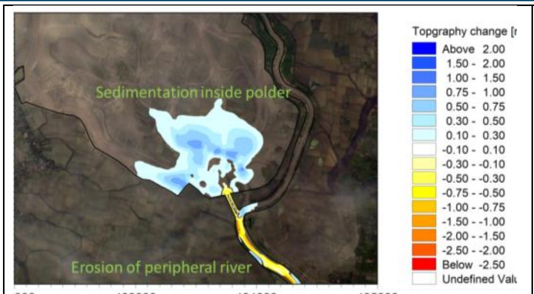
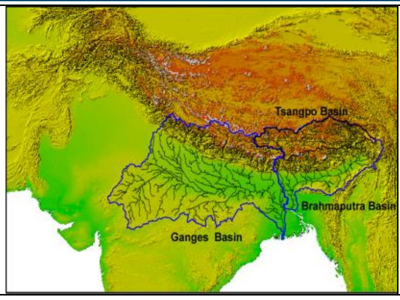
Ministry of Water Resources

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-6

June 2020

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Bangladesh Water Development Board

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Bangladesh Water Development Board
Coastal Embankment Improvement Project, Phase-I (CEIP-I)

Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone

Office: Flat #3/B, House #4, Road #23/A, Banani, Dhaka 1213, BANGLADESH Phone +880 1307 693299

Memo No: CEIP/LTMRA/0620/72 10 Jun 2020

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

Attn: Dr. Md. Mizanur Rahman, Project Director

Dear Dr Rahman,

Subject: Submission of Quarterly Progress Report-6

It is our pleasure to submit herewith three copies of the Quarterly Progress Report-6. This is the 6th Quarterly Progress Report describing the progresses made between 1st January 2020 and 31st March 2020. The report comprises seven chapters describing development of input datasets for modelling including coastal database, Modelling long term processes, subsidence and climate change studies, Polder development plan and design parameters.

We regret that the submission of the report has been delayed due to interruption of the COVID-19 crisis.

Thanking you,

Yours sincerely,

Dr Ranjit Galappatti
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, DHI
Dr Alessio Giardino, Deltares Project Manager
Mr Zahirul Haque Khan, Deputy Team Leader
Mr AKM Bodruddoza, Procurement Specialist

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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

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. QPR-5 covering the period 1 October 2019 to 31 December 2019 was submitted in February 2020. This is the Sixth Quarterly Progress Report describing the progress made between 1 January to 31st March 2020.

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. 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																															
	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																															
	D-3:4	GIS based National Coastal Polder Database/ Management Information System/ Database																															
	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																																
	D-4A-1:2,3	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-1:4	Technical reports (one report for 4A-1 Final Report on Morphological Trend)																															

Table 1.1 (contd) Activity Schedule Page 2

D-4A-2		**Morphology on a meso scale**
	D-4A-2:1	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-2:2,3	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; 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-2 - FINAL REPORT ON ESTUARINE MORPHOLOGY)
D-4A-2		**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
	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)
		Other special purpose models
D-4D-3	**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

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 sediment needed to counteract this subsidence.
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, Costs and benefits. 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-6.3	**D-6.2 & D-6.3**	Report on Management plans for the polders including review approaches of polder management and performance monitoirng mechanism 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

DHI

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				
	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				
	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			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	30	***26***		Update Polder Inventory, Characterisitcs, (incl land use, population, economic activity, … Problems requiring solutions Ongoing (include 17 Polders)
	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	***22***		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.	Polder Development Plan	Feasibility Report on each of 3-5 Polders	10 to 14	***24***		Study has commenced
	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		Draft Report on 3-5 Polders	4-21	21		Awaiting study results
				Final Report on 17 polders	21-30	21		Include within Development Plan
	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 Oveall Delta	24	***27***		Awaiting results of other studies
				Cost Benefit Analysis	new item	***21***		Will be included into Report on 3-5 polders
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			Part of the inception report
D-6.2	D-6.2 & D6.3	Report on Management plans for the polders	Polder Management	Polder Management Plan including:	30	***28***		
		Detailed delivery plan to be developed during the inception phase		6-2: Review approaches for polder development and				
D-6.3		Report on participatory monitoring mechanism with goals and targets		6-3 : Performance Monitoring Mechanisms				
		Detailed delivery plan to be developed during the inception phase		Detailed Delivery Plan				
D-7	D-7	An investment plan describing a phaased polder improvement roadmap and required budget 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	Investment Plan and Fund Raising	Investment Plan fo Enitire CEIP	24-30 none	***28***		Suggested to be merged into one report "Investment Plan and Fundraising Strategy
D-8		Action Plan for Capacity Building	Capacity Building and Technical Sustainability	Action Plan for Capacity building	6			Under preparation
		On the job technical training in country		In-country on-the- job Training	0 - 24	3-27		Requires more BWDB participstion
	D-8	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	Outreach programme	Workshops	12,16,24,27		√ (3, 6, 7)	3 workshops to date; Reports submitted
		Workshop Report		Workshops Report			√ (4, 11, 11)	

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	Feb-21
		Macro	Macro scale River Model	Model Set up Calibration & Validation	a		Feb-21
		Macro	Macro scale River Model	Model Set up Calibration & Validation	a		Feb-21
		Macro	GBM Basin Model Applications	Climate Change Simulations	b		Feb-21
		Macro	Macro scale River Model Applications	Climate Change Simulations	b		Feb-21
		Macro	Macro scale River Model Applications	Climate Change Simulations	b		Feb-21
		Macro	Sediment Budget Analyses	Long Term Sediment Balances in Delta			Feb-21
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		Nov-20
		Meso	Baleswar-Bishkhali Model	Model Set up Calibration & Validation	a		Nov-20
		Meso	Lower Meghna	Model Set up Calibration & Validation	a		Nov-20
		Meso	Sangu	Model Set up Calibration & Validation	a		Nov-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 geospatial datasets should include full meta-data and be stored and archived in Database of BWDB	Meso	Pussur Sibsa	Long Term Morphology Applications	b		Feb-21
		Meso	Baleswar-Bishkhali Model	Long Term Morphology Applications	b		Feb-21
		Meso	Lower Meghna	Long Term Morphology Applications	b		Feb-21
		Meso	Sangu	Long Term Morphology Applications	b		Feb-21
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		Jun-20
		Meso	Sibsa	Model Set up Calibration & Validation	a		Jun-20
		Meso	Baleswar	Model Set up Calibration & Validation	a		Jun20
		Meso	Bishkhali	Model Set up Calibration & Validation	a		Jun-20
		Meso	Lower Meghna	Model Set up Calibration & Validation	a		Jun-20
		Meso	Sangu	Model Set up Calibration & Validation	a		Jun-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 geospatial datasets should include full meta-data and be stored and archived in Database of BWDB	Meso	Pussur	Erosion Prediction Report	b		Nov-20
		Meso	Sibsa	Erosion Prediction Report	b		Nov-20
		Meso	Baleswar	Erosion Prediction Report	b		Nov-20
		Meso	Bishkhali	Erosion Prediction Report	b		Nov-20
		Meso	Lower Meghna	Erosion Prediction Report	b		Nov-20
		Meso	Sangu	Erosion Prediction Report	b		Nov-20
D-4A-2: 4	Technical report (one report for 4A-1 and 4A-2)	Meso	**FINAL REPORT ON BANK EROSION MODELLING**		D		Nov-20
			Other special purpose models				
		Meso	Pussur-Sibsa fine sediment model- ext	Pussur Sibsa Fine Sediment Model	E		Nov-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 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. 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
D-4A-3: 1, 2, 3	The model setup developed will be updated under this project with all accompanying	Micro	Pilot TRM Model for Polders 24 etc	TRM Model for Polder 24	F		Nov-20

TOR Reference	TOR Deliverables	Scale	Model	Description each			Delivery Dates
	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**	5 or more polder models	Drainage Model Reports	**H**		Sep-20
			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 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 sediment needed to counteract this subsidence.		Field Campaigns (several)	Continuous GPS & Surface Elevation Tables, Borehole sampling, luminescence testing etc			Dec-20
			Subsidence Geospatial Datasets	Report		Aprl to Oct 2020	
			Detailed Technical Reports on Subsidence and Flood Plain Sedimentation			Oct-20	Dec-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				May-20
			CLIMATE CHANGE EFFECTS			Oct-20	
			Clinmate Change & Preciptation,			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 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.		Salinity intrusion & Groundwater Salinity			Oct-20	Feb-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	Dec-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	Dec-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). The additional data collection carried out during this quarter, including the Geophysical data collected by the US university teams, are 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 January 2020 to March 2020, no bathymetry survey has been carried out. The progress of other survey activities is shown in Table 2-1 to Table 2-6.

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

Table 2.1: Progress of discharge observation

SL no.	Location/ River Name	Target (Number)		Progress upto Dec-2019	Progress in between Jan - Mar 2020	Cumulative progress upto March-2020	Remarks
		TOR	Modified				
A	3 main rivers						
1	Bahadurabad, Brahmaputra	18	48	14	5	19	
2	Hardinge Bridge, Ganges	18	48	15	5	20	As per post inception consultation (Twice a months for 2 years)
3	Bhairab Bazar, Upper Meghna	18	48	18	5	23	
Total of A		54	144	47	15	62	
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		8	7	1	8	
6	Nalian, Shibsha		8	7	1	8	
7	Charduani, Baleswar	44	8	7	1	8	For each location 8 measurement: 1 spring in every two months and -1 neap in every six months for the periods of one year.
8	Bhandaria, Baleswar		8	7	1	8	
9	Polder-17/2, Gangril		8	7	1	8	
Total of C		44	40	35	5	40	
D	Additional 3 tidal River						
10	Dasmina, Tetulia	0	2	2	1	4	2 nos. measurement during June-Oct-19, 1 Spring+ 1 Neap
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	Progress upto Dec-2019	Progress from Jan-Mar 2020	Cumulative Progress upto Dec 2019
A	3 main rivers						
1	Bahadurabad, Brahmaputra	18	48	1056	1241	432	1673
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	2556	180	2736
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	561	72	633
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 Dec-2020	Progress in between Jan to Mar-2020	Achieved upto Mar-2020	
1	Suspended Sediment sampling	33	23	0	23	More sample will be collected during June-Sep 2020.
2	Collection of Bed Sample	55	63	0	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 Dec 2019 ($stat^n$-month)	Progress from Jan-Mar 2020 (statn-month)	Cumulative Progress up to Mar 2020 (statn-month)	Remarks
A	Recording of Water level at Hironpoint, Pusur/Kaikhali, Ichamoti							
1	Kaikhali, Ichamoti	15-Feb-19	12	12	10	3	13	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. Data collection will be continued upto May 2020.
B	Recording of water level in others areas							
1	Dularshar, outfall of Rabnabad Channel	18-Feb-19	40	12	10	3	13	Data collection will be continued upto May 2020.
2	Taltoli, outfall of Biskhali /Baleswar	17-Feb-19		12	10	3	13	Data collection will be continued upto May 2020.
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	43	6	49	

Table 2.5: Progress of Salinity Data Collection

Stat^n ID	Station Name	River_Name	Easting (m)	Northing (m)	Start date	Progress upto Dec-2019	Progress from Jan-Mar 2020	Cumulative Progress upto Mar-2020
1	Bashantapur	Isamoti	706840	2486285	12-Feb-19	10.5	3	13.5
2	Kaikhali	Modan Gauga	714395	2455144	13-Feb-19	10.5	3	13.5
3	Kobadak	Kobadak	738053	2459252	15-Mar-19	9.5	3	12.5
4	Nalian	Shibsha	749190	2486655	13-Feb-19	10.5	3	13.5
5	Gangrail	shundor mohol	746284	2509461	10-Mar-19	9.5	3	12.5
6	Khulna	Rupsha	764985	2523883	8-Mar-19	9.5	3	12.5
7	Bardia/ Nabaganga	Noboganga	773750	2555764	19-Feb-19	10.0	3	13.0
8	Chapailghat	Modhumati	786778	2544530	13-Feb-19	10.0	3	13.0
9	Patgati	Modhumati	797052	2533438	16-Mar-19	9.5	3	12.5
10	Mongla	MonglaNala	767846	2487421	10-Mar-19	9.5	3	12.5
11	Joymoni	Pussur	770059	2478036	9-Mar-19	9.5	3	12.5
12	Gasiakhali	Gasiakhali	796021	2484687	22-Mar-19	9.3	3	12.3
13	Char Doani	Baleswar	800083	2449931	13-Feb-19	10.5	3	13.5
14	Bishkhali DS	Bishkhali River	808483	2439742	6-Mar-19	9.5	3	12.5
15	Hiron Point	Pusur	756533	2412633	10-Mar-19	9.5	3	12.5
16	Mohipur	Shibbaria Khal	200814	2419537	25-Feb-19	10.0	3	13.0
17	Khepupara Kol	Adhanmanik	214449	2431880	13-Feb-19	10.5	3	13.5
18	Madhupara	Andharmanik	222130	2433381	13-Feb-19	10.5	3	13.5
19	Amtali	Burisuar	213580	2450306	5-Mar-19	9.8	3	12.8
20	Patuakhali	Buriswar	217267	2473096	15-Mar-19	9.5	3	12.5
21	Burhanuddin	Tetulia	257606	2494785	3-Mar-19	10.0	3	13.0
22	Daulatkhan	Meghna	264409	2504558	13-Feb-19	10.5	3	13.5
23	Hilsha	Ganeshpura	255886	2524418	13-Feb-19	10.5	3	13.5
24	Moju Chowdurir	Lower Meghna	271573	2524453	13-Feb-19	10.5	3	13.5
25	Ramgati	Lower Meghna	296451	2496925	2-Mar-19	10.0	3	13.0
26	Char Elahi	Outfall of Noakhali Khal	316468	2512380	13-Feb-19	10.5	3	13.5
27	Musapur	Little Feni outfall	334907	2517844	1-Mar-19	10.0	3	13.0
28	Kalurghat Brid	Karnafuly	379618	2469046	27-Feb-19	10.0	3	13.0
29	Patenga	Karnafuly	378241	2459360	13-Feb-19	10.5	3	13.5
30	Sangu Outfall	Sangu	380988	2449507	28-Feb-19	10.0	3	13.0
Total (station-month)						300	90	390

Table 2.6: Progress of Monitoring Section

SL no.	River name	Left bankPosition in UTM		Target as per TOR (event)	Progress up to Dec-2019	Progress in between Jan 2020 to Mar 2020	Cumulative Progress up to Mar-2020	Remarks
		Easting (m)	Northing (m)					
1	Pusur	762273	2501059	4	2	1	3	Next data collection is scheduled in May-2020
		765884	2494718					
2	Sibsha	751161	2487806	4	2	1	3	so
		751557	2482153					
3	Kobadak	734559	2474997	4	2	1	3	so
		735522	2468624					
4	Chunkuri	759390	2500705	4	2	1	3	so
		758092	2498287					
5	Badurgacha	753417	2504229	4	2	1	3	so
		749232	2499644					
6	Dhaki	755788	2498307	4	2	1	3	so
		751834	2493821					
7	Gangril	739773	2522911	4	2	1	3	so
		746214	2515543					
8	Gashikhali	772383	2496263	4	2	1	3	so
		769190	2489629					
9	Andharmanik	206871	2432616	4	2	1	3	so
		214473	2433381					
10	Galachipa	233074	2451448	4	2	1	3	so
		232892	2462016					
11	Baleswar	808406	2488650	4	2	1	3	so
		796650	2467005					
12	Lower Meghna	259138	2565429	4	2	1	3	so
		261237	2543677					
13	Shangu			4	1	1	2	so
Total				52	25	13	38	

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 2.7.

Table 2.7: 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 2.8) from the existing hand tube wells. The list of the selective locations for water sampling is given in Table 2.9 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 2.8: 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).

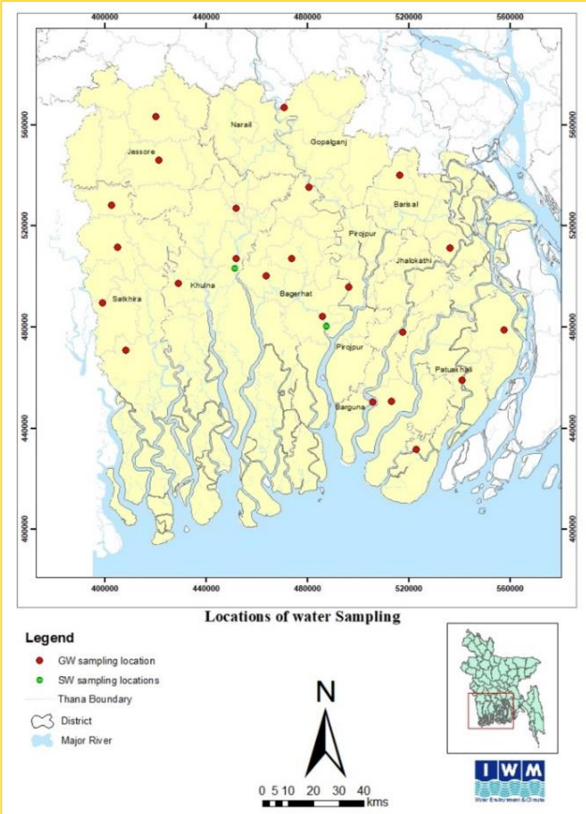

Figure 2-2: Locations of Water sampling

The areas under different salinity level in groundwater during September and January is given in Table 2.9

Table 2.9: List of the Selective Locations for Water Sampling

Remarks	**Salinity (mg/l)**	**Area (km²)**	
		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

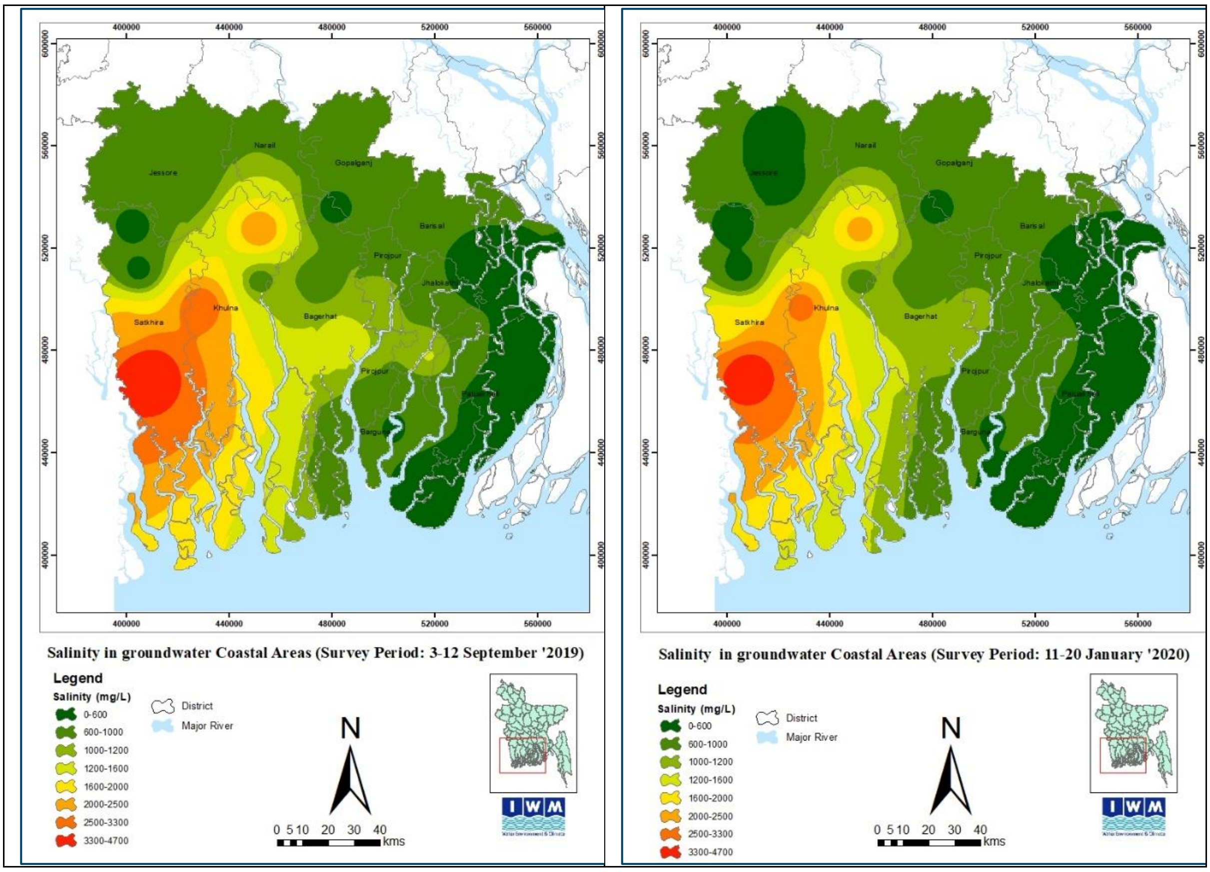

Figure 2-3: Groundwater Salinity in Monsoon & Post-monsoon

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.

