including full metadata and stored and archived in Database of BWDB. Tidal and salinity curves for key locations in the coastal zone (about 20, to be designated by BWDB) in the wet and dry season at present, and at 25, 50 and 100 years from now. Exceedance frequency curves for water levels in the same 20 stations at present, and at 25, 50 and 100 years from now. Define extreme water levels in the polder of coastal zone at 25, 50 and 100 years from now, due to cyclonic storm surges	**Bay of Bengal**	Storm Surge Model	Analysis of Synthetic Cyclone Events & Selection of events	**G1**		Dec-19
		Bay of Bengal	Storm Surge Model	Storm Surge Modelling			Dec-20
		Bay of Bengal	Wave Propagation Model	Wave Modelling			Dec-20
		Bay of Bengal	Salinity Model	Salinity Modelling	**I**		2020 end

TOR Reference	TOR Deliverables	Scale	Model	Description each			Delivery Dates
D-4A-3: 1, 2, 3	The model setup developed will be updated under this project with all accompanying technical document with detailed explanation of the methodology and assumptions. A report that describes the pros and cons of the different methodologies to prevent water-logging within the polder and sedimentation of tidal river system including polder-subsidence. The report will include meta-data on the models used and measurements, recommendations for polder design including drainage and long term management plan, and recommendations for pilot area/ polder to implement the ideas, such as but not limited to location, methods and measurements. Recommended plan to manage sediment at the downstream stretch of the tidal river and in the polder.	**Micro**	Pilot TRM Model for Polders 24 etc	TRM Model for Polder 24	**F**		Mar-20
		Micro	5 or more polder models	Drainage Model Reports	**H**		await conceptual designs selections 2020
			METEOROLOGY (these are covered under other modelling and data topics)				
			SUBSIDENCE				
D-4B: 1, 2,3	Geospatial datasets of total subsidence at present and for 25, 50 and 100 years from now, including full metadata and stored in Database of BWDB and Estimate the annual rate of subsidence. Detailed Technical Report with description and explanation of geospatial analysis of the total subsidence in the four regions of the polder area of the coastal zone at present and for 25, 50 and 100 years from present, including description of the causes of subsidence, full metadata and stored in Database of BWDB. Report on the total subsidence in specific polders (designated by BWDB) in 25, 50 and 100 years from now when no sediment is supplied to the polder, including the amount of sediment needed to counteract this subsidence.		Field Campaigns (several)	Continuous GPS & Surface Elevation Tables, Borehole sampling, luminescence testing etc			
			Subsidence Geospatial Datasets	Report		Aprl to Oct 2020	
			Detailed Technical Reports on Subsidence and Flood Plain Sedimentation			Oct-20	
			METEOROLOGY (these are covered under other modelling and data topics)				
D-4C: 1, 2	Technical Report describing current trends and future scenarios in rainfall in the polder area of coastal zone for four coastal regions (including estimation of rainfall distribution over the year) and cyclone frequency and intensity for the next 25, 50 amd 100 years from now, including meta-data of the datasets used for the trend analyses and store and archived in Database of BWDB. The Research Team shall include a description of the statistical and downscaling methods used for reproducibility reasons. Geospatial Dataset and archived in Database of BWDB.		Technical reports & Database				
			CLIMATE CHANGE EFFECTS			Oct-20	
			Climate Change & Precipitation,			Oct-20	
						Oct-20	
D-4D: 1, 2, 3	Geospatial datasets of High Water, Low Water and maximum salt intrusion in all river branches for average tide in the wet and dry season at present and at 25, 50 and 100 years from now, including full meta-data stored and archived in database of BWDB. Geospatial datasets of groundwater salinity at 3 relevant levels (in the upper shallow, lower shallow and deeper aquifers, to be designated by BWDB) at present and at 25, 50 and 100 years from now, including full metadata and stored and archived in Database of BWDB. Tidal and salinity curves for key locations in the coastal zone (about 20, to be designated by BWDB) in the wet and dry season at present, and at 25, 50 and 100 years from now.		Salinity intrusion & Groundwater Salinity			Oct-20	
D-4D: 4, 5	Exceedance frequency curves for water levels in the same 20 stations at present, and at 25, 50 and 100 years from now. Define extreme water levels in the polder of coastal zone at 25, 50 and 100 years from now, due to cyclonic storm surges.		Extreme Storm Surges			Oct-20	
D-4D: 6	Technical Report with description and explanation of the geospatial datasets of surface and ground water salinity, and the tidal salinity and water level curves, including description of relevant seasonal variations, used models, indication of more and less likely scenarios and full metadata. The Research Team shall also discuss the effect of at least two relevant options of redistribution of river water in the South West delta on salt intrusion.		**Detailed Technical Reports on Climate Change Effects**			Nov-20	

1.3 Components 1, 2 and 3

Component No 1 (Inception Phase) has been completed during the first Quarter. The Work Plan proposed and approved in the Inception Report will provide broad guidance for the later activities.

Component No 2 (Literature Review) is the first activity listed for the post inception period. Much progress was achieved in this activity, keeping in mind the need to keep up with the outputs from new field campaigns, other related studies and projects, which will continue to provide additional knowledge and insights. The first Interim Literature Review was published in the month of April 2019. This report was published as Appendix A of the previous Progress Report (QPR-3).

It is anticipated that the next interim Review will be prepared in early 2020. It is intended that a section on “Lessons Learnt” will be included in the Second Interim Literature Review and in subsequent reports.

The major activities undertaken during the previous and current quarter are Data Collection as inputs for Modelling (Component 3). This is described in Chapter 2.

The data collection effort has already begun to culminate in the development of a major Database designed for use in managing the Coastal Zone of Bangladesh. This is described in Chapter 3.

2 DEVELOPMENT OF INPUT DATASETS FOR MODELLING PHYSICAL PROCESSES

2.1 Collecting Existing Data

IWM already has a very comprehensive database comprising hydrometric, meteorological and morphological and environmental data collected over many decades all over the territory of Bangladesh and the adjacent ocean. These data have the advantage of having been used many times over in a large model studies which have also established the quality of the data through repeated verification.

The present study requires the addition of socio-economic data and its subdivision in to a polder-wise demarcated body of data. The availability of data is described in the Inception Report and is too large to be included in this progress report. The reader is directed to the Inception report for an outline of availability. Appendix A of the Second Quarter Progress Review Report gives a list of available data.

2.2 Field Surveys carried out by IWM

2.2.1 Mobilization

The survey team was mobilized on 05 February 2019. A team of 12 personnel comprising the IWM survey Expert, experienced hydrographic surveyor and land surveyors has been deployed for conducting the planned data collection campaign as per specification.

2.2.2 Summary of Field Survey Activities

In this quarter from October to December 2019, no bathymetry and monitoring section survey have been carried out. The progress of other survey activities is shown in Table 2.1 to Table 2.5.

The survey methodology employed by IWM survey teams is described in details in the Second Quarterly Progress Report.

The collection of data for the ground-water resources assessment is described in a separate sub-chapter No. 2.3.

Table 2.1: Progress of discharge observation

SL no.	Location/ River Name	Target (Number)		Progress upto Sep-2019	Progress in between Oct - Dec 2019	Cumulative progress upto Dec-2019	Remarks
		TOR	Modified				
A	3 main rivers						
1	Bahadurabad, Brahmaputra	18	48	10	4	14	As per post inception consultation (Twice a months for 2 years)
2	Hardinge Bridge, Ganges	18	48	10	5	15	
3	Bhairab Bazar, Upper Meghna	18	48	13	5	18	
Total of A		54	144	33	14	47	
B	Lower Meghna						
4	Chandpur, Lower Meghna	3	5	5	0	5	2 spring+ 1 neap during monsoon and 2 nos. 1 Spring +1 Neap for dry season
C	5 nos. Tidal rivers surrounding the Polders.						
5	U/S of Mongla port, Pusur	44	8	6	1	7	For each location 8 measurement: 1 spring in every two months and -1 neap in every six months for the periods of one year.
6	Nalian, Shibsha		8	6	1	7	
7	Charduani, Baleswar		8	6	1	7	
8	Bhandaria, Baleswar		8	6	1	7	
9	Polder-17/2, Gangril		8	6	1	7	
Total of C		44	40	30	5	35	
D	Additional 3 tidal River						
10	Dasmina, Tetulia	0	2	2	1	4	2 nos. measurement during June-Oct-19, 1
11	Kakchira, Bishkhali	0	3	3	0	3	Total 3 nos. -1 spring in dry season and 1-Neap+1-Spring for monsoon
12	Taliar dwip,Shangu	0	2	1	1	2	2 nos. measurement during June-Oct-19, 1 Spring+ 1 Neap
Total of D		0	7	6	2	9	

Table 2.2: Progress of suspended sediment sampling for total concentration

SL no.	Location/ River Name	Discharge observation		Suspended Sediment Sampling for Total concentration			
		As per TOR	Modified	As per TOR	Cumulative Progress upto Sep-2019	Progress from Oct-Dec 2010	Cumulative Progress upto Dec 2019
A	3 main rivers						
1	Bahadurabad, Brahmaputra	18	48	1056	809	432	1241
2	Hardinge Bridge, Ganges	18	48				
3	Bhairab Bazar, Upper Meghna	18	48				
B	Lower Meghna						
4	Chandpur, Lower Meghna	3	5	234	149	0	149
C	5 nos. Tidal rivers surrounding the Polders.						
5	U/S of Mongla port, Pusur	44	40	3432	1708	444	2456
6	Nalian, Shibsha						
7	Charduani, Baleswar						
8	Bhandaria, Baleswar						
9	Polder-17/2, Gangril						
D	Additional 3 tidal River (as per modified plan)						
10	Dasmina, Tetulia	0	2	0	448	80	561
11	Kakchira, Bishkhali	0	3				
12	Taliar dwip,Shangu	0	2				

Table 2.3: Progress of suspended sediment and bed sampling for grain size distribution

SL no.	Item	Sediment Sampling				Remarks
		As per TOR	Progress upto Sep-2019	Progress in between Oct to Dec-2019	Achieved upto Dec-2019	
1	Suspended Sediment sampling	33	10	13	23	suspended Sediment sampling during discharge observation (1 sample of minimum 40 liter volume during each observation) for 11 locations in 3 times
2	Collection of Bed Sample	55	60	3	63	Collection of five bed samples from each river discharge observation

Table 2.4: Progress of water level data collection

SL. No.	Name of Location/River	Installation Date	Quantity as per TOR	Modified Target (stat^n-month)	Progress up to Sep 2019 (stat^n-month)	Progress from Oct-Dec 2019 (statn-month)	Cumulative Progress up to Dec 2019 (statn-month)	Remarks
A	Recording of Water level at Hironpoint, Pusur/Kaikhali, Ichamoti							
1	Kaikhali, Ichamoti	15-Feb-19	12	12	7	3	10	As per post inception consultation, water level data collection is being conducted at Kaikhali instaed of Hiron point and Hironpoint data will also be collected from Mongla port as well.
B	Recording of water level in others areas							
1	Dularshar, outfall of Rabnabad Channel	18-Feb-19	40	12	7	3	10	Continue
2	Taltoli, outfall of Biskhali /Baleswar	17-Feb-19		12	7	3	10	Continue
3	Chandpur, Lower Meghna	1-Feb-19		4	4.5	0	4.5	Closed at June30, 2019
4	Dasmina(Hajir hat), Tetulia	8-Apr-19		4	4.5	0	4.5	Closed at 22/08/2019
5	Joymuni, Pusur	14-Mar-19		4	5	0	5	Closed at 22/08/2019
6	Nalian, Shibsha	15-Mar-19		4	5	0	5	Closed at 22/08/2019
7	Charduani, Baleswar	31-Mar-19		4	4	0	4	Closed at 22/08/2019
Total				44	37	6	43	

Table 2.5: Progress of Salinity Data Collection

Stat^n ID	Station Name	River_Name	Easting (m)	Northing (m)	Start date	Progress upto Sep-2019	Progress from Oct-Dec 2019	Cumulative Progress upto Dec-2012
1	Bashantapur	Isamoti	706840	2486285	12-Feb-19	7.5	3	10.5
2	Kaikhali	Modan Gauga	714395	2455144	13-Feb-19	7.5	3	10.5
3	Kobadak	Kobadak	738053	2459252	15-Mar-19	6.5	3	9.5
4	Nalian	Shibsha	749190	2486655	13-Feb-19	7.5	3	10.5
5	Gangrail	shundor mohol	746284	2509461	10-Mar-19	6.5	3	9.5
6	Khulna	Rupsha	764985	2523883	8-Mar-19	6.5	3	9.5
7	Bardia/ Nabaganga	Noboganga	773750	2555764	19-Feb-19	7.0	3	10.0
8	Chapailghat	Modhumati	786778	2544530	13-Feb-19	7.0	3	10.0
9	Patgati	Modhumati	797052	2533438	16-Mar-19	6.5	3	9.5
10	Mongla	MonglaNala	767846	2487421	10-Mar-19	6.5	3	9.5
11	Joymoni	Pussur	770059	2478036	9-Mar-19	6.5	3	9.5
12	Gasiakhali	Gasiakhali	796021	2484687	22-Mar-19	6.3	3	9.3
13	Char Doani	Baleswar	800083	2449931	13-Feb-19	7.5	3	10.5
14	Bishkhali DS	Bishkhali River	808483	2439742	6-Mar-19	6.5	3	9.5
15	Hiron Point	Pusur	756533	2412633	10-Mar-19	6.5	3	9.5
16	Mohipur	Shibbaria Khal	200814	2419537	25-Feb-19	7.0	3	10.0
17	Khepupara Kol	Adhanmanik	214449	2431880	13-Feb-19	7.5	3	10.5
18	Madhupara	Andharmanik	222130	2433381	13-Feb-19	7.5	3	10.5
19	Amtali	Burisuar	213580	2450306	5-Mar-19	6.8	3	9.8
20	Patuakhali	Buriswar	217267	2473096	15-Mar-19	6.5	3	9.5
21	Burhanuddin	Tetulia	257606	2494785	3-Mar-19	7.0	3	10.0
22	Daulatkhan	Meghna	264409	2504558	13-Feb-19	7.5	3	10.5
23	Hilsha	Ganeshpura	255886	2524418	13-Feb-19	7.5	3	10.5
24	Moju Chowdurir	Lower Meghna	271573	2524453	13-Feb-19	7.5	3	10.5
25	Ramgati	Lower Meghna	296451	2496925	2-Mar-19	7.0	3	10.0
26	Char Elahi	Outfall of Noakhali Khal	316468	2512380	13-Feb-19	7.5	3	10.5
27	Musapur	Little Feni outfall	334907	2517844	1-Mar-19	7.0	3	10.0
28	Kalurghat Brid	Karnafuly	379618	2469046	27-Feb-19	7.0	3	10.0
29	Patenga	Karnafuly	378241	2459360	13-Feb-19	7.5	3	10.5
30	Sangu Outfall	Sangu	380988	2449507	28-Feb-19	7.0	3	10.0
Total (station-month)						210	90	300

2.3 Ground Water Quality Assessment

Data has been collected for assessing the groundwater levels and salinity during the past two quarters. The progress is described in the following sub-sections.

2.3.1 Field Visit

For collection of data and information from the field, so far two field visits have been conducted during September'2019 and January'2020. The main objectives of the field visits, were water sampling from different hand tube wells and river for measuring the water quality. The list of the field visits is given in Table 2.6.

Table 2.6: List of Field Visits

SL No	Team Members	Period	Activities
1.	1. Md. Tarikul Islam 2. Arnob Barua	2nd Sep'19 to 11th Sep'19	Collection of Groundwater and Surface water samples at different selective locations
2.	1. Arnob Barua	11th Jan'20 to 20th Jan'20	Collection of Groundwater and Surface water samples at different selective locations

2.3.2 Data Collection, Analysis and Processing

For achieving the objectives of the study, different types of data have been collected both from primary and secondary sources. The data collected from the secondary sources includes hydro geological, meteorological data, topographic and aquifer properties data. Since available data from secondary sources are limited, some data have also been collected from field level through a dedicated survey programme. Primary sources data includes mainly water quality (pH, EC and salinity) of groundwater and surface water. A brief description of the collected data is presented in the following section.

a) **Collection of GW & SW Quality Data:** In order to have a clear picture about the spatial and temporal variation of water quality, it was planned to collect water sampling from 25 different selective locations of the study area during monsoon, post-monsoon and dry season. The locations of sampling have been selected in such a way that it represents the whole study area. In order to get the surface water quality, surface water sample have also been collected at two different locations. Accordingly, the team from IWM collected water samples (Figure 2.1) at selective locations during September 2019 and January 2020. Groundwater samples have been collected (Table 2.7) from the existing hand tube wells. The list of the selective locations for water sampling is given in Table 2.8 and the locations are shown in Figure 2.2. From the collected water samples, pH, EC and salinity have been measured.

Figure 2.1: Water Sampling at Field and Quality Measurement

Table 2.7: Collected and surface water sampling

Sl No.	Sample ID	Address	UTM_X	UTM_Y
1	GW01	Jessore New Market, Khajura Bus Stand Petrol Pump (Prantik Petrol Pump), Jessore Sadar, Jessore.	726768	2564886
2	GW02	Monirampur Adarsha Primary School, Monirampur, Jessore.	728425	254785
3	GW03	Besides Talikarkhana, Mouza-Sripotipur, Kalaroa, Satkhira.	710133	2529607
4	GW04	Satkhira Sadar, Kasim Super Market, Satkhira.	712640	2513038
5	GW05	Nalta Union Parisad, Kaliganj (Shamim Cloth Store), Satkhira.	707336	2490879
6	GW06	MM Plaza, Shyamnagar, Badhoghata, Shatkhira	716802	2472302
7	GW07	Bidhan Chandra Sana's House, Shibbati Bridge, Shibbati, Paikgacha, Khulna	737028	2499177
8	GW08	Darus Sunnah Salafia Madrasa (Abu Naser Hospital Mor), BN School	759414	2529420
9	GW09	Darus Sunnah Salafia Madrasa (Abu Naser Hospital Mor), BN School, Khulna Sadar, Khulna	759414	2529420
10	GW10	Bismillah Hotel, Katiarangla Bazar, Batiaghata, Khulna	759837	2509480
11	GW11	Bhagarbazar Mor, Rampal, (Behind Liton's House), Bagerhat	771709	2502872
12	GW12	Behind Md Alam Sikder's Hotel, Morelganj Ferri ghat, Morrelganj Bagerhat	794459	2487363
13	GW13	Abdullah Villa, Holding No#57, Baleswar Bridge, Pirojpur	804652	2498986

Sl No.	Sample ID	Address	UTM_X	UTM_Y
14	GW14	Singair mosque Tubewell, Bagerhat Sadar, Bagerhat.	781826	2509894
15	GW15	Mollahat Thana Masjid, Mollahat, Bagerhat.	788099	2538363
16	GW16	128 No Purbo Barashur Govt Primary School, Kashiani, Gopalganj Near Batiapara Mor	777526	2569701
17	GW17	Bypass Helipad Agaijhara, Bakal Union Barisal	208771	2543184
18	GW18	CnB Road, Kazipara (in front of Molla Pharmacy) Barisal Sadar, Barisal	227872	2513854
19	GW19	Al Hasan store in front of Betagi Bus stand Mosque, Betagi Bus stand, Barguna.	208621	2481006
20	GW20	Char Colony Road, House of Piara Begum, Barguna Town Hall, Barguna Sadar, Barguna	203523	2453585
21	GW21	Bainchotki Ferrighat beside Md Ashraf Ali's Shop, Bainchotki, Barguna	196140	2453445
22	GW22	Beside Bauphal Thana, in a Madrasa, Patuakhali	248675	2480984
23	GW23	Panna Commisioner's House, Patuakhali Sadar,	212959	2434382
24	GW24	Abu Huraira Mosque, central mosque of amkhola Bazar, Golachipa, Patuakhali	231682	2461636
25	GW25	Kolapara Bus Stand, Bismillah Filling Station	212958	2434381
26	SW01	Katiarangla ghat, Poshur River, Batiaghata Khulna	759913	2509480
27	SW02	Morelganj Ferri ghat, Morrelganj Bagerhat	794361	2487337

Using the measured salinity data, a spatial distribution map has been prepared and shown if Figure 2.3. It is observed that the groundwater salinity has decreased during January with respect to September. This may happen due to impact of rainwater recharge. Based on concentration of salinity in groundwater, the zone has been demarcated as fresh water zone (<1000 mg/l) and saline zone (>1000 mg/L). From the spatial distribution of salinity map, it is observed that the northern and western part of the study area is under fresh water zone but the south-western part is under saline zone. It is observed that saline zone (>1000 mg/L) has been decreased by 12.53% in January 2020 with respect to September 2019. In Satkhira, Bagerhat and Khulna district, the salinity in groundwater is >1000 mg/l. In Barisal, Jhalkathi, Pirojpur, Patuakhali and Barguna districts, the salinity in groundwater is (<1000 mg/L).

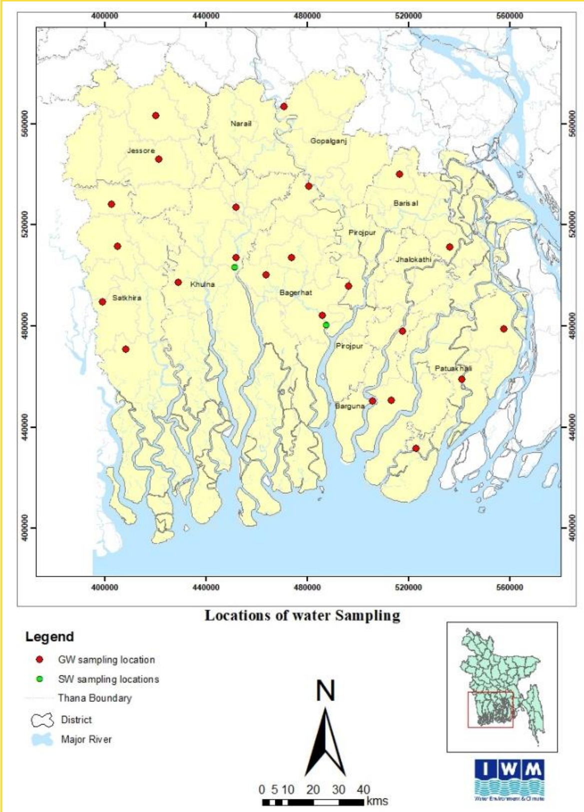


Figure 2.2: Locations of Water sampling

The areas under different salinity level in groundwater during September and January is given in Table 2.8.

Table 2.8: List of the Selective Locations for Water Sampling

Remarks	Salinity (mg/l)	Area (km^2)	
		Sep-19	January-20
Fresh water Zone<1000 mg/L	<600	3489.234	5013.161
	600-1000	9861.496	9636.186
Saline zone >1000 mg/L	1000-1200	2565.126	2488.228
	1200-1600	2731.477	2362.721
	1600-2000	1898.536	1808.598
	2000-2500	1598.394	1399.517
	2500-3300	1053.756	686.1424
	3300-4700	515.0379	318.5027

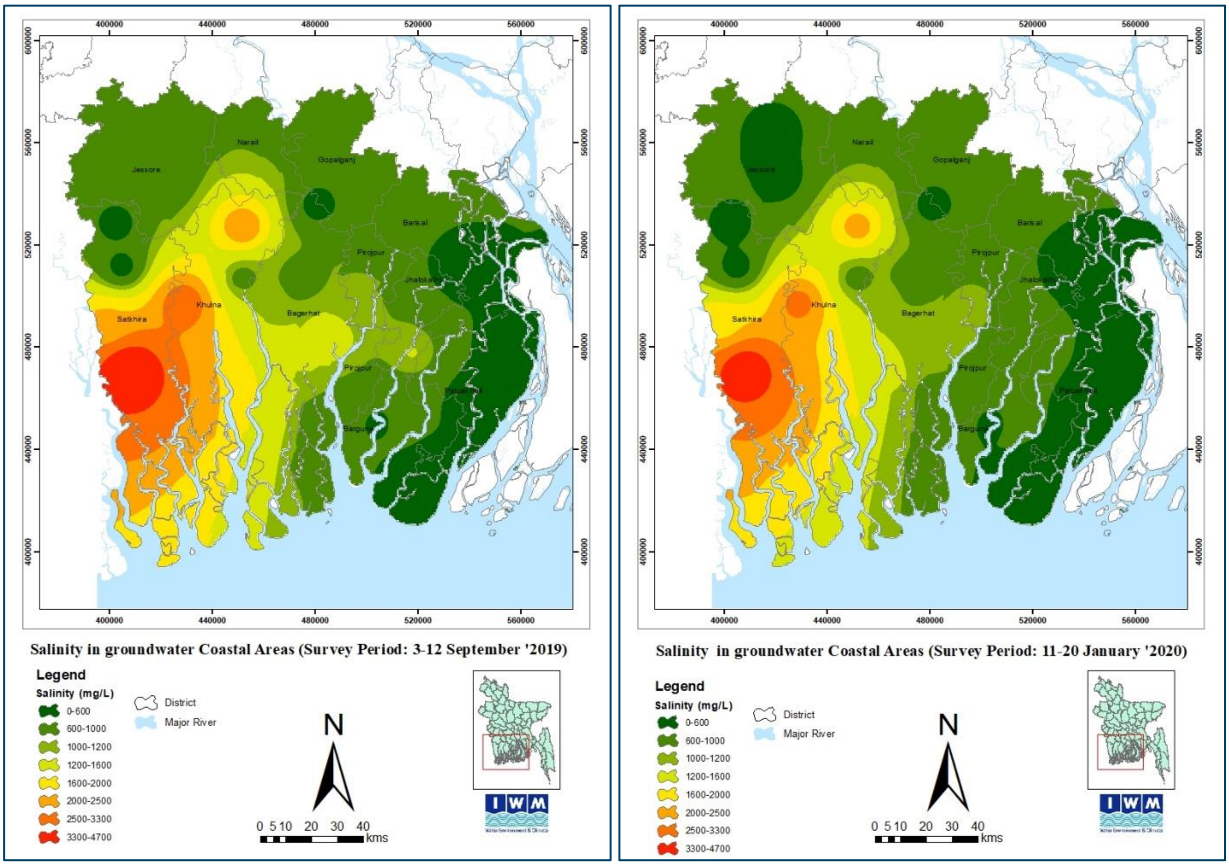


Figure 2.3: Groundwater Salinity in Monsoon & Post-monsoon

Surface water Salinity: The surface water salinity has been measured at two locations i.e. at Khulna & at Bagerhat and shown in Figure 2.4. It is observed that salinity in surface water has been increased in January'2020 than September'2019. This scenario is quite opposite than that of groundwater salinity. This is happened due to reduction of fresh water flow during January. In Katianangla bazar, Khulna station the salinity has been found 1680 mg/l whereas, in September it was only 176.8 mg/l. Though in Bagerhat, the salinity has not been increased as much as Khulna.

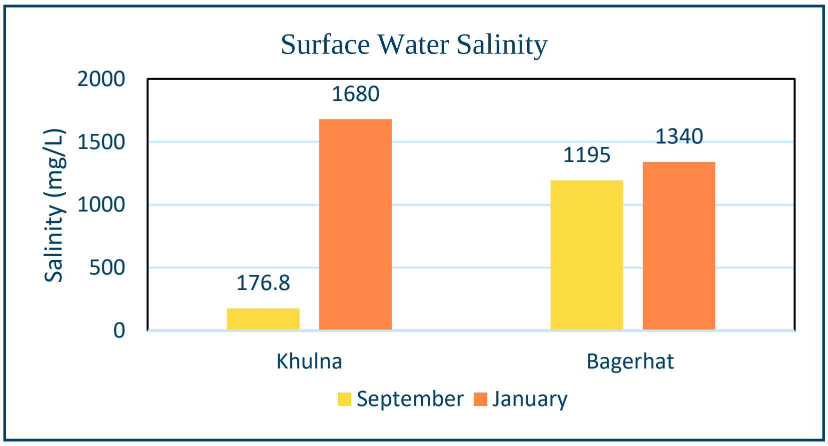


Figure 2.4: Surface Water Salinity in Monsoon & Post-monsoon

Collection of Groundwater Level Data: Groundwater level data is required for model inputs and for assessing groundwater resources in the study area. So far, groundwater level data for 96 observation wells have been collected from BWDB for the duration of 1990 to 2016. The collection of the groundwater level data upto March'20 is under process. The consistency checking of the collected data is being done.

Collection of Rainfall data: Rainfall data is needed as input for model. Seven rainfall stations are available in the model areas. Rainfall data for all the stations have been collected upto 2017. The collection of remaining period upto March'20 is under process.