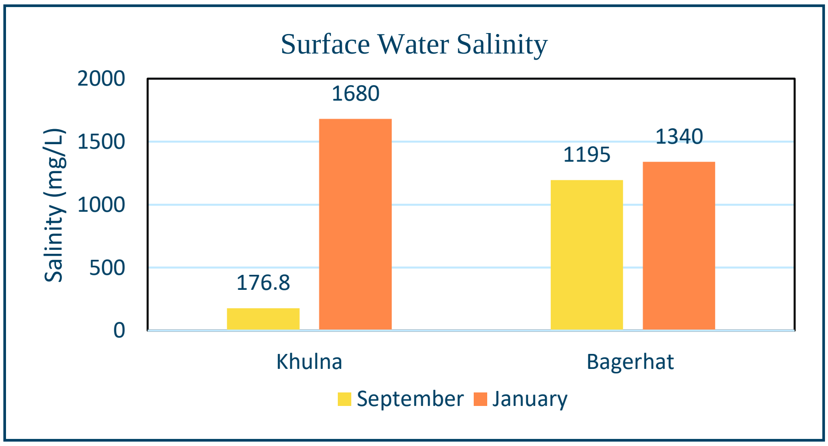

Figure 2-4: Surface Water Salinity in Monsoon & Post-monsoon

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.

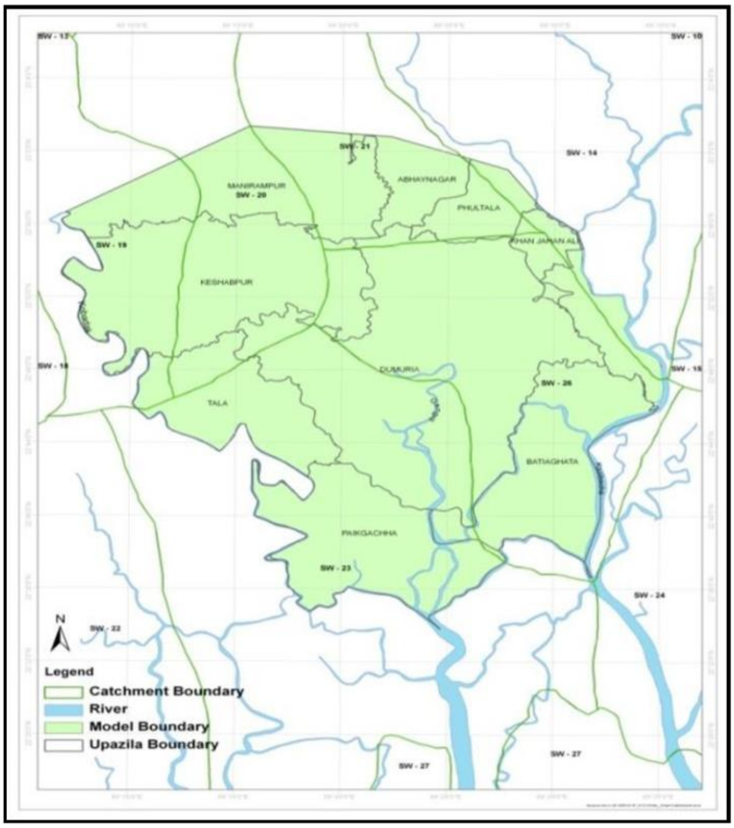

Figure 2-5: Location of Model Area

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 km^2 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.

2.4 Field Surveys

2.5 being carried out by US University Teams

Participants:	IK-9	Michael S. Steckler, LDEO, Columbia University	
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		Céline Grall, CNRS LIENSs, La Rochelle, France	
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	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:

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

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. 2.7) 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. 2.9). The other was installed on a rod 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

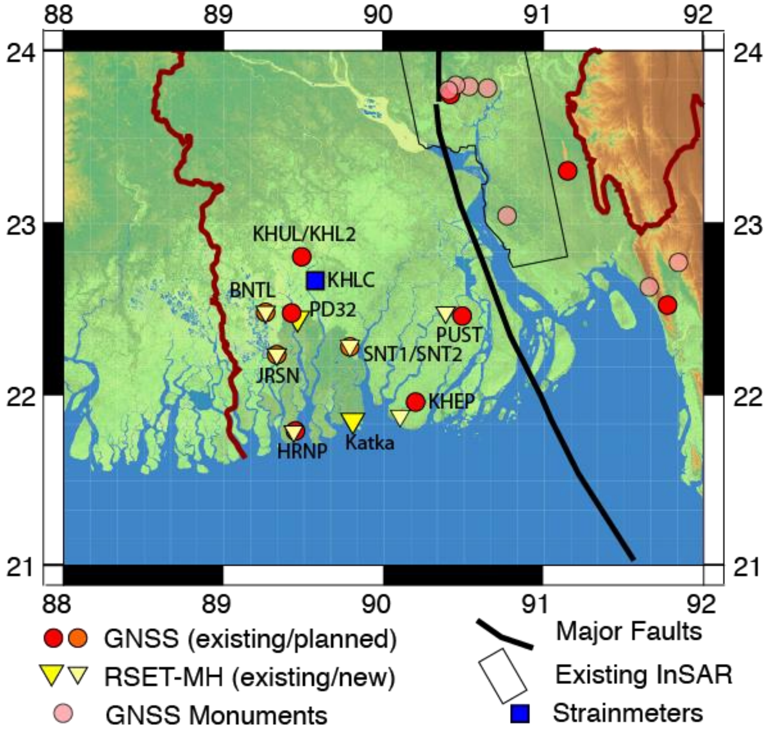


Figure 2-7: Map of GPS and RSET sites installed, upgraded or serviced in July 2019. All GPS sites except HRNP have cellular connections for data downloads. HRNP point data is downloaded by the RSET team when they service the RSET.

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.

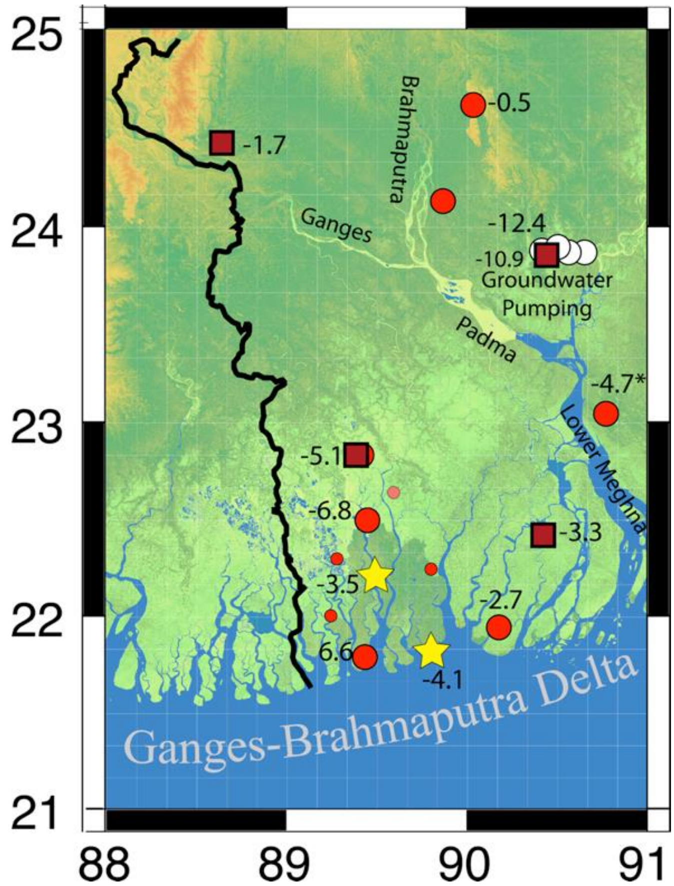


Figure 2-8: *Map of SW Bangladesh showing subsidence rates obtained from GPS and historic sites.*
Maroon squares: GPS sites installed in 2003;
Large red circles: GPS sites installed from 2007-2012;
Small red circles: new sites installed in 2019.
Yellow stars: historic sites analysed for subsidence.

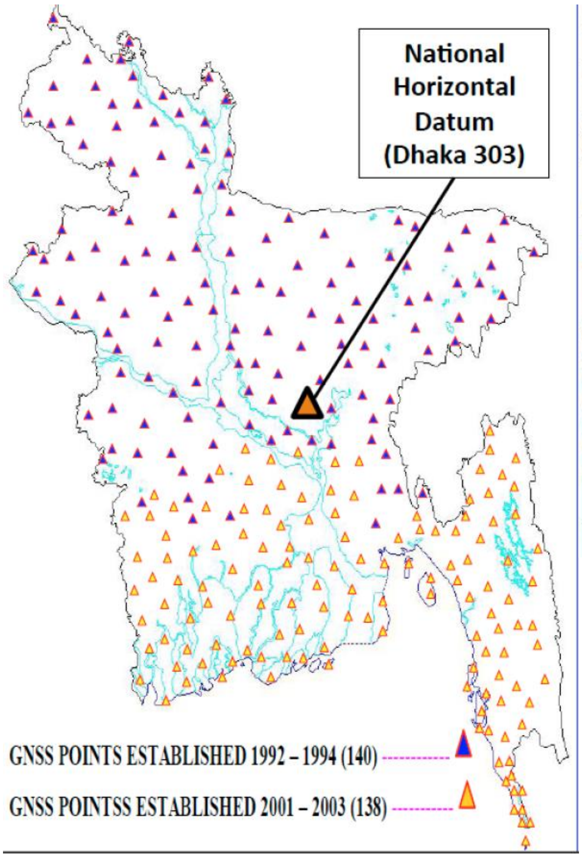
Figure 2.8 shows a summary of the subsidence rates obtained so far. Sites in the northwest of Bangladesh at Rajshahi (RAJS) and Madhupur (MPUR) yield low subsidence rates of -1.7 and -0.5 mm/y. These sites are located NW of the hinge zone where the total sediment thicknesses are much less than beneath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

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.



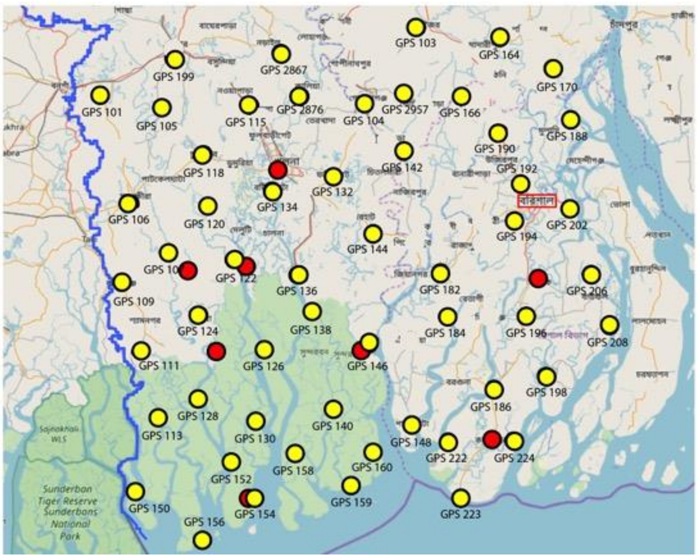


Figure 2-9: *Map on the left shows the position of the 278 geodetic monuments installed by the SoB. The map above is a close up of the field area showing the 55 monuments targets for reoccupation with yellow circles. The red circles are the positions of our existing continuous GPS installations.*

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.

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.*

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.

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.*

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 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.

2.4.4 Completion of the Survey

Céline Grall stayed in Barisal to work with the Barisal University team for a few more days, then joined me in Dhaka for a conference and meetings. Upon completion of her meetings in Dhaka, Dr. Grall rejoined Hasnat Jaman and his students for further measurements. They shifted to Khulna as a base and continued the survey from January 17-28, 2020. 24 sites were visited. They collected new GPS measurements from 16 sites. Two of the sites had tall monuments (GPS 199 and GPS 2876) and need a different tripod. Six sites had obstructed views and need a levelling survey similar to the one done at GPS 206. One site was buried or destroyed and could not be found.

Due to the need for a surveyor at multiple sites and the likelihood that a surveyor would also be needed at some of the sites in the Sundarbans, Hasnat Jaman arranged for a surveyor from IWM to accompany the team for the rest of the GPS campaign. Prof. Jaman led the survey of the remaining 9 land sites with the surveyor on February 20-29, including site GPA 196 at Patuakhali, which could not be measured during the first phase of the campaign.

The final thirteen sites were best accessed by boat. Twelve are in the Sundarbans, mainly at Forestry Stations, and one is at Joymonirgol, adjacent to the Sundarbans. The team used the M/V Mabana from March 7-16 to reach the sites. A surveyor again accompanied the team. Measurements were made at 9 sites, the remainder having been eroded by the shifting tidal channels. Two of the sites (GPS 140 and GPS 160), in addition to needing the surveyor were badly eroded (Fig 2.12). The measurements are suspect. In all, 48 of the 55 identified sites were occupied and campaign GPS data was collected (Fig. 2.12). Processing of the data from 2002 and 2020 is underway and we expect to be able to obtain subsidence rates at ~44 sites.

Photograph -1 A) Badly eroded monument GPS 140 in the Subdarbans. B) Monument GPS 194 along the edge of a road. There is concern about whether some monuments, such as this one may be disturbed by local ground motions.

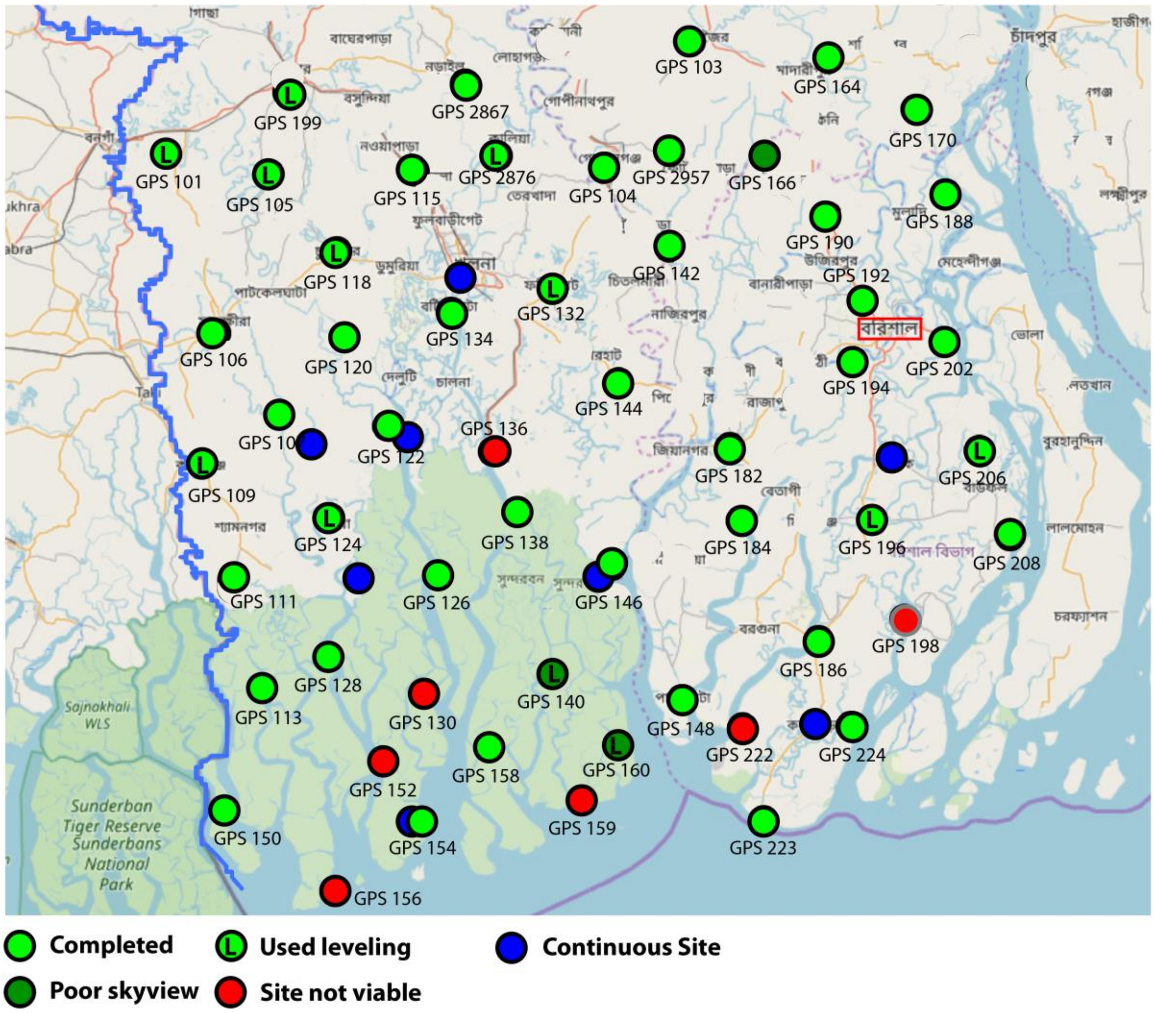


Figure 2-12: GPS locations showing the data collected during the 2020 GPS expedition.

2.4.5 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 most of the data is of high quality and we expect to be able to obtain subsidence rates from 44 sites. For the 2020 survey, we have calculated the offsets from the phase centre of the antennas to the monument using the slant height measurements made at the beginning and end of each occupation during the survey (Fig. 2-13). For monuments where the brass pin has been eroded, an estimate has been made of that amount and a correction added, where possible. Similarly, where levelling has been done, the elevation has been corrected by the vertical offset of the temporary mark and the monument determined by the surveyor. Estimates of all of the uncertainties have been carried forward for all the sites. We have completed conversion of the data to RINEX format and done quality control checks on the data. Initial automatic processing using the GIPSY software on the JPL website as a further quality check. For final processing, 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 of the 2020 data. The processing will be done using both GAMIT and GYPSY software.

In order to obtain the most 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, near the coast and thus could contribute 1-2 mm/y to the subsidence estimates 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 2003-2014. However, data for 2002 and more recent data spanning the period of observations is necessary. Syed Shamsil Arefin at the Project Office has been assigned to obtain this data. Obtaining this data has been delayed by the COVID-19 lockdown.

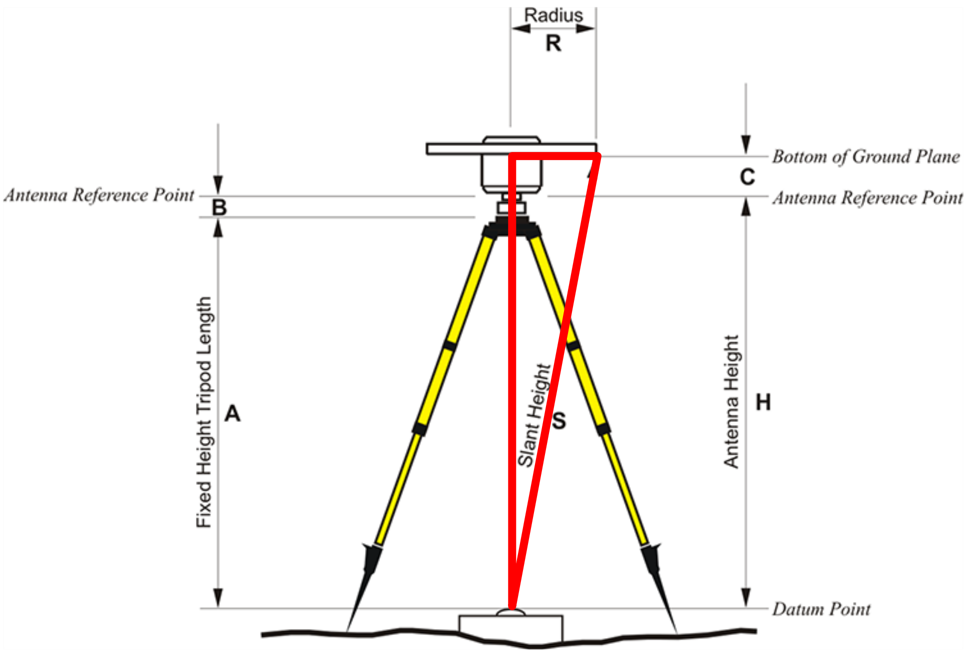


Figure 2-13: Schematic showing the measurement of the slant height for an antenna mounted on a tripod. The vertical height to the reference point at the base of the antenna is then calculated as $H = \sqrt{(S^2 - R^2)} - C$.

3 DEVELOPMENT OF THE COASTAL DATABASE

3.1 Introduction

This report presents the progress of developing an Interactive Geodatabase for Coastal Zone (IGDCZ) which has been achieved during the 6th quarter (January 2020 to March 2020) of the project. The development of IGDCZ database is included in Component-3 in the ToR of the project having the objectives are:

- To collect all input datasets, undertake Quality Assurance/Quality Checking (QA/QC) and update/modify datasets as necessary for use in the modelling of the physical processes in the coaster zone of Bangladesh
- To improve the process of data collection, QA/QC and data dissemination and sharing among the government agencies

In order to achieve the objectives of the project, a set of tasks and activities mentioned in the ToR are being carried out. One of the major tasks is to collect data from both field survey and secondary sources. After successful validation, verification and processing, processed data are being uploaded into the database. There are several numbers of spatial and non-spatial layer and dataset have been identified, are being collected and uploaded in the database. A Web GIS based application is being developed for visualizing, analysing and updating these datasets and layers in GIS environment. This application is secured and password protected. Different levels of users (privileged and general users) can the application.

The datasets were processed and included in the database in a way that will be comprehensive, consistent, reliable and complete according to the sources, methods of data collection and processing. The final database will be open for designated users selected by BWDB and the option will be given to further update the database by the privileged users of BWDB. Most of the data are spatial, geo-referenced with real-world situation are maintained in Geodatabase, and the non-spatial data (tabular data) are maintained in tabular forms in the database.

The Web GIS based Application includes several modules organized in a dashboard, these are Web GIS module, Metadata module, User Registration module, Document Archive module and a User help (user manual).

Progress at a Glance: Following Table 3.1 presents the database development progress up to the 6th Quarter of the project.

Table 3.1: Progress at a Glance

Sl No	Task & Activities	Progress (%) Upto 5th Quarter	Progress (%) 6th Quarter	Overall Progress (%)
1	Inception Phase			
1.1	Review Existing Systems	100	-	100
1.2	Consultation with Project Team	continue		continue
1.3	Consultation with Project Client	continue		continue
1.4	Requirement Analysis	100	-	100
1.5	Data Requirements and Data sources	100	-	100
1.6	Conceptual System Architecture	100	-	100
1.7	Inception Report	100	-	100
2	Data Collection and Processing			
2.1	Coastal Bank Erosion (Satellite Image)	0	95	95
2.2	Landuse Classification (Satellite Image)	0	25	25
2.3	Other Data Collection (shapefile & tabular)	60	10	70
2.4	Other Data Processing (shapefile & tabular)	60	10	70
3	GIS Mapping			
3.1	Polder Maps for Data Collection	0	50	50
4	Database Design & Development			
4.1	Database Design	100	-	100
4.2	Database Design Report	100	-	100
4.3	Database Development	60	10	70
5	Web GIS Application Development			
5.1	IGDCZ Prototype Development	100	-	100
5.2	Full Version Development	35	15	50
5.3	Testing & Debugging	30	10	40
5.4	Fully operational commissioning	-	-	-
6	Training & Technology Transfer	-	-	-
7	Feedback and update	continue		continue

3.2 Data Collection

Data Collection is an ongoing process, from the initiation of the project relevant dataset are being collected from field survey and secondary sources. The secondary sources are actually the principal sources of data sets such as, BWDB, WARPO, BMD, GSB, BBS, IWM and SoB and other relevant organizations. There are more than 60 numbers of data layers are being processed for the database.

The data collections are performed in three ways: i) Field Survey, ii) Secondary sources, and iii) Remote Sensing through Satellite Image Processing techniques.

i) Field Survey

Several number of data sets have been collected from field level survey. Collection of data through field survey able to represent the current scenario of the coastal areas. Long Term project has initiated different type of field investigation/survey to identify the changes in water level, discharge, water quality, sedimentation, coastal erosion, embankment breaching, embankment condition, water logging etc. These collected data are being processed and simultaneously updated the database.

ii) Secondary Sources

The data from secondary sources include the basic spatial and non-spatial data, the sources are BWDB, WARPO, DBHWD, BMD, SOB, LGED, RHD, GSB, IWM, BARC, BBS etc. The secondary data also include Topographic ground height, Hydrometeorological and Hydrological historical data time series data, cross section data of river/khal, cross section data of Embankment, locations of polder physical infrastructures such as Embankment, Protective work, Hydraulic Structures etc. locations river and canals/khals, communications such as roads and bridges, and water ways etc. population distribution, settlement areas, location of administrative areas such as districts, upazila and union etc. All these mentioned data are being collected from relevant principal sources.

iii) Satellite Image Processing

The temporal changes of the locations of coastal bank lines, temporal changes in Land use classification are being generated from satellite image processing. The locations of bank erosion and land use classification are extracted using Image interpretation and classification techniques.

- Coastal Bank Erosion

The coastal banks are more dynamic in Bangladesh. It is of a vital need to know the coastal bank erosion during the last several years. In order to do this a study has been done on temporal change on coastal bank erosion using remote sensing satellite image analysis. This study utilized several historical LandSat Images of the year 1989, 1995, 2000, 2005, 2010, 2015 and 2020 and making spatial comparisons of bank line periodic changes @5 years over the last 20 years.

- Land use Classification

The delineation of landuse classification task is ongoing. The landuse classification exercise includes the land use change over the last 30 years using satellite image classification techniques in remote sensing application. This exercise is utilizing LandSat images of the year 1989, 2000, 2005, 2010, 2015 and 2020 to get the temporal changes of land use classifications in the coastal area. This will produce a landuse classification dataset for the coastal database.

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 Preparation of Polder Maps

More than 60 numbers of individual polder maps have been prepared for field data collection. These maps were composed with basic features in order identify different locations of embankment breach, bank erosion, water logging areas, sedimented areas, embankment type by changes, embankment conditions, locations of structure etc. in the polder areas. These field information on maps will be used to update coastal database. Subsequently, IWM is updating the database according to the collected field information.

3.4 Web GIS based Application Development

A Web GIS based database application entitled “Interactive Geodatabase for Coastal Zone (IGDCZ)” is currently under development. The progress and achievement of this development has been presented in the midterm workshop held at BWDB head quarter. The web GIS based application has several modules such as i) Dashboard ii) GIS Core module as Interactive GIS iii) Metadata iv) Documents v) Project Management, vi) Feedback and vii) Tutorial.

User Login
This web GIS application is protected by login and password from any un-authorized users, login or login on, signing in, or signing on is required to access this database application. This requires the user should have proper credential to access the database application. The user login is typically email Id of users and standard password of the user. The new user should be registered in the system, the registration will be done by the System administrator or manager for the users. Figure 3.1 presents the User Login page.

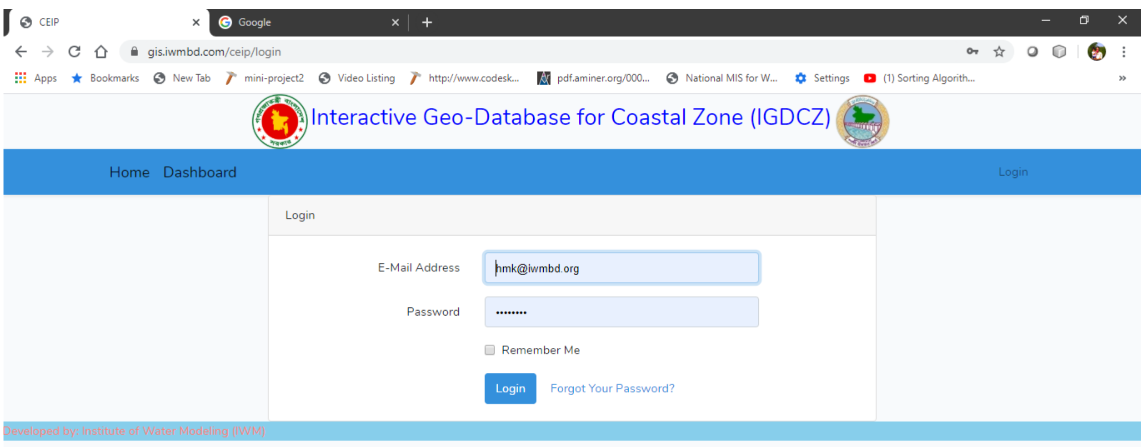


Figure 3-1: User Login Page

- **Dashboard:** A Dashboard containing the access point of different modules in the application is shown in the following Figure 3.2.

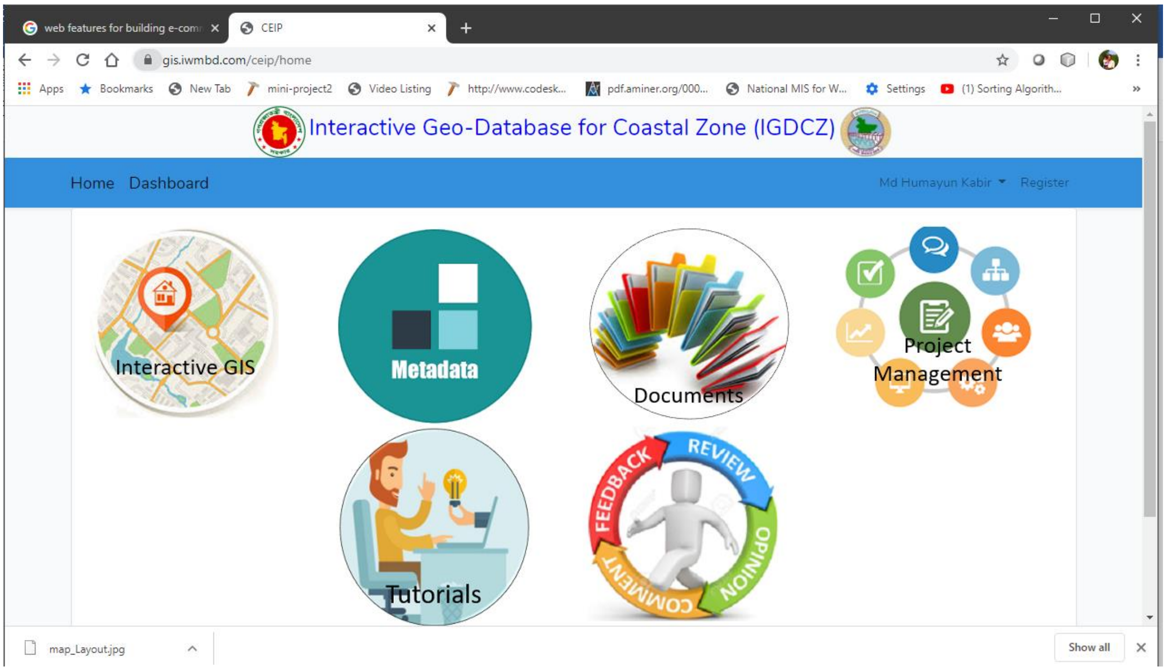


Figure 3-2: Dashboard

- **Interactive GIS:** This module provides web GIS service to the users. All the related spatial and non-spatial data layers are organized in a web GIS environment in which any layer or dataset can be visualized interactively from the database. Proper symbols and colours are used to distinguish different type of features in the map. Standards tools, menus and dialog widows have been used to interact with the respective operations. The map elements such as standard legend, north arrow and scale bar are also used in the map interface. A spatial feature search/query is also given in this module, so that user can identify any spatial feature on the map which dynamically locates and simultaneously zooms to the selected features. The web interface of this Interactive GIS module is shown in the following Figure 3.3.

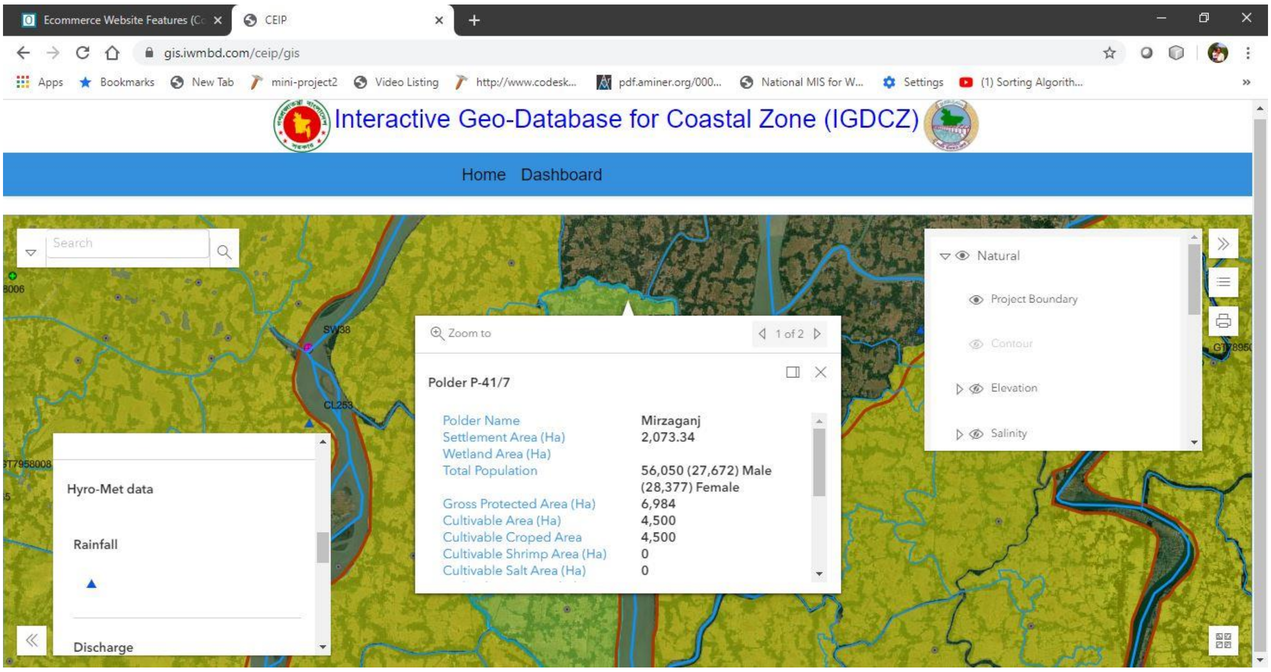


Figure 3-3: Interactive Web GIS Module

Hydrological time series data are organized in the database according to observation station, different types of hydro-meteorological data such as surface water level, groundwater depth, rainfall, temperature, salinity etc. are organized in the database. Each type of observation stations is organized in spatial layers in the map. Following Figure 3.4 shows a hydrograph prepared by the system.

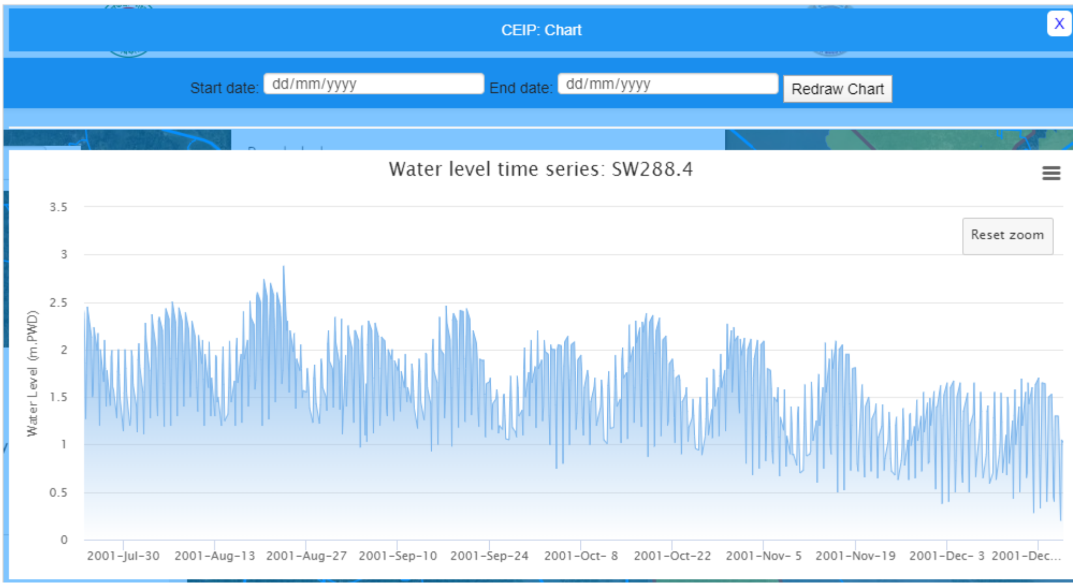


Figure 3-4: Hydrograph of Surface water Time Series data

Facilities for preparing composed map into map layout are also developed and included in the application and shown in the following Figure 3.5 for printing or exporting in graphics or PDF formats.

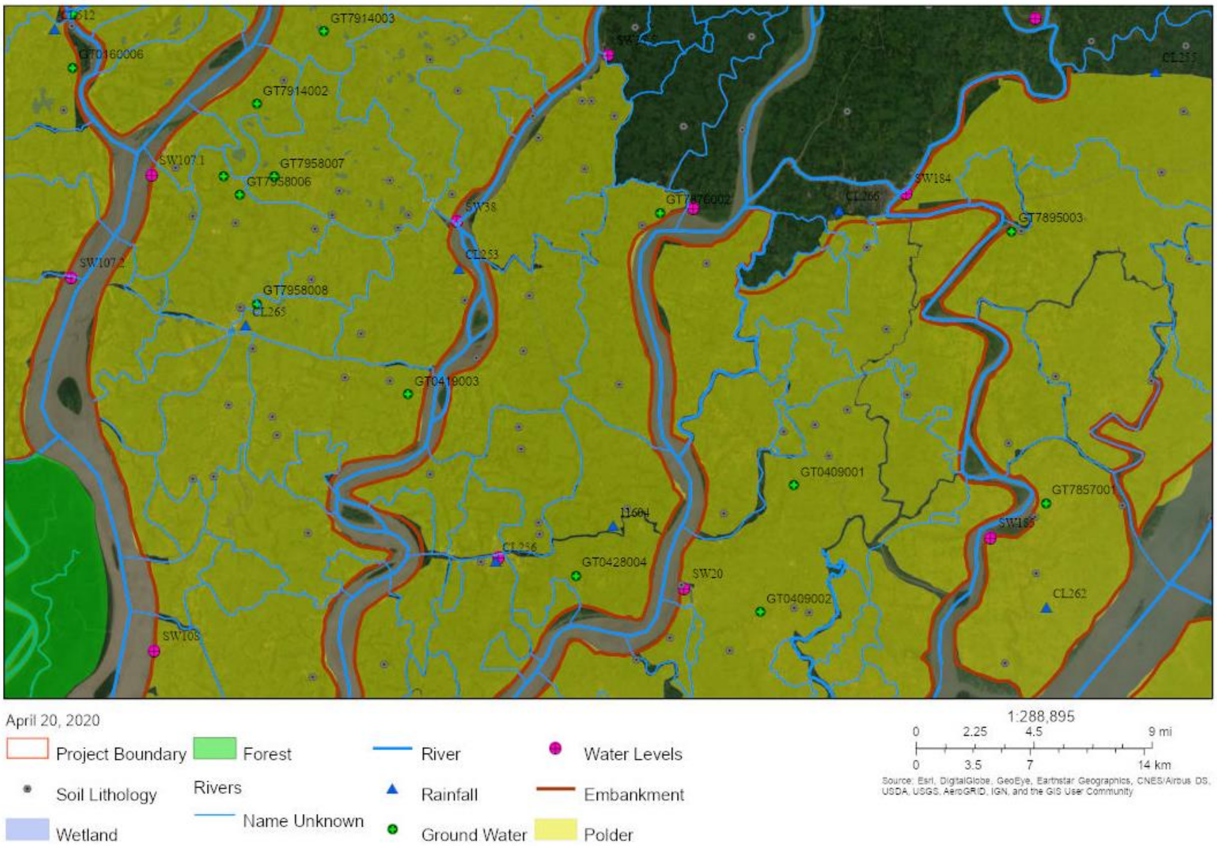


Figure 3-5: Map Layout for Printing

- **Documents**: A document archive system was developed with the system. Any required document can be stored in the server and whenever it is required can easily be retrieved from the server. Following Figure 3-6 Presents the document archive interface. The archive file can be any valid file format.