Collection of Aquifer Properties Data: Aquifer properties data is required to understand the aquifer geometry and aquifer characteristics. Aquifer characteristics data include hydraulic conductivity, transmissivity and specific yield. These properties are used as main parameters in groundwater model for assessing groundwater resource base and development potential. Aquifer properties data have been collected from BWDB. The collected data are being processing for model inputs.

Collection of Lithological data: In order to identify the extension of different aquifer and aquitard units. Litholog data from different relevant sources like DPHE, BWDB in the study area have been collected. A total of 1737 nos lithologs data have been collected. The collected data are being checked and processed.

Updating of Groundwater Model: Under this study, the model that was developed under "Joint Action Research on Salt Water Intrusion in Groundwater in the Coastal Area", would be updated to see the impact of salinity in groundwater due to climate change. The model area (Figure 2.5) of 1534 km² covers thirteen upazilas of Khulna, Jessore and Satkhira districts. The model area is bounded on the north by groundwater observation wells, on the west by the Kobadak river, on the east by the Rupsha river and on the south by a channel connecting Kobadak and Rupsha. So far, the different input files are being updated. After updating of all the input files, the model will be updated.

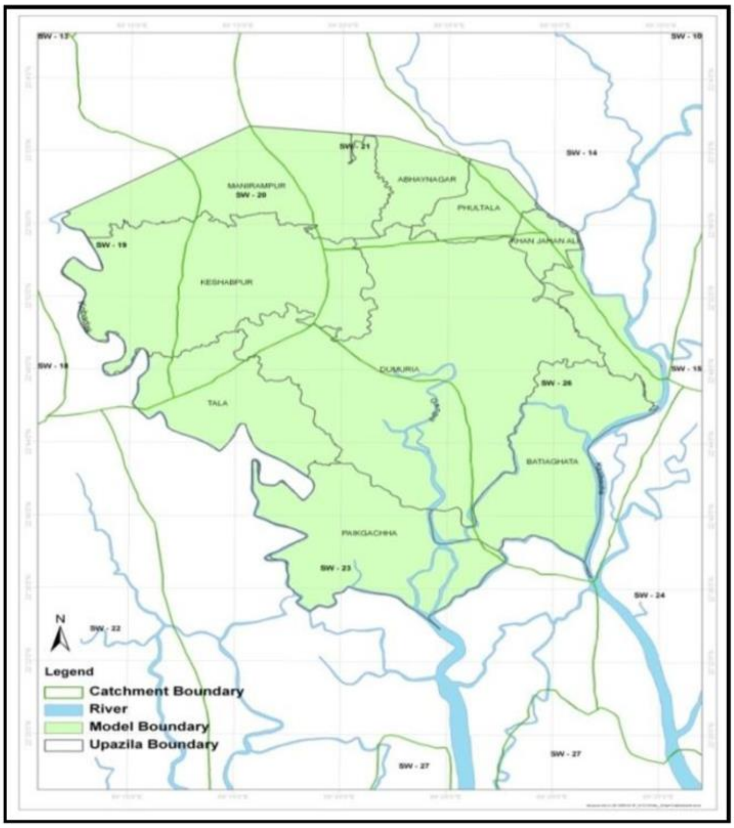


Figure 2.5: Location of Model Area

2.4 Field Surveys being carried out by US University Teams

Participants:	IK-9	Michael S. Steckler, LDEO, Columbia University steckler@ldeo.columbia.edu Céline Grall, CNRS LIENSs, La Rochelle, France cgrall@ldeo.columbia.edu	
	NNK-12	Salam Sikder,	IWM
	NNK-26	Shaikh Nahiduzzaman,	IWM
		Muktidir Sober,	IWM
		Ershadul Mondal,	Survey of Bangladesh
		Hasnat Jaman,	Barisal University
		Nahin Rezwan,	Barisal University
		Saiful Islam,	Barisal University
		Masud Rana,	Dhaka University

Figure 2.6: Group photo at Barisal University of survey team flanked by Barisal University students. M.A. Salam Sikder later replaced Shaikh Nahiduzzaman on the field team.

2.4.1 Background for the survey

Deltas are dynamic environments in which the landscape is continually changing. Rivers and channel shift, both depositing and eroding sediments. The land is continually sinking due to compaction and isostasy creating space for new sediments. Furthermore, sea level is rising threatening inundation of the land and increasing the vulnerability to cyclones and storm surges. The fragile balance of the between these processes can be summarized by the following equation:

$$\Delta_{RSL} = \Delta E + C_n + C_A + M - A \tag{1}$$

modified from Syvitski et al. (2007), in which

Δ_{RSL}	=	Vertical change in delta surface elevation (m/yr)
ΔE	=	Eustatic Sea Level Rise (m/yr),
C_n	=	Natural Compaction (m/yr),
C_a	=	Accelerated Compaction (m/yr),
M	=	Crustal Vertical Movement (m/yr),
A	=	Aggradation Rate (m/yr).

Thus, while sea level rise directly affects the elevation of the delta, subsidence compounds the effect by lowering the land surface. Sediments are then of critical importance in filling this newly created accommodation space to maintain he delta. In many deltas globally, damming and control of the rivers has led to a loss of sediments delivered to the delta. In the Mississippi and Mekong Deltas, this decrease in sediment input is leading to significant land loss in the deltas. Our objective is to quantify the magnitude and distribution of the subsidence rates to better understand the processes controlling them, and evaluate the balance and relative sea level rise in the Ganges-Brahmaputra Delta.

Published results from Bangladesh suggest both very high rates of up to 18 mm/yr (Syvitski et al., 2009) and low rates of 0-2.5 mm/yr (Sarker et al., 2012). Brown and Nichols (2015) compiled over 200 measurements of subsidence in the delta. However, by mixing multiple types of measurements with insufficient constraints on the settings of them, they obtained subsidence rates that varied from 44 to -1 mm/y, including broad ranges of values at individual sites. A critical problem is distinguishing between subsidence and sediment accumulation rates. A recent analysis of average subsidence rates (Grall et al., 2018) over the Holocene (last 10,000 years) used >400 tube wells with almost 200 C^{14} dates drilled by Steve Goodbred and his partners. Grall et al. (2018) attempted to separate components due to sediment accumulation, sea level rise and subsidence. Results revealed a systematic variation of subsidence rates across the delta. In SW Bangladesh subsidence increase from near zero rates landward of the Hinge Zone to 4.5 mm/yr at the southern coast of Bhola Island.

The first component of the subsidence study was to rehabilitate existing continuous GPS sites and install new ones. We had already established 5 GPS in the field area (Fig. 1) at Patuakhali (PUST), Khepupara (KHEP), Polder 32 (PD32), Khulna (KHUL and KHL2), and Hiron Point (HRNP). PUST and KHUL were established in 2003, but the old instrumentation only provided intermittent data and none over the last decade. KHUL was replaced by KHL2 in 2014, but the receiver removed from its location. The other stations were installed in 2012. However, the receiver at KHEP was removed for repairs.

During July-August, 2019, 4 new sites were scouted and installed (Fig. 2.7) at Sonatola (SNT1, SNT2), Jorshing (JRSN) and Baintola (BNTL), and all of the previous sites had system upgrades and/or repairs. All GPS sites were successfully installed/upgraded, and data from existing sites was collected. In addition, cellular modems for data transmittal were upgraded/added to all GPS sites except HRNP (although a cellular tower has been installed near the site, coverage is only 2G and does not support data communications). Computer hard drives for older PUST and KHUL GPS were located, but still require data download.

At Sonatola, two GPS antennas and receivers were installed. One was installed on the roof of a reinforced concrete column of a primary school (SNT1), similar to other continuous installations in Bangladesh (Fig. 2.8). The other was installed on a rod (Fig.

2.9) identical to the nearby RSET (SNT2). This will enable direct measurement of any subsidence occurring beneath the bottom of the 80' long rod. For the RSET

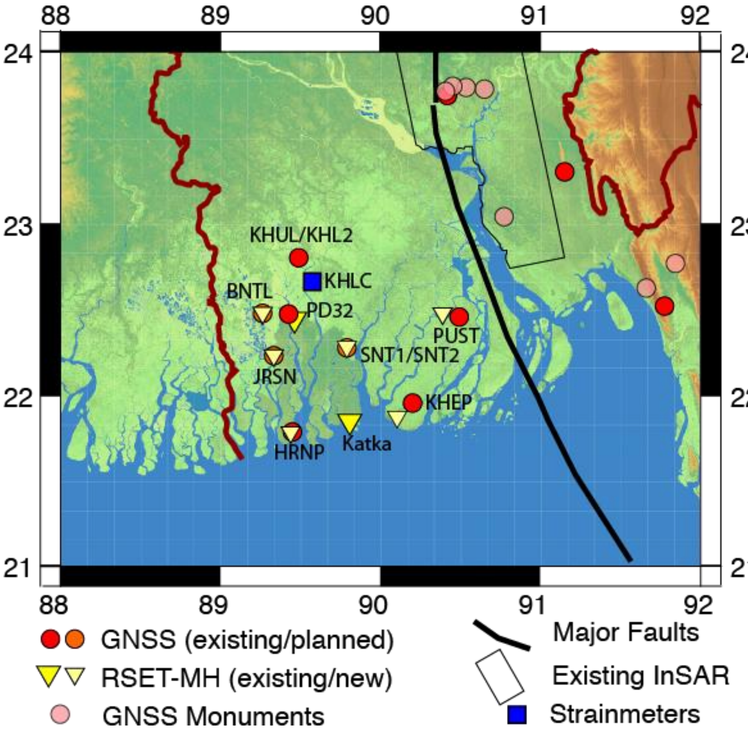


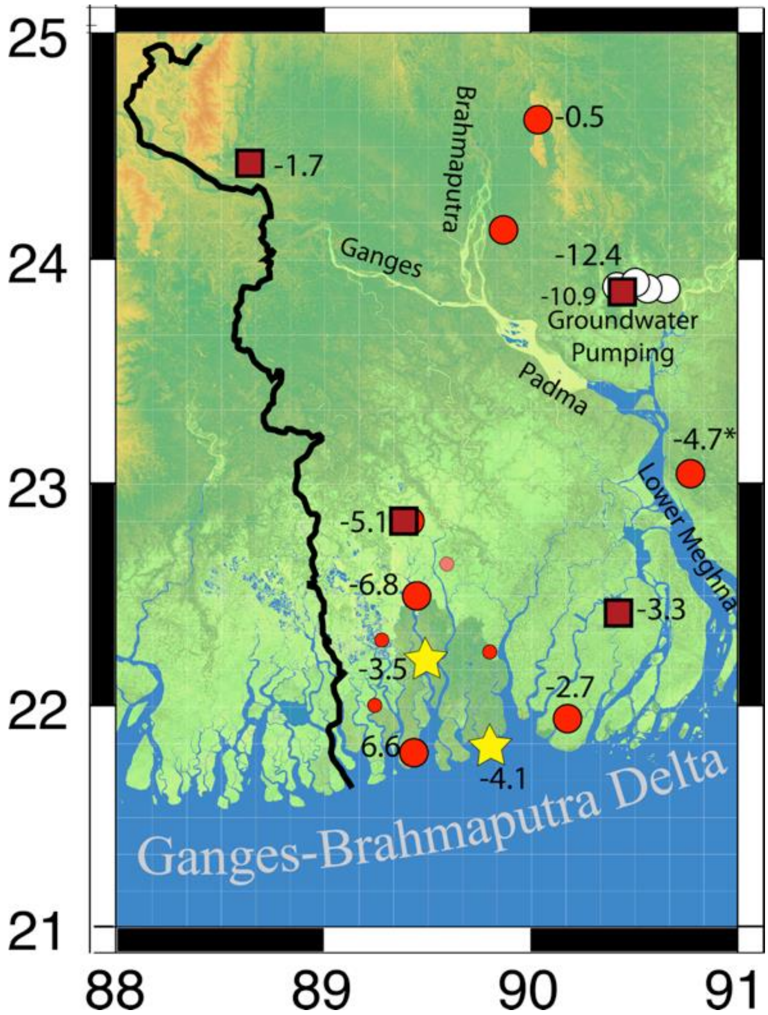
Figure 2.7: Map of GPS and RSET sites installed, upgraded or serviced in July 2019. All GPS sites except HRNP have cellular connections for data downloads. HRNP point data is downloaded by the RSET team when they service the RSET.

In addition, we were able to install campaign GPS monuments on the Hiron Point (Fig. 2.10) and Khepupara tide gauges, and two at Barisal University. These campaigns monuments will allow subsequent monitoring of subsidence. Measurements at the two tide gauges will also be able to help assess the stability of the stability of the tide gauges. At Khepupara, the tide gauge location has been shifted multiple times and corresponds to changes in rates of apparent relative sea level rise at the tide gauge.

Figure 2.8 shows a summary of the subsidence rates obtained so far. Sites in the northwest of Bangladesh at Rajshahi (RAJS) and Madhupur (MPUR) yield low subsidence rates of -1.7 and -0.5 mm/y. These sites are located NW of the hinge zone where the total sediment thicknesses are much less than beneath the deep Bengal Basin. Two sites in Dhaka (DHAK and WDBG) have sufficient data to estimate subsidence rates. Both sites are near the center of the cone of withdrawal from

Table 2.9: GPS Installations

SITE NAME	Polder #	Location Description	Latitude	Longitude	Date Installed	Subsidence Rate (mm/y)
SNT1	35/1	Sonatola primary school	22.2522	89.8050	7/20/2019	new
SNT2	35/1	Field near SET	22.2556	89.8056	7/20/2019	new
JRSN	14/1	Jorshing primary School	22.4982	89.2301	7/24/2019	new
BNTL	7/2	Baintala primary school	22.2480	89.3444	7/25/2019	new
HRNP		Forest ranger station	21.81642	89.45940	10/21/2012	-6.6
PD32	32	Gunari High school	22.50460	89.43589	10/20/2012	-6.8
KHL2		Khulna University	22.80217	89.53273	2/06/2014	-5.1
PUST	43/2	Patuakhali Science and Technology University	22.46513	90.38339	5/24/2003	-3.3
KHEP	48	radar station (Met Dept)	21.98668	90.21968	10/19/2012	-2.7



groundwater abstraction in Dhaka. They yield similar subsidence rates of -10.9 and -12.4 mm/y. In the SW delta field area, the eastern sites (PUST -3.3 mm/y and KHEP -2.7 mm/y) yield rates similar to the long-term rates found by Grall et al., (2018).

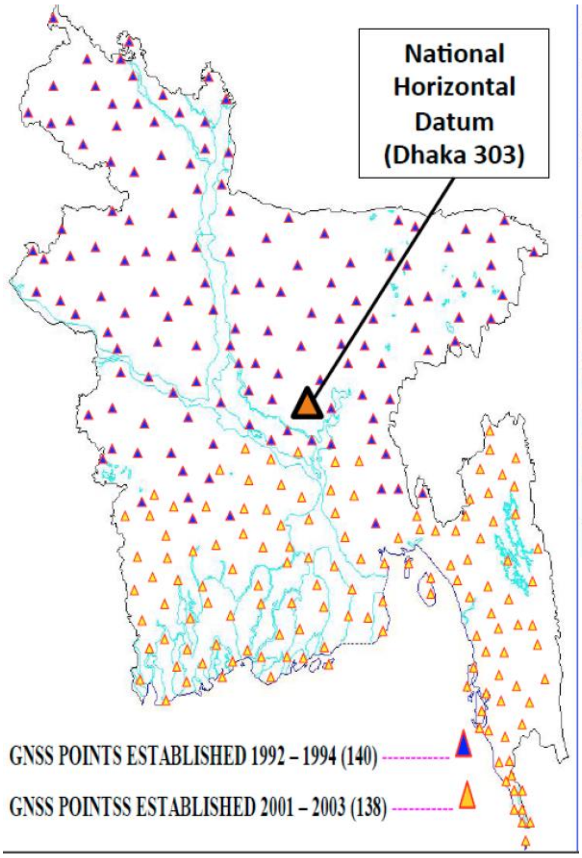
Subsidence estimates from two historic sites from 300-400 years ago also yield subsidence estimates similar to Grall et al. (2018) at 3.5 and 4.1 mm/y. However, the GPS sites in the western coastal zone (KHUL/KHL2 -5.1 mm/y, PD32 -6.8 mm/y, HRNP -6.6 mm/y) yield rates 2-3 mm/y greater. We believe that this is due to the muddier sediments in the western part of the delta that are more susceptible to shallow compaction.

Figure 2.8: *Map of SW Bangladesh showing subsidence rates obtained from GPS and historic sites.*
Maroon squares: GPS sites installed in 2003;
Large red circles: GPS sites installed from 2007-2012;
Small red circles: new sites installed in 2019.
Yellow stars: historic sites analysed for subsidence.

2.4.2 Objectives of the Survey

The continuous GPS sites, while providing excellent data on the subsidence rates in Bangladesh, are sparse and do not enable us to sufficiently map out the spatial variability of the rates. However, the Survey of Bangladesh, in conjunction with JICA established geodetic monuments throughout Bangladesh (Fig. 2.9). Sites in southwestern Bangladesh were primarily installed in 2001-2. They were surveyed with a Leica GPS system for 4 hours in 2002. Some of the sites were resurveyed in 2010/2011. The sites are15-30 km apart with a total of ~55 sites in southwestern Bangladesh providing excellent coverage of the region for densifying the subsidence map. The time span between the initial measurements and now is ~18 years. While sites occupied only at the start and end of that time span will not yield subsidence rates as accurate as the continuous sites, the density of the sites will allow patterns of subsidence to be better discerned.

Our plan is therefore to visit all of the sites and remeasure the elevation with GPS occupations of 24 hours or longer to maximize the precision of the measurements. We expect, and found, that some of the sites are disturbed and no longer viable, while others have extensive tree cover that impedes accurate GPS reading. However, most of the sites are still viable and will yield an excellent data set to densify the GPS subsidence rate measurements.



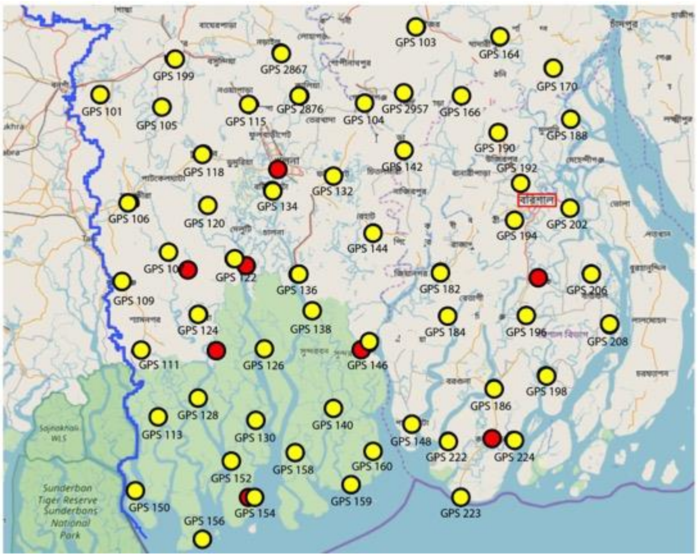


Figure 2.9: Map on the left shows the position of the 278 geodetic monuments installed by the SoB. The map above is a close up of the field area showing the 55 monuments targets for reoccupation with yellow circles. The red circles are the positions of our existing continuous GPS installations.

2.4.3 Field Survey

The field survey is taking place in several stages. In the first stage from January 3-January 11, We had a large team travel to Barisal University to occupy stations and provide training for Hasnat Jaman and his students, Nahin Rezwan,and Saiful Islam, at Barisal University. The international members of the team were Céline Grall and Michael Steckler. We had two surveying experts, Ershadal Mondal of SoB and Muktidir Sober of IWM. Shaikh Nahiduzzaman and Salam Sikder of IWM alternated as members of the project. Masud Rana, a Dhaka University student working on the GPS and RSET data from the project also participated. For equipment, Steckler brought 3 GPS survey systems (GPS receiver and antenna, tripod and tribrach/optical plummet, solar panel and solar power controller) from UNAVCO in the U.S. Dhaka University contributed 2 GPS survey systems, which are generally used for monitoring subsidence around Dhaka. IWM and Sob each contributed one GPS system (Fig 2.10A). However, the SoB system uses rechargeable batteries that need to be swapped every 3-4 hours, so that it was not practical to use their GPS for the 24 hour observations. The left us with 6 usuable GPS systems.

On the first day, we tested all of the equipment as Barisal University and provided initial training to Barisal University students. A critical component of the measurements is setting up the tripod and tribrach directly over the monument measurement point (Fig. 2.10B) and levelling it. Getting the tripod and tribrach both level and over the measurement point is an iterative process that can take some time (Fig. 2.10C). Mondal and Sober provided their expert experience in efficiently setting up the tripod and tribrach. After that, GPS antenna is attached and its recording and power systems set up (Fig. 2.10D). Then, the slant height of antenna above the point must be accurately measured in order to be able to obtain the elevation of the monument.

Following training, we purchased final supplies including batteries and material for fencing to protect each site. We then installed one site on the first day. At that site, material excavated for the construction of a new school building buried the geodetic monument. However, with the help of the local people, we were able to find and uncover it, and make our first measurement. Over the following days, we were able to install 2-3 GPS systems each day. The next day, we would set up 2-3 new sites and then return to the previous day's sites. On the return, we would confirm the system was still level and centred, the antenna properly oriented north and remeasure the slant height. The sites would then be disassembled and packed back up.

Initially, the entire team went to each site. As we became more experienced, we began to split into separate groups. Initially one group would go to pick up a previous day's site while the other continued the set up of the last site. Later, we separated and had each

Figure 2.10: ***A).*** *Monument GPS 198 was badly tilted and in the river.* ***B)*** *Example of a teller monument requiring a different tripod. The blocked sky view due to the building suggests that levelling to the monument would be best.* ***C)*** *Monument GPS 223 was surrounded by a squatter's home. However, with trimming trees and lowering the roof, we were able to obtain good measurements.* ***D)*** *Sober holds the survey rod while the IWM surveyor conducts a levelling line between the monument and the GPS system in the open field.*

*Figure 2.11: **A).** The suite of surveying equipment laid out in from of one of our vans and driver. **B)** close up of the buried monument at site 202. The brass pin with and X marking the measurement point is visible in the center of the concrete monument. **C)** Mondal and Sober using the tribrach and optical plummet on the tripod to center and level the antenna monument. **D)** Masud and Hasnat next to a competed station. The still open box holds the GPS receiver and power supply equipment. The solar panel is next to it, and everything is surrounded by a fence to keep the site from being disturbed.*

group deploy and/or pick up sites. Still, we had a number of long days completing our tasks due to traffic and ferry delays, not arriving at our hotels to after 10 pm or in one case almost midnight. For most of the time, we worked out of a base in Barisal. For sites farther south, we shifted to staying in Kuakata for two nights before returning to Barisal.

Most of the sites were reachable by our vans. For some sites, we needed to use country boats, autorickshaws, lagunas, bicycle vans and walking to get to them. During this initial phase, we visited 18 sites. We were able to make measurements at 15 of them. One site (GPS 198) was found tilted and in the river (Fig. 2.11A). One site (GPS 196) had a different taller monument that needs a special tripod (Fig. 2.11B). The SoB has this type of tripod and we will borrow one from them. One site was found in a pond of raw sewage (GPS 222), so no measurements were made. A number of sites required cutting or trimming of tree branches or whole trees. At one site, a squatter had built a home around the site, but with trimming branches and lowering his roof, we were able to use the sites (GPS 223; Fig. 2.11C). At site GPS 166, the tree cover was such that the measurements are not good. At another tree-covered site, we were able to arrange for an IWM surveyor to come the next day. We set up the GPS in an open field with a temporary mark. Then the surveyor was able to level between the monument and the temporary mark to obtain the difference in elevation to ±1 mm (Fig. 2.11D). With the completion of the 18 sites, most of us returned to Dhaka, together with the SoB and IWM equipment. All the monuments near Barisal had been occupied. Céline Grall stayed for a few more days, then joined me in Dhaka. While I returned to the U.S., Dr. Grall upon completion of her meetings in Dhaka rejoined Hasnat and his students for further measurements. On her return, they shifted to Khulna as a base and continued the survey. 21 sites were visited. They collected new GPS measurements from 12 sites. At one site (GPS 109) only a small amount of data was collected so the measurement needs to be redone. Two site had tall monuments (GPS 199 and GPS 2876) and need a different tripod. Five sites had obstructed views and need a levelling survey similar to the one done at GPS 206. One site was buried and could now be found. Three more sites need to be done by car and 13 site are in or near the Sundarbans and require a boat for access.

2.4.5 Completion of the Survey

If they have not already done so, the Barisal University team will survey site GPS 182, GPS 184 and GPS 148 by car. The sites that require levelling need a surveyor from IWM to accompany the team. The 3 sites with a tall monument that require a small tripod can also be done using levelling. One of the two sites we encountered with a poor sky view (GPS 188) can also be redone using levelling. However, there is no open field near GPS 166. GPS 109 and GPS 2867 had poor data recovery and should be redone. If a surveyor can join the team, these can be done during the last week of February.

Thirteen sites are best accessed by boat. Most of these sites are in the Sundarbans at Forestry Stations. A surveyor accompanying the team would be beneficial as we do not know whether they will have clear sky views. Based on Google Earth imagery, at least a couple of sites have been eroded by the shifting tidal channels. An ideal time for this work will be the first two weeks of March, 2020. I need to collect and return the 3 GPS systems that I borrowed from UNAVCO in the U.S. when I come to Bangladesh in March. If any of the work remains to be done after that time, another field expedition will need to be scheduled for the Fall.

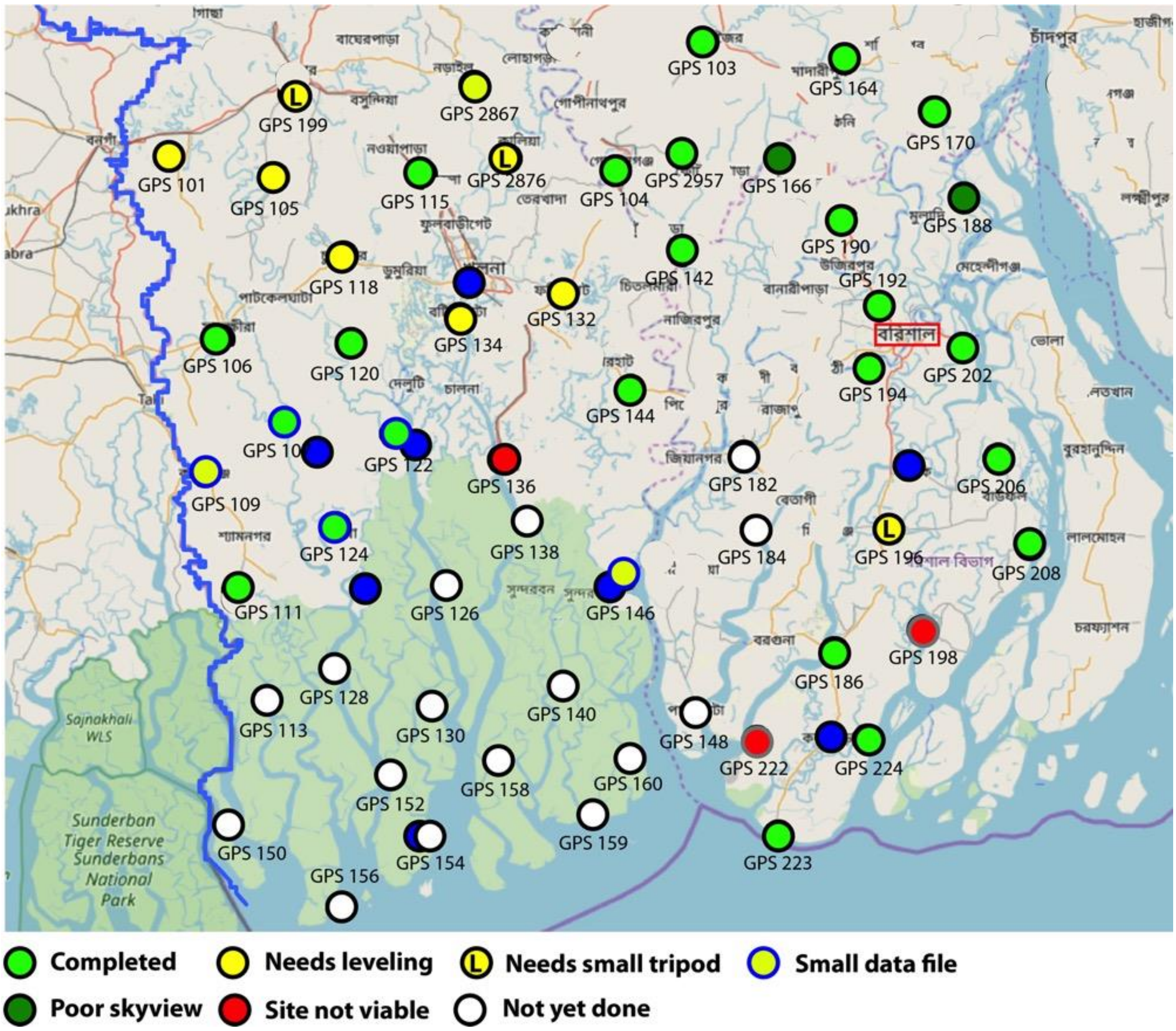


Figure 2.12: GPS Locations

2.4.6 Processing of the Data

We have copies of the original 2002 surveys and the GPS antenna-monument height offsets. We have requested that the SoB provide the GPS measurements that took place in 2010/2011 at some of the monuments. These additional data will help confirm that the subsidence is linear and improve the subsidence estimates. Preliminary examination of the data has confirmed that almost all of the data is of high quality. We have engaged Dhiman Mondal, a GPS processing expert at the Haystack Observatory of MIT to lead the processing team. In addition, Bar Oryan, a graduate student at Lamont, Hasnat Jaman at Barisal University and his students, and Masud Rana at DU will also participate in the processing. The processing will be done using both GAMIT and GYPSY software.