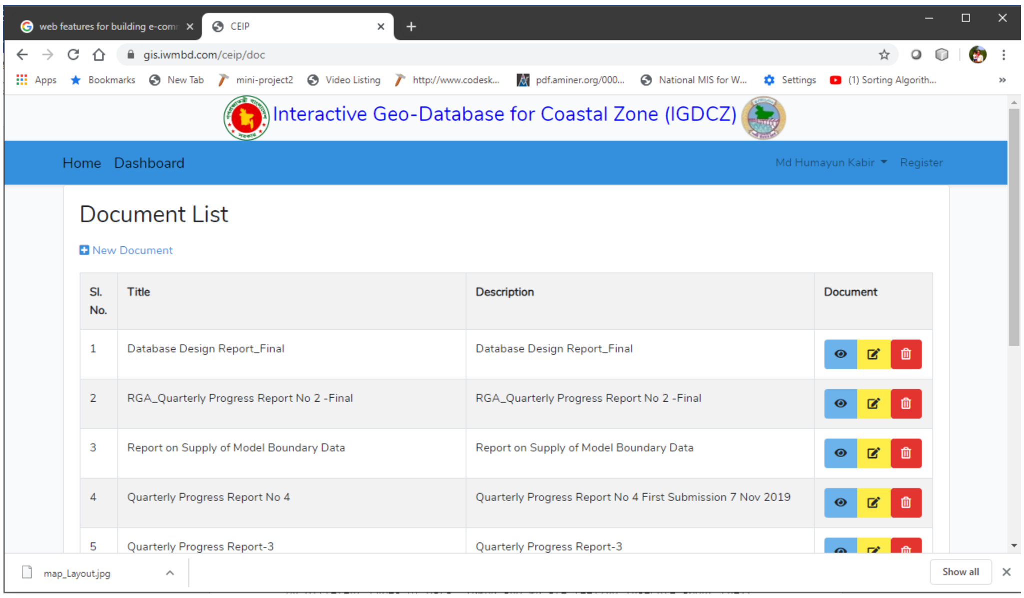


Figure 3-6: List of archived documents.

Following **Error! Reference source not found.** presents the retrieved file in pdf format.

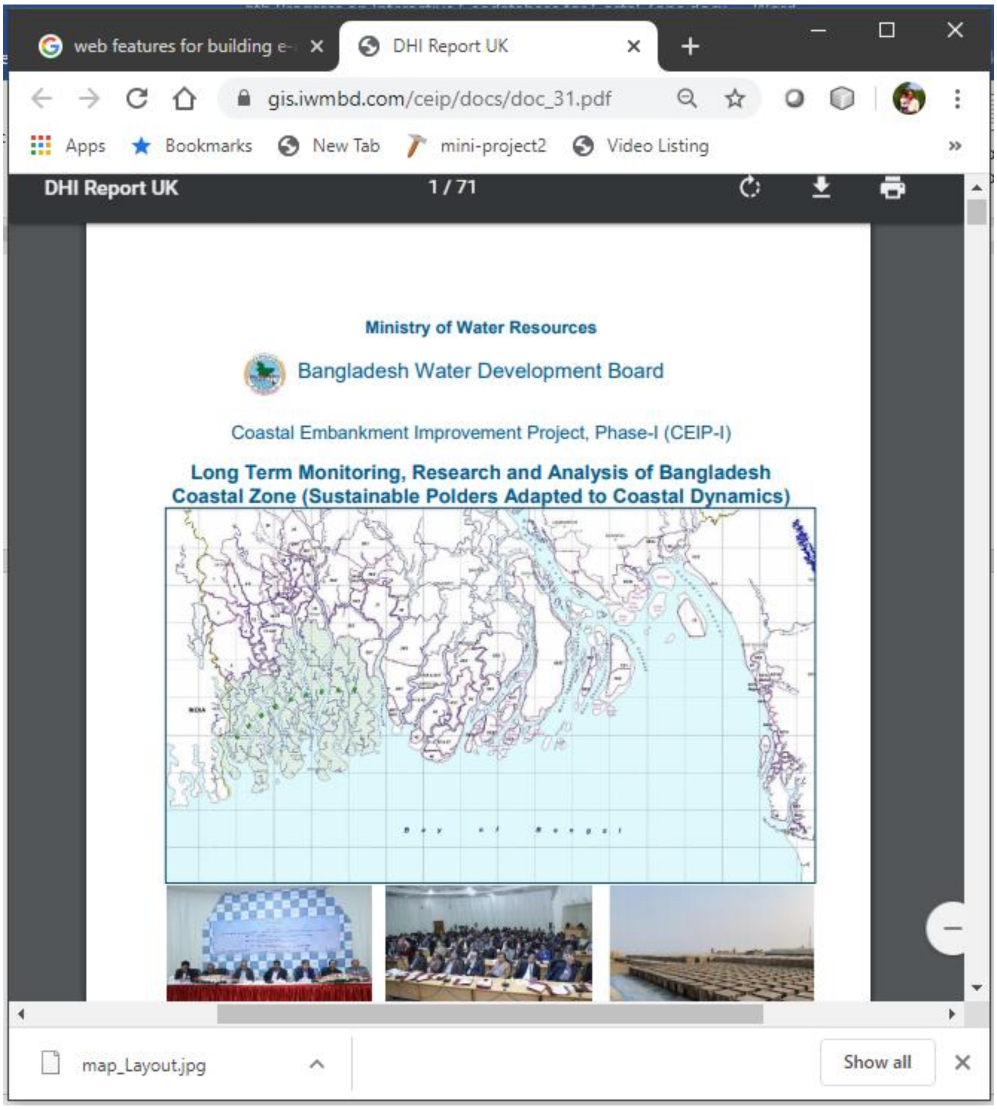


Figure 3-7: Retrieved file from the server

- **User Registration:** The IGDCZ database application is password protected, the un-authorized user can't access this web-based application. User should be registered with the system having login ID and password to access this software. The registrations are done for three levels of users such as **Administrator, Application users** and **Viewer.** These four levels of users are provided with specific roles which are given the following table (Table 3.2).

Table 3.2: Role based user privileges

	• **Access /administrative role in ArcGIS Server** • **Access /administrative role in Database Server** • **Can make Map services in ArcGIS Server** • **User management *(add, remove and update)*** • **Allocate Manager and AppUser privileges** • **Can access and browse all types spatial and non-spatial data** • **Data export** • **Non-spatial data update** • **Hydrograph generation** • **Map layout and export/print.**
	• **Can browse all types spatial and non-spatial data** • **Data export *(option given by manager)*** • **Non-spatial data update *(option given by manager)*** • **Hydrograph generation** • **Map layout and export/print *(option given by manager) etc.***
	• **Can browse selected spatial and non-spatial data.**

In order to be a registered User of the application, user need to provide his/her particulars to the System Administrator. The System Administrator will register the users and will provide the credentials to the users to access the database application. The System Administrator will configure their roles and privileges in the System. A user registration page is presented in the following Figure 3-8.

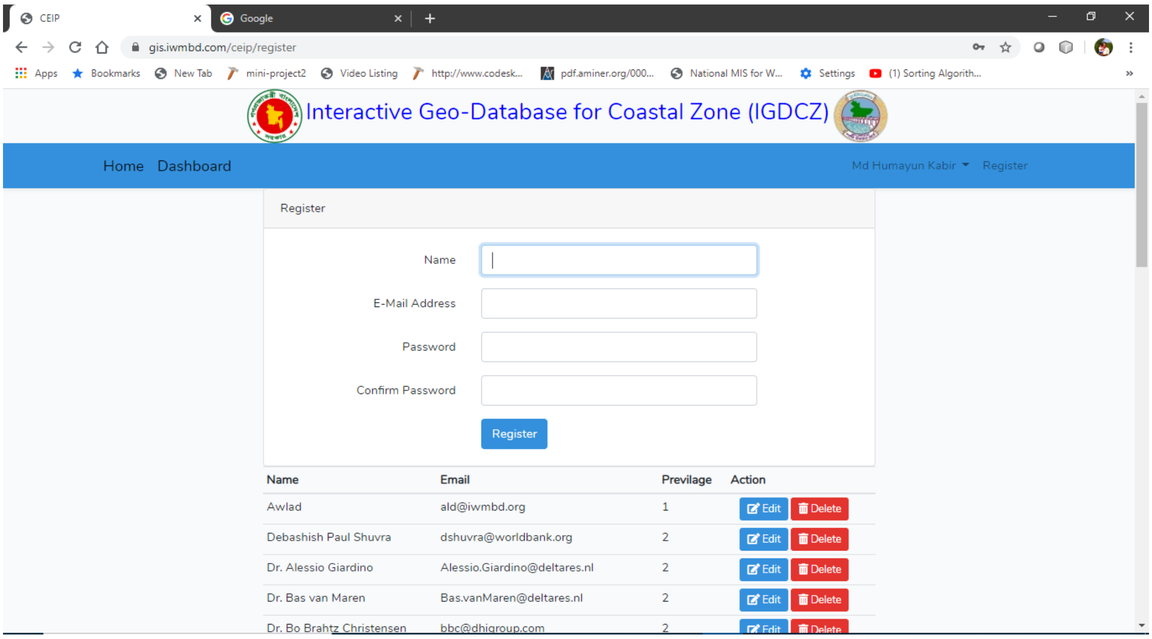


Figure 3-8: User Registration Panel

3.5 Software Security

Software security can be implemented to protect software against malicious attack and other hacker risks so that the software continues to function correctly under such potential risks. Security is necessary to provide integrity, authentication and availability and ease of use of the software. The Web GIS Based IGDCZ application is developed with appropriate security measures. The architecture of IGDCZ application has been built with three tiers which are the Presentation tier, Application tier, and Data tier.

Presentation Tier- The presentation tier is the front-end consists of the user interfaces. These interfaces are built with HTML5, JavaScript, CSS, ArcGIS APIs, ArcGIS Services. This tier is protected by access control login user and password, only privileged users can access the system.

Application Tier- The application tier contains the functional business logic which drives an application's core capabilities. This tier is also protected by the login user and password. Since, this layer is managed by ArcGIS Server which is highly protected from any un-authorized users.

Data Tier- The data tier comprises of database/data storage system and data access layer. Since this data layer constitutes the use of Oracle Database for this application. Oracle database is highly secured and provides multi-layered security including controls to evaluate risks, prevent unauthorized data disclosure, detect and report on database activities and enforce data access controls in the database with data-driven security. Data is accessed by the application layer via gateway of Spatial Data Engine (SDE) schema held in the Oracle database.

Apart from the above security measures, the Operating system are also protected by the Firewall in and out flow of unauthorized access. To enrich the protection of ArcGIS Server can be done by implementing Security Socket Layer (SSL), SSL is subject to procured.

3.6 Database User Manual

A well-organized database user manual can provide assistance and guide the users to use the application successfully. A user manual of developed IGDCZ application will be prepared in the next quarter of the project in order to successful use of the developed system. The tentative contents of the database user manual will be in two-fold documents which are:

- Database User Manual: This will include mostly the instruction manual to successfully use the system. This manual will be prepared in the next quarter of the project.
- Database Reference Manual: Contents of this document are more concentrated on the technical instructions of the developed database. A database reference manual will be prepared after final development of IGDCZ application and database.

The tentative outlines of contents of these above two manuals are given below:

1) **Tentative contents of Database User Manual**

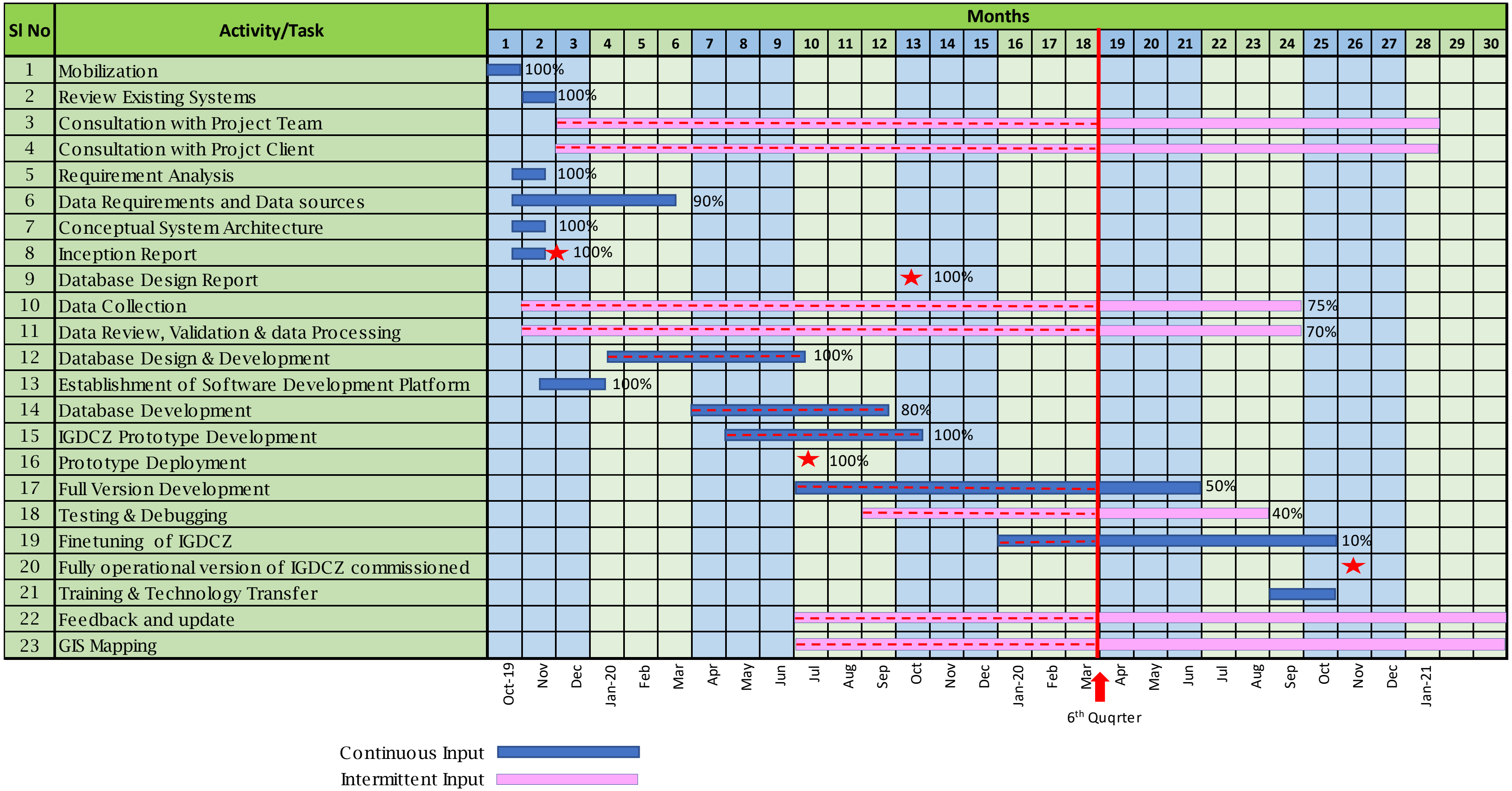
- Introduction
- User Requirements
- Data Requirements
- Hardware and Software Requirements
- Getting Started
    - User Login
    - User Registration
- IGDCZ Modules
    - Interactive GIS
    - Document Archive
    - Metadata Module
    - Tutorials
- Data Import/Export
- Reporting
- Spatial & Non-Spatial Data Update
- Software Troubleshooting
- Software Maintenance
- Conclusion

2) **Tentative contents of Database Reference Manual**

- Overview of IGDCZ
- Development of IGDCZ
- System Architecture
- IGDCZ Database Development
    - IGDCZ Modules
- Platform and Technology
    - Operating System
    - Database Server
    - GIS Server
    - Application Server
    - Front-end Back End tools
- Data Organization
- Database Maintenance
    - Database Maintenance
    - Backup, Recovery and Restore
    - Database Troubleshooting
    - Performance Tuning
- Database System Upgrade
- Conclusion

3.7 Work Plan

Table 3.3: IGDCZ Development Workplan



3.8 Activity in the Next Quarter

A target workplan is presented in the following Table 3.4 for the next 7th quarter of the project. The data collection from field is an important task to reflect the current field situation in the database. In order to do this, a series of polder maps have been produced for the project survey team. The remaining maps will be prepared and provided during the next quarter. The identification of temporal changes on of coastal bank line erosion from Satellite image is about to complete. The land use classification from the use of satellite image will also be completed by the end of next quarter. The other tasks will be continued normally to achieve the target during the next quarter of the project.

Table 3.4: Workplan for Next Quarter

Sl No	Task & Activities	Progress (%) Up to 6th Quarter	Progress (%) 7th Quarter	Overall Progress (%)
1	Inception Phase			
1.1	Review Existing Systems	100	-	100
1.2	Consultation with Project Team	continue		continue
1.3	Consultation with Projct Client	continue		continue
1.4	Requirement Analysis	100	-	100
1.5	Data Requirements and Data sources	100	-	100
1.6	Conceptual System Architecture	100	-	100
1.7	Inception Report	100	-	100
2	Data Collection and Processing			
2.1	Coastal Bank Erosion (Satellite Image)	95	9	100
2.2	Landuse Classification (Satellite Image)	25	75	100
2.3	Other Data Collection (shapefile & tabular)	70	15	85
2.4	Other Data Processing (shapefile & tabular)	85	15	70
3	GIS Mapping			
3.1	Polder Maps for Data Collection	50	50	100
4	Database Design & Development			
4.1	Database Design	100	-	100
4.2	Database Design Report	100	-	100
4.3	Database Development	70	15	85
5	Web GIS Application Development			
5.1	IGDCZ Prototype Development	100	-	100

Sl No	Task & Activities	Progress (%) Up to 6th Quarter	Progress (%) 7th Quarter	Overall Progress (%)
5.2	Full Version Development	50	25	75
5.3	Testing & Debugging	40	20	60
5.4	Fully operational commissioning	-	-	-
6	Training & Technology Transfer	-	-	-
7	Feedback and update	continue		continue

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. Model development is now almost complete and applications are underway.

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

		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
D-4A-1	**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.

Progress of work on this model has been delayed and interrupted by the COVID-19 crisis. The progress made in 5th and 6th Quarters will be incorporated in the 7^{th} Quarterly Progress Report to account for not showing progress on Hydrotrend.

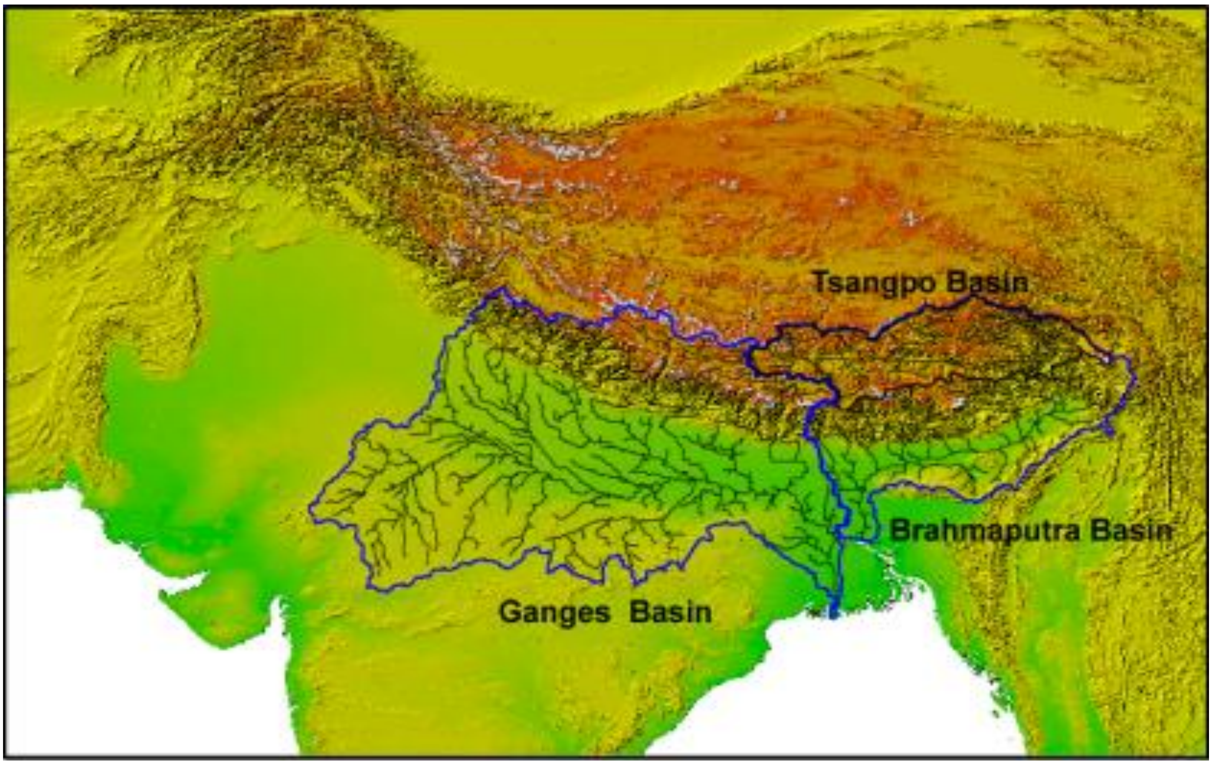


Figure 4-1: Map showing the Ganges and Brahmaputra basins

A list of input data types such as terrain (eg DEM), land use, 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