In order to obtain accurate estimates of the subsidence, the data must be corrected for the large seasonal vertical motions in Bangladesh. These reach up to 5-6 cm in parts of Bangladesh, although they are smaller, 2-3 cm, neat the coast. These fluctuations are due to elastic loading by the weight of the groundwater and surface water that accumulates during the monsoon. While they can be roughly estimated, accurate values require modelling of the water loading. This can be done using water level data from the BWDB. We have such data for 2002-2014. However, more recent data spanning the period of observations is necessary. Syed Shamsil Arefin at the Project Office has been assigned to obtain this data

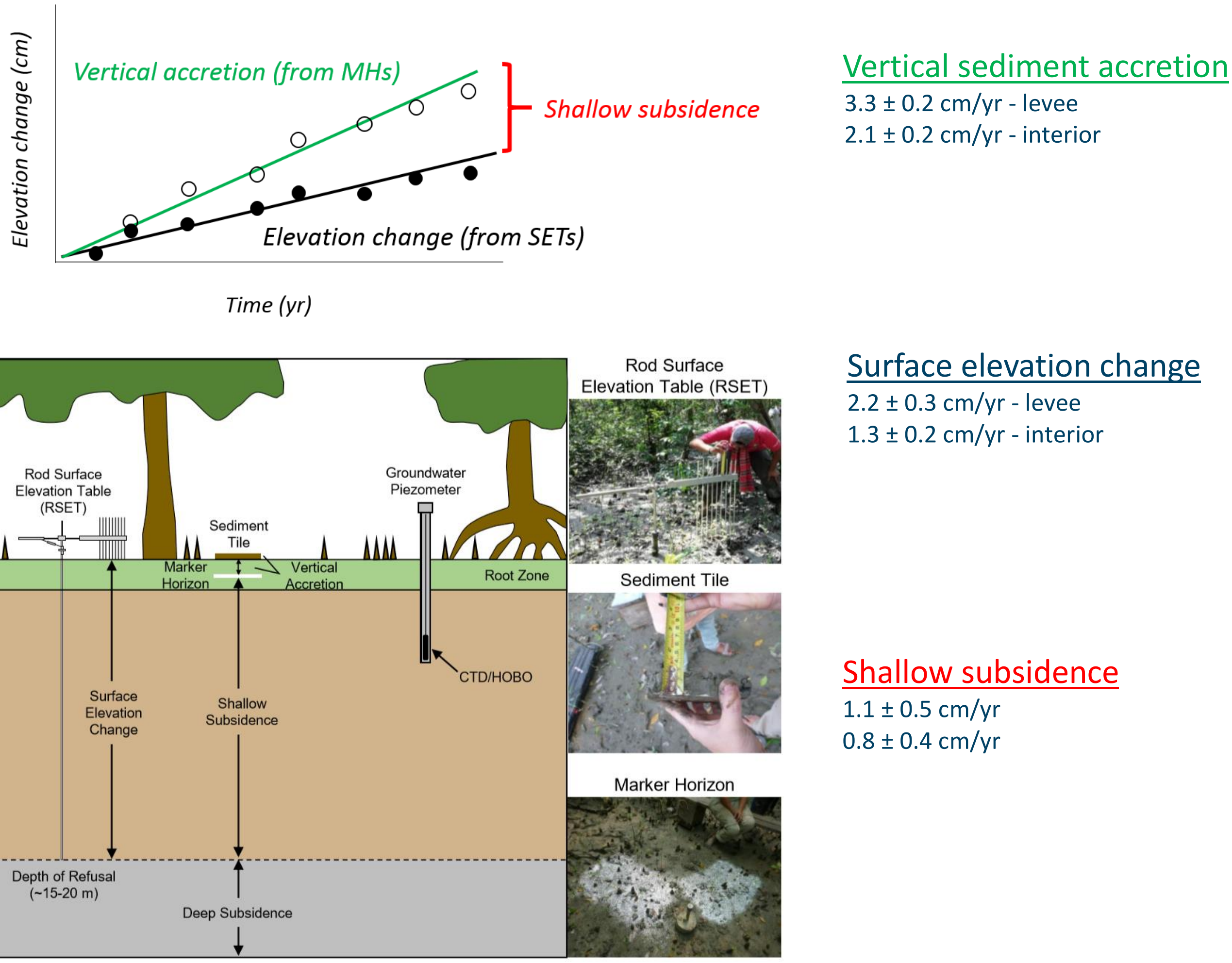


Figure 2.13: Surface Elevation Tables – measuring sedimentation and shallow subsidence

3 CONTINUING DEVELOPMENT OF THE COASTAL DATABASE

Collecting Existing Data

3.1 Introduction

Significant progress was made during this Quarter in developing an Interactive Geo-Database for the Coastal Zone.

Several consultations have been carried out with project stakeholders to determine the requirements of the current and future users of the database. As the database was to be transferred and installed at the BWDB at the closure of the study, close consultations were carried out with the database administrators at the BWDB to ensure that there was software and structural compatibility between databases.

A Committee has been appointed by the Director General of BWDB to ensure that the database would satisfy all the software and licencing requirements in the BWDB, and in the longer term be able to satisfy the relevant standards promulgated by the Government of Bangladesh.

There are several systems and database are running in BWDB central server**.** The following similar systems are reviewed and analysed in order to develop the proposed Polder database.

3.2 Data Collection

Data collection is one of the major tasks of the project, most of the data were utilized from different secondary sources such as BWDB, WARPO, BMD, GSB, BBS, IWM and SoB. The Long-term project has itself been collecting conducting field level survey to collect different types related data. The Land use, River erosion and settlement data have been extracted from Satellite images using suitable image classification methods

3.3 Data Review, Validation and Data Processing

There are 66 numbers of layers/datasets have been identified and has been collecting and processing for developing the database. Most of them have been processed and uploaded into the database. Few of them yet to be collected from relevant sources. Following table illustrates the overall status of Data Processing, data upload in IGDCZ database.

Table 3.1: Status of Datasets/Layer Preparation

Category No	General Category	Layer No	Layers	Data Processed (√/X)	Data Uploaded in Database (√/X)	Source	Progress (%)
1	General Admin	1	o Division	√	√	IWM	100
		2	o District	√	√	IWM	100
		3	o Upazila	√	√	WARPO	100
		4	o Union	√	√	BBS	100
2	BWDB Field Operation	5	o Zone	√	X	BWDB	100
		6	o Circle	√	X	BWDB	100
		7	o Division	√	X	BWDB	100
3	Natural	8	o Rivers	√	√	WARPO & IWM	100
		9	o Wetlands and water bodies	√	√	Haor	100
		10	o Topography (DEM)	√	√	CPWF	100
		11	o Average Ground Height by polder	√	X	CEIP	100
4	Communications	12	o Roads, Bridge & Culverts	√	√	RHD & LGED	60
		13	o Inland waterways	√	X	BIWTA	100
5	Environmental	14	o Ecology	X	X	Long-Term	
		15	o Bio-diversity	√	X	Long-Term	
		16	o Forestry	√	√	AEZ Map	100
		17	o Aquatic, Fish (open & Culture)	X	X	Long-Term	
		18	o ECA	X	X	Long-Term	

Category No	General Category	Layer No	Layers	Data Processed (√/X)	Data Uploaded in Database (√/X)	Source	Progress (%)
6	Morphological	19	o River erosion	X	X	Satellite Image	
		20	o Coastal Erosion	X	X	Satellite Image	
		21	o River Sediment	√	X	CEIP	100
		22	o Bathymetry (Coastal and River)	√	√	CEIP	50
7	Hydro-meteorological	23	o Surface Water level	√	√	BWDB & Long Term	80
		24	o River discharge-MDD	√	√	BWDB	80
		25	o River discharge	√	√	BWDB	80
		26	o Ground water levels	√	√	BWDB & Project	80
		27	o Borehole lithology	√	√	BWDB	100
		28	o Rainfall	√	√	BWDB & Project	80
		29	o Evapotranspiration	√	X	BWDB	
		30	o Cyclone Track	√	√	IWM	100
		31	o Humidity	√	X	BWDB	
		32	o Temperature	√	√	BWDB	80
		33	o Surface Water Quality	X	X		
		34	o Groundwater Quality (Arsenic)	√	X	BGS	100
8	Demographic/Socio-economic	35	o Population	√	√	BBS	100
		36	o Literacy	√	X	BBS	
		37	o Health facilities	√	X	a2i	100

Category No	General Category	Layer No	Layers	Data Processed (√/X)	Data Uploaded in Database (√/X)	Source	Progress (%)
		38	o Livelihood and income	X	X	BBS	
		39	o Land use	X	X	Satellite Image	
		40	o Locations of Schools, College, Madrasa	√	X	a2i	100
		41	o Locations of Power Station	X	X	LGED	
		42	o Locations of Warehouse	X	X	LGED	
		43	o Cyclone Shelter	√	X	a2i	100
		44	o Lanch Ghat/Terminal	√	X	BIWTA	100
9	Agriculture	45	o Cropping	X	X	DAE	
		46	o Irrigation	X	X	BADC	
		47	o Production	X	X	DAE	
10	Interventions	48	o Polders	√	√	BWDB	100
		49	o Embankments	√	√	BWDB	100
		50	o Embankments Breach	X	X	BWDB	
		51	o Embankments Type by Chainage	X	X	BWDB	
		52	o Embankment Height (points)	√	√	CEIP	100
		53	o Embankment Cross Section	√	√	CEIP	100
		54	o Hydraulic Structures	√	√	BWDB	100
		55	o Protective works	X	X	BWDB	
		56	o Canals	√	√	BWDB	100

Category No	General Category	Layer No	Layers	Data Processed (√/X)	Data Uploaded in Database (√/X)	Source	Progress (%)
		57	o Calan Cross Section	√	√	CEIP	80
		58	o Settlement	√	√	Satellite Image	100
11	Impacts/Model Results	59	o Flooding and inundation	√	X	IWM	100
		60	o Drought	√	X	BARC	
		61	o Salinity	√	X	BWDB & CEIP	50
		62	o Salinity Surface water	√	√	IWM	80
		63	o Subsidence	X	X	Project	
12	Physiography	64	o Physiographic Unit from AEZ Map	√	X	AEZ Map, SRDI	100
13	Soil	65	o Soil (Texture)	√	√	AEZ map, SRDI	100
15	Geology	66	o Geological Map	X	X	BGS	

3.4 Web GIS based Application Development

A Web GIS based database application entitled "Interactive Geodatabase for Coastal Zone (IGDCZ)" is under development stage. A full-scale development of this application is under developing stage and 40% progress which has been achieved during the reporting period and overall this progress is 65%. Subsequently, testing and debugging tasks have been conducted. The URL of IGDCZ application is: https://gis.iwmbd.com/ceip . Following features, tools/modules are being developed with the web application.

- Login User Interface
- Dashboard
- Web GIS Module
- Import & Export Module
- Data Entry Module
- Document Achieve
- Metadata Module and
- others

3.5 Software and Hardware Platform

The IGDCZ Database application uses the development servers at IWM office which will finally be deployed into BWDB Central GIS and Database Server computers. The software and Hardware platforms are:

Table 3.2: Software Platform

Sl. No	Items	Software Description
1	GIS Server	ESRI ArcGIS Server Enterprise Edition
2	Database Server	Oracle 11g Database PostgreSQL for Spatial Database
3	Backend and Frontend tools	Laravel Framework, Java Script, ArcGIS API, Json, Bootstrap, CSS, HTM
4	Web Server	Microsoft IIS/Apache

Table 3.3: Hardware Platform

Sl. No	Items	Software Description
1	Web Server	Standard high-speed Server Computer
2	Database Server	Standard high-speed Server Computer
3	GIS Server	Standard high-speed Server Computer

3.6 User Security

The database and web GIS based application software are secured with user authenticated and password. The final version of the Database application will have a User Administration module through which the System Manager/Database Administrator can provide privileges and permission to the different levels of users in BWDB and relevant agencies and projects. Currently three categories

- Administrator: Administrator/Manager of the application and database
- Valued User: Can read and download data
- General Users: Can read the data & contents only

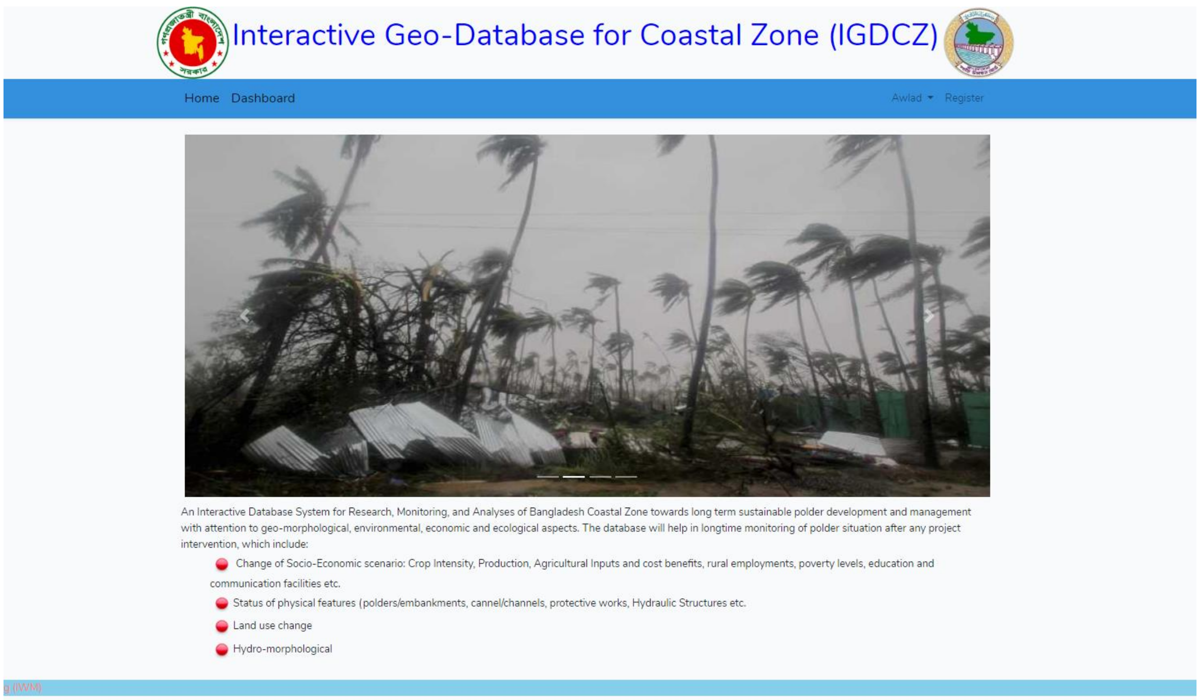


Figure 3.1: Home Page of IGDCZ Application

Figure 3.2: Dashboard

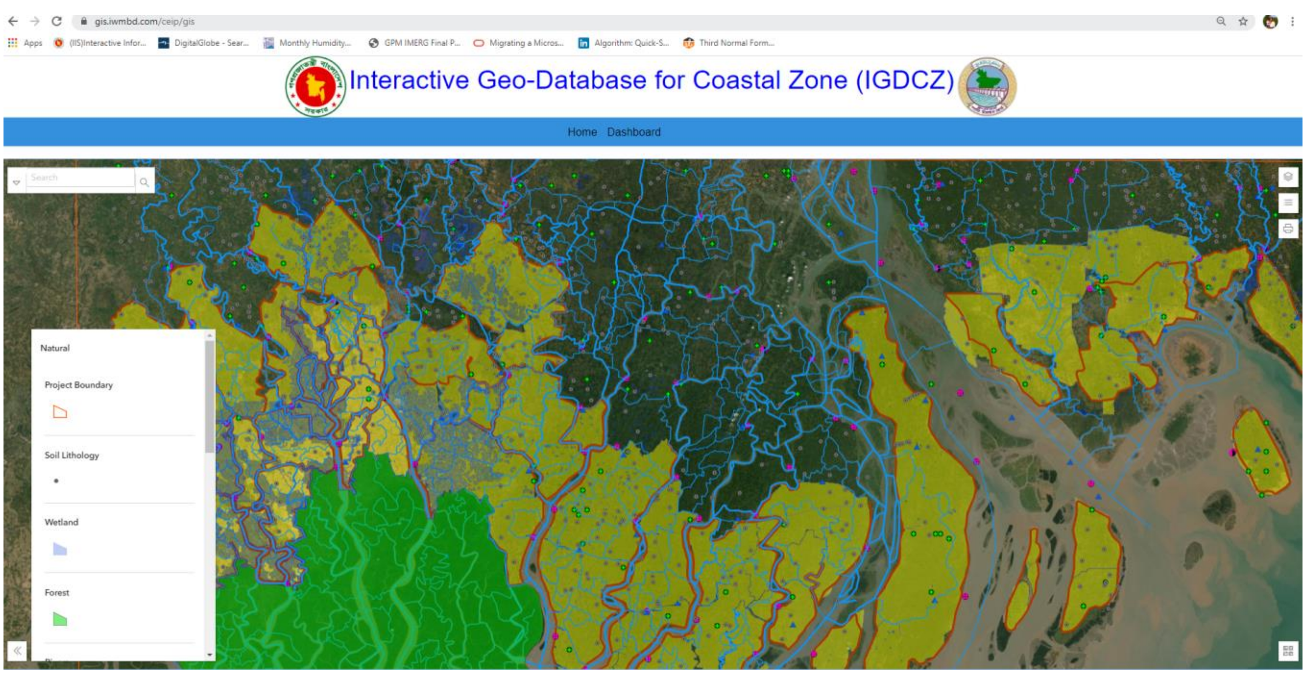


Figure 3.3: Interactive GIS Module

3.7 Workplan

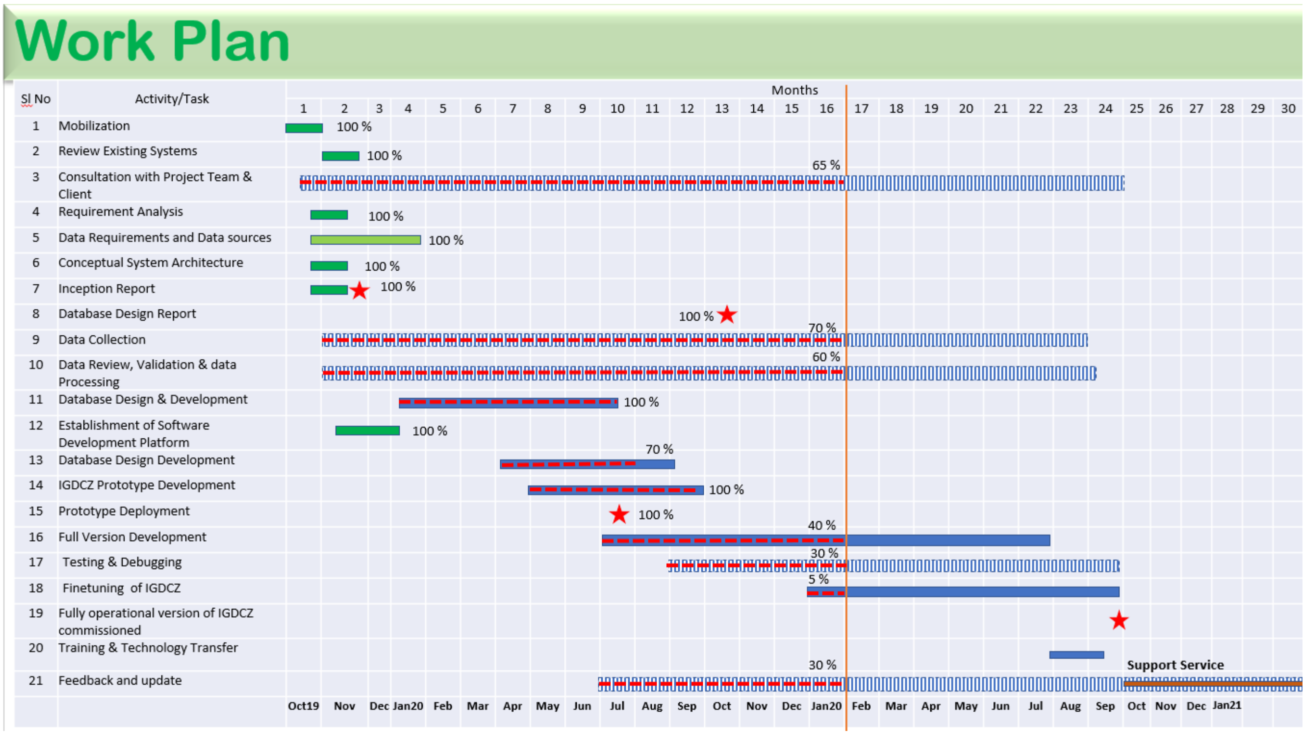


Figure 3.4: Work Plan

3.8 Activity in the Next Quarter

The IGDCZ database is under development stage, the respective datasets are being collected, processed and uploaded into the Geodatabase. The plan for the next quarter is to update the polder database with the following datasets:

- Land use focusing on agricultural including historical and temporal distribution of land use classification with fresh water demand of all types land use categories using Remote Sensing Techniques as indicated in the ToR.
- Erosion and Accession feature layers using Remote Sensing Techniques
- Update the database with Hydrometeorological time series data (remaining data of 2013 to available latest year)
- Update the database with Canal Cross Section data
- Update the database with Embankment Type and Design Parameters
- Other layers/datasets as available.

4 MODELLING LONG TERM PROCESSESS

4.1 Introduction

A very large proportion of the work carried out by the consultant on this project comprises the development and application of many types of mathematical models for predicting the long-term processes (evolution) of the conditions in the Bengal Delta. The evolution of the Bengal Delta under the disturbances imposed upon it by natural processes and by human interventions occur at many different length and time scales.

There are many different types of models, using a variety of formulations and many versions of standard software being used in this study. Table 4.1 Lists the Models that are under development by the project team.

Table 4.1: Models currently under development

	LIST OF MODELLING ACTIVITIES		
	Modelling Activity	Sub description	Scale
A	GBM Basin Model	Hydrotrend	Macro
B	Macro scale River Model	Delft3D Main River system (2D)	Macro
C	Macro scale River Model	Delft3D Main River system (1D)	Macro
D	Pussur Sibsa	Delft3D: Modelling of long term Morphology	Meso
E	Baleswar-Bishkhali Model	Delft3D: Modelling of long term Morphology	Meso
F	Lower Meghna	Delft3D: Modelling of long term Morphology	Meso
G	Sangu	Delft3D: Modelling of long term Morphology	Meso
H	Pussur Sibsa	MIKE21C: Modelling of bank erosion process	Meso
I	Baleswar-Bishkhali Model	MIKE21C: Modelling of bank erosion process	Meso
J	Lower Meghna	MIKE21C: Modelling of bank erosion process	Meso
K	Sangu	MIKE21C: Modelling of bank erosion process	Meso
M	Pussur-Sibsa fine sediment model- ext	Delft3D Fine Sediment (2D/3D)	Meso
N	Pilot TRM Model for Polder 24	MIKE11, MIKE21 AND MIKE FLOOD	Micro
O	Storm Surge Model	Generating Synthetic Storm Events	Bay of Bengal
P	Storm Surge Model	MIKE21FM & CYLONE MODEL	Bay of Bengal
Q	Salinity Model	Delft3D Salinity (2D/3D)	Total Coast

4.2 Macro Scale Models: GBM Basin wide Applications

Table 4.2: Macro Scale Modelling

D-4A-1		**Modelling of the long-term physical processes; Morphology on a macro scale**
	1a	Basin scale modelling (HydroTrend) Products: HydroTrend model, report, data upstream boundary conditions
	1b	MIKE Basin Model of GBM Basin Products: Upstream Boundary Conditions for multiple Scenarios
	1c	Macro scale river modelling (Reinier, Wang) Products: Delft3D-FM 1D model, report, data water/sediment budget
	1d	Macro scale coastal modelling (Dano) Products: Delft3D-FM 2D model, report, data long-term erosion/sedimentation
	2	**Geospatial datasets of main sources and deposits of sediment at present (reference modelling results), including full meta-data restored and archived in Database of BWDB**
	3	**Geospatial datasets of main sources and deposits of sediment for 100 years from present (scenario modelling results), including full meta-data are published on archived in Database of BWDB**
	4	**Technical Report (one report for 4A-1 and 4A-2)** [2)+C44]

4.2.1 The Hydrotrend model

The Hydrotrend model is a model applied to the entire GBM Basin (see Figure 4.1). This is the key that controls all the inputs to the GBM Delta.

A detailed update of progress in this activity will be provided in the next Quarterly Progress Report.

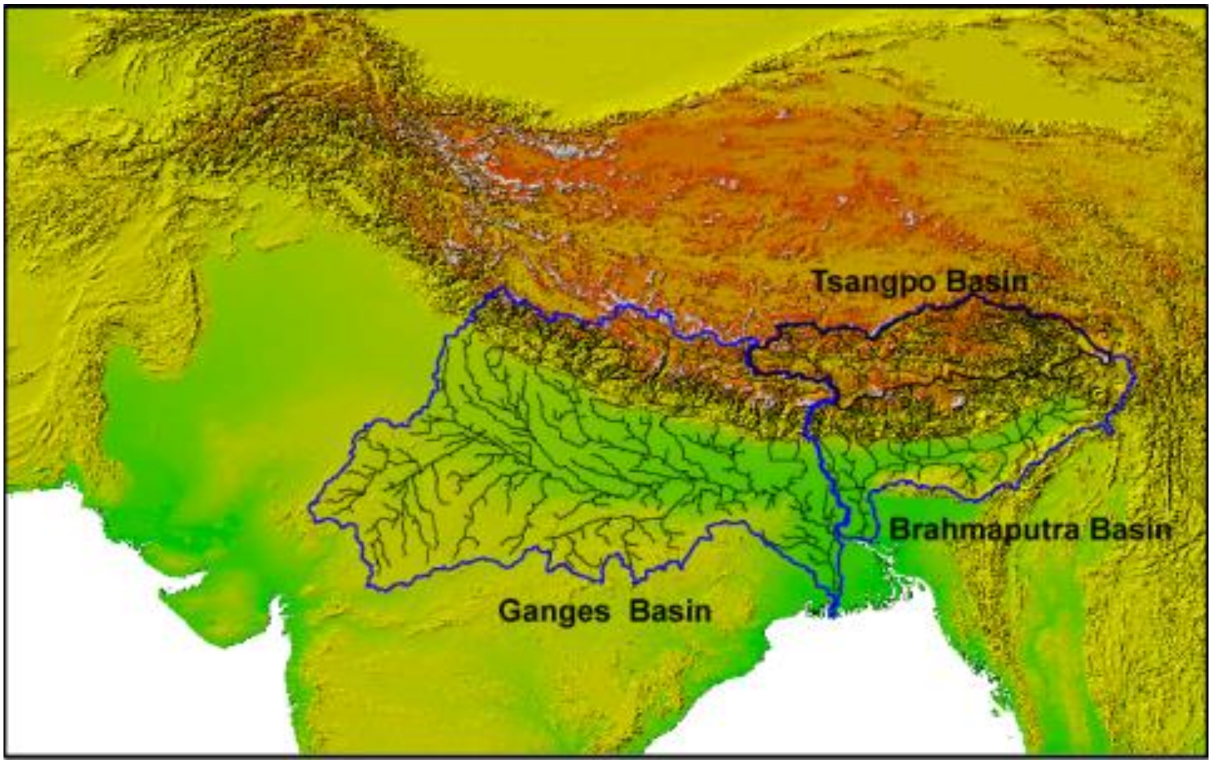


Figure 4.1: Map showing the Ganges and Brahmaputra basins

A list of input data types such as terrain (eg DEM), landuse, precipitation, erosion properties etc.

The main input file (HYDRO.IN) which contains: project title, input–output directory, simulation length, yearly and monthly climate statistics (such as precipitation observed in the basin, average temperature at downstream of the basin, lapse rate etc.), glacier parameters, groundwater parameters and parameters that describe the possible river distributaries;

Hypsometric Input file (HYDRO0.HYPS) which is analysis of the Digital Elevation Model (DEM) of the basin;

Another optional input file (HYDRO.CLIMATE) can be used which contains sequential climate input instead of the statistical realizations of the climate otherwise defined in HYDRO.IN. The sequential climate input minimum–maximum time step ranges from 1-hour to 1-day.

Scenarios we plan to use in the model

- Future with climate change;
- Future with implementation of Indian River Linking Project (IRLP);
- Future with both climate change and implementation of IRLP

Model outputs (eg water and sediment at Hardinge, Bahadurabad etc)

- The outfall of the model domain is at Farakka (not Hardinge bridge) in the Ganges and Bahadurabad in the Brahmaputra River. The model will provide the following outputs for base and future scenarios:
- Water discharge, discharge velocity, width and depth at the river mouth;
- Bed load and the suspended sediment concentrations for each grain size.

4.2.2 Macro Scale Models: Large Rivers System

The macro-scale models will be developed for the major river systems of Bangladesh. These models are divided into two modelling approaches:

1) River branch modelling approach (1D)

- To derive a sediment budget for the Bangladesh Ganges-Brahmaputra-Meghna (GBM) delta
- To assess the effects of changing boundary conditions (climate change, upstream damming) on the sediment budget
- To derive boundary conditions for smaller scale (i.e. meso scale) sub-models

2) Coastal modelling approach (2D)

- Large-scale tidal propagation and flow distribution
- To study coastal hydrodynamics and sediment transport pathways
- Sand and fine sediment distribution
- Pathways for fine sediment
- Morphology of major channels on decadal scales
- To forecast long-term morphological changes for different scenarios
- To derive boundary conditions for meso-scale models

Both the River branch (1D) modelling and Coastal modelling (2D) will be developed using Delft3DFM modelling system.

1) **1D Ganges-Brahmaputra-Meghna macro scale model**

Macro scale 1D river branch modelling will be carried out in two approaches.

a) Modelling with measured river cross section

b) Modelling with schematized river cross section

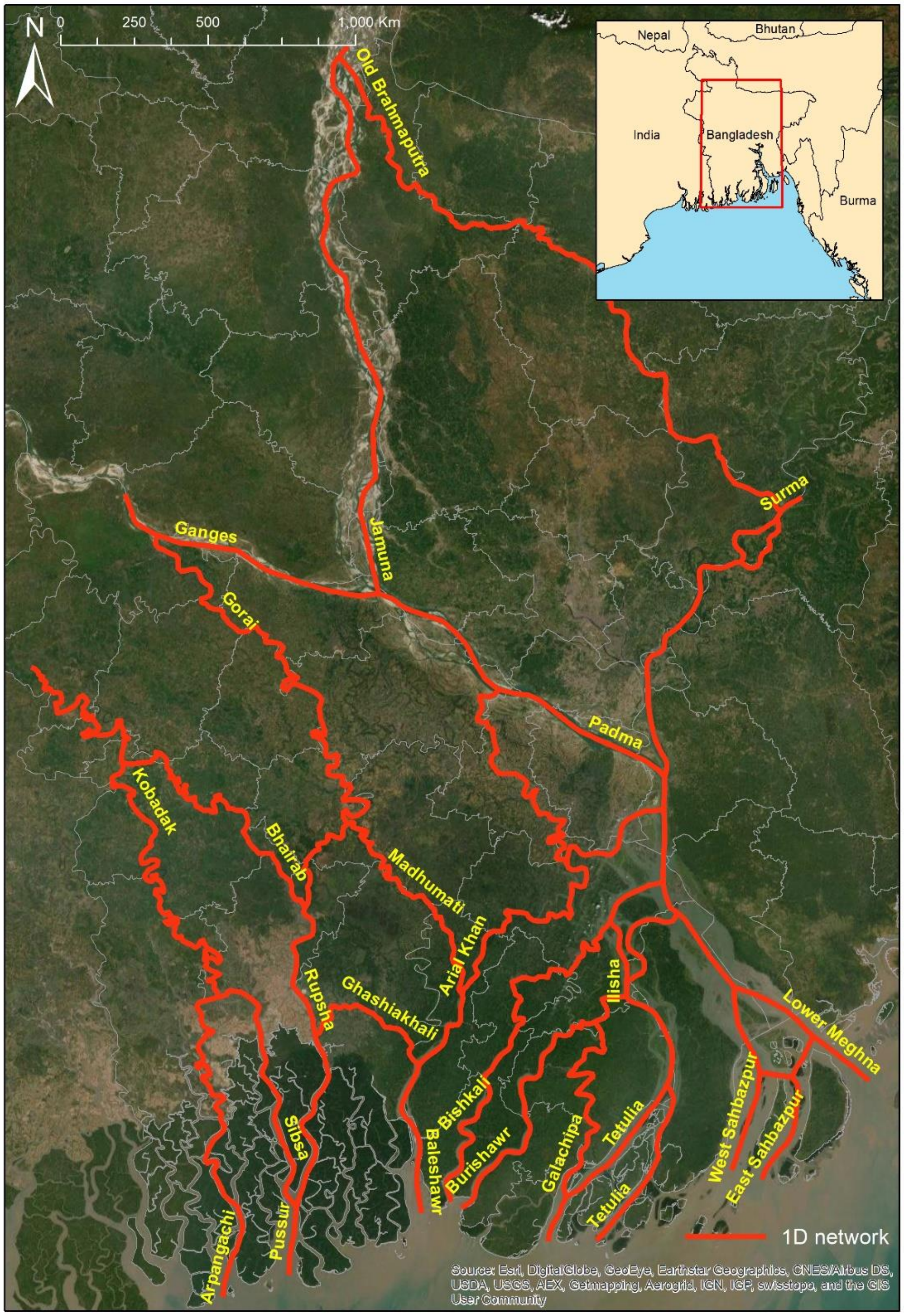


Figure 4.2 River network for the Delft3D-FM 1D model.

Modelling with measured river cross section

The measured cross-sectional profile method uses the observations at strategically chosen locations which are directly imposed on to the model. This type of model set-up is ideal for hydrodynamic modelling as the cross-sectional profiles most closely resemble the morphology of the river at the modelled time period.

The spatial distribution of the bathymetric observations selected to impose on the model are shown in Figure 4.3 and examples of measured cross-section are shown in Figure 4.4.

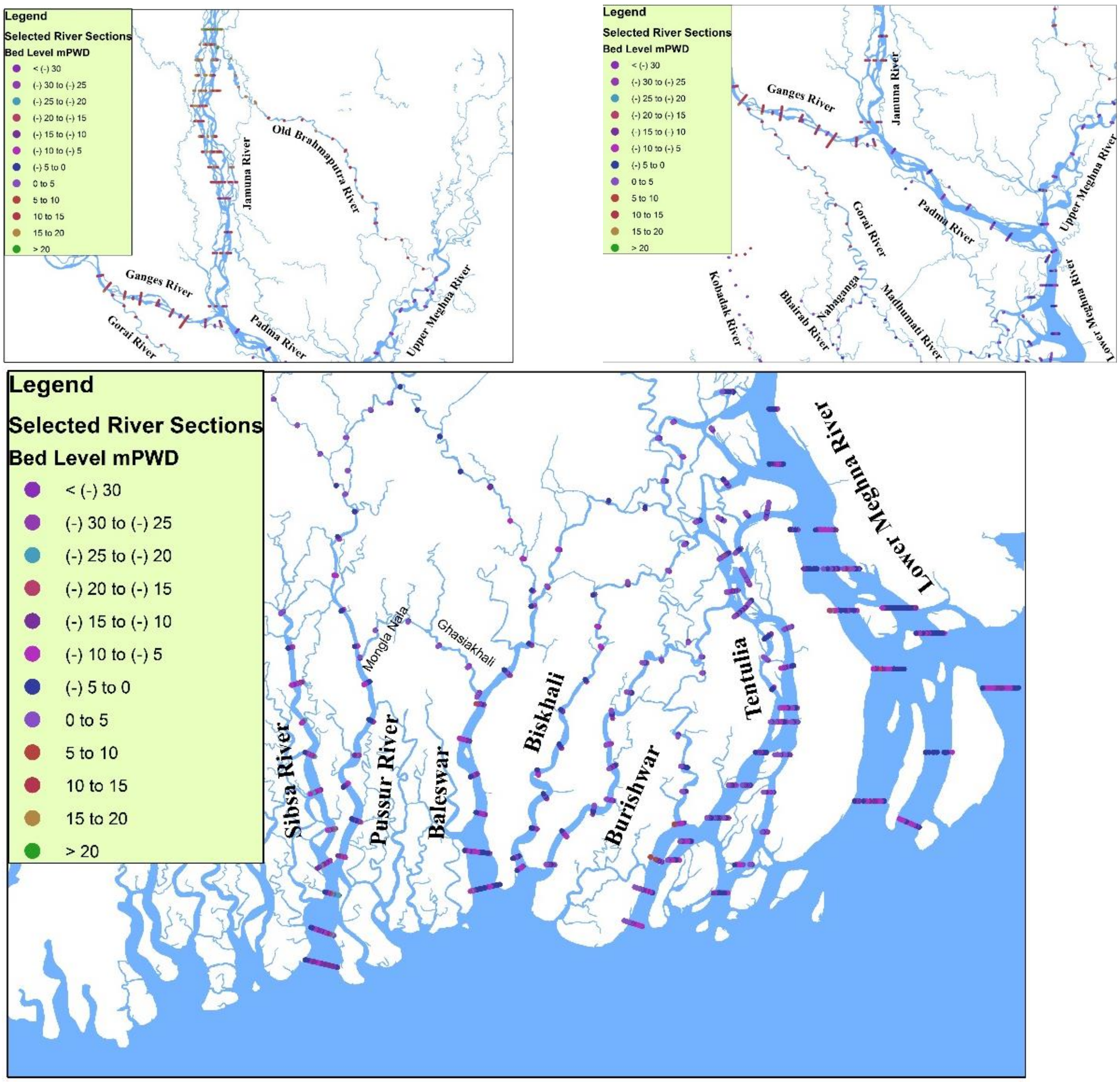


Figure 4.3: Maps showing the selected measured cross sections imposed on the model.

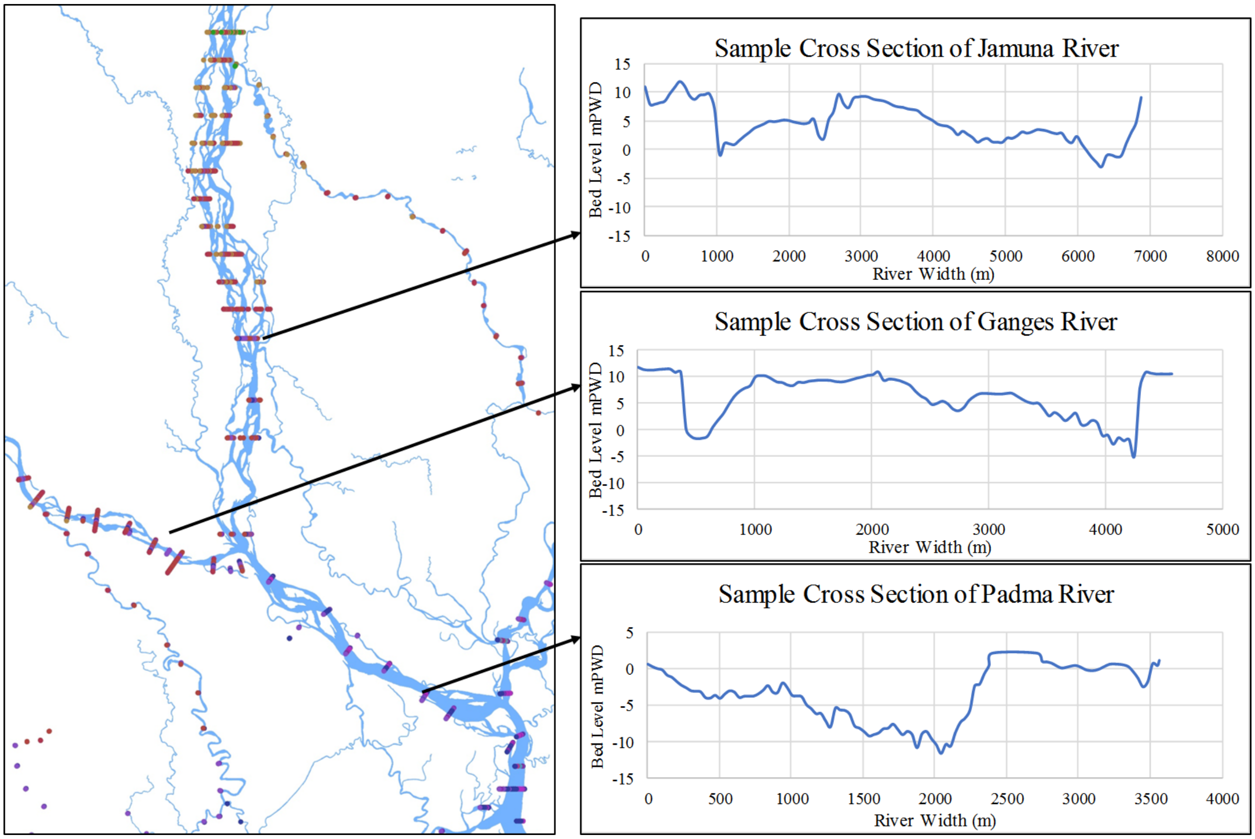


Figure 4.4: Sample cross section of Ganges, Jamuna and Padma river

Modelling with schematized cross sections

The schematized cross-sectional profile method uses a large quantity of bathymetric observations to define the characteristic hypsometry of a specific part of the river system. This type of model set-up is ideal for long-term morphodynamic modelling as the cross-sectional profiles depend less on space- and time dependent variations (e.g. the presence of dunes in one of the datasets)

Schematized profiles are constructed from subsets of the bathymetric dataset, selected by (manually defined) polygons that cover a part of a river branch (Figure 4.5). The subset of the bathymetric dataset is used to calculate:

- The total area covered by the subset of the data
- The length and width of the river covered by the subset of data
- The distribution in elevation (histogram) of the subset of the data

The distribution in elevation is schematized by gridding the bathymetric observations to a uniformly spaced grid covering the polygon. A probability density histogram (Figure 4.6a) is made of the height levels of the gridded observations. A hypsometric curve is established based on the total area of the polygon and the values of the gridded dataset of elevation (Figure 4.6b). With the information on the width of the river section and the hypsometric curve, a characteristic symmetric profile can be established (Figure 4.6c). This cross-sectional profile is defined in x,y,z coordinates and positioned at the net node closest to the centre of the polygon (Figure 4.6d).

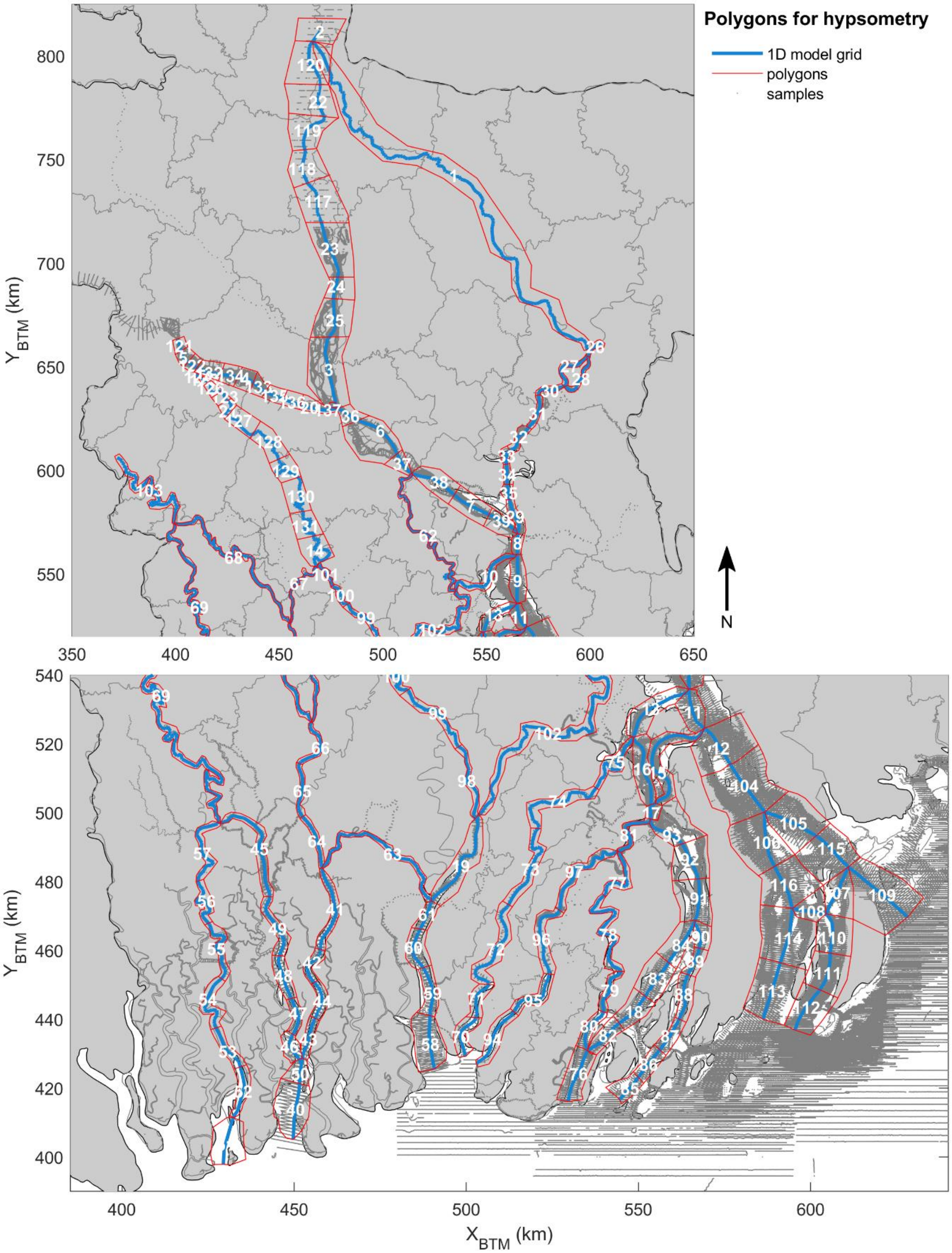


Figure 4.5: Map of the GBM delta with the model network (blue), the topo-bathymetric observations (gray dots), and the polygons (red) defining subareas of the river branches for schematization of the hybrid profiles.

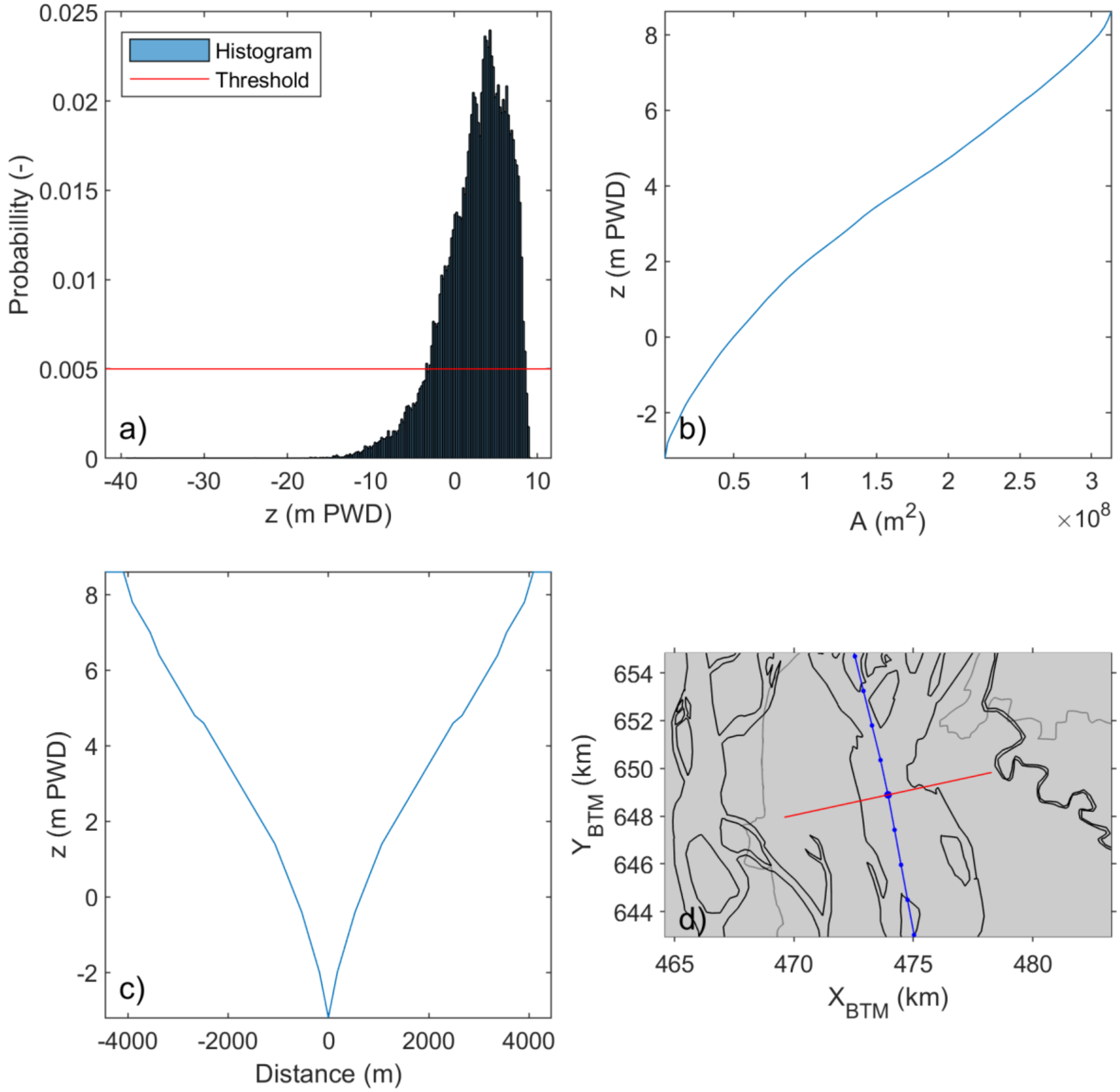


Figure 4.6: Methodology of schematizing cross-sectional profiles, illustrated for the downstream part of the Brahmaputra: a) histogram of the topo-bathymetric observations within the subarea defined by the polygon and probability threshold value chosen for outlier filtering; b) hypsometric curve derived from the histogram and total area derived from a boundary fitted polygon to the considered data, c) schematized cross-sectional profile constructed from the hypsometric curve and the calculated river width; d) positioning of the cross-sections.

4.3 Meso Scale Models for Long Term Morphology

Table 4.3: Meso Scale Modelling for Long Term Morphology

D-4A-2		**Modelling of the long-term physical processes; Morphology on a meso scale**
	1a	Pussur-Sibsa (Delft3D-FM & Delft3D 4)
	1b	Baleshwar (Delft3D-FM)
	1c	Lower Meghna (Delft3D-FM)
	1d	Chittagong (Delft3D-FM)
	2	Geospatial datasets of erosion and sedimentation in the coastal zone stored and archived in Data base
	3	Geospatial datasets of erosion and sedimentation in the coastal zone for possible scenarios 25, 50 and 100 years from now stored and archived in Data base
	4	Technical Report (one report for 4A-1 and 4A-2)

The main objective of this modelling is to develop morphological models for the selected rivers around the polder areas and estimate future long-term morphological changes under different scenarios. The selected meso scale modelling groups are following (Figure 4.7):

Pussur – Sibsa River system (Polder 32 & 33)

Baleswar – Bishkhali River system (Polder 35/1, 39/1, 39/2, 40/1, 40/2, 41 & 42)

Lower Meghna- Tentulia River system (Polder 56/57,55/1,55/2, 55/3 & 59/2)

Sangu River system (Polder 63/1a, 63/1b & 64/1b)

The general approach for this modelling is the following:

- Preliminary study of historical morphological changes in the larger tidal rivers by using available bathymetry data
- Setup and Calibration – Setup, calibrate and validate the model with field measurements and remote sensing data.
- Morphological hindcast – reproduce the morphology from previous different periods.
- Scenario runs - Study future changes in the morphodynamic processes based on possible scenarios.
- Output - Geospatial datasets of erosion and sedimentation in the river system at present for various seasons and for possible scenarios 25, 50 and 100 years from now, for various seasons and circumstances.

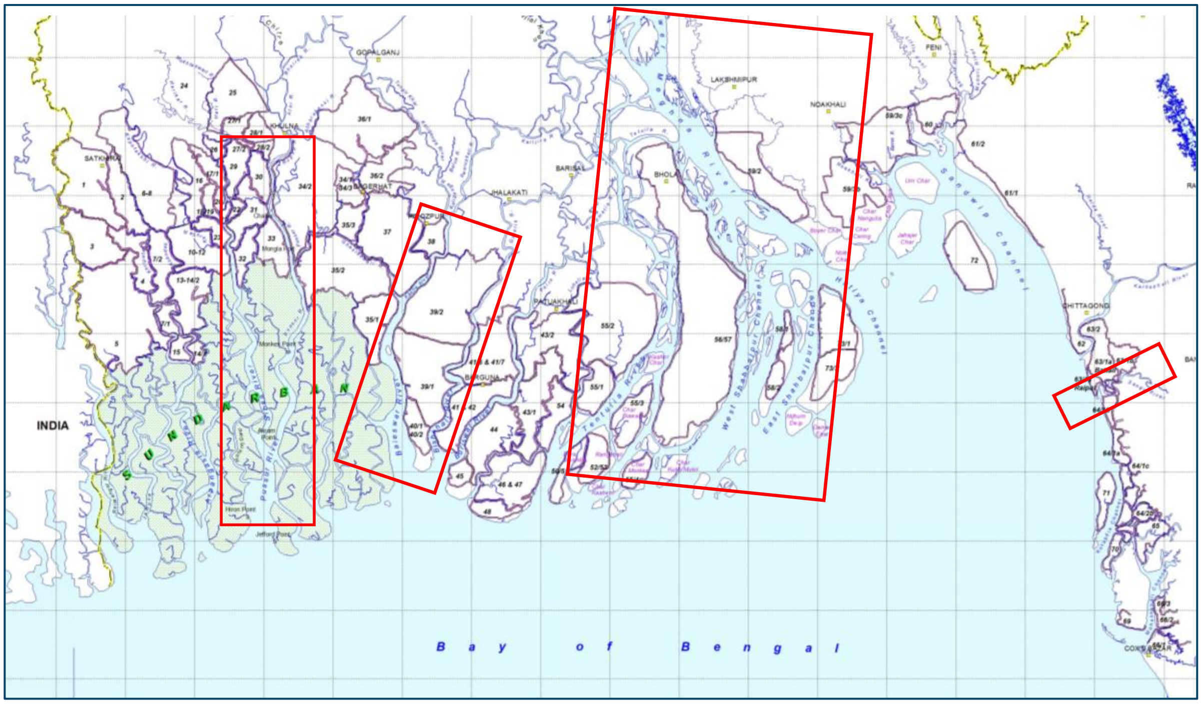


Figure 4.7: Map of meso scale modelling groups for long term morphology

4.3.1 Pussur-Sibsa River system for meso scale modelling for long term morphology

The morphological model development for Sibsa-Pussur river system was carried out for 2011. The Pussur-Sibsa river is cohesive in nature whereas some bed samples at middle of the channel shows non-cohesive sediment. We therefore added two sediment fractions: Sand and Mud.

At first, we tried to setup the model with constant boundary conditions with combined sand and mud, which is shown in Table 4.4. The side channel boundaries were set to zero (no sediment input). However, the definition of the boundary conditions will be improved by applying information from the 1D macro scale model, which will provide a more realistic boundary condition for this model. At present, that model has not been completed yet.

Table 4.4: Sediment concentration boundaries for the morphological model

Boundary	Sand (kg/m^3)	Mud (kg/m^3)
Sibsa (u/s)	0.40	0.45
Pussur (u/s)	0.40	0.45
Heron Point (d/s)	0.50	0.20

The application of the fluff layer concept improved model skill compared to runs without fluff layer, to the extent that SSC levels are within the same order of magnitude. As in the 2D model the observed SSC is presented here as cross-sectionally averaged values. The modelled base SSC levels are similar to observed values. Fine tuning the fluff layer model could probably increase model skill.