DHI

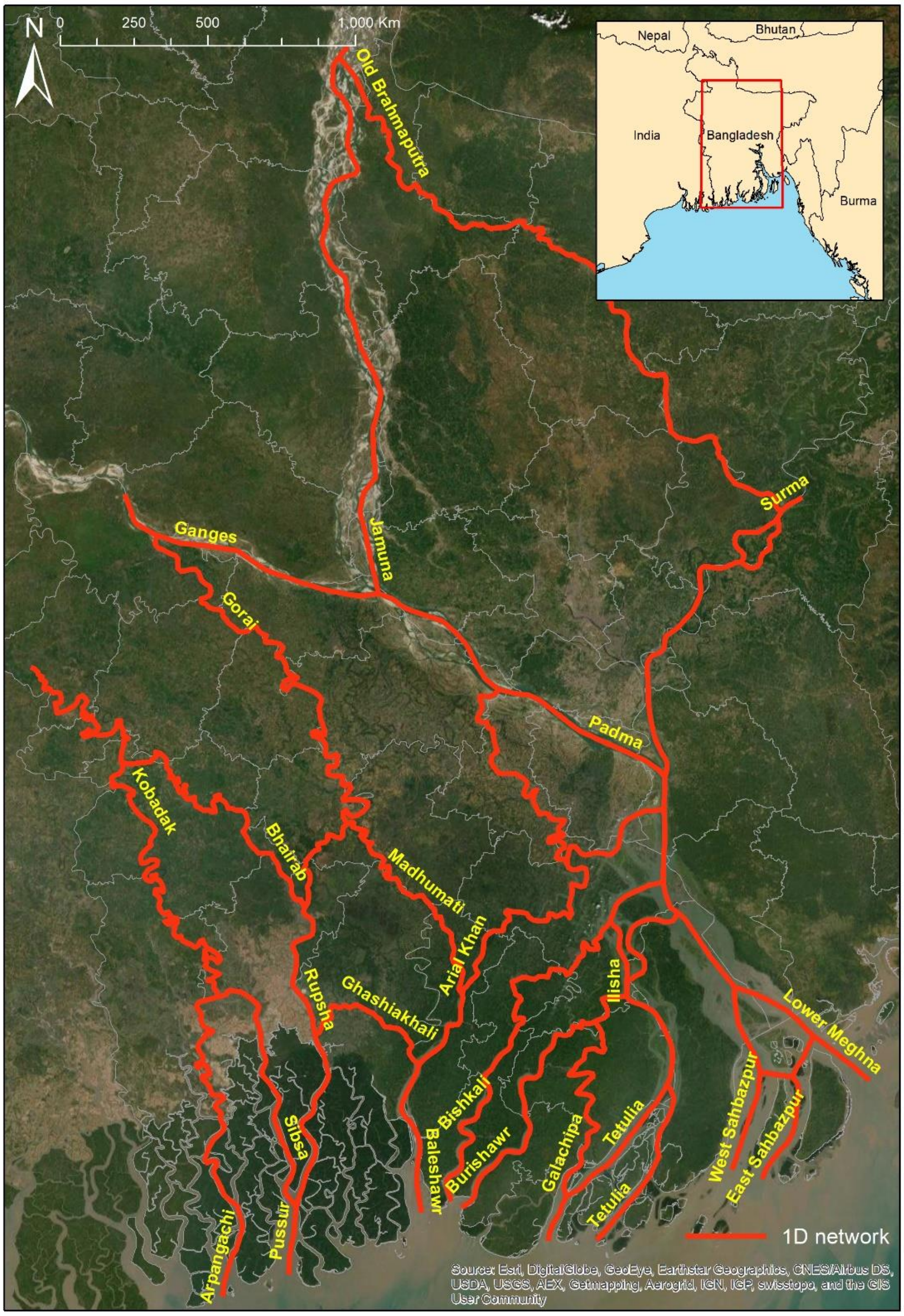


Figure 4-2: River network for the Delft3D-FM 1D model.

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.

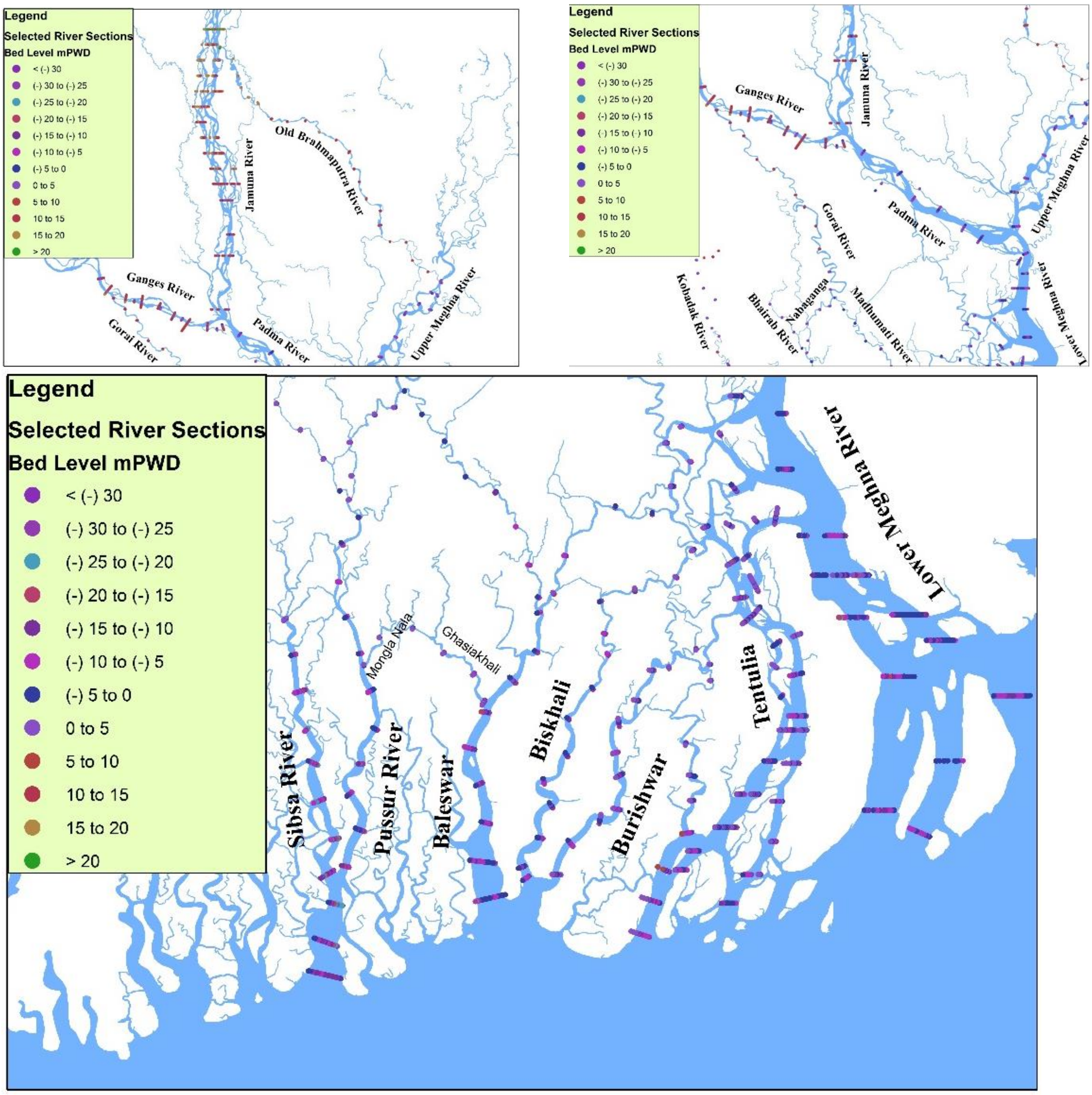


Figure 4-3: Maps showing the selected measured cross sections imposed on the model.

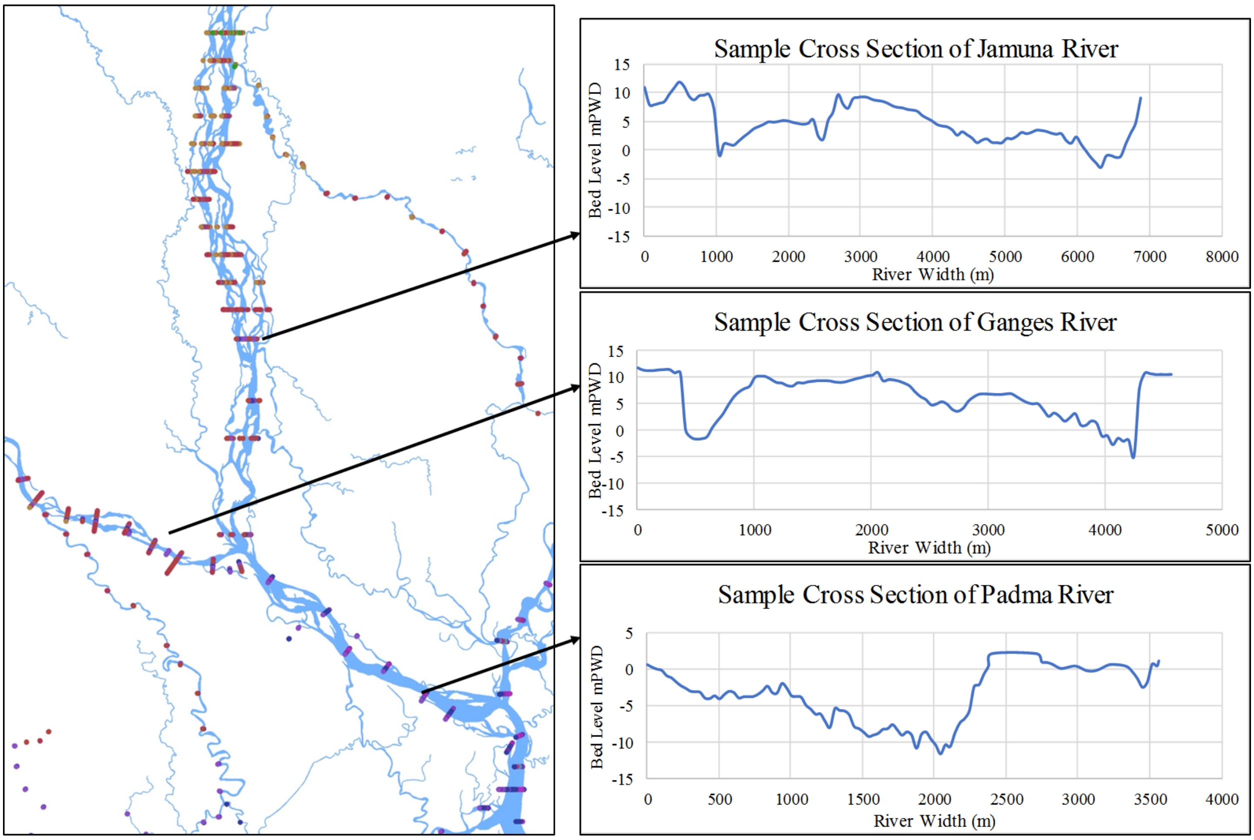


Figure 4-4: Sample cross section of Ganges, Jamuna and Padma river

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).

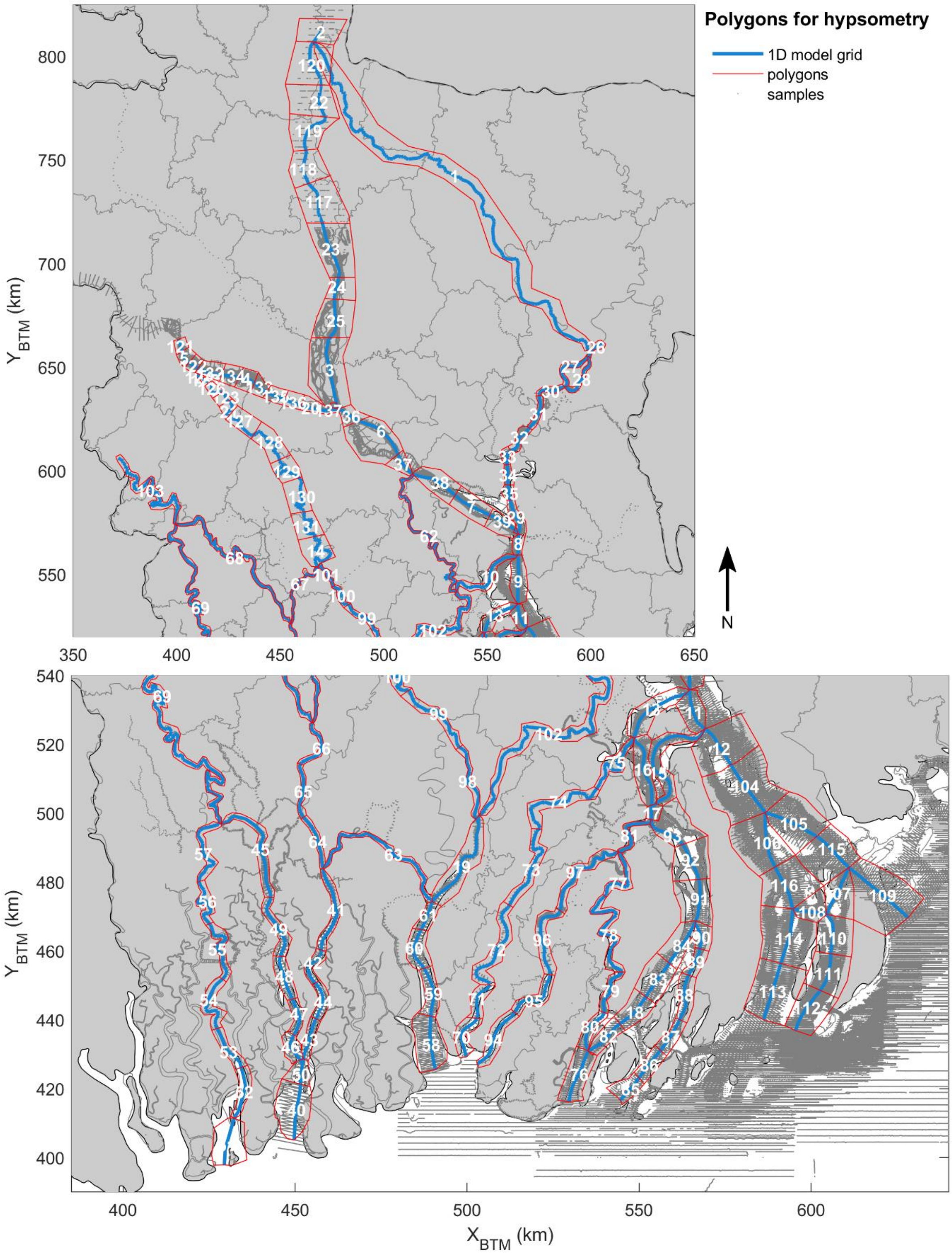


Figure 4-5: Map of the GBM delta with the model network (blue), the topo-bathymetric observations (gray dots), and the polygons (red) defining subareas of the river branches for schematization of the hybrid profiles.

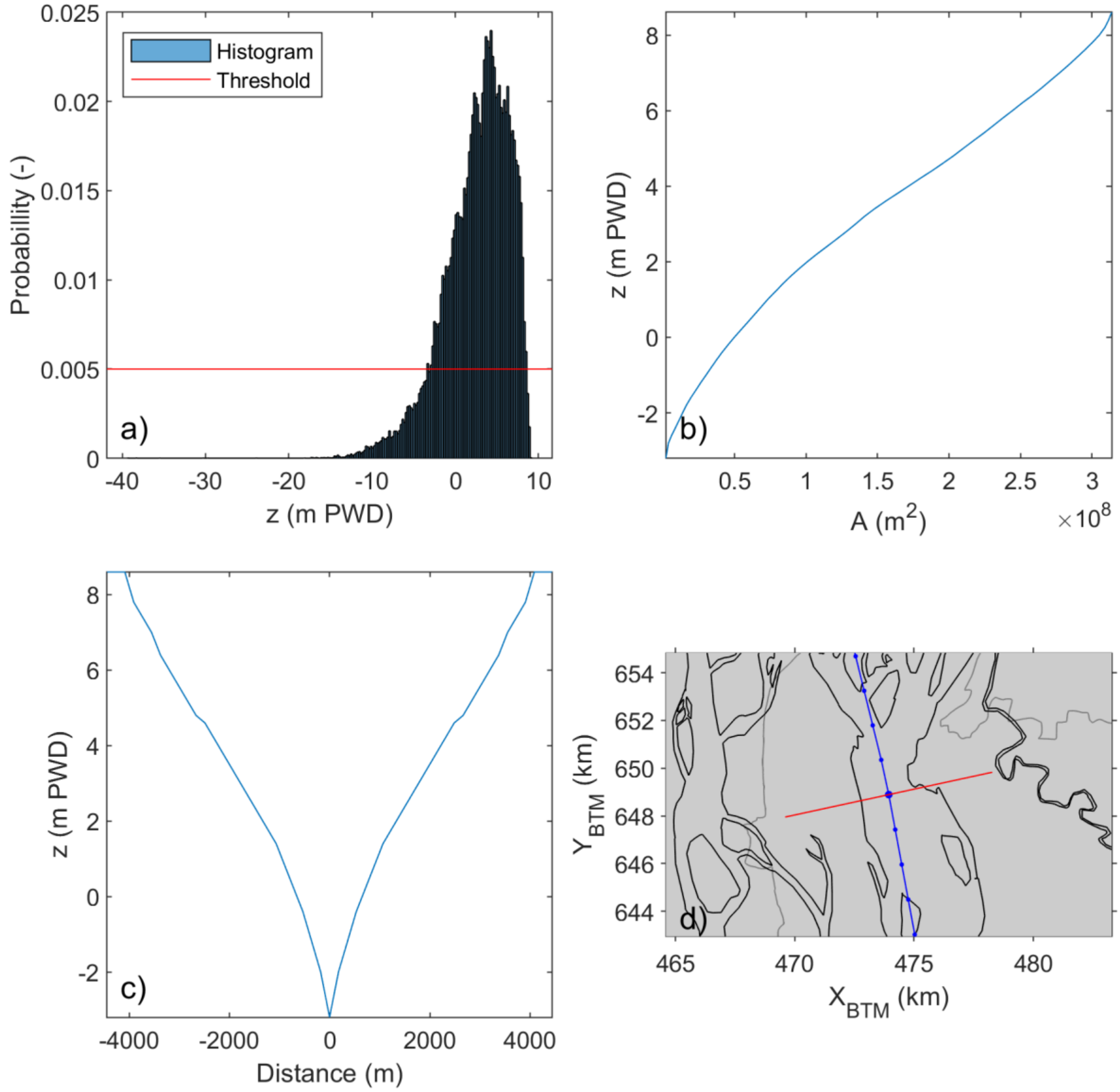


Figure 4-6: Methodology of schematizing cross-sectional profiles, illustrated for the downstream part of the Brahmaputra: a) histogram of the topo-bathymetric observations within the subarea defined by the polygon and probability threshold value chosen for outlier filtering; b) hypsometric curve derived 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

		Modelling of the long-term physical processes; Morphology on a meso scale
D-4A-2	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.

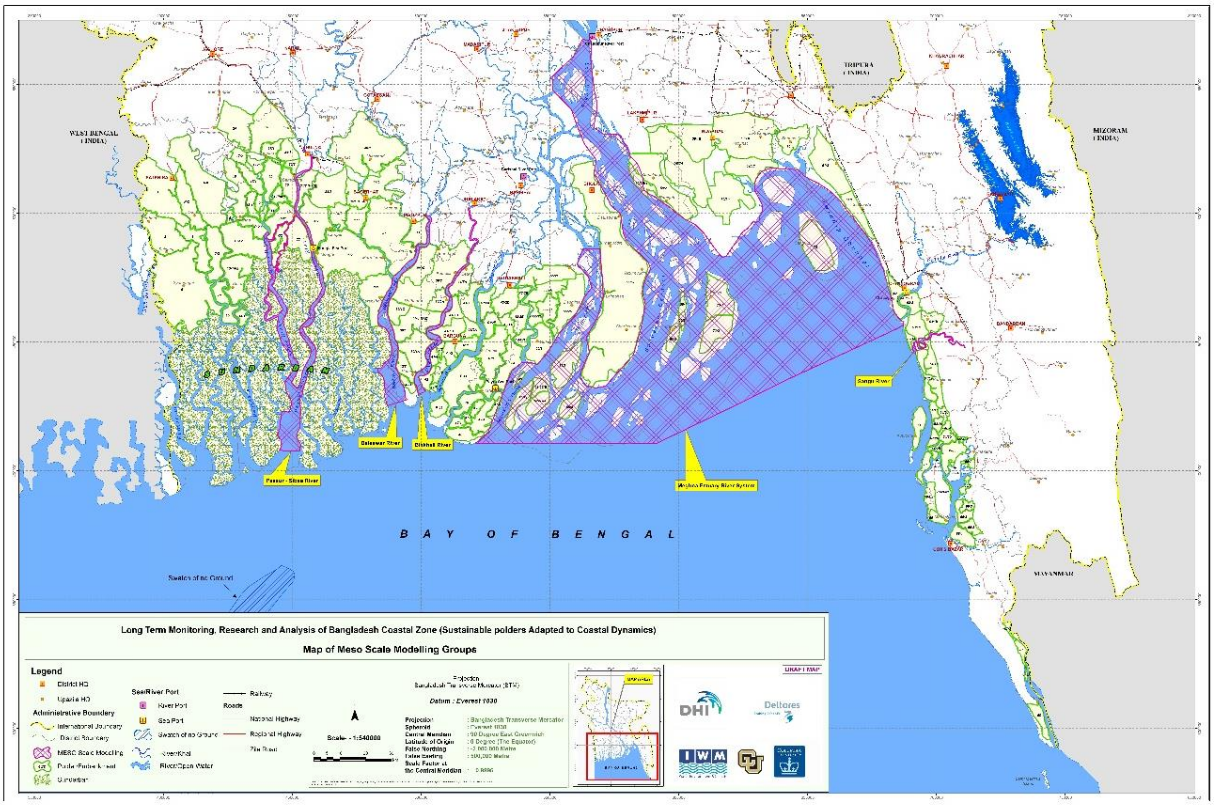


Figure 4-7: Map of meso scale modelling groups for long term morphology

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

The preliminary morphodynamics model development for Sibsa-Pussur river system was carried out for reproduce the morphological development for the known period (2011 to 2019). For the robust simulation, the boundaries were squeezing which included the seasonal variability. For preliminary stage, the tidal constituent M2 and M4 were consider which is the main driving force in this area. The mean vs seasonally varying vs realistic time series and squeezing of time series shown in Figures below (Figure 4.8).