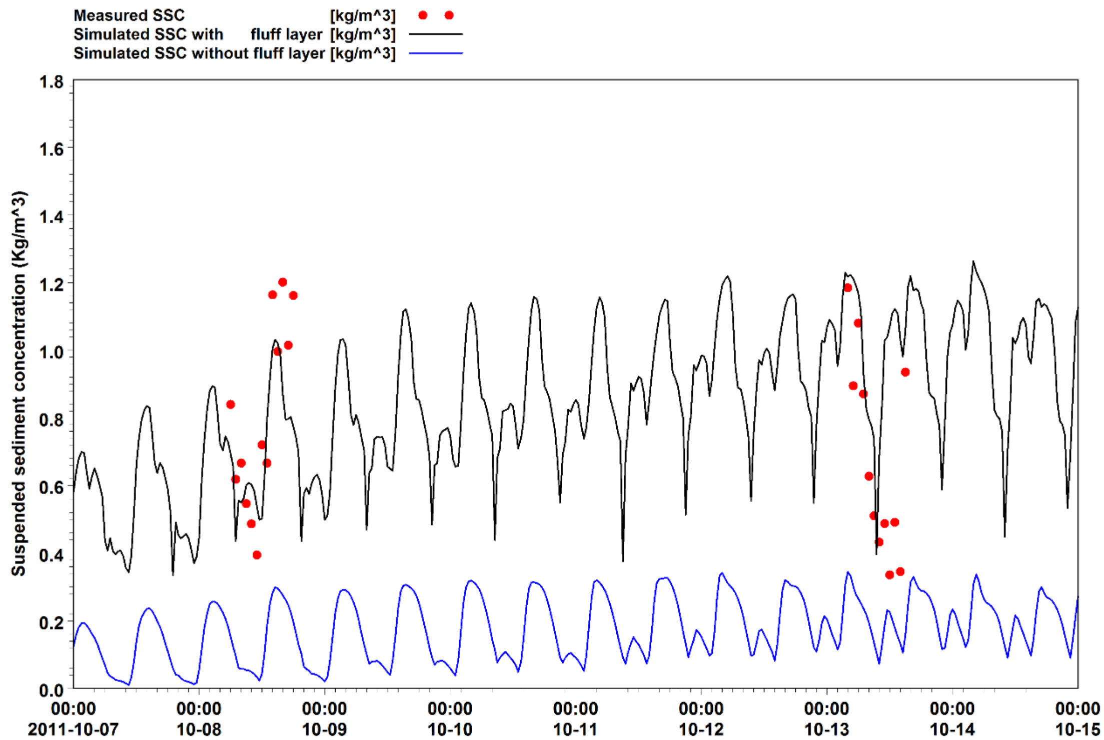


Figure 4.8: Comparison of modelled (with and without fluff layer) and observed Suspended Sediment Concentration at Mongla during monsoon

4.3.2 Baleswar-Bishkhali River system for meso scale modelling for long term morphology

The Hydrodynamic model of Baleswar-Bishkhali river system were calibrated and validated with measure data of year 2011 and 2015. The locations of the field data are shown in Figure 4.9. Water Level and discharge calibration shows good correlation with measured and simulated water level data. The discharge calibration at Charkhali in Baleswar River during dry season are illustrated in Figure 4.10 and Figure 4.11 for spring and neap tide respectively.

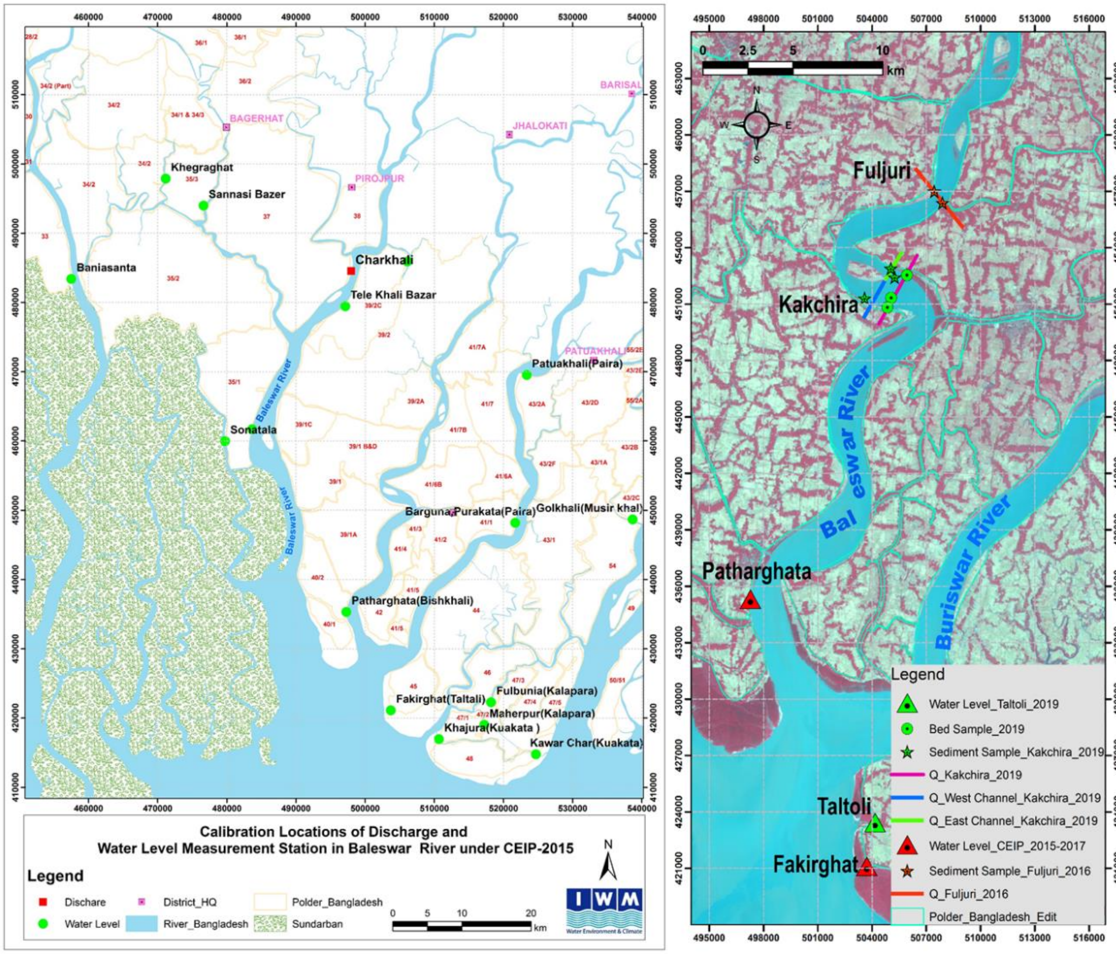


Figure 4.9: Field data collection map for 2015, 2016 and 2019 in Baleswar River

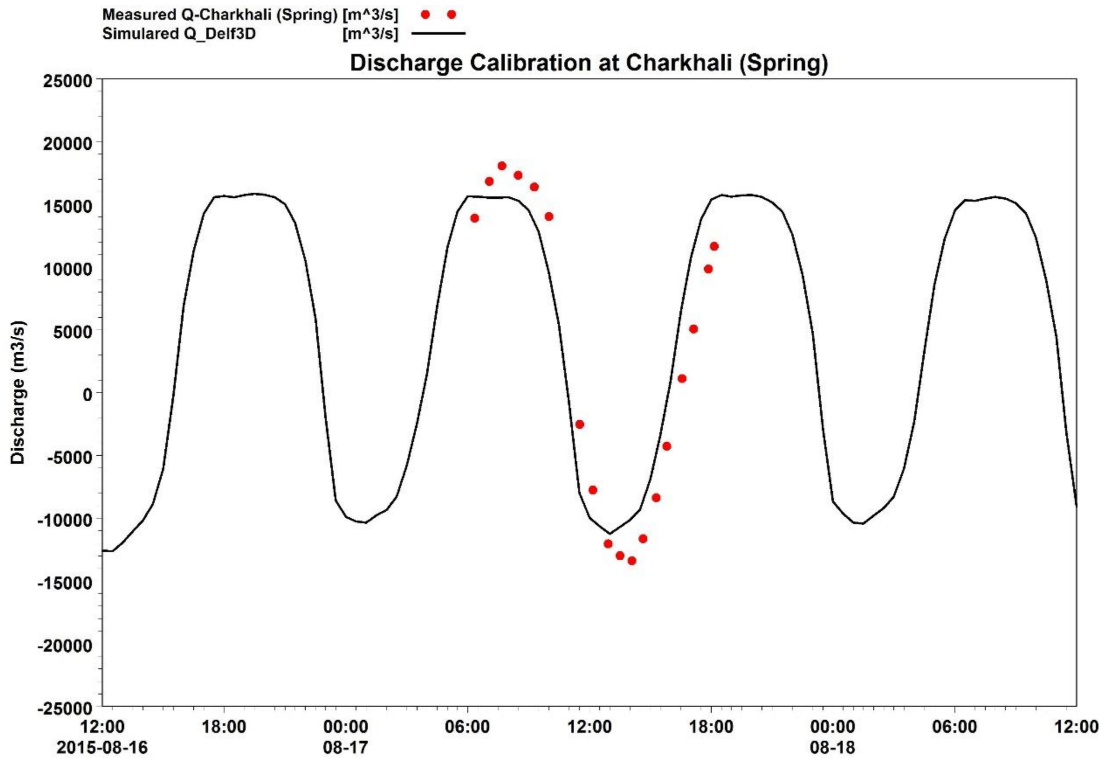


Figure 4.10: Discharge Calibration at Charkhali (spring) in Baleswar River for 2015

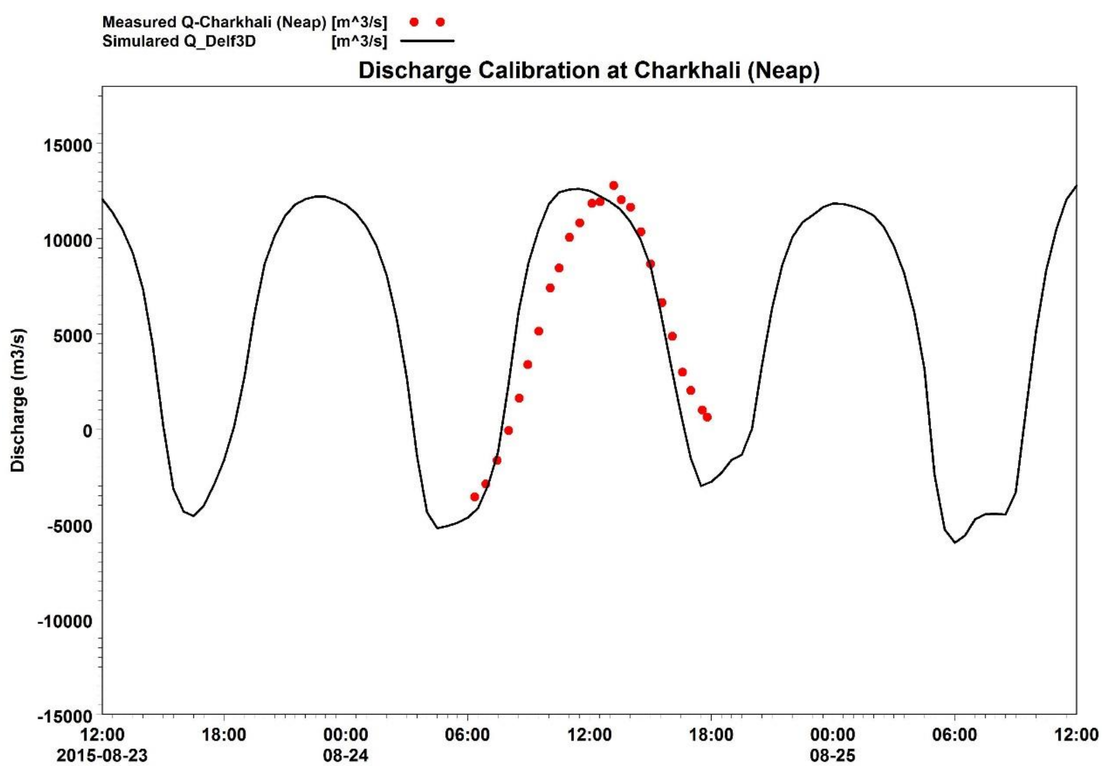


Figure 4.11: Discharge Calibration at Charkhali (Neap) in Baleswar River for 2015

4.3.3 Lower Meghna Estuary for meso scale modelling for long term morphology

The hydrodynamic model of Meghna Estuary Model was calibrated with the field data during 2009 (Figure 4.12) for both dry and monsoon season to make the model performance to a satisfactory level. The water level calibration at Char Langta and discharge calibration at Monpura-Jahajmara in East-Shahbazpur Channel (Jahajmara) during monsoon season are illustrated in Figure 4.13 and Figure 4.14 respectively. Water Level and discharge calibration shows good correlation with measured and simulated water level data with constant roughness (n=.010).

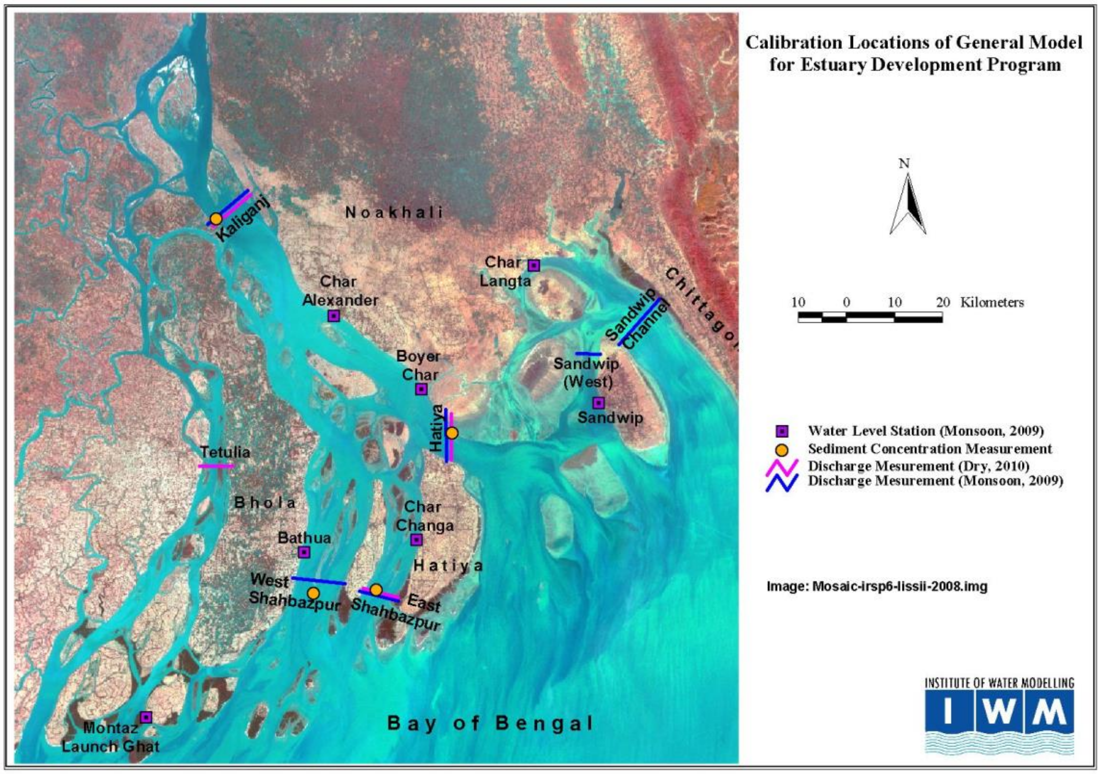


Figure 4.12: Locations for Lower Meghna Estuary meso model during 2009

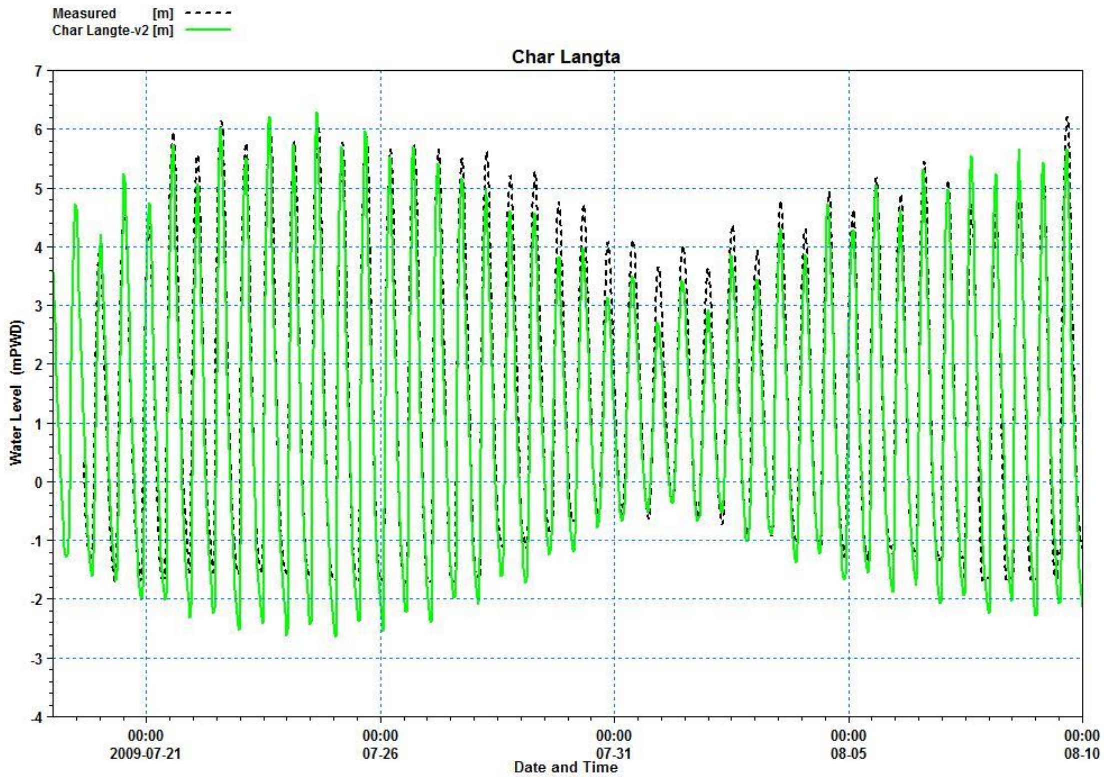


Figure 4.13: Water Level Calibration at Char Langta

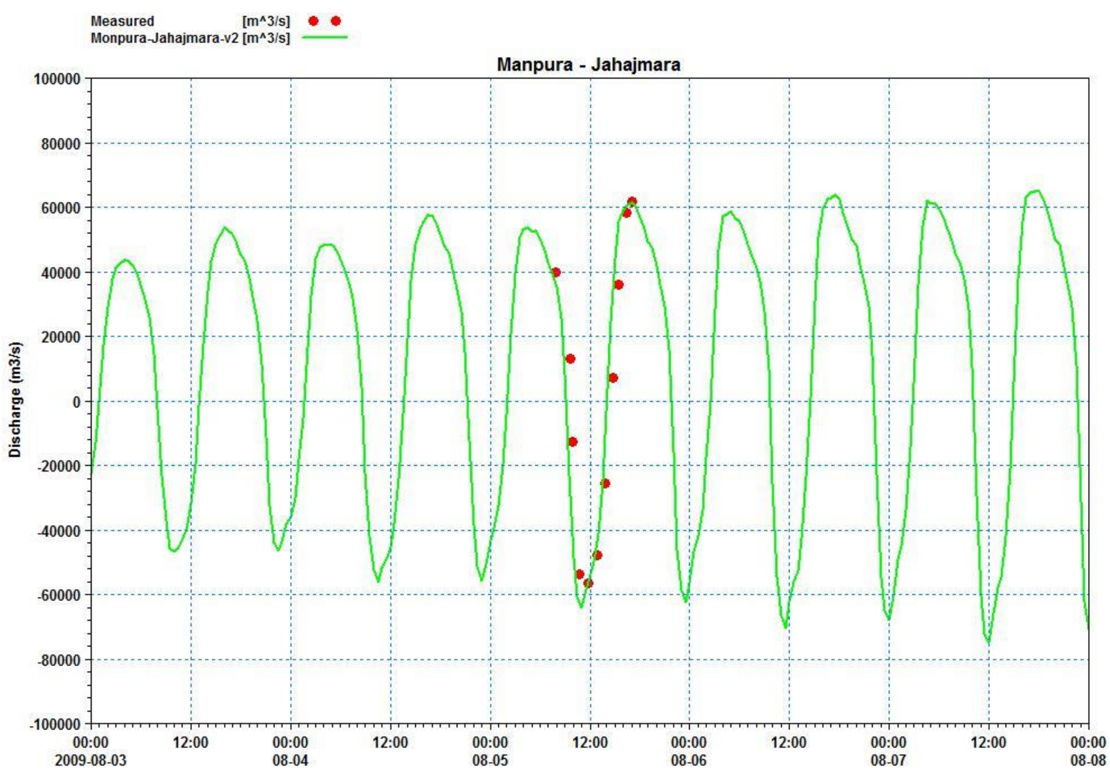


Figure 4.14: Discharge Calibration at Monpura-Jahajmara

4.3.4 Sangu River system for meso scale modelling for long term morphology

The Sangu river is modelled in one numerical grid in a single model. The available 2018 bathymetry data for the upstream part of the river channel was interpolated on the unstructured curvilinear grid and downstream was calculated using FM grid system. Figure 4.15 shows the grid and bathymetry for the Sangu river.

The Sangu model has one upstream boundary and three downstream boundaries. Upstream boundaries were collected from the calibrated and validated Eastern Hilly Regional Model (reference). The downstream boundary conditions are derived from BOB Model. All the boundaries were extracted from the Eastern Hilly Regional Model.

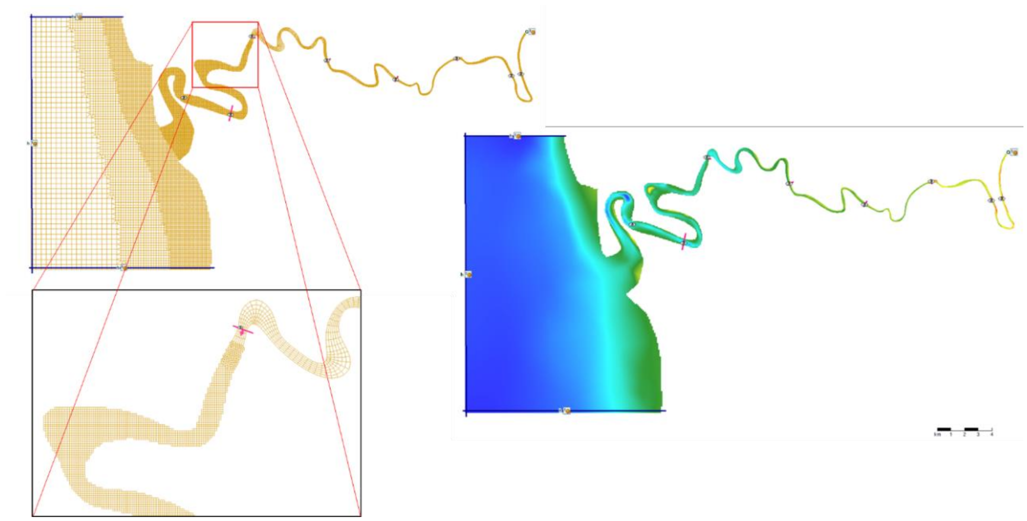


Figure 4.15: Computational mesh and interpolated bathymetry for the Sangu river (2018)

The Delft3D FM sediment transport model calculates transport rates on a flexible mesh (unstructured grid) covering the area of interest on the basis of the hydrodynamic data obtained from a simulation with the Hydrodynamic Module (HD) together with information about the characteristics of the bed material. That is why a well calibrated and validated hydrodynamic model is needed to develop a reliable sediment transport model. The model was calibrated with field data during 2018 in dry season (see Figure 4.16 to Figure 4.19).

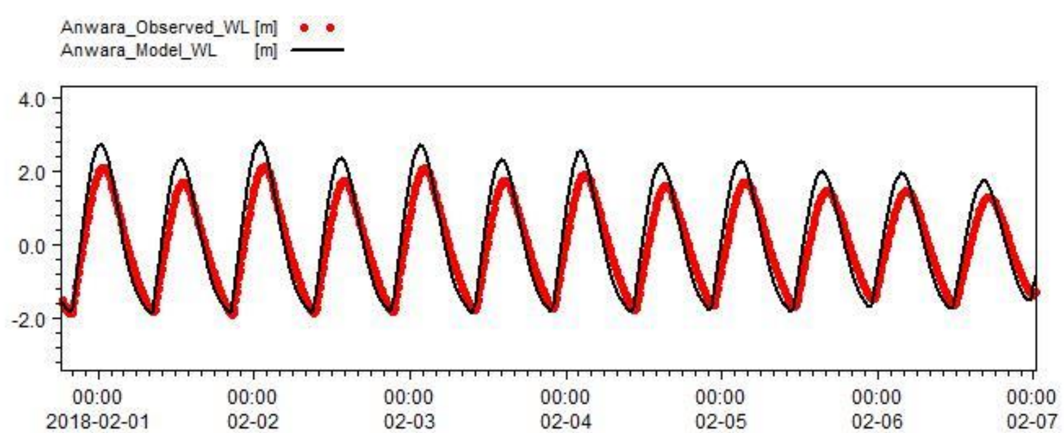


Figure 4.16: Comparison between observed and computed water level at Anwara during Dry

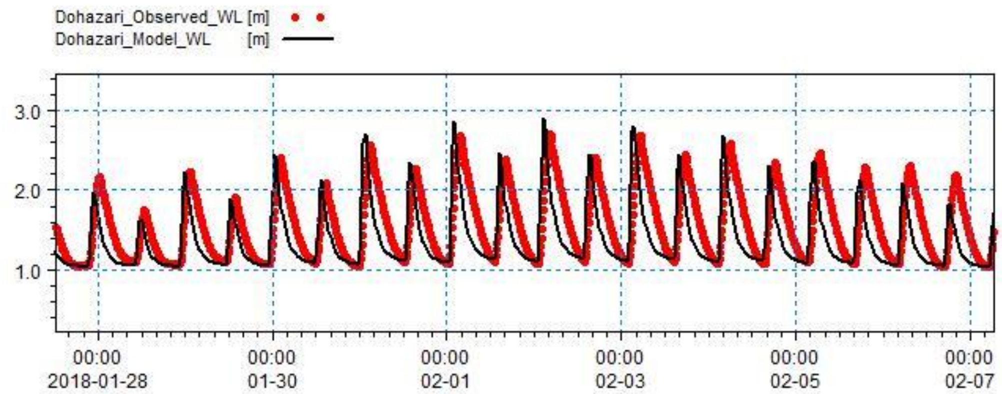


Figure 4.17: Comparison between observed and computed water level at Dohazari during Dry

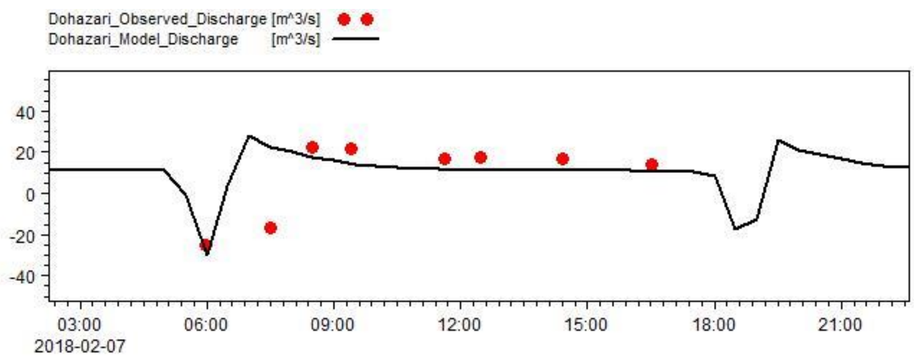


Figure 4.18: Discharge calibration at Dohazari during neap tide (ebb is positive, and flood is negative)

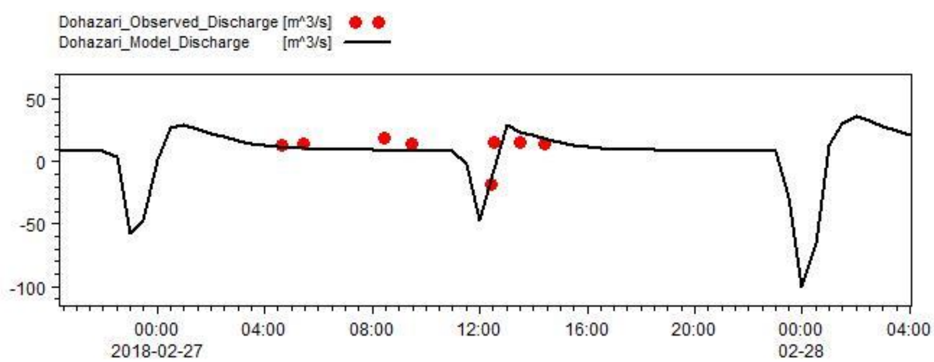


Figure 4.19: Discharge calibration at Dohazari during spring tide (ebb is positive, and flood is negative)

4.3.5 Pussur-Sibsa River system for meso scale modelling for fine sediment

A Delft3D 4 curvilinear model is setup for the Pussur – Sibsa system to investigate the role of sediment transport processes, tidal dynamics, and human interventions in detail. The domain runs from the seaward boundary at Hiron Point, but extends far landward, close to the tidal limit. This model is setup in a 2D high resolution and a low resolution version, and the low resolution version in 2D as well as 3D. Especially the high resolution models covers many peripheral rivers as well as transverse rivers (connecting the Pussur with the Sibsa rivers) – See Figure 4.20. The Sundarbans is part of the model domain, modelled as a system of shallow creeks and vegetated land with an elevation close to high water.