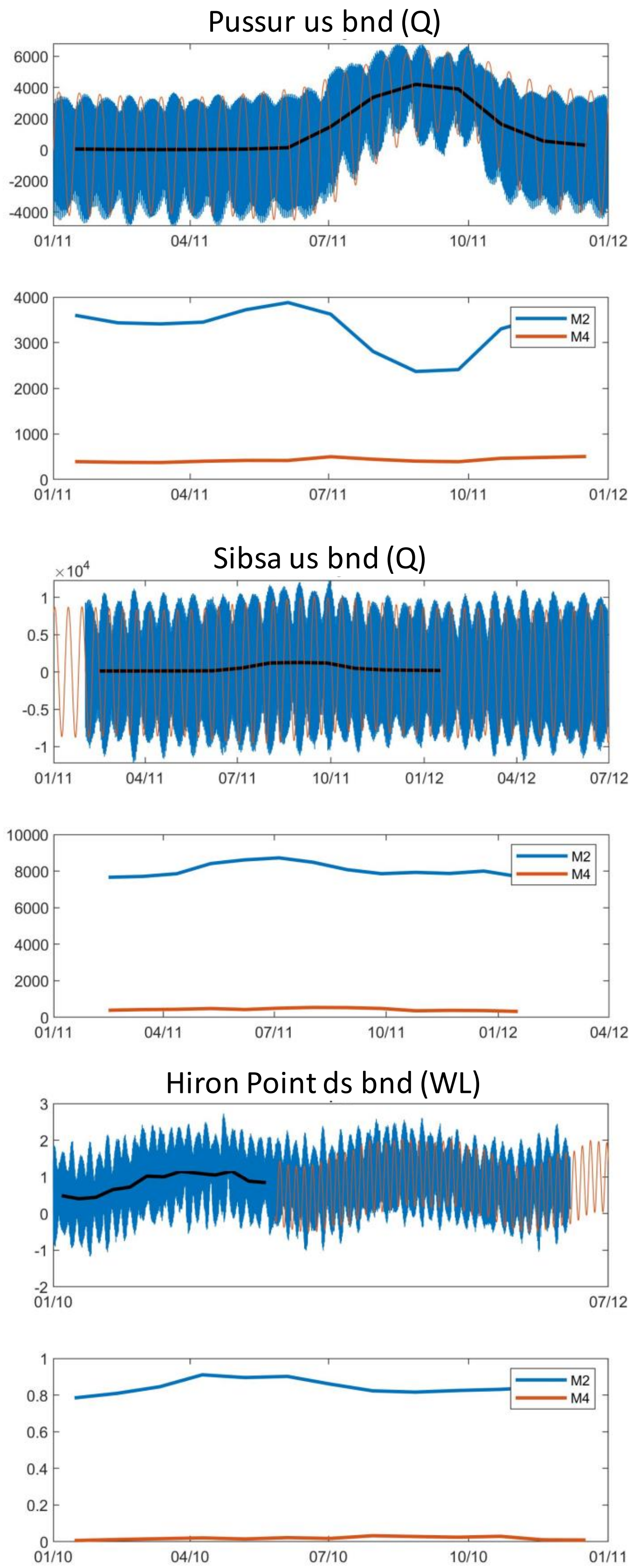


Figure 4-8: Morphodynamics boundaries for Pussur Sibsa river system for 2011-2019

The sedimentation/erosion pattern for 2011-2019 is shown in the following figure (Figure 4.9). The improvement of this model is on-going.

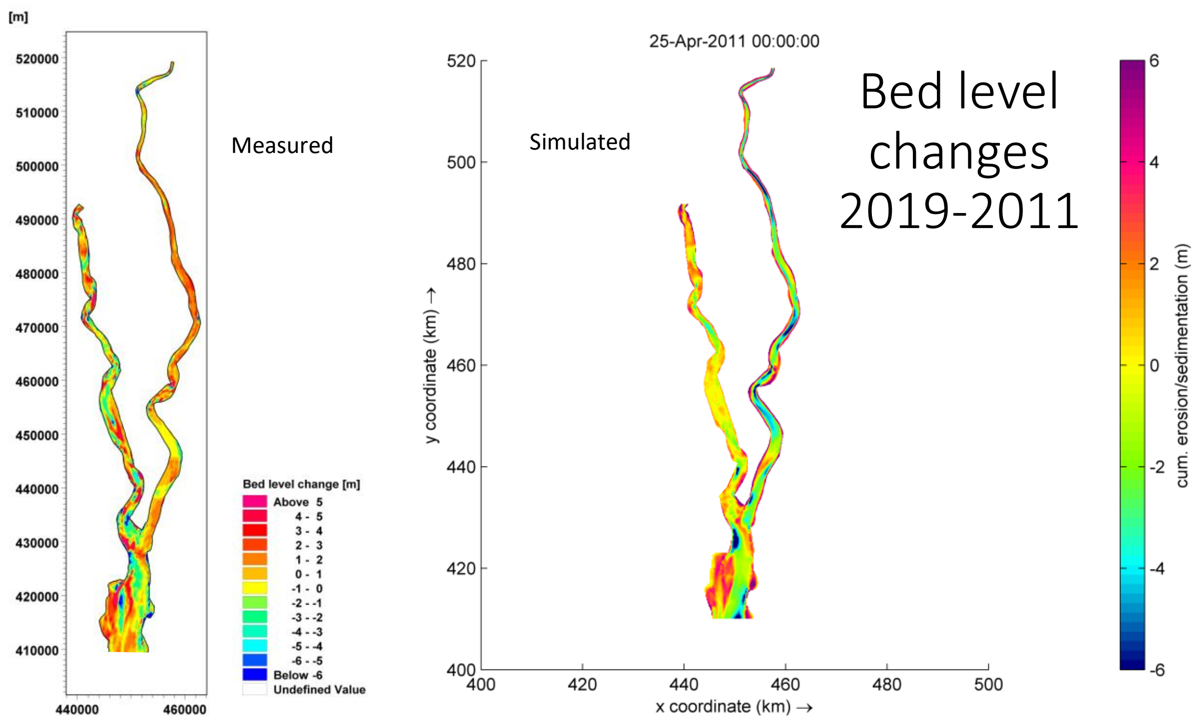


Figure 4-9: Erosion/deposition map for 2011 to 2019

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

The preliminary morphodynamics model development for Baleswar-Bishkhali river system was carried out for reproduce the morphological development for the known period (2011 to 2019). For the robust simulation, the boundaries were squeezing which included the seasonal variability. For preliminary stage, the tidal constituent M2 and M4 were consider which is the main driving force in this area. The mean vs seasonally varying vs realistic time series and squeezing of time series shown in Figures below (Figure 4.10 and Figure 4.11).

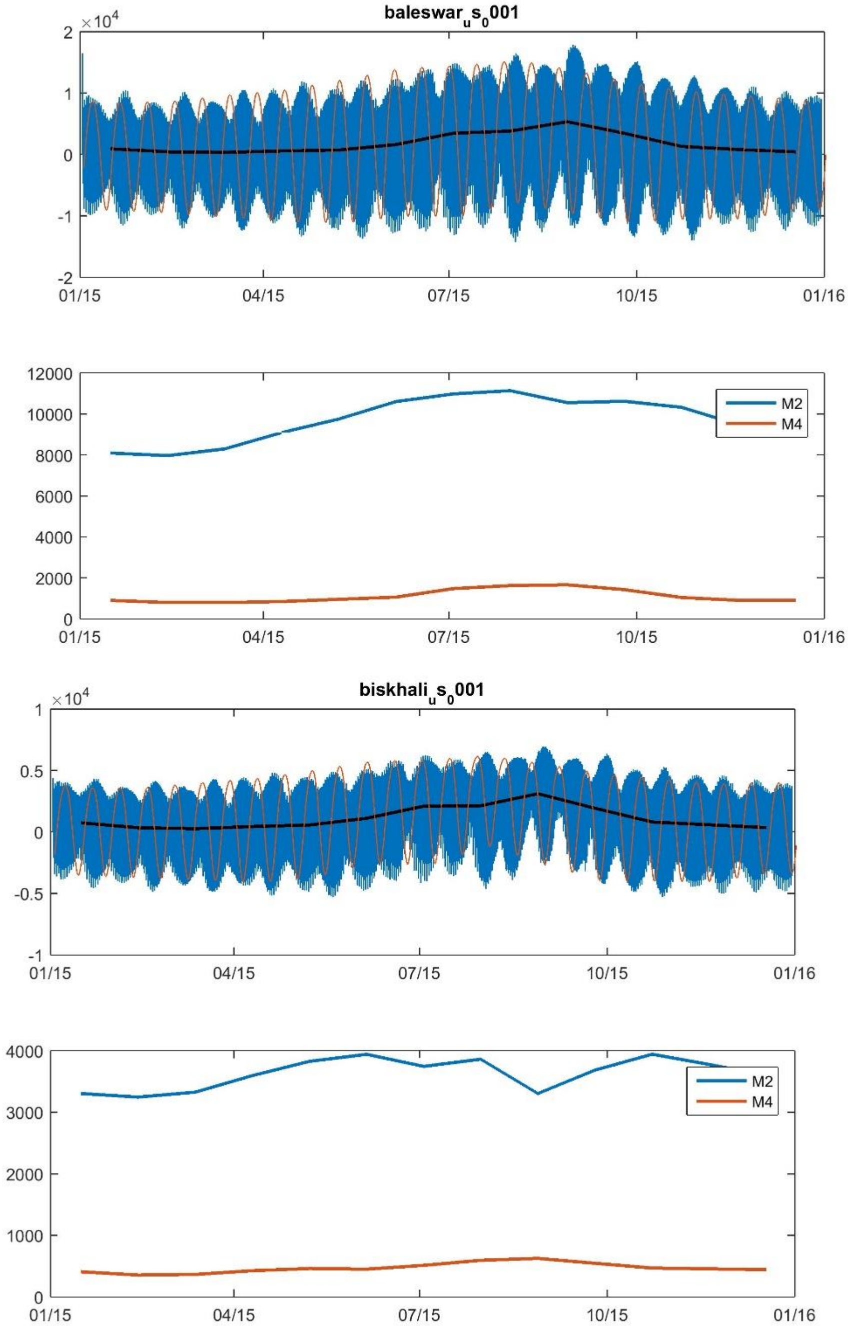


Figure 4-10: Morphodynamics boundaries (Discharge) for Baleswar-Bishkhali river system for 2011-2019

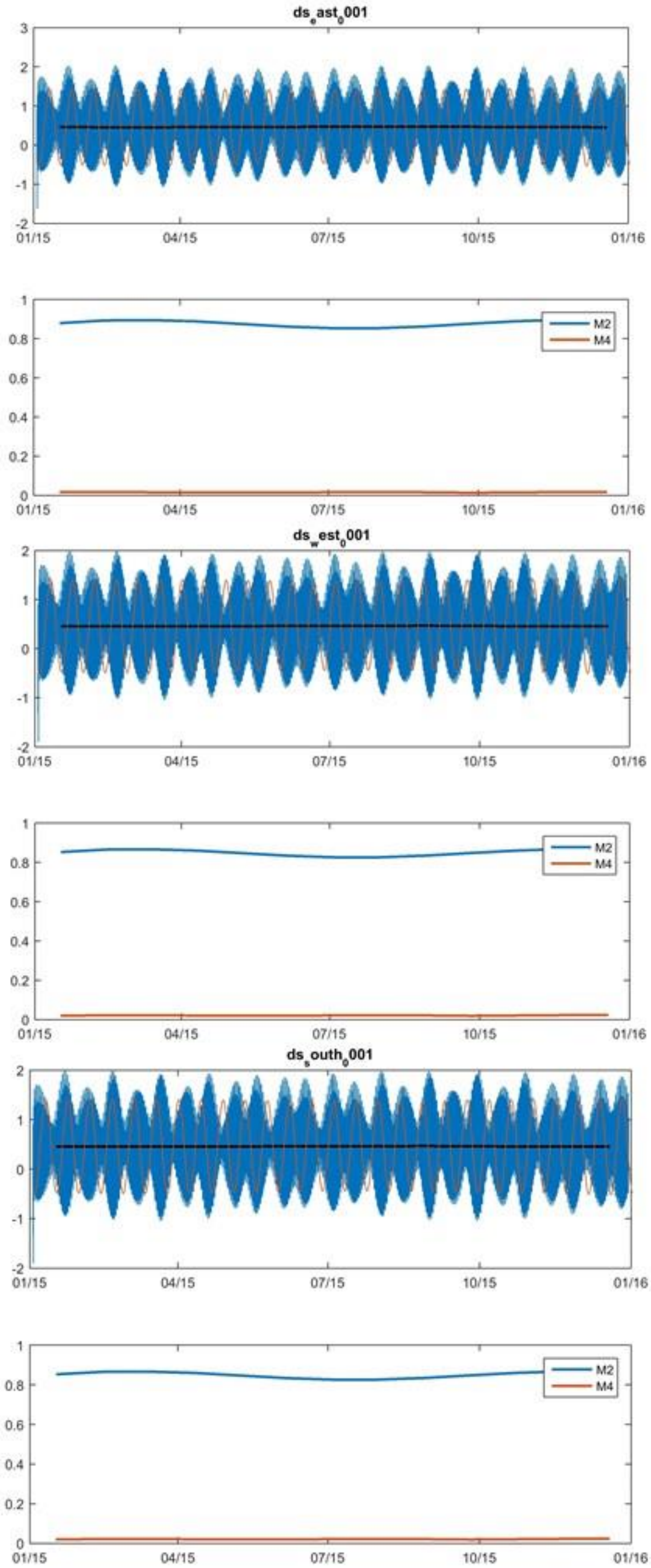


Figure 4-11: Morphodynamics boundaries (Water Level) for Baleswar-Bishkhali river system for 2011-2019

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

New Lower Meghna Estuary Grid

The Bathymetry were updated with the new improved grid (Figure 4.12)

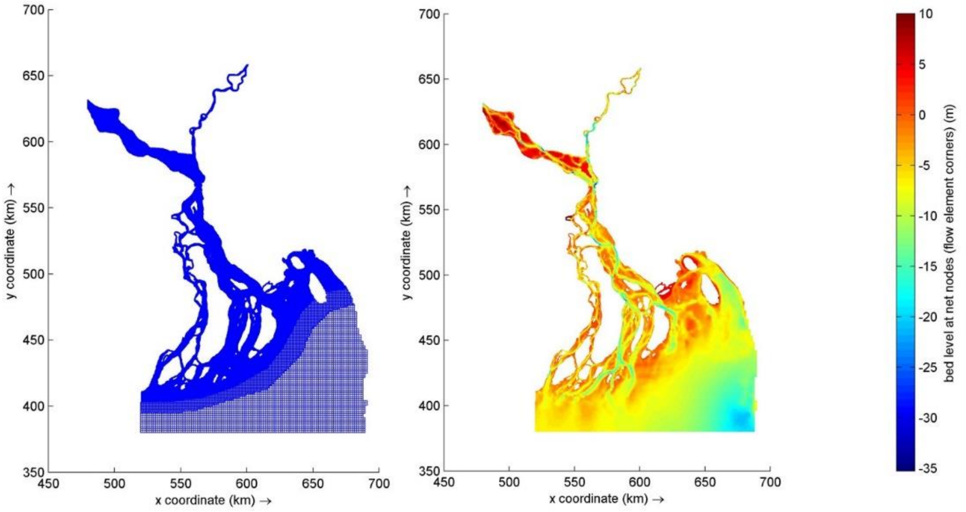


Figure 4-12: Upgraded grid and Bathymetry for Lower Meghna Estuary meso model during 2009

Boundary conditions

Mean vs seasonally varying vs realistic time series
Squeezing of time series

For the longterm simulation, the boundaries were squeezing which included the seasonal variability. For preliminary stage, the tidal constituent M2 and M4 were considered which is the main driving force in this area. The mean vs seasonally varying vs realistic time series and squeezing of time series shown in Figures below (Figure 4.13 and Figure 4.14).

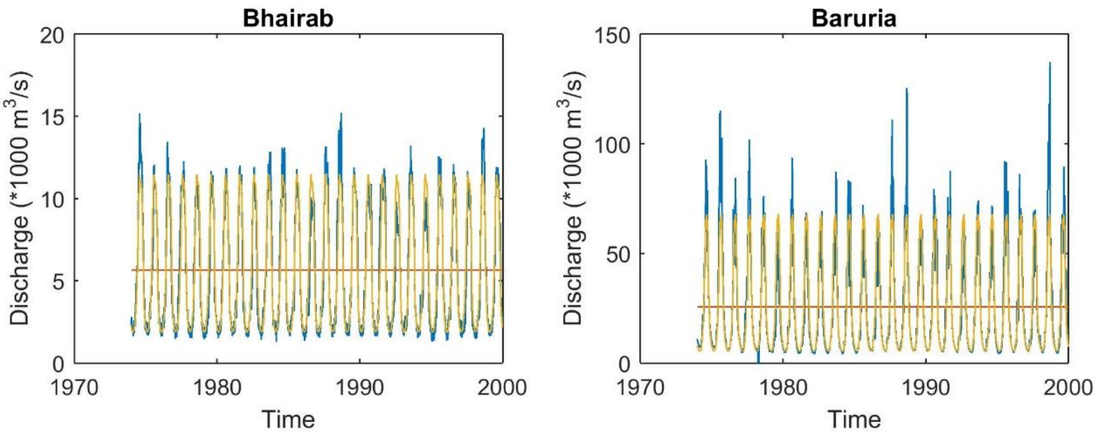


Figure 4-13: Morphodynamics Discharge boundaries of Bhairab Bazar and Baruria (Mean vs Realistic)

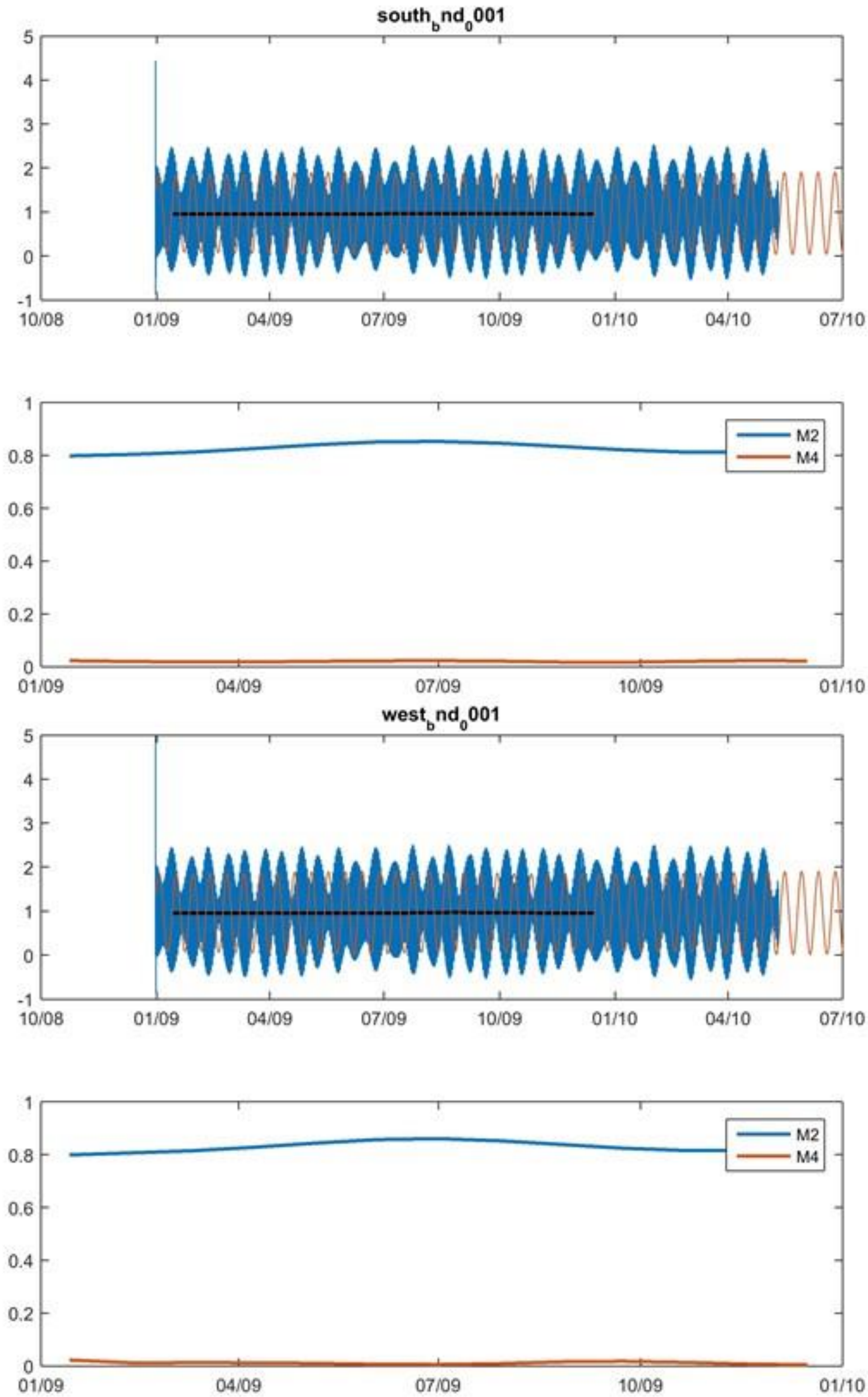


Figure 4-14: Morphodynamics Downstream Water Level boundaries for Lower Meghna Estuary meso model (2009-2020)

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

Sangu river model was already well calibrated for dry season. The monsoon calibration is ongoing for the latest 2019 data.