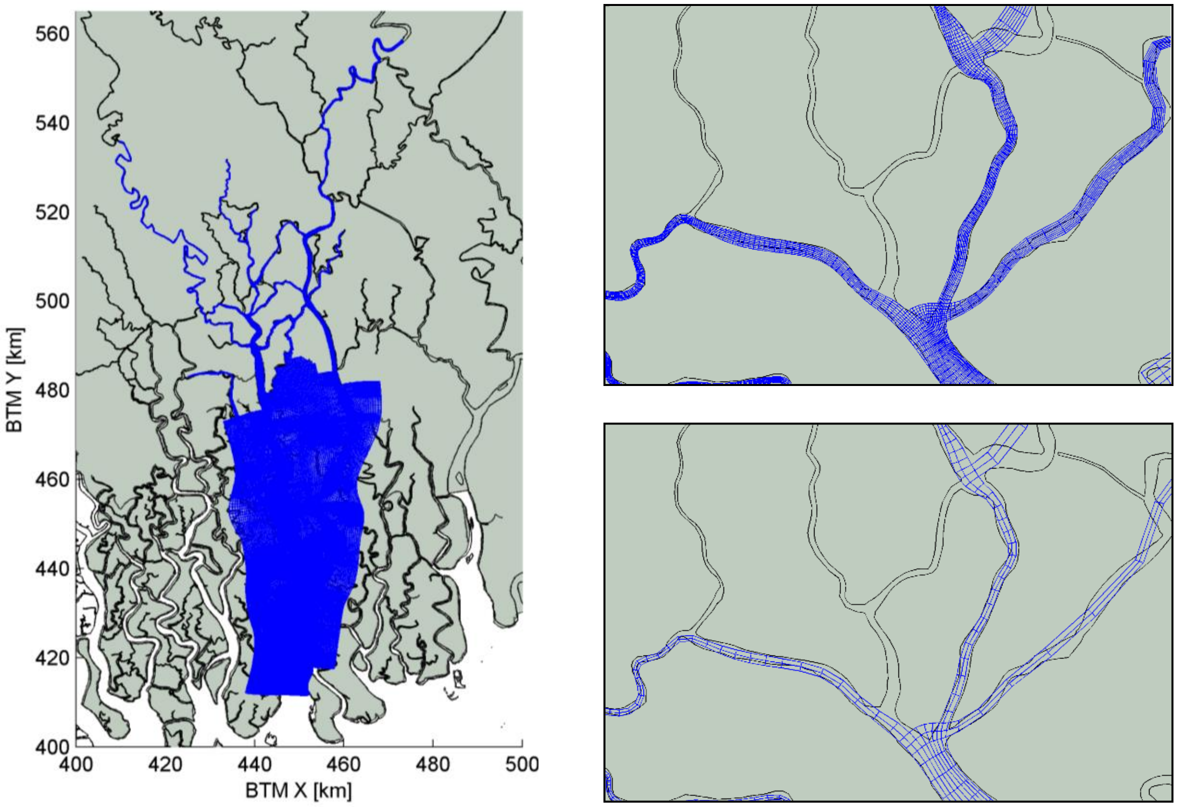


Figure 4.20: Model domain (left) and detail of the Upper Sibsa river with the refined grid (top right) and the coarse grid (lower right)

The hydrodynamic model is calibrated with available water levels (Mongla, Rupsha, and Ranai) and discharge data collected during various 13-hours measurements campaigns (see Figure 4.21). This model is subsequently extended with a fine sediment transport module, calibrated quantitatively against sediment concentration observations (as in Figure 4.22), and phenomenologically against residual transport patterns.

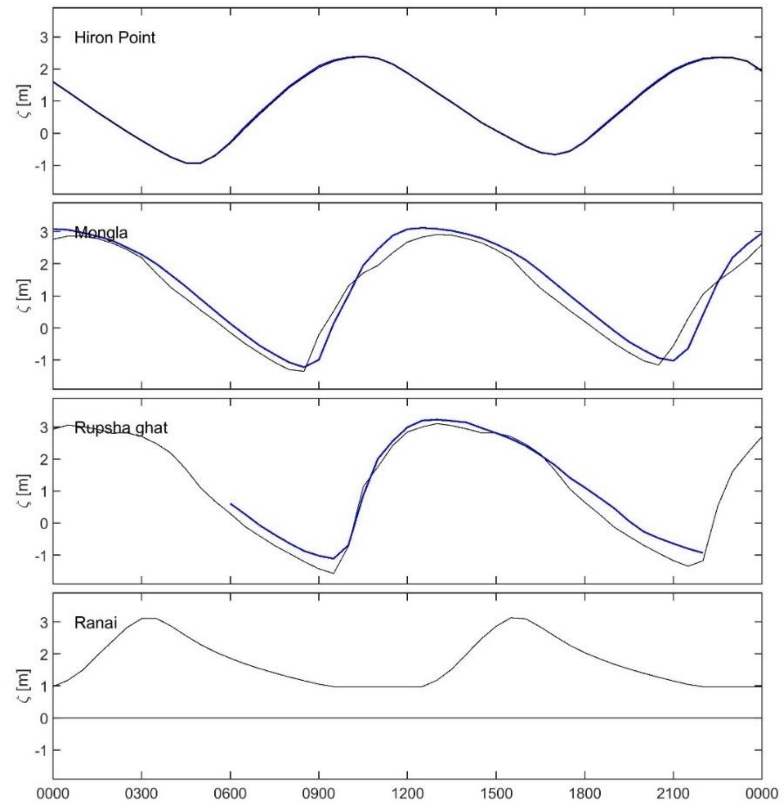


Figure 4.21: Computed (black) and observed (blue) water levels on March 2011 at Hiron Point, Mongla, Rupsha Ghat and Ranai

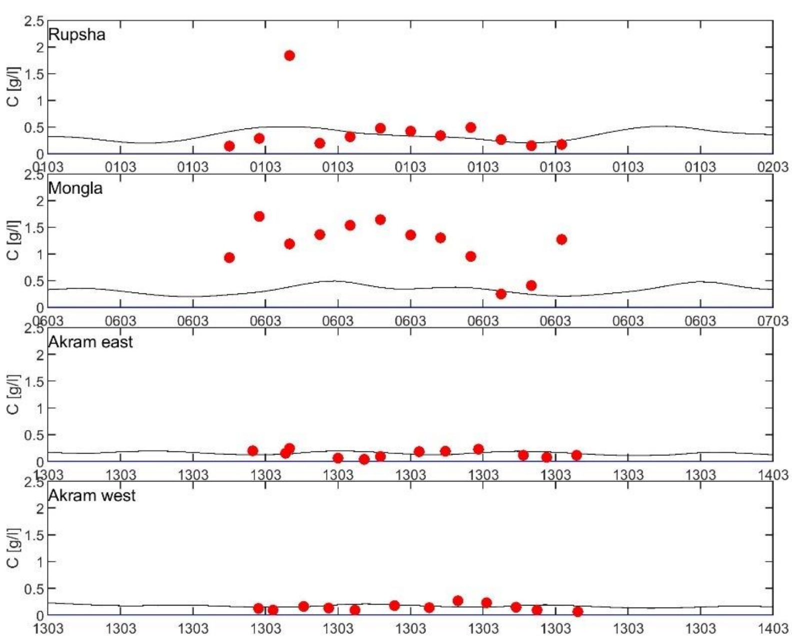


Figure 4.22: Computed (black) and observed (red) SSC on 13 March 2011 at Rupsha, Mongla,and Akram.

4.4 Meso Scale Models for Bank Erosion

Table 4.5: Meso Scale Modelling for Bank Erosion Prediction

D-4A-3		**Modelling of Bank Erosion Processes; Morphology on a Meso scale**
	1	Several models setup & developed to study bank erosion processes - to model recent occurrences and to hindcast erosion of a medium term time scale. Identify three or four key vulnerable sites A, B, C for detailed study
	2a	Site A: Tagetted field investigations, model schematisation & set up, simulations for hindcasting and forecasting & risk assessemt, testing preventive measures and other proactive interventions
	2b	Site B: Tagetted field investigations, model schematisation & set up, simulations for hindcasting and forecasting & risk assessemt, testing preventive measures and other proactive interventions
	2c	Site C: casting and forecasting & risk assessemt, testing preventive measures and other proactive interventions
	¨3	Report on Erosion Guidelines and Recommendations, early warning methodology & Erosion Management Strategy

During 2019 we have worked on four models, see locations in Figure 4.23. Baleswar; Sibsa; Pussur ; Bishkhali

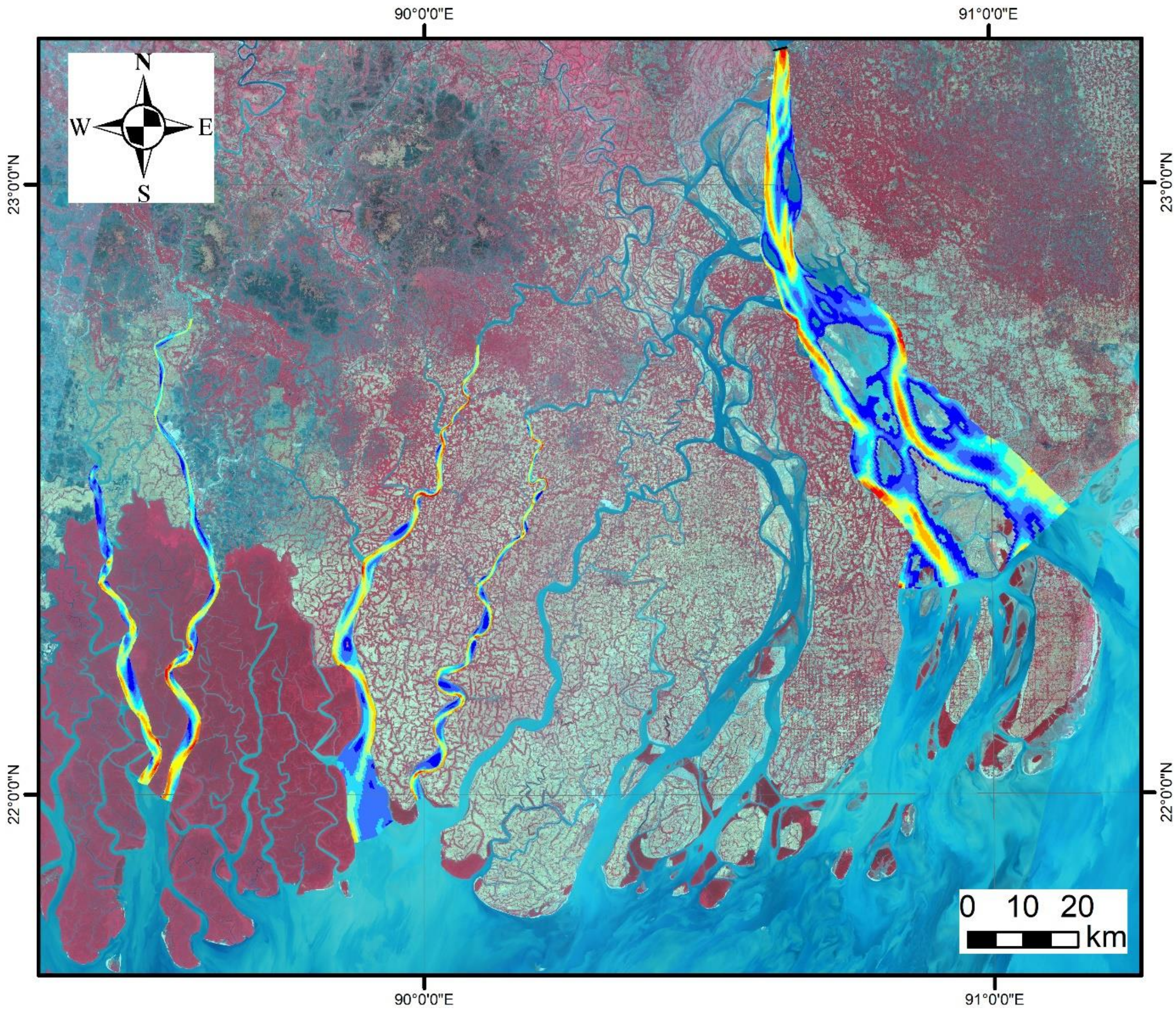


Figure 4.23: The four models developed during 2019, from west (left): Sibsa, Pussur, Baleswar, Bishkhali, and to the right is seen the Lower Meghna model currently under initial development.

Hydrodynamic models were developed initially, and then we focused in the fall of 2019 on getting two models close to final state for application:

- Baleswar
- Sibsa

Draft "Model Development Reports" were completed in December.

These also acted as templates for the rest of the models to be developed into application form. The steps taken in the developments of the morphological models are:

- Generate grid
- Contour bathymetry
- Prepare boundary conditions (upstream discharge, downstream water level, side channel source/sink)
- Calibrate hydrodynamics
- Calibrate sediment concentrations
- Hindcast bed levels 2011-2019
- Hindcast bank erosion 2011-2019

As the work progressed, we realized that the two bathymetry datasets, which we have for most models, namely the 2011 GRRP bathymetry and the 2019 bathymetry for the current project, provide the best opportunity for calibrating the morphological models. The 2011 and 2019 bathymetries were both collected by IWM with similar good resolution for contouring the 2-dimensional bathymetries. The time scale of 8 years was deemed useful because:

- Too short time: Transients from initial conditions will impact the solution too much (initial adjustment)
- Too long time: The morphological model becomes too uncertain (errors accumulate)

In addition, we have bank lines from 2011 and 2019 from the Landsat images. For Bishkhali we only have the 2019 bathymetry data.

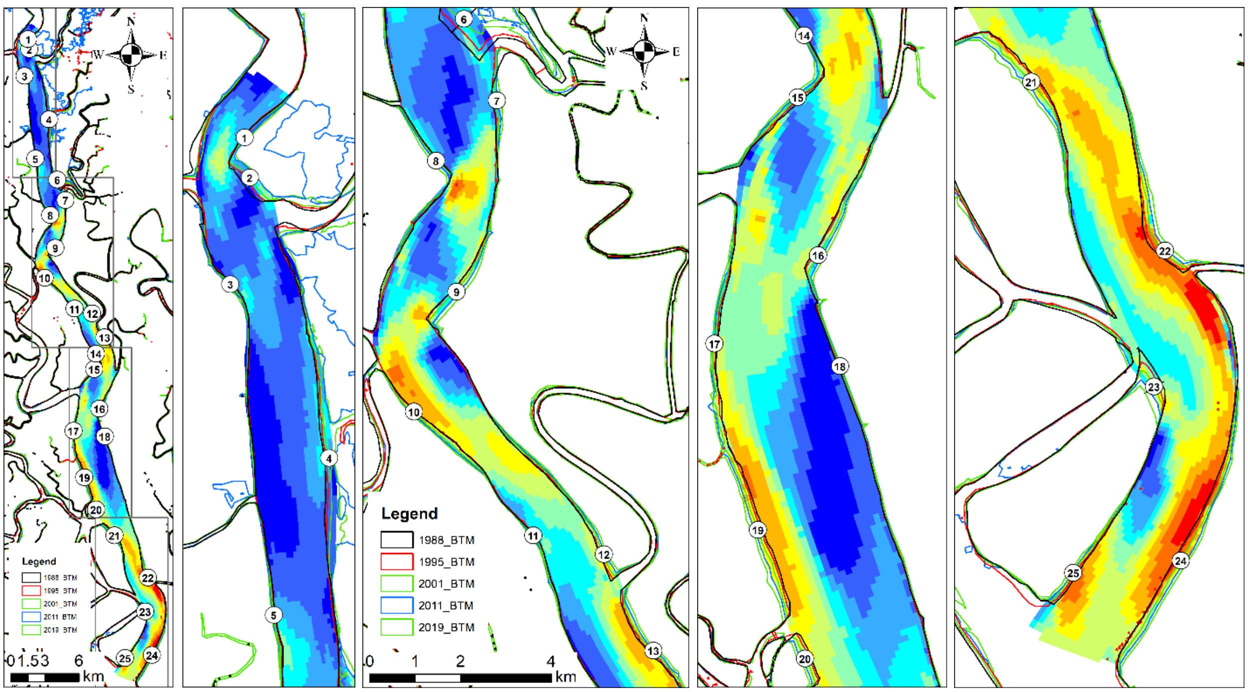


Figure 4.24: Identification of eroding banks in Sibsa River from Landsat 1988-2019 images.

The analysis of bank erosion from Landsat images was commenced in the beginning of 2019, and we have completed most of the analyses for the four models. The analysis has given some very important conclusions for the study:

- Bank erosion is systematic and seemingly predictable in a manner where future short-term erosion can be estimated from near-past short-term erosion.
- Almost all eroding banks have deep water and are in outer bends, which means bank erosion formulas correlating bank erosion to near-bank hydraulic parameters is likely going to work well.

The analysis is ongoing for Lower Meghna for which we do not expect the same systematic and predictable behavior.

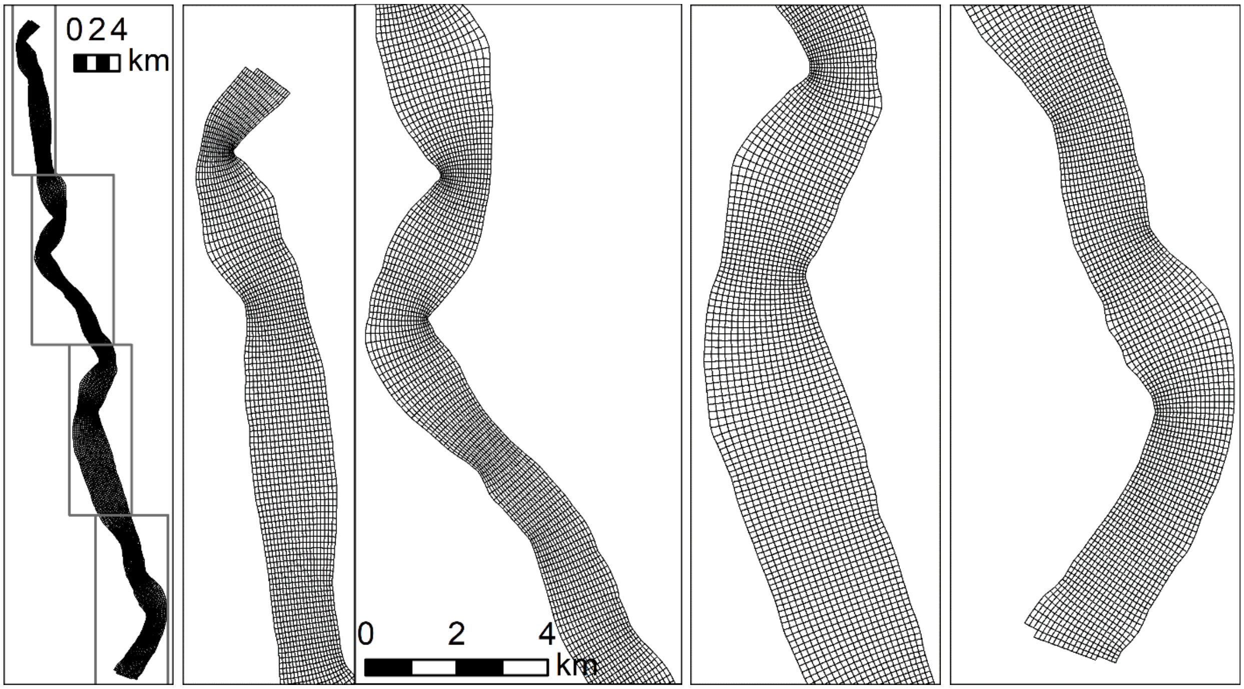


Figure 4.25: Curvilinear grid applied for Sibsa River.

The Sibsa River curvilinear grid is shown in Figure 4.25. The 2011-2019 morphological hindcast simulations are quite demanding, so the grids were made coarser than originally planned, and the floodplain was removed from the Sibsa River model because it has very little influence.

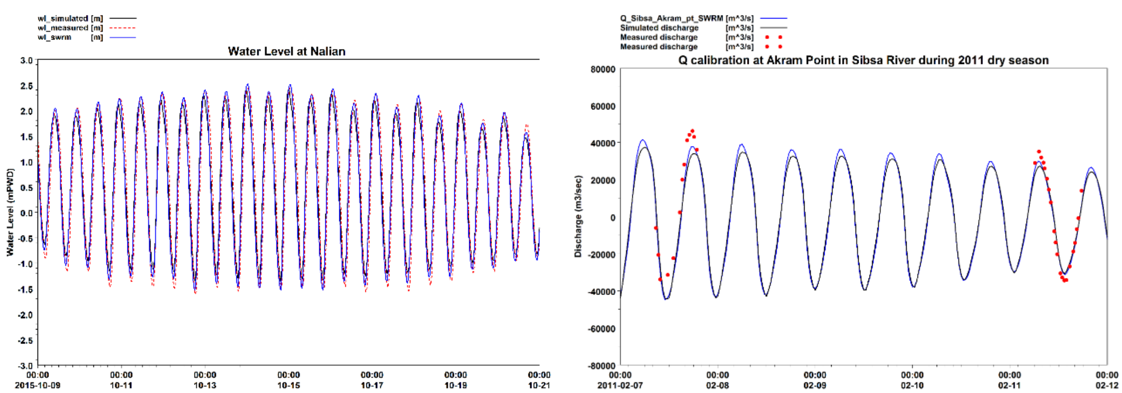


Figure 4.26: Examples of calibration of the Sibsa River model, left: Water levels at Nalian (2015), right: Discharges at Akram Point (2011).

Hydrodynamic calibration is usually easier than morphological calibration. Examples of calibrated water levels and discharges are given in Figure 4.26.

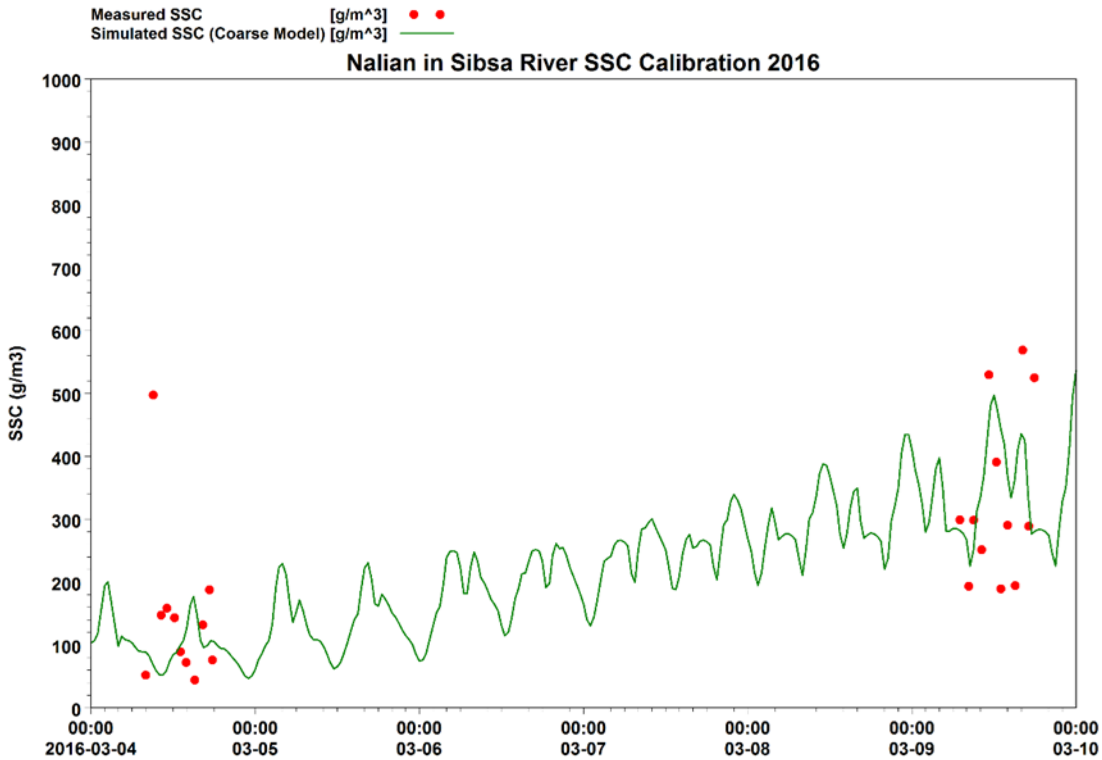


Figure 4.27: Example of cohesive sediment calibration in Sibsa River at the Nalian station.

The Sibsa River was initially developed using a silt model, which is easily calibrated to observed concentrations, as shown in Figure 4.27.

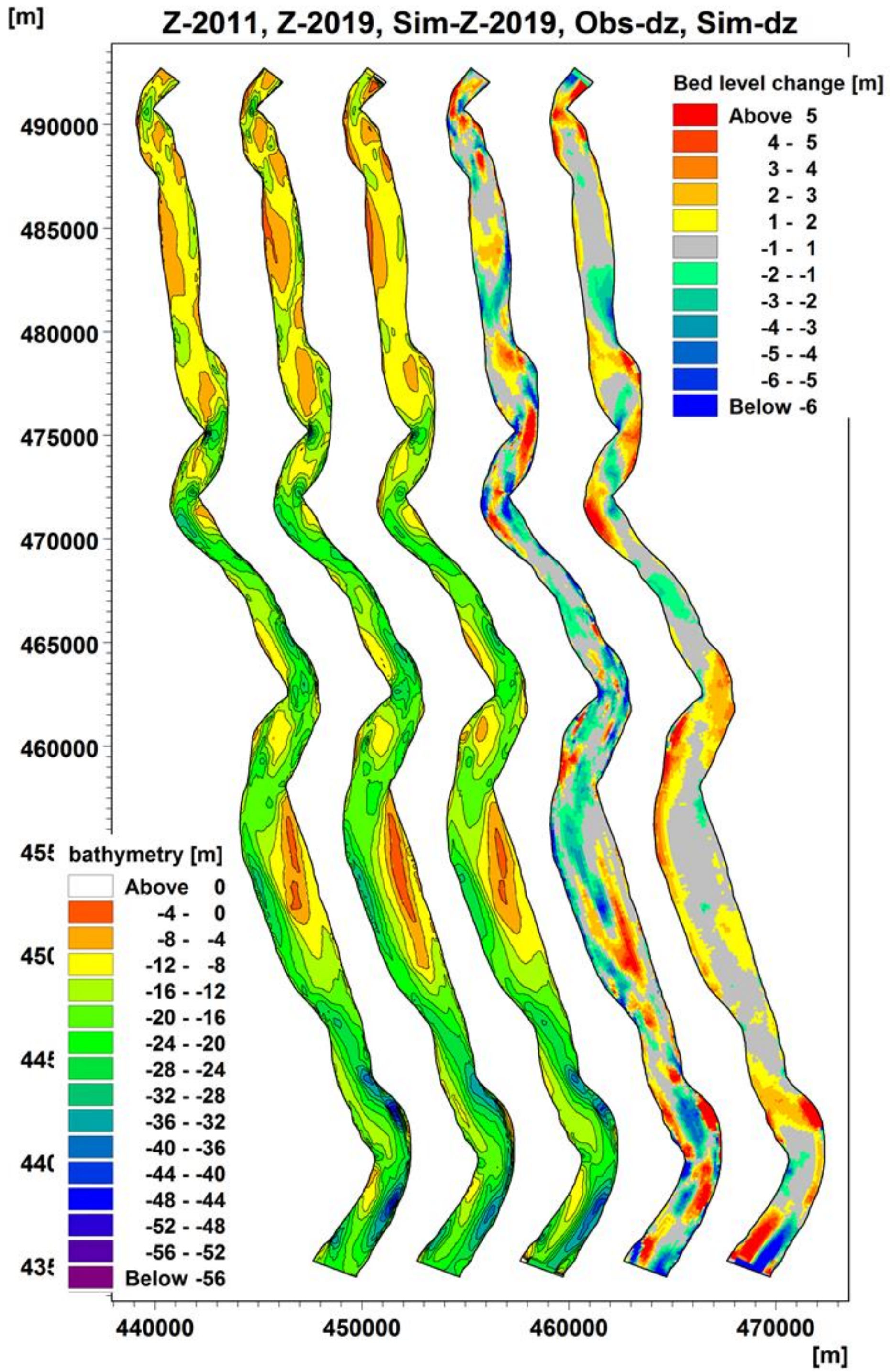


Figure 4.28: Calibration of bed levels by hindcasting the 2011-2019 bathymetry development. This type of figure will be seen in many reports, and it shows from the left: Observed 2011 bathymetry, observed 2019 bathymetry, simulated 2019 bathymetry, observed bed level changes 2011-2019 and simulated bed level changes 2011-2019.