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 4.15. 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.

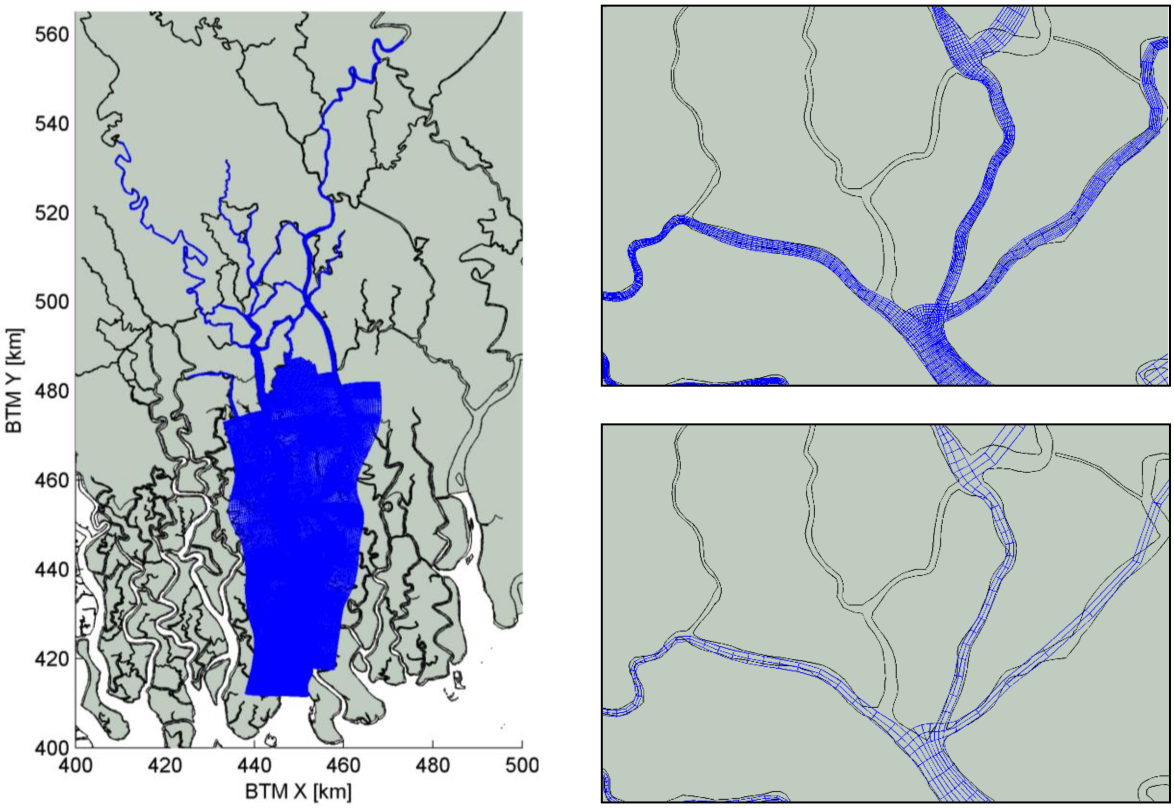


Figure 4-15: Model domain (left) and detail of the Upper Sibsa river with the refined grid (top right) and the coarse grid (lower right)

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 4.16). This model is subsequently extended with a fine sediment transport module, calibrated quantitatively against sediment concentration observations (as in Figure 4.17), and phenomenologically against residual transport patterns.

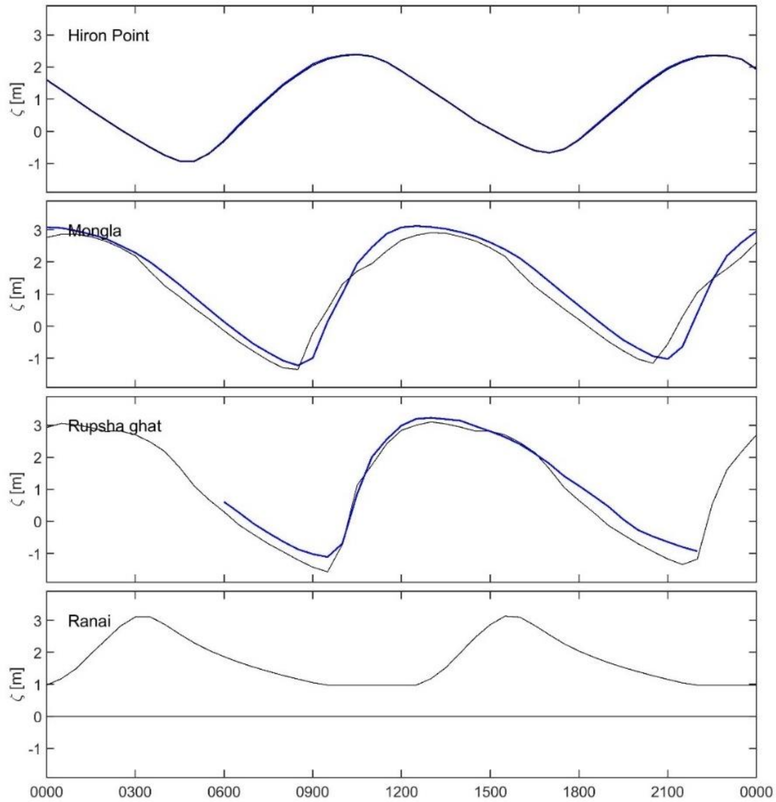


Figure 4-16: Computed (black) and observed (blue) water levels on March 2011 at Hiron Point, Mongla, Rupsha Ghat and Ranai

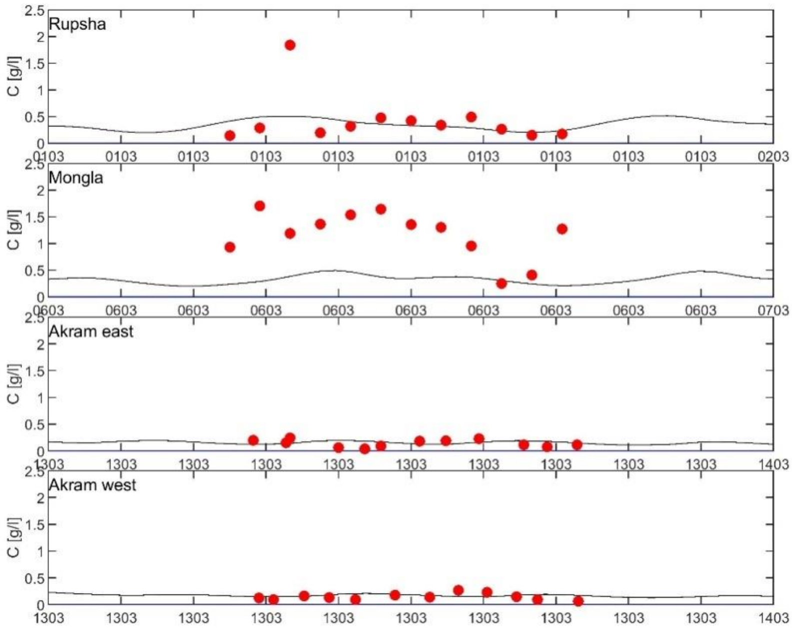


Figure 4-17: Computed (black) and observed (red) SSC on 13 March 2011 at Rupsha, Mongla,and Akram.

4.3.6 Plume Model for Fine Sediment Pathway

A Delft3D FM model is setup for the Fine sediment pathway to investigate the role of sediment transport processes, tidal dynamics, and human interventions in detail. The domain runs from the seaward boundary at Bay of Bengal and upstream boundary at Hardinge bridge in Ganges, Bahadurabad in Jamuna and Bhirab Bazar in Meghna river. This model is setup in a reolution varying from 150m to 9600m gradually from upstream to downstream part of the model domain. Especially the high-resolution grid covers many peripheral rivers (e.g Gorai).

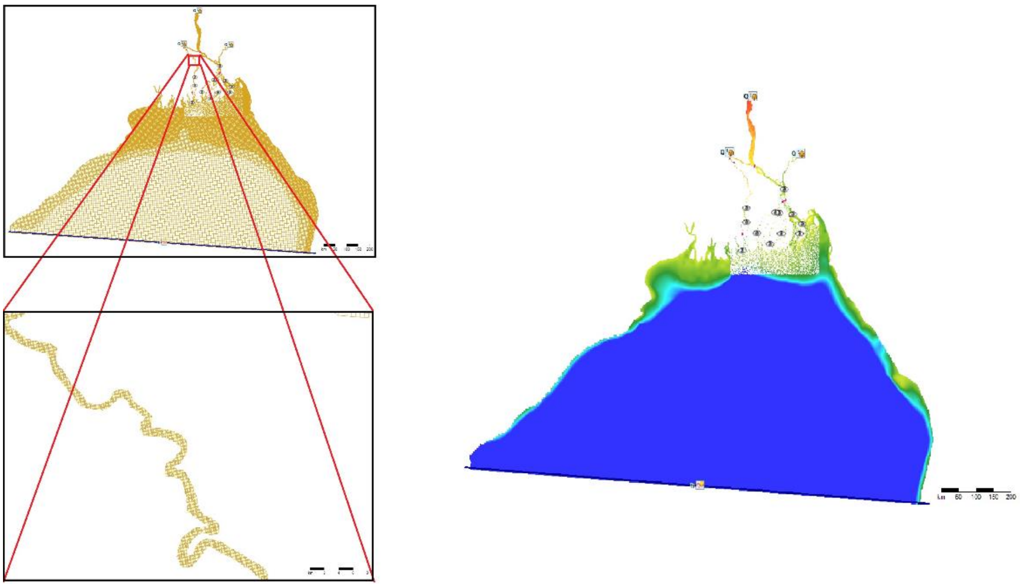


Figure 4-18: Grid and bathymetry for Plume model

The Model is in HD setup phase and the bathymetry is being updated for better model performance. After the bathymetric correction the model will be ran for Hydrodynamic calibration and calibration will move forward for next step.

4.4 Meso Scale Models for Bank Erosion

Table 4.4: 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 4.19. Baleswar; Sibsa; Pussur ; Bishkhali

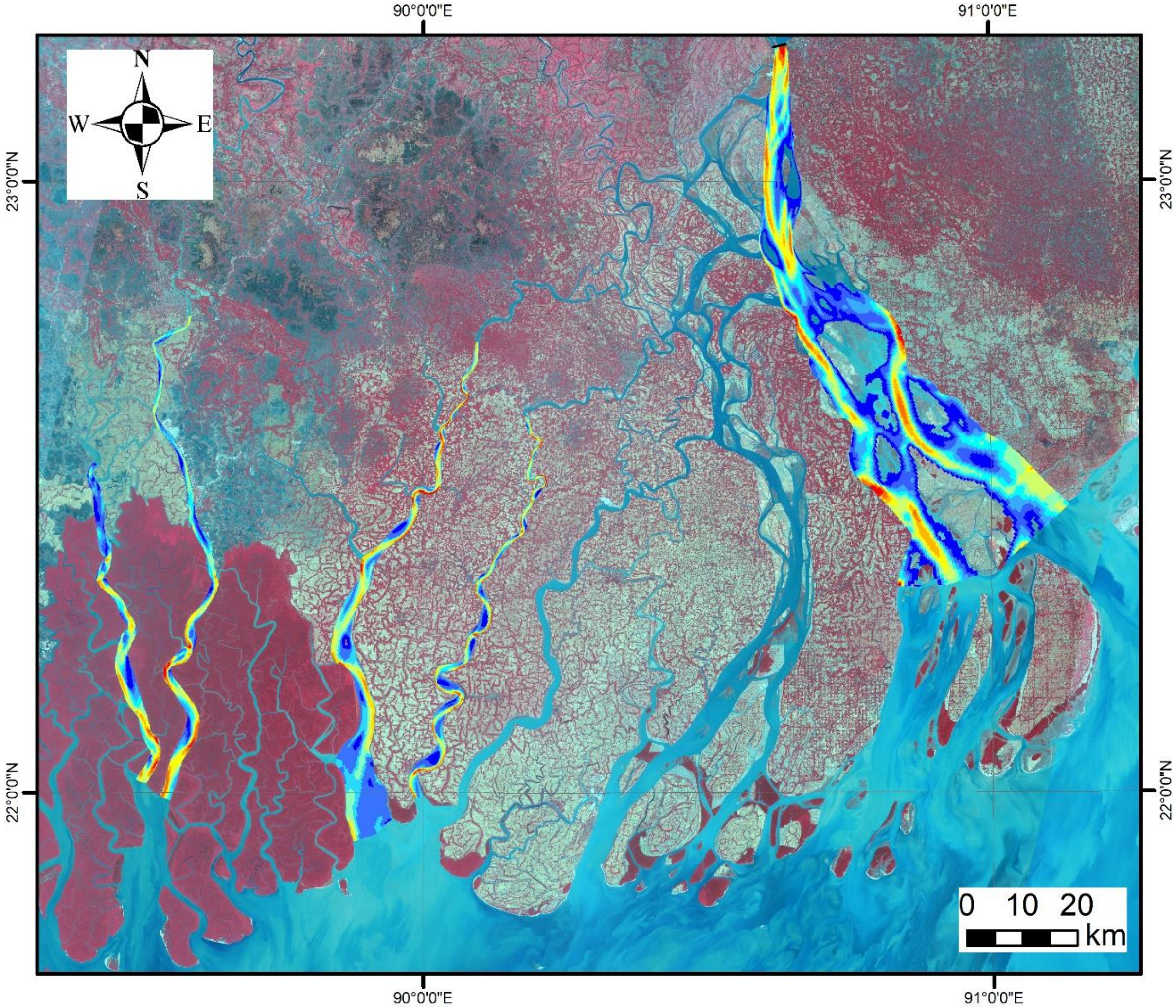


Figure 4-19: The four models developed during 2019, from west (left): Sibsa, Pussur, Baleswar, Bishkhali, and to the right is seen the Lower Meghna model currently under initial development.

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.

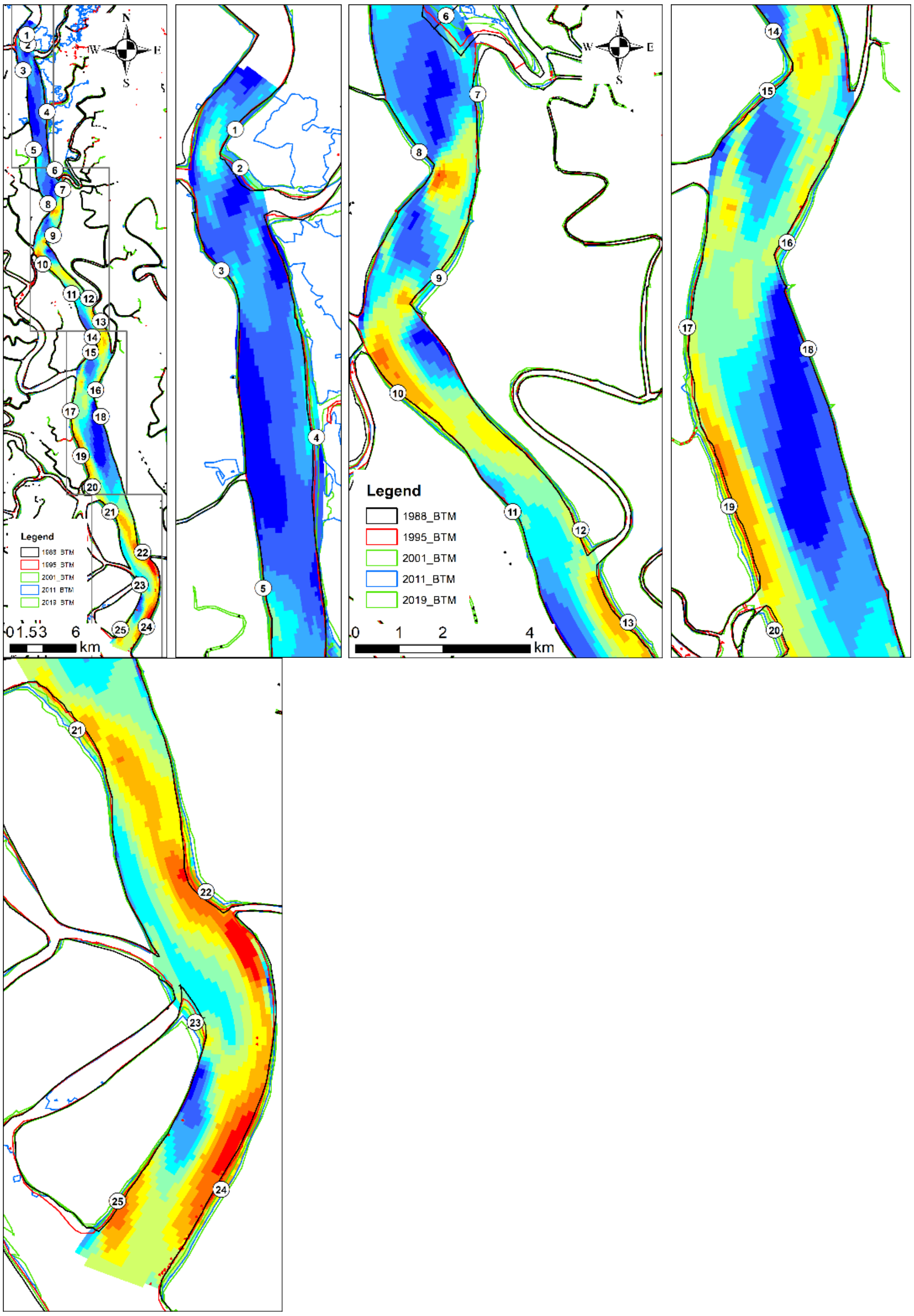


Figure 4-20: Identification of eroding banks in Sibsa River from Landsat 1988-2019 images.

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.