Calibration to observed concentrations does not guarantee a good morphological model. A lot of effort was directed into the 2011-2019 hindcast, and the bed levels can be seen in Figure 4.28, along with the bed level changes. The Sibsa River model has some shortcomings in the middle reach of the river, while the upstream model performance is extremely good. Correctly hindcasting bed levels over 8 years is considered difficult, and one should never expect to get perfect results. We believe there are two main issues at play in the lower Sibsa:

- The Akram Point discharges are underpredicted for spring flood conditions
- The sediment in the downstream end of Sibsa is sandy

For Akram Point it is difficult to repair the behavior, as the MIKE 21C model receives boundary conditions from the SWRM (South West Regional Model). For the sediment we are currently investigating a 2-fraction model with silt and sand, but such models are far more data demanding than single fraction models.

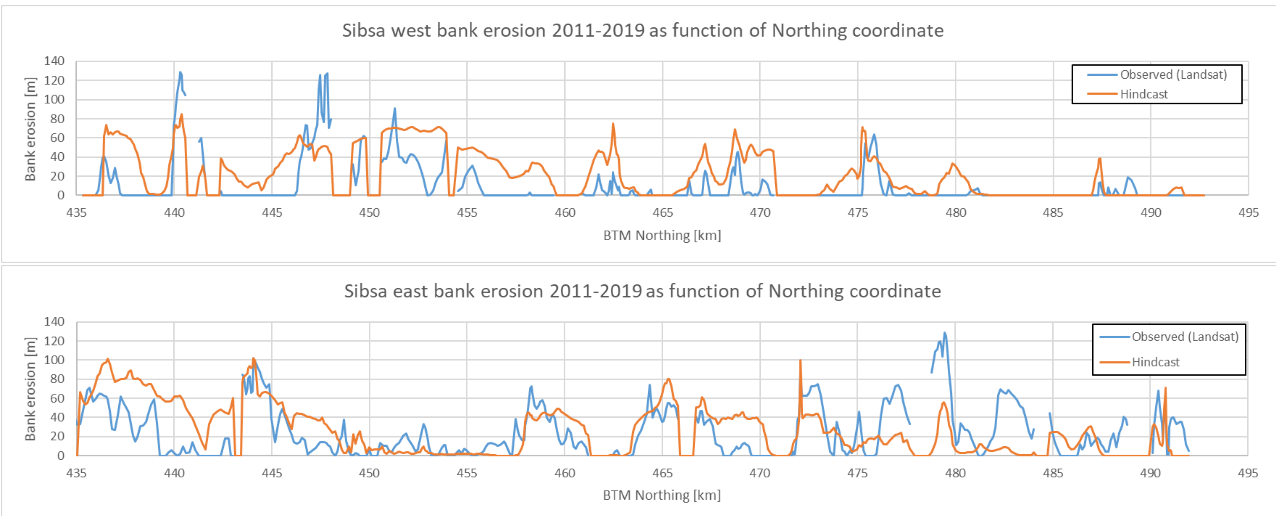


Figure 4.29: Bank erosion hindcast 2011-2019 for Sibsa River using a variant of the Hasegawa (1989) bank erosion formula.

Figure 4.29 shows a comparison of simulated and observed bank erosion in Sibsa River using a variant of the Hasegawa formula. We have looked at several bank erosion formulas, and found that bank erosion is best predicted from near-bank water depth and flow velocity, such that bank erosion increased with both. The most suited scientific approach is the so-called near-bank excess velocity concept. We are using a variant of the Hasegawa formula, which gives good predictions in the rivers using similar parameters.

4.5 Morphological Models for TRM (Micro Scale)

Table 4.6: Morphological Modelling on Micro-scale

D-4A-4		**Modelling of the long-term physical processes; Morphology on a micro scale**
		Identify a number of polders requiring especially detailed study (beyond the crest levels and standard drainage designs practiced in the most recent CEIP-1) to investigate operational and management alternatives for sustainably overcoming waterlogging and drainage congestion
		2) A report that describes the pros and cons of the different methodologies to prevent water-logging within the polder and sedimentation of tidal river system including polder subsidence. The report will include meta-data on the models used and measurements, recommendations for polder design including drainage and long term management plan, and recommendations for pilot area/polder to implement the ideas, such as but not limited to location, methods and measurements
		Recommend plans to manage sediment at the downstream stretch of the tidal river and in the polder

Tidal River Management has been implemented in some of the polders (polder 6-8 and Polder 24) in south western region. After detailed study of reports on tidal river management (TRM) Polder 24 has been identified as a good case for a pilot model. IWM collected a lot of data at Polder 24 before and after the implementation of the TRM. The available data including:

- River cross-sections, several datasets were collected
- Floodplain elevations, including levees (very important for the hydraulics)
- Discharges and water levels (tidal cycle)
- Sediment particle size distribution data
- Sediment concentrations during the tidal cycle

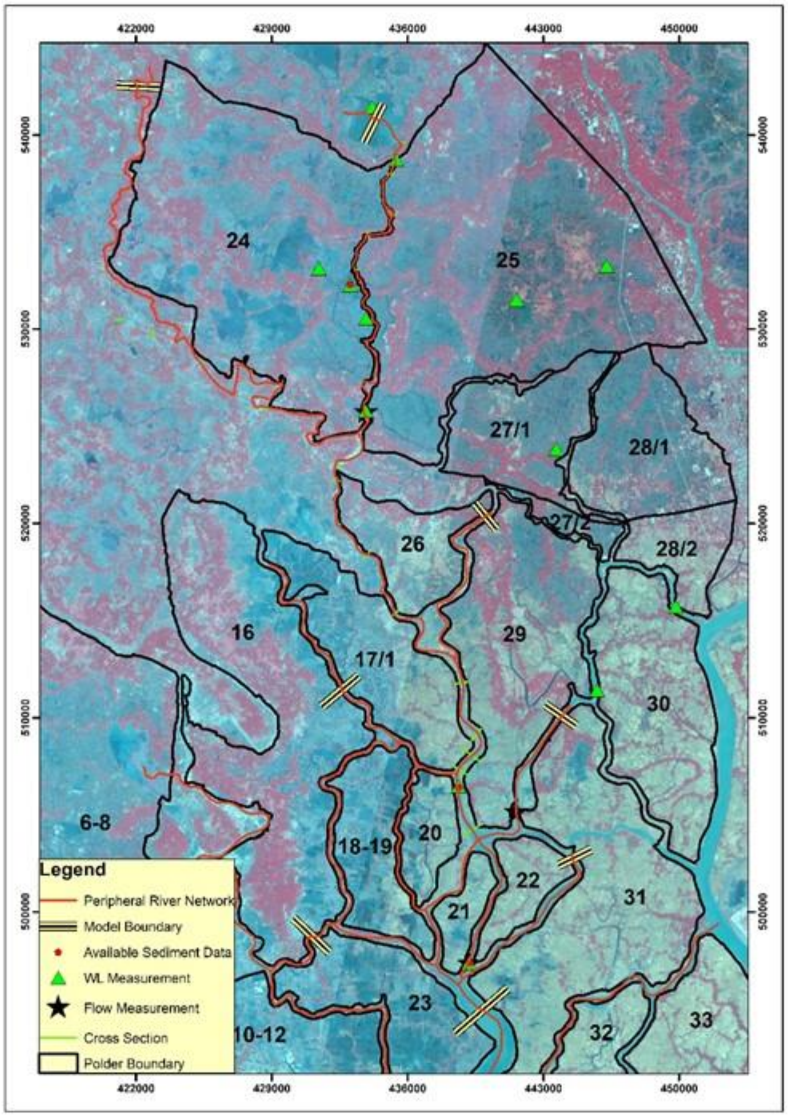


Figure 4.30: River Network for Mike 11 Model Extracted from SWRM

4.5.1 Polder 24

The available data for Polder 24 is extremely suited for morphological modelling because it allows determination of sedimentation and erosion over time, which is not normally available for modelling studies. IWM also deliberately collected bathymetry data associated with specific interventions, which also calls for the use of modelling to understand the processes, which has a lot of potential value for conducting TRM.

In other words, the data offers opportunities that we do not normally get in modelling. The first step in the study should be to reproduce the developments documented in the IWM data and reports, i.e. hindcasting, which is normally not possible at this level of detail.

For the initial model development for the TRM, existing data is being reviewed and currently in progress of identifying the peripheral river hydrodynamics using Mike 11 model. The Mike 11 hydrodynamic model is under process of extracting and hydrodynamic analysis of river network for the TRM location from the existing SWRM model. After this following step would be performed,

- Create local MIKE 11 model to be combined with the MIKE 21 model
- Verify that the MIKE 11 model behaves as the SWRM model
- Include a sediment transport formulation into the MIKE 11 model
- Calibrate the sediment transport model
- Cut the local MIKE 11 model into branches to be connected to the MIKE 21 model
- Combine the M11 branches and the M21 model to create a MIKE FLOOD model for pre and post TRM conditions
- Investigate different TRM strategies using short term simulations (neap-spring cycle)
- Morphological modelling of the transition processes in the peripheral rivers and the beel

4.5.2 Pilot Tidal River Management (TRM) model for Polder 24

The TRM basin in Polder 24 (East Beel Khuksia) was brought into operation on 30th November 2006. Ahead of the opening of the TRM basin about 0.8 x 106 m3 was dredged from the peripheral Hari River along a reach of approximately 8 km to amplify the tide. Before the opening of the TRM basin the tidal volume of the Hari River was about 0.9 x 106 m3 but increased to 1.95 x 106 m3 after two months of operation and 5.3 x 106 m3 after 5.5 months. The major part of the tidal volume increase is caused by flushing of the peripheral rivers that at Rania was deepened by more than 2 meters. A minor part of the tidal volume increase is related to seasonal variations of the tide, which typically has the largest range in the months of March and April.

The significant impact of the TRM basin on the tidal volume and its ability to flush the peripheral rivers and prevent drainage congestion during a relatively short morphological time scale makes it interesting to investigate using a numerical model. Furthermore, the numerical model has the advantage that different kind of management measures can be investigated and compared in order to develop optimal solutions.

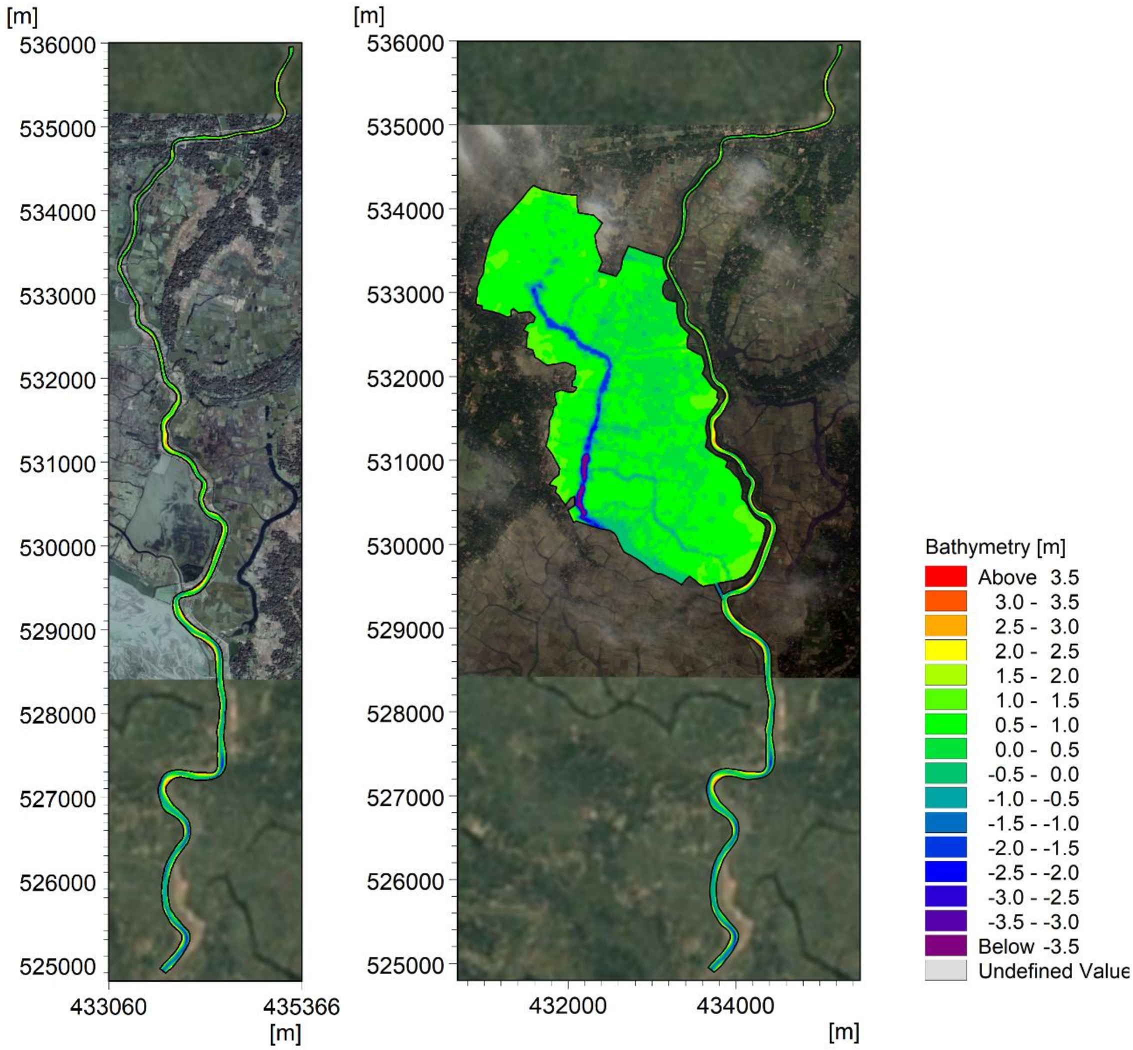


Figure 4.31: Model bathymetry with and without beel applied for TRM.

In January and February 2020, the construction of the MIKE 21 model for TRM of Polder 24 was continued and the first morphological model results and findings has been established. Figure 4.31 shows the model bathymetries for the Hari River with and without the beel being applied for TRM modelling. The polder bathymetry is constructed to reflect the conditions inside the beel at an early stage (February 2007) and before being significantly impacted by TRM. The Hari River bathymetry is constructed based on surveyed cross sections from 2015, i.e. years after the cease of TRM and thereby considered to represent conditions of a river branch silted up.

Topographic surveys inside the beel was made in February 2007 and May 2007. The observed deposition pattern during the three months of TRM was used to verify the concepts being applied for the morphological model. It was found that the deposition mainly took place in the southern part of the beel near the opening.

Figure 4.32 shows the surveyed topography change and the modelled topography change during the three months of operation. Ponds and khals were not included in one of the topographic surveys, so the obtained differences north of the indicated red line cannot be trusted. It is found that the morphological model is able to create a deposition pattern caused by the TRM similar to the one being observed. Figure 4.33 shows a closeup of the deposition pattern inside the beel and the erosion pattern in the peripheral Hari river. It is from the modelling results seen that the TRM operation only improves the drainage congestion issues downstream the breach into the polder.

The continuing work will focus on modelling longer periods and investigate whether it is possible to optimize the TRM concept, i.e. to accelerate the sedimentation and/or to ensure a more evenly distribution. Previous applications of TRM have shown that sediment mainly settle out near the openings made into the beels, it is therefore of interest to derive measures that can ensure a more evenly distribution of the sediment deposits.

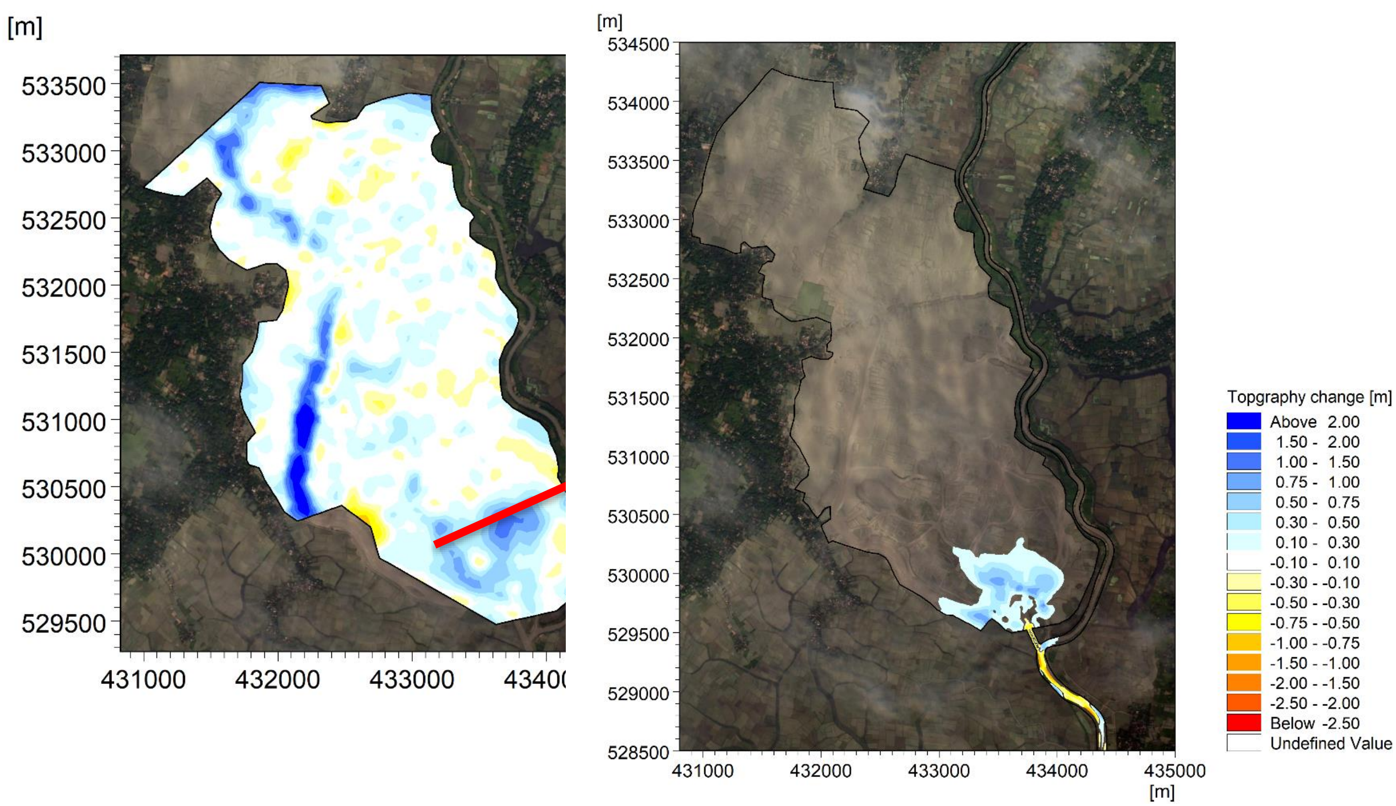


Figure 4.32: Observed and modelled deposition pattern inside the beel during the period from February 2007 to May 2007.

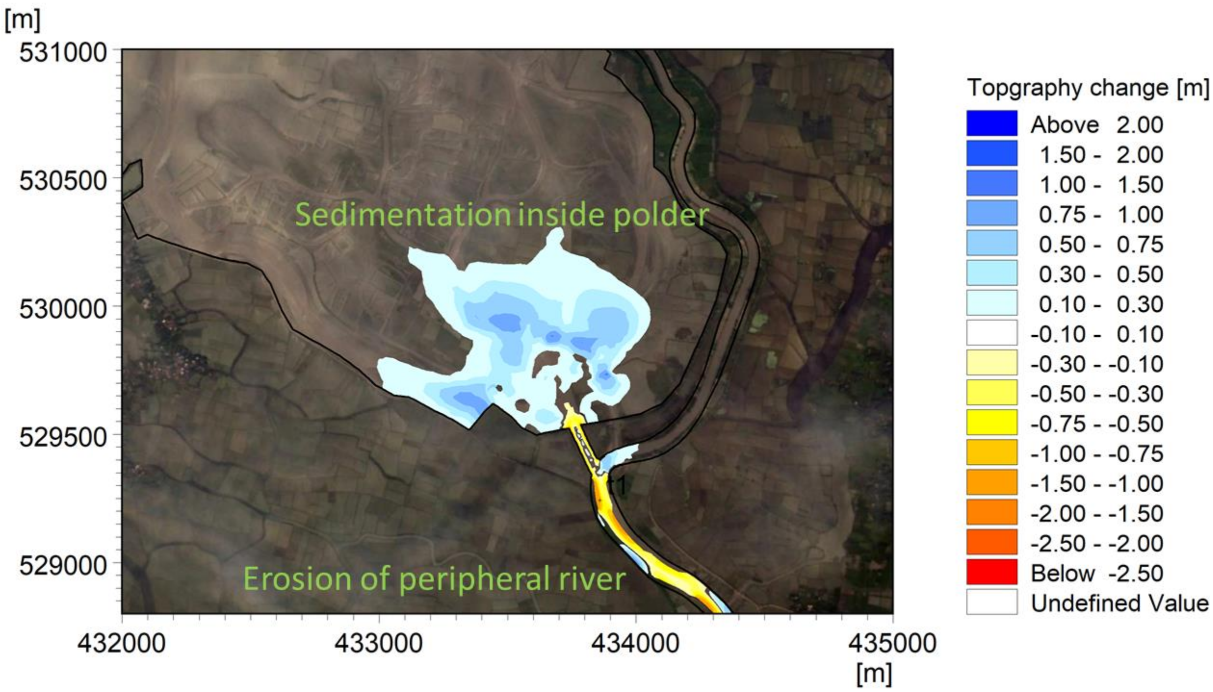


Figure 4.33: Closeup of the deposition pattern inside the polder and the erosion of the peripheral river

5 OTHER STUDIES

5.1 Subsidence and Delta Building

The approach to studying subsidence and delta building has been described in detail in the Second Quarterly Progress Report (QPR-2). The field work proposed was postponed because of an administrative difficulty and the rescheduled programme is to commence on 15 July 2019.

Subsidence is a key process to be quantified, and remote-sensing techniques, notably Differential INSAR data analysis does show some promise to arrive at spatially-distributed maps of subsidence. D-InSAR use the repeat passes of radar instruments on satellite and analyses the phase change, Λϕ, of the returned radar signal between different passes.

$$\Delta\phi = \Delta\phi_g + \Delta\phi_a + \Delta\phi_t + \Delta\phi_d + \Delta\phi_n + \Delta\phi_o$$

In deltaic regions, phase changes may be due to ground deformation, atmospheric beam delay, topography change, decorrelation, thermal noise or orbital drift. Our analysis corrects for all of these factors, but for monsoonal regions dry season acquisitions turn out the most reliable (Higgins et al., 2014).

The field work done during this period with respect to subsidence measurement and delta building is described in Chapter 2, Section 2.3.

5.2 Cyclones/ Storm Surges

5.2.1 Changes in cyclone intensity and frequency

Bangladesh is a global hotspot for tropical cyclones and it adverse impacts on society (Dasgupta et al., 2016). For example, between 1960-2004 more than half a million inhabitants of Bangladesh died as a consequence of TCs, primarily due to storm surge (Schultz et al., 2005).

In the current situation, generally-speaking, tropical cyclones (TC) generate in the Bay of Bengal, propagate northwards and make landfall in a southwest / northeast direction at Bangladesh (see Figure 5-2). Once on land, the intensity of the TC decreases due to lack of warm water supply and increased land roughness. Generation occurs both during pre-monsoon (April, May, June) as in the late rainy season period (September, October, November, December; see for more information Dasgupta et al., 2016).

About 23 number of severe cyclone hit the coast of Bangladesh from 1960-2016. Figure 5-1 shows the occurrence of cyclone in pre-monsoon and post-monsoon. The increase of wind speed due to climate change about 5-11% in accordance with 5th IPCC report. Increase of cyclonic wind speed causes increase of storm surge height.

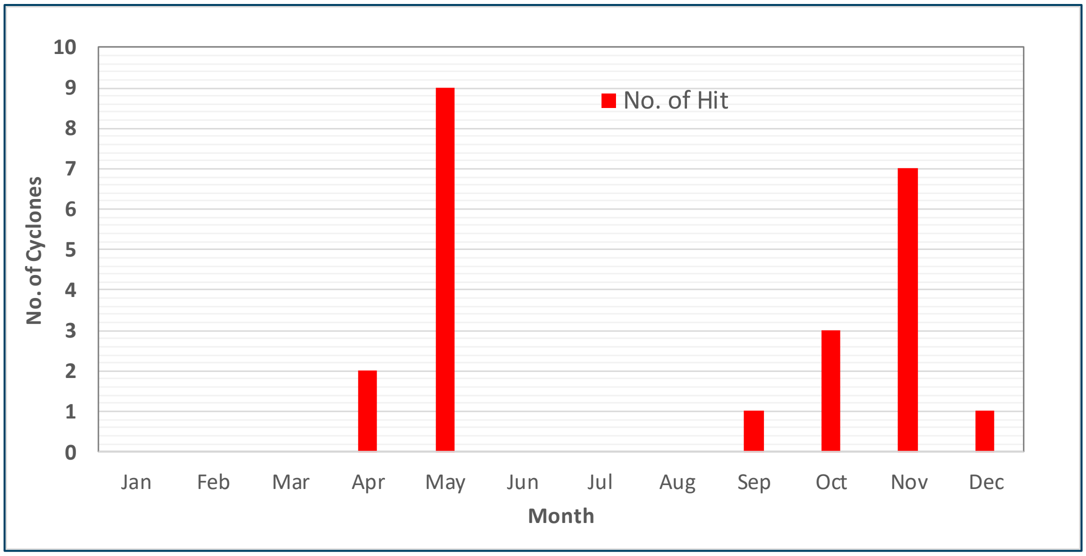


Figure 5.1: The occurrence of cyclone in pre-monsoon and post-monsoon season in Bangladesh coast during 1960-2016.

In 45 years of time, the Joint Typhoon Warning Center (JTWC) for the Indian Ocean (IO) basin, reported 45 TCs with wind speeds higher than 20 m/s. This means there is, on average, every year a TC that makes landfall in Bangladesh. When only focusing on the most intense TCs (maximum wind speeds higher than 50 m/s; denoted as extremely severe cyclone storm and super cyclone storm) the probability decreases with 80%. This means that, on average, every 5 or 6 years such a heavy TC makes landfall in Bangladesh.

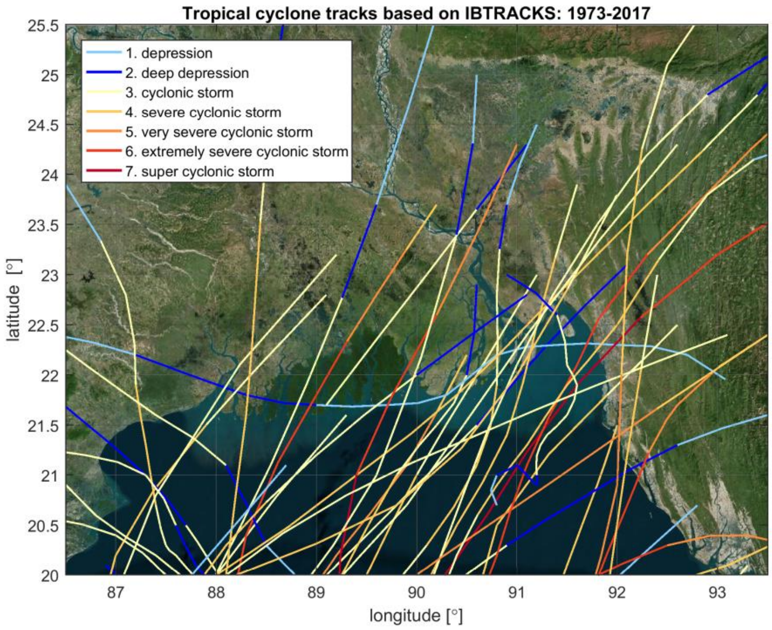


Figure 5.2: Tropical Cyclone (TC) tracks and intensity based on the IB TRACKS database. Here the joint typhoon warning centre for the Indian Ocean (IO) was used as data source. The tracks are color-coded based on the India Meteorological Department (IMD).

Future situation

For the future situation, it is challenging to detect any change in tropical cyclone activity based on data. When observing the data from the Joint Typhoon Warning Centre, this suggests a larger number of TCs for the time period 1980 – 2000 with respect to the years before/after. The same can be said for the number of the most extreme TCs only. Six out of the eight TCs with wind speeds larger than 50 m/s occurred in the ten-year time period 1988 – 1997, while only one event occurred after 2000 (i.e. TC Sidr, 2007 with a maximum reported wind speed of 67 m/s). Therefore, the data seems to suggest a decreasing trend in the number of (strong) TCs. However, due to relatively short data record, one need to assume that these perceived trends are based on randomness.

Knutson et al. (2015) carried out a numerical modally study to assess projection in TC frequency and intensity for different oceanic basins. CMIP5 multi-modal ensembles were used to compare conditions under RCP 4.5 for the late twenty-first century to the period 1982-2005. For the North Indian Ocean, an average increase of 19.5% in the frequency of TCs of all different intensities was found, with a peak in increase for TCs with stronger intensities (category 4-5). This was also accompanied by an increase in duration maximum wind speed (3%) and precipitation rate (10-20%).

5.2.2 Analysis based on measured data

The following datasets have been collected and will be analyzed statistically in order to derive possible long-term trends:

- Water level data

- Cyclone tracks and intensity

- Rainfall data

- River discharges

- Temperature data

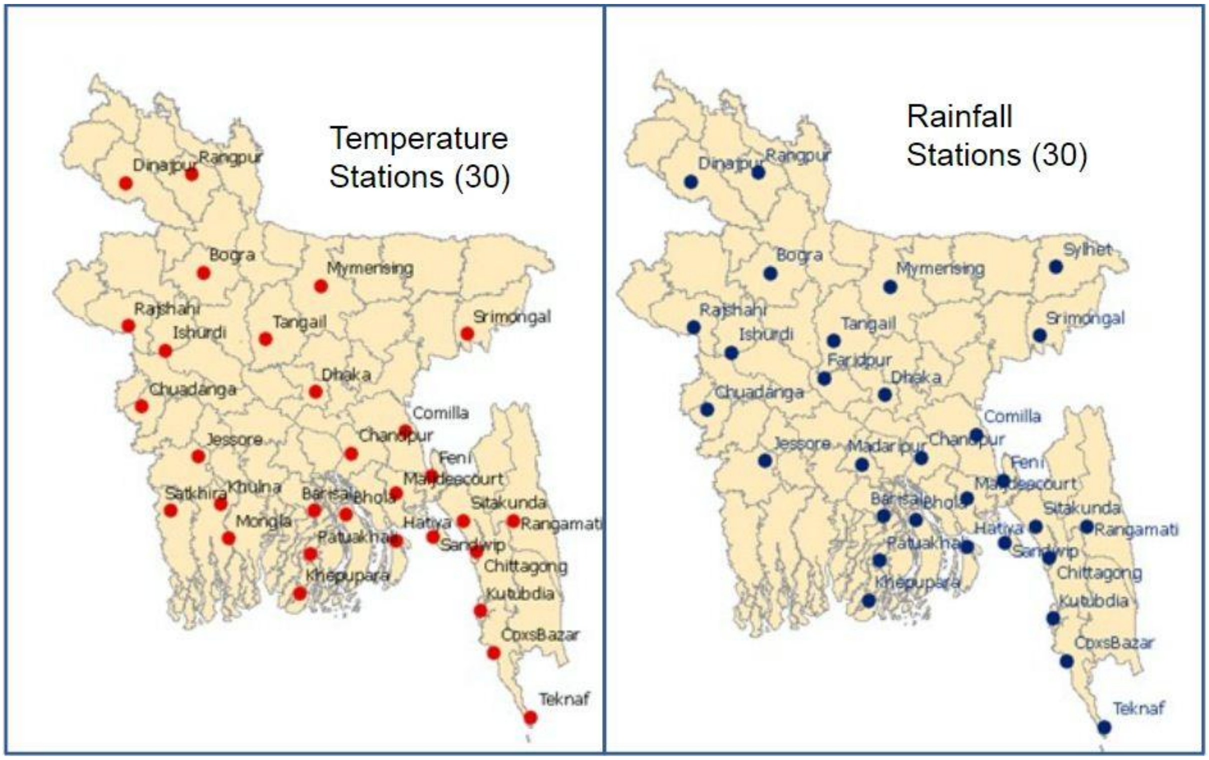


Figure 5.3: Temperature and rainfall stations across Bangladesh.

6 POLDER RECONSTRUCTION PROGRAMME

6.1 Background

Devising a polder reconstruction programme must be based on agreement on a set of clearly enunciated objectives. There is much literature available as project reports on solving problems associated with the Coastal Embankment System over the past 60 years. These reports cover areas of water resources and flood protection, drainage, operation and maintenance of systems, environment, agriculture, fisheries, socio-economic data etc. In more recent times questions of sustainability have begun to play a larger role in design and planning of new systems.

The Coastal Embankment Improvement Programme was initiated in August 2010 as a phased programme of improving the Coastal Embankment System, which had already been in existence for 50 years, to improve its resilience to Climate Change after attention was focussed by two major cyclones, Sidr and Aila, in 2007 and 2009, which caused damage in excess of USD 2 Billion. At that time there were 139 polders protecting the livelihoods of 28 million people from inundation. While it was necessary to protect the embankment system from storm surges originating in the Bay of Bengal which was now recognised as being subject to sea level rise driven by climate change and the lands subject to subsidence, It was clear that the polders would need to be classified in terms of their vulnerability so that a phased improvement programme could be devised to take up the gradual strengthening of the embankment system to resist the impact of climate change and other

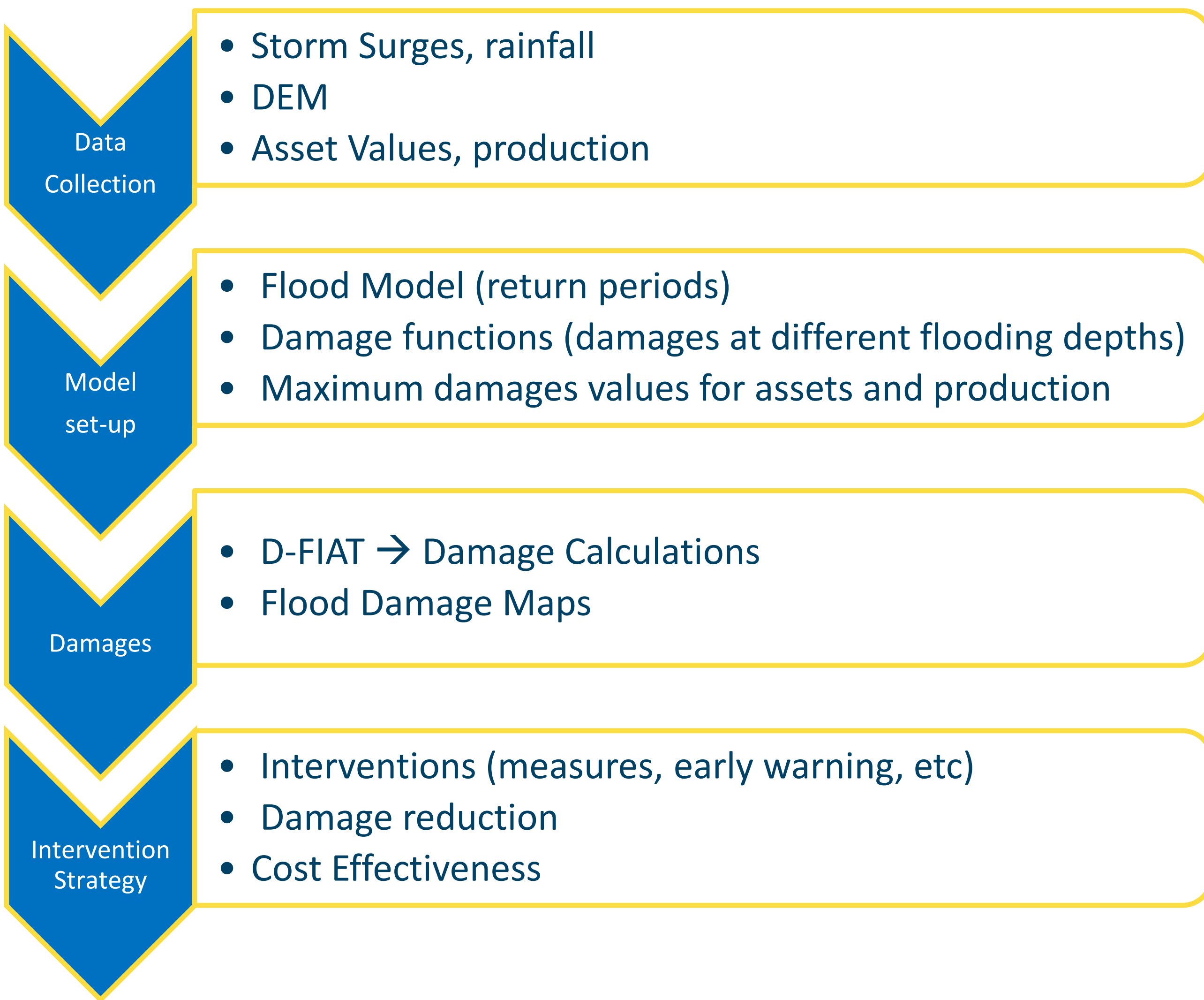
17 polders were selected for CEIP-I as the first stage of this project. The selection was done on the basis of a multi-criteria analysis of all 139 polders in 2010. The selection criteria were based on the actual physical attributes of the polder and hydraulic structures and the vulnerability assessment of the respective BWDB Engineers responsible for and possessing intimate knowledge of each polder. The selection of groups of polders for intervention was also influenced by the need to keep the selected polders in groups within close proximity for convenience of access and for determining the design parameters and model boundary conditions.

These 17 polders – now being addressed by the first stages of the CEIP programme, were taken up in 2010 and the designs were based on the knowledge and understanding of physical phenomena and socio-economic development in the coastal zone at that time. Given the much greater and detailed understanding we have of phenomena now and the rapid economic development that had taken place over the past two decades, it is necessary to revisit the analysis of the 139-polder assessment in order to determine priorities for development. It is also necessary to review the design and planning of the first stage of CEIP in the light of the most up-to-date knowledge.

A new data collection campaign has been launched by this project to collect the most up-to-date dataset to revisit the analysis of the 139 polders under the guidance of the international and national experts who have prepared a Road Map for the Investment Plan, illustrated below:

THE ROAD MAP

DATA COLLECTION



ANALYSIS

Data Collection

- General data on polders (surface, population, FS, production, etc.)
- Institutional analysis
- Measures (Unit Prices, Effectiveness, Institutional requirements, etc)
- Boundary conditions (SLR, Sediments, Water Balance, CC, Economic parameters, etc)

Problem Analysis

- Water related (Flood damage, Salinisation, Water availability)
- Erosion/Scour
- Subsidence
- Institutional Setting (Operation and Maintenance, Budget, FS, Market Access, etc)

Problem Quantification

- Quantification of identified problems (e.g. flood risk maps)
  - flood risk maps
  - Salt intrusion
  - Sediment loads, Erosion/Sedimentation

Measure "Database"

- Identification of types of measures for identified problems
- Effectiveness of measures
- Cost Effectiveness Analysis (CEA) of measures

Strategy Development

- Identification of CE measures for identified problems per polder
- Combine measures into strategies per polder and Bangladesh
- Institutional requirements
- Budget

Investment Plan

- Identification of potential financing sources (which funding type – Loan, Grants-, conditions – e.g. GCF, only CC related works)
- Prioritisation and Timing of investments

It is necessary to revisit the original multicriteria analysis and make revisions based on our current understanding of phenomena, which have evolved based on new knowledge of matters such as land subsidence, climate change and changes in the catchments in the upper delta. The original selection was based on the data available in the year 2011. The second group of 10 polders selected (but not finalised) for CEIP-2 was also selected in 2012 based mainly on the same dataset.

It is now possible to take full advantage of the Polder Database being set up and populated under this project (see Chapter 3) and use it as the principal tool for analysing the properties of the polders into categories suitable for deciding on a strategy for polder reconstruction. The new database would need to be expanded to include much more information in demographic, administrative, socio-economic, environmental and other characteristics in order to make it suitable as a tool for devising a reconstruction strategy.

A large-scale data collection exercise is now underway to cover all 139 polders covered by the polder system. While it will not be possible to match the level of detail achieved by CEIP-I in the coverage of the 17 polders selected for CEIP Phase I, it is necessary to use all means at hand to improve the coverage of the remaining 122 polders. The 5 polders that have been selected for the pilot study and design would of course be given special treatment.

6.2 Selection of 3-5 Polders for Pilot Study

The Terms of Reference demands that three to five “representative polders” were selected to conduct conceptual designs on a pilot basis to also introduce innovative design approaches where appropriate. These pilot polders were to provide additional guidance towards introducing innovative designs to broaden the choices available to the designers. 5 polders were selected after detailed examination of their physical and geographical characteristics after detailed field inspections. The final choice was ratified by the committee convened by the Project Director.

The details of the selection process are given in the Polder Selection Report (2019). These polders are now under detailed study prior to design. Table 6.1 summarises the salient features of the selected polders.

Table 6.1: Five Polders Selected for Pilot Design Study

<table>
<tr><th>Polder Name</th><th>District</th><th>Coastal region</th><th>Key Characteristics</th></tr>
<tr><td>Polder 15 (CEIP-1)</td><td>Satkhira</td><td rowspan="2">South-West Coastal region</td><td rowspan="2">➢ Very little Freshwater flow from upstream River（Ganges）
➢ Influenced by strong tidal action, salinity problem is acute.
➢ Peripheral river Sedimentation is a major Problem; which creates drainage problem. People inside coastal polder
➢ Experiencing prolonged water logging.
➢ River bank erosion problem</td></tr>
<tr><td>Polder 29 Blue
Gold programme</td><td>Khulna</td></tr>
<tr><td>Polder 40/1</td><td>Barguna</td><td>South-Central</td><td>➢ Polder Embankment is facing river Erosion problem.
➢ Vulnerable to cyclonic storm surges.</td></tr>
</table>

Polder Name	District	Coastal region	Key Characteristics
		Coastal region	
Polder 59/2	Noakhali	South-East Coastal region	➢ Morphologically active land accretion is dominant than erosion. ➢ Severe river erosion due to, thalweg migration. ➢ Vulnerable to cyclonic storm surge. ➢ Some area subjected to prolonged water logging due to encroachment and land reclamation by closing of Tidal creeks.
Polders 64/1a & 64/1b	Chittagong	Eastern Hilly region	➢ Vulnerable to storm surge. ➢ Prone to flash flood due to steep gradient of river and intense rainfall. ➢ Water logging ➢ Erosion around Sangu River

The five polders selected above have properties that are representative of the polder system and the full range of interventions necessary to provide solutions to identified problems, taking into account their physical characteristics, and their location within the coastal zone. It is felt that a thoughtful approach to the design of these 5 polders will enable the development of approaches that will be useful in for responding to the diverse problems to be overcome within the polder system.

The expanded multi-criteria analysis applied to the polder database, will help us to select a strategy for the staged re-construction of several groups of polders.

During the reporting period the polder management and investment planning team made a field visit to the polders 59/2 and Polder 64/1a and 64/1b, in order to acquit themselves with the problems in the field and discuss with local stakeholders about their day to day problems facing them. Especially the problem of bank erosion in polder 59/2 seems to be a challenging issue. For polder 64/1a and 64/1b different sites with coastal erosion and bank protection works were visited.

6.3 Strategic Approach towards devising a Polder Reconstruction Programme

Table 6.2: Indicators for Polder Data Description

1. Sl No	2. unique identifier
3. Polder description	
4. Polder No	5. Official number (name?) of the polder
6. Type of Dyke	7. coastal, internal, fluvial
8. Location of the Polder (Upazila)	9. Administrative upazila
10. District (Zila)	11. Administrative zila
12. Gross Area of the Polder (HA)	13. Surface of the polder (gross)
14. Embankment Length (Km)	15. Length of embankment. Should be specified to type of dike
16. Land use	17. State land use in different categories and surfaces and value, including urban and rural areas (urban, agricultural, industry)?
18. Population	19. per polder
20. Accessebility	21. Ease of transport (road, rail, ship), density of road and rail network?
22. Production value	23. Assess economic importance of polder in terms of value added, contribution to GDP
24. Problem identification	
25. Breach of Embankment (Km)	26. This is part of the problem identification. "Breach" should be further specified
27. Erosion (Km)	28. The nature and extend of erosion should be specified
29. Requirement of BPW (Km)	30. What is this?
31. Location in the Risk Zone	32. This should specify IWRM/ICZM zone, catchment, other? Tidal surge, salinity, flooding, river erosion and cyclones, Make use of the "hot spot" terminology?
33. Drainage Congestion (Ha)	34. This is part of problem identification, drainage problems. How should this be described? Also related to waterlogging in low lying areas in a polder (could be linked to solution increase land level)
35. Salinisation	36. Is salinisation currently a problem, could it in the future, does it have an impact on (agricultural) production, water supply? Linked to the possibility in provision in fresh water
37. Subsidence	38. What is the subsidence rate of the polder, important for dimensioning of solutions
39. Sedimentation	40. Is there sedimentation, does it affect the polder, opportunity to expand polder, opportunity to use sediment for land reclamation, increase of polder level?
41. Climate change	42. Are there specific effects of climate change (SLR, increased river discharge, droughts) that could impact the FSR in the polder?
43. Flood probability	44. Current protection level from floods of the polder
45. Flood risk	46. Annual expected damages from floods, cyclones? People affected? Value at risk? Is important for the prioritisation of interventions and setting of standards
47. Cyclone probability/risk	48. Susceptibility to cyclones and effects/risks
49. Water quality	50. General water quality from pollution
51. Security	52. Are there security related risks in the polder

53. Environment	54. Would there be potential environmental concern in extension or intensification from polder operation or polder expansion or construction activities?
55. Socio-economic situation	56. Is there significant difference in socio-economic status between polder, do we need to account for distributional effects (1 Tk. is worth more for a poor person than a rich person)
57. FSR/lively hoods	58. Would (or have) potential problem a significant larger impact on FSR/livelihoods than in other polders (also linked to distributional effects)
59. Opportunities	
60. Innovations	61. Could innovative approaches be tested or implemented in construction/problem solving
62. Polder management	63. Can benefits be obtained through combining polder together (or risks reduced by splitting up)
64. Raising of polder level	65. Could polder be subject to increased land level through sedimentation measures?
66. Land reclamation	67. Would land reclamation (or intensification) be possible
68. Urban development potential	69. Would there be a potential for urban developments or real estate development
70. Co-financing	71. Could measures be included that could improve opportunities for combined financing of measures ("leveraging" or revenue generation for government budget)
72. Implementation	
73. Opinion of Stakeholder	74. Which stakeholders? Should the stakeholders not do the actual scoring?
75. Rehabilitation Cost (Crore BDT)	76. This is cost of rehabilitation (LCC; both investments and O&M costs), but to which standards, solving which problems? Based on general assumptions for interventions and unit costs? Which interventions do we include in the plan? Should we limit ourselves to BWDB mandate? Include other interventions? Are other interventions prerequisites for success? Is budget availability a constraint?
77. Economic feasibility	78. The proposed interventions should meet certain economic criteria and benefits in present value should be larger than LCC.
79. Climate change component	80. Which component of the investment are CC related?
81. Compliance to BDP goals	82. 1. Ensure safety against water and climate change related disasters 2. Ensure water security and efficiency of water usages 3. Ensure integrated river systems and estuaries management 4. Conserve and preserve wetlands and ecosystems 5. Develop effective institutions and equitable governance for intra and trans-boundary water resources management 6. Achieve functional and optimal use of land and water
83. Compliance to SDGs	84. All 17 or take selection? SDG1 No poverty SDG2 Zero hunger SDG8 Decent work and economic growth SDG9 Industry, innovation and infrastructure SDG10 Reduced inequality SDG11 Sustainable cities and communities SDG13 Climate action SDG14 Life below water SDG15 Life on land
85. Resource efficiency	86. Do the measures increase resource efficiency, e.g. land and water, labour, etc?
87. Flexible	88. Are interventions flexible, i.e. leave opportunity for future interventions
89. Robust	90. Are interventions robust, i.e. interventions provide protection/increased opportunity under future increased challenges
91. NBS vs Grey infra	92. Promote the use of NBS, including room for the river approach? (in accordance with BDP)
93. Transfer of problems	94. Avoid that interventions in one place lead to bigger problems elsewhere

95. Resilience	96. Look at reduction of impact as well as faster recuperation time
97. O&M	98. Are adequate provisions for maintainability in place?
99. Special Criterion	
100. Remarks	101. Narrative description of the polder stating overall assessment?

The availability of the new polder database facilitates the re- visiting of the old multicriteria analysis in with the advantage of much more data and detailed knowledge of physical processes that govern their responses of natural hazards.

Table 6.2 shows the additional data types that have to be gathered in order the facilitate the multicriteria analysis. This is Step 1 of the Road Map.

The analysis that precedes the collection of all the data and analyses for preparing the Road Map, the selection of the strategy and the detailed consultations that are required before evolving the investment plan would take a long period of time.

In the selection of possible interventions, meetings were held with the Blue Gold project and two World Bank TA projects on coastal resilience and innovative interventions, in order to use the experiences from these projects. In collaboration with the Blue Gold project the idea of “collaborative design workshops” was proposed. It is proposed to have a test, or pilot, activity with this approach for polder 29. This in order to assess the potential of this approach, especially for the measures within the polder for solutions for change in farming system, TRM and water logging. The approach would also allow for the identification of suggestions for improved polder operation and management activities in which local water management groups could take part.

6.4 Investment Plan for the Entire CEIP

The preparation of the investment plan will be described in QPR-6 onwards.

7 DESIGN PARAMETERS, CONSTRUCTION MANAGEMENT & MONITORING

It is the intention of this Research Study that the design parameters used in the future stages of CEIP should take full advantage of new knowledge generated by this project and other projects in the intervening period of 10 years.

The physical design parameters used 10 years ago (for maximum surges levels, wave attack and land subsidence, estimated sea level rise) can be updated with new data and modelling. However, these revised values are not likely to cause major changes in the designs already executed. Nevertheless, it is incumbent upon us to recompute these parameters using the most up-to-date data and modelling outputs.

7.1 Improvement of Physical Design Parameters

It is necessary to revise the estimates we have made of the main design parameters are influenced by the following:

Embankment Design:

e) Maximum storm surge level: Based on more increased modelling accuracy, based on a larger selection of storm events, Wave propagation, incidence and overtopping

f) Ground subsidence: A more detailed knowledge of local subsidence levels are now known

g) Drainage Functionality: Impact of climate change on rainfall and cyclone intensity, More detailed drainage models and alternative drainage arrangements,

h) Impacts of sea level rise and *long-term* morphological impacts (peripheral river sedimentation impacts) on drainage efficiency

Polder Management:

a) Previous design approaches did not pay much attention to the longer-term viability of polder economies in the face of land use changes, urbanisation and industrialisation as well as the improving socio-economic capacity of the population. It is necessary to keep these possibilities in mind for some polders which would be more susceptible to these changes on account of their locations

b) Emphasis on proper water management practices and the need to have infrastructure to support this must also feature in the design. There is also a great deal to learn about improving small scale water management infrastructure from sister projects like the Blue-Gold project.

c) Polder level consultations of the proposed interventions

The conceptual design of the 5 specially selected polders (see Table 6.1) will be based on all the design considerations enumerated above. These five designs will provide guidance for planning the improvement of all the 122 polders and that would comprise the polder development plan leading to formulation of the Investment Plan.

Polder Improvement Plan

The improved design parameters used for designing the 5 specially selected polders will alsp be extended to the entire polder network. For instance, the Bay of Bengal Model of storm surge and wave propagation will be used to determine the embankment crest levels for the entire embankment system.   In addition the internal polder drainage designs would also be completed in parallel.

These design parameters will be determined within the next Quarter in time for formulating the Polder Development Plan

8 INVESTMENT PLAN FOR ENTIRE CEIP

The investment Plan will be discussed in QPR-6

9 CAPACITY BUILDING

The national consultants engaged in the project were able to interact closely with visiting experts and jointly carry out the tasks necessary to analyse data and develop and set up numerical models. The national consultants have received on the job training while working intensively with several visiting experts on various aspects of this study. The names of the experts who worked with the project in the 5th Quarter (October to December 2019 inclusive) are shown below together with their areas of expertise:

Code	Name	Subject Area
IK-1	Dr. Ranjit Galappatti	Project Management
IK-5	Dr. Bo Brahtz Christensen	Micro Scale Polder Modelling
IK-6	Dr. Søren Tjerry	Riverbank Erosion Modelling and Prediction
IK-2	Prof. Zheng Wang	River and Estuarine Morphology
IK-3	Prof. Dano Roelvink	River and Coastal & Estuarine Morphology
IK-4	Dr. Marcel Marchand	Integrated Coastal Zone and Polder Management
IK-7	Dr. Irina Overeem	Macro Scale Morphology
INK-10	Mr. Henrik Rene Jensen	Storm Surge and Wave Dynamics
INK-15	Dr. Kim Wium Olesen	River Morphologist & Micro Scale Polder Modelling
INK-11	Dr. Alessio Giardino	Climate Change Risk Assessment and Adaptation
INK-12	Mr. Mark de Bel	Economic Analysis & Planning
INK-16	Dr. Mick van der Wegen	Estuarine Modelling
INK-17	Dr. Bas van Maren	Fine Sediment Modelling
INK-31	Mr. Reinier Schrijvershof	Morphodynamic Modelling

The modelling work continues uninterrupted, with regular consultation over skype and emails, after the visiting experts return to their home offices, the modelling work.

IWM has vast experience on water management modelling on coastal polder, cyclonic storm surge modelling. A program for on job training of BWDB engineers on polder water management, storm surge and salinity modelling is being developed in this quarter. We have not yet been successful in obtaining the longer-term secondment of BWDB staff for intensive training in modelling.

On the Job Training

Project Director on 26 January 2019 issued an office order (ref: CEIP-1/S-4/1404) that two BWDB officials would be joining Long Term monitoring project office to participate in the modelling works, data processing and other relevant works with the assistance from the consultants. The concerned officials according to the office order have started participating in the above project activities at two days in a month (last working day of 2nd and 4th weeks of the month). Details of the officials are given below.

Sl No.	Name and Designation	Name of office
1	Mr. Md Majedur Rahman, Executive Engineer	Design Circle-4, BWDB, Dhaka
2	Mr. Zakaria Parvez, Executive Engineer	Haor Flood Management and livelihood Improvement project, BWDB, Dhaka

9.1 Training Courses and Study Tours

No special Training Courses or new Study Tours were arranged during the 5th Quarter. Three BWDB engineers are currently engaged in following the MSc course at IHE, Delft.

9.2 Stakeholder Workshops

The Inception Workshop which was held 9 January has already been reviewed and acted upon by the entire water resources community in Bangladesh. The Final Inception Report, containing responses to several rounds of comments was finally published on 20 February 2019 and accepted by the Client.

There were two Stakeholder Consultation Workshops; first to be held in Barisal on 30 March 2019, and the second to be held in Khulna. The second Workshop was eventually held on 27 April 2019. The Workshops were held under the patronage of the State Minister of Water Resource, the Secretary of the Ministry and other senior officials. There was a wide cross-section of participants from a range of stakeholder organisations with lively discussions and exchanges of views. Almost the entire proceedings, which were conducted in Bangla has been documented. The reports await translation into English pending submission officially to the Client and the World Bank.

A third workshop is scheduled to be held in Chittagong in the next quarter.

10 CONCLUSION

This report describes the extent of work done in the Fifth Quarter of this project from 1 October 2019 to 31 December 2019.

Only the outline of the work is described in this report because of the fact that the technical/scientific results of the work are being presented in a separate series of technical reports published by the project.

Some difficulties have been experienced by the fact that the contract budget does not cover some expenditure that are unavoidable.   Among these are the payment of the domestic air travel costs for project staff and the payment of customs duties and taxes that arise when goods and equipment are imported to be handed over to the BWDB after they are deployed for field work. It will be necessary to apply to the Project Director to obtain additional budget to cover these costs.