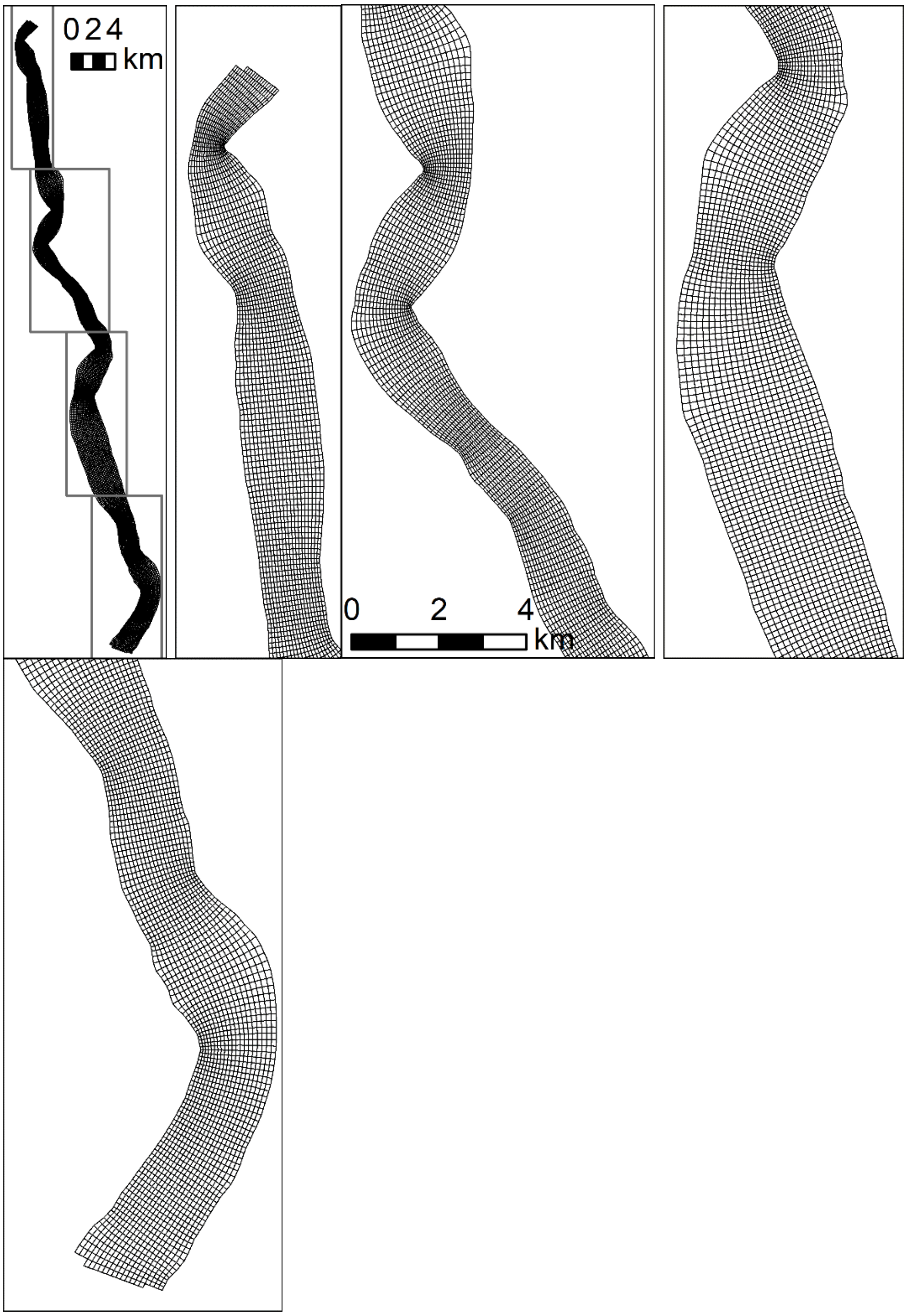


Figure 4-21: Curvilinear grid applied for Sibsa River.

The Sibsa River curvilinear grid is shown in Figure 4.21. 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.

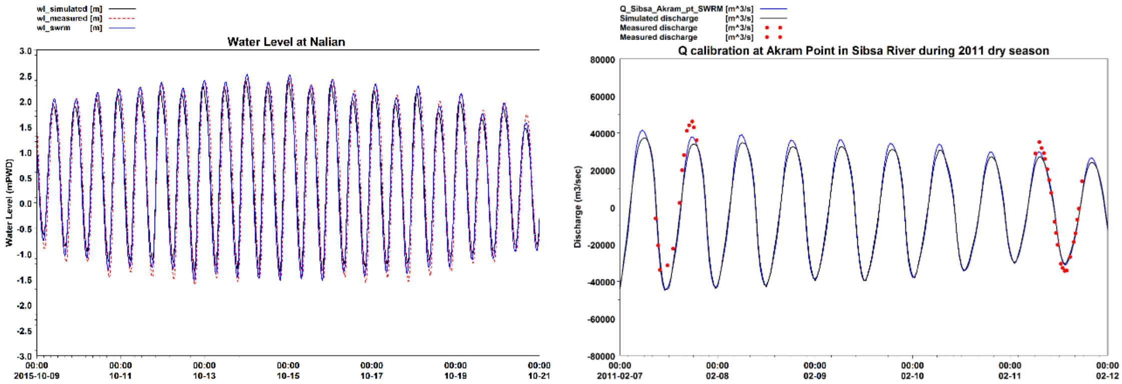


Figure 4-22: Examples of calibration of the Sibsa River model, left: Water levels at Nalian (2015), right: Discharges at Akram Point (2011).

Hydrodynamic calibration is usually easier than morphological calibration. Examples of calibrated water levels and discharges are given in Figure 4.22.

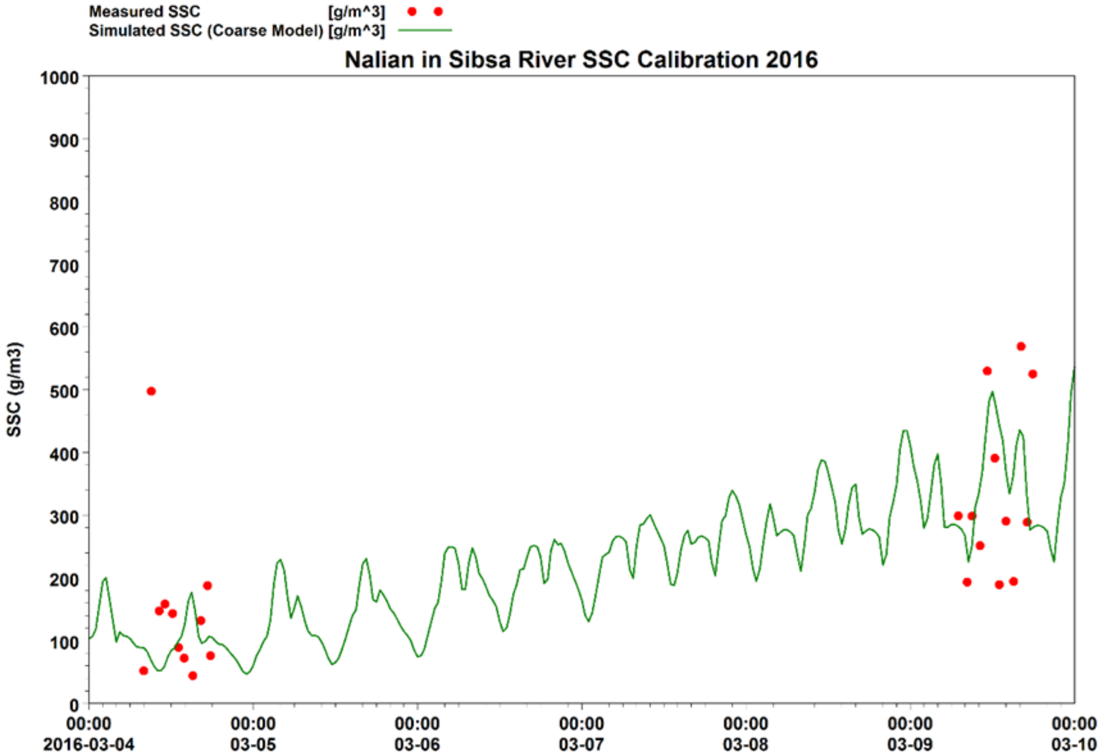


Figure 4-23: Example of cohesive sediment calibration in Sibsa River at the Nalian station.

The Sibsa River was initially developed using a silt model, which is easily calibrated to observed concentrations, as shown in Figure 4.23.

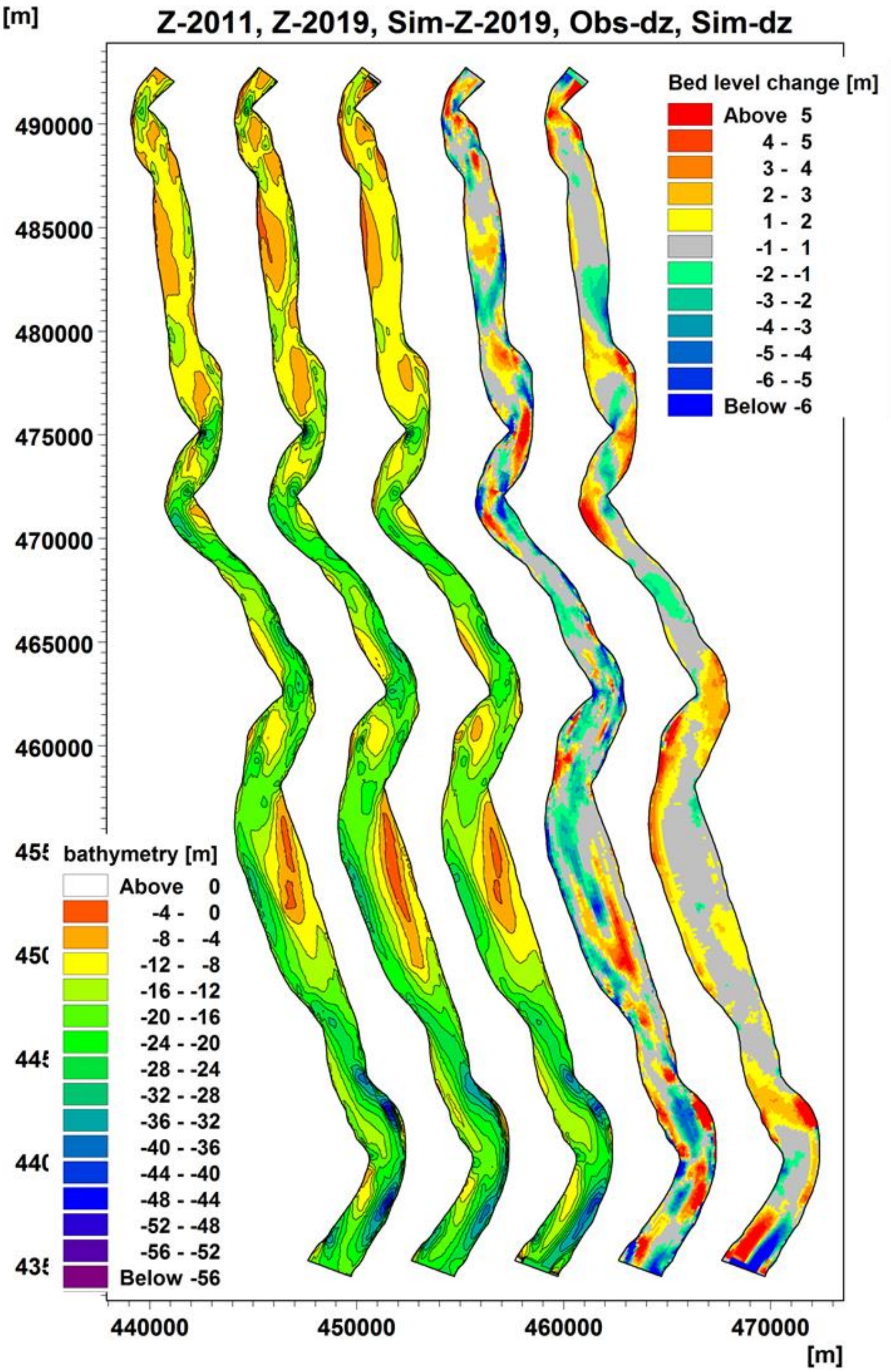


Figure 4-24: Calibration of bed levels by hindcasting the 2011-2019 bathymetry development. This type of figure will be seen in many reports, and it shows from the left: Observed 2011 bathymetry, observed 2019 bathymetry, simulated 2019 bathymetry, observed bed level changes 2011-2019 and simulated bed 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 4.24 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.

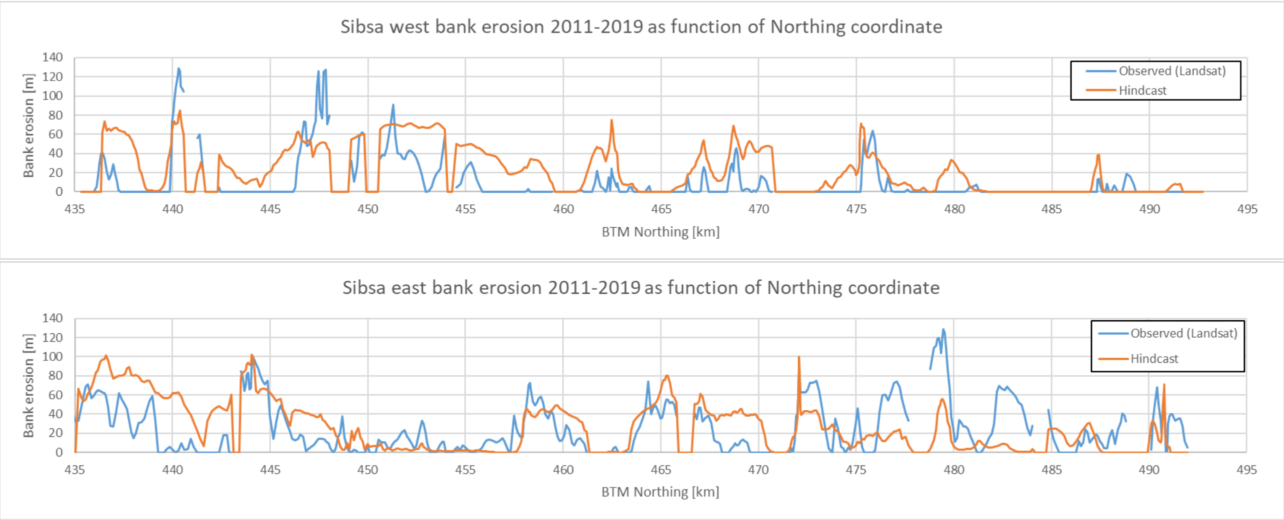


Figure 4-25: Bank erosion hindcast 2011-2019 for Sibsa River using a variant of the Hasegawa (1989) bank erosion formula.

Figure 4.25 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 4.5: 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

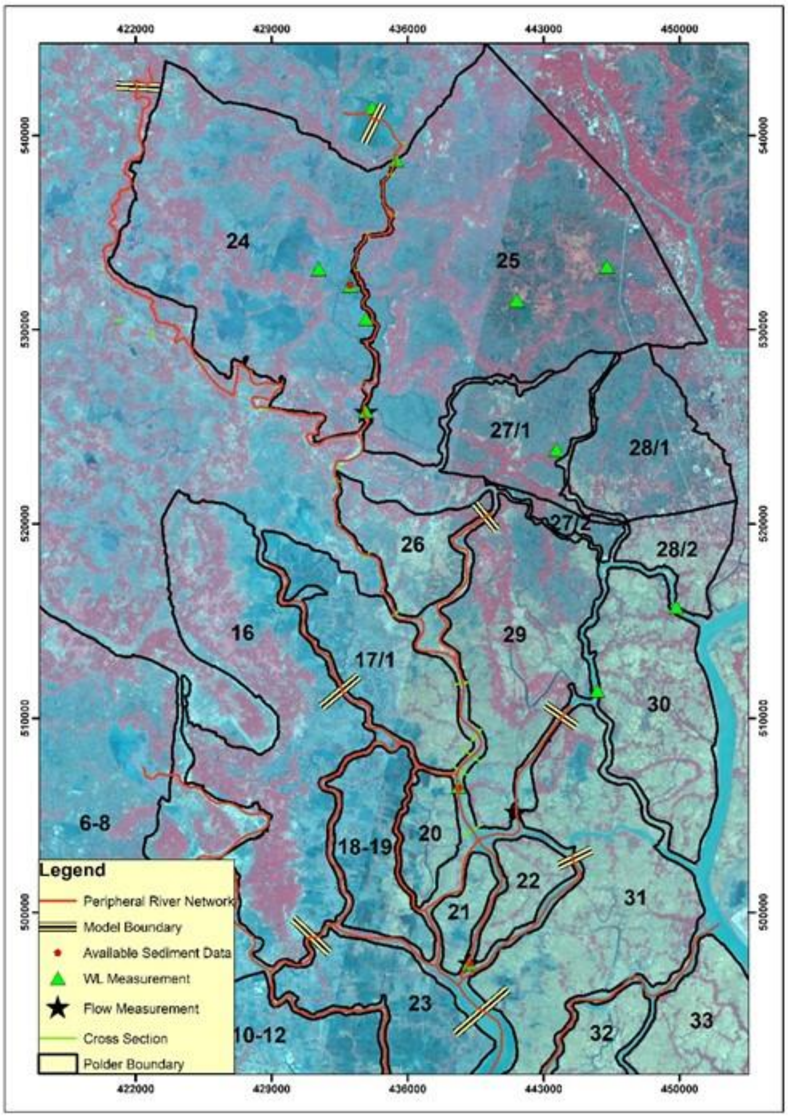


Figure 4-26: River Network for Mike 11 Model Extracted from SWRM

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.

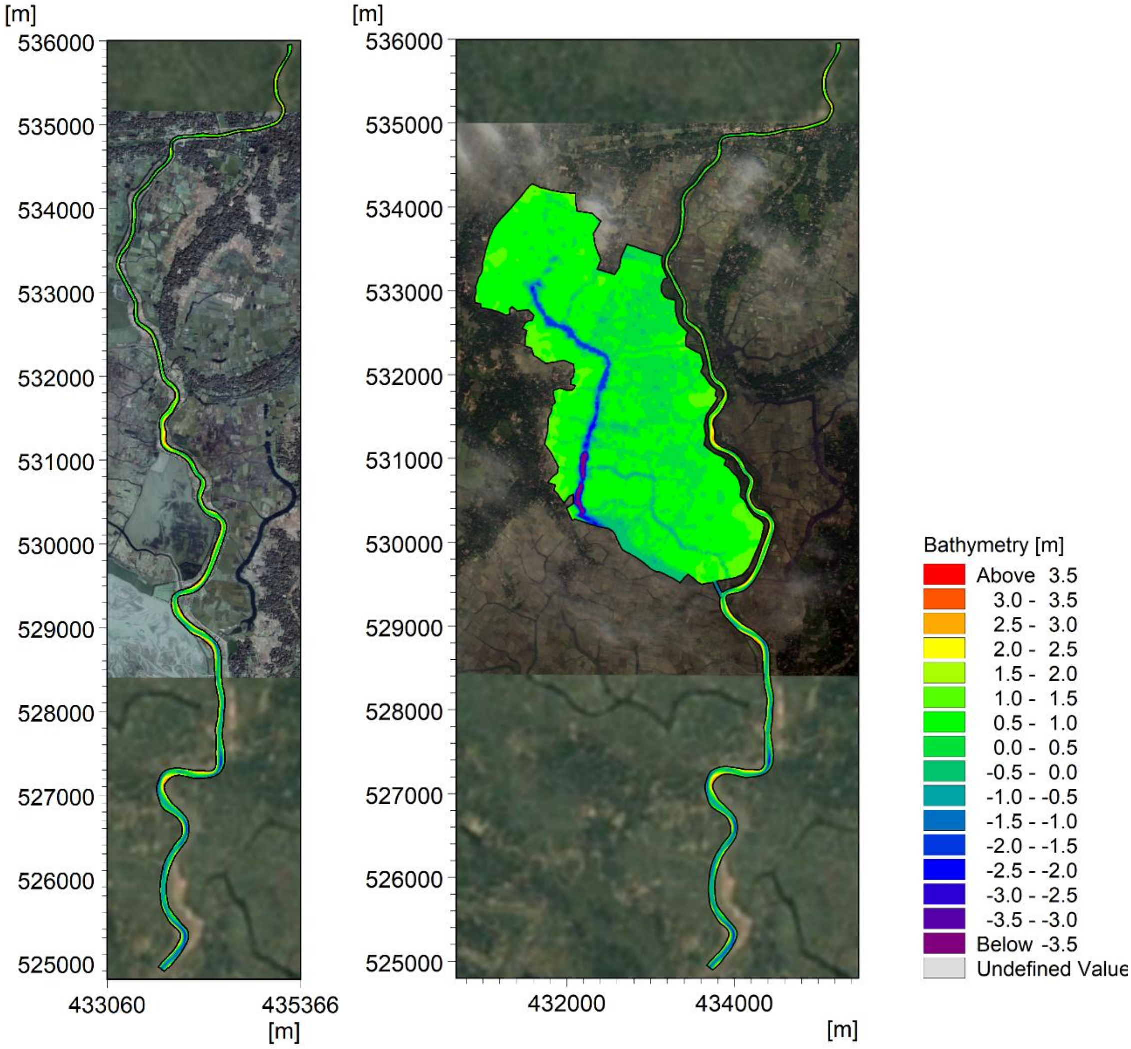


Figure 4-27: Model bathymetry with and without beel applied for TRM.

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 4.27 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 4.28 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 4.29 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.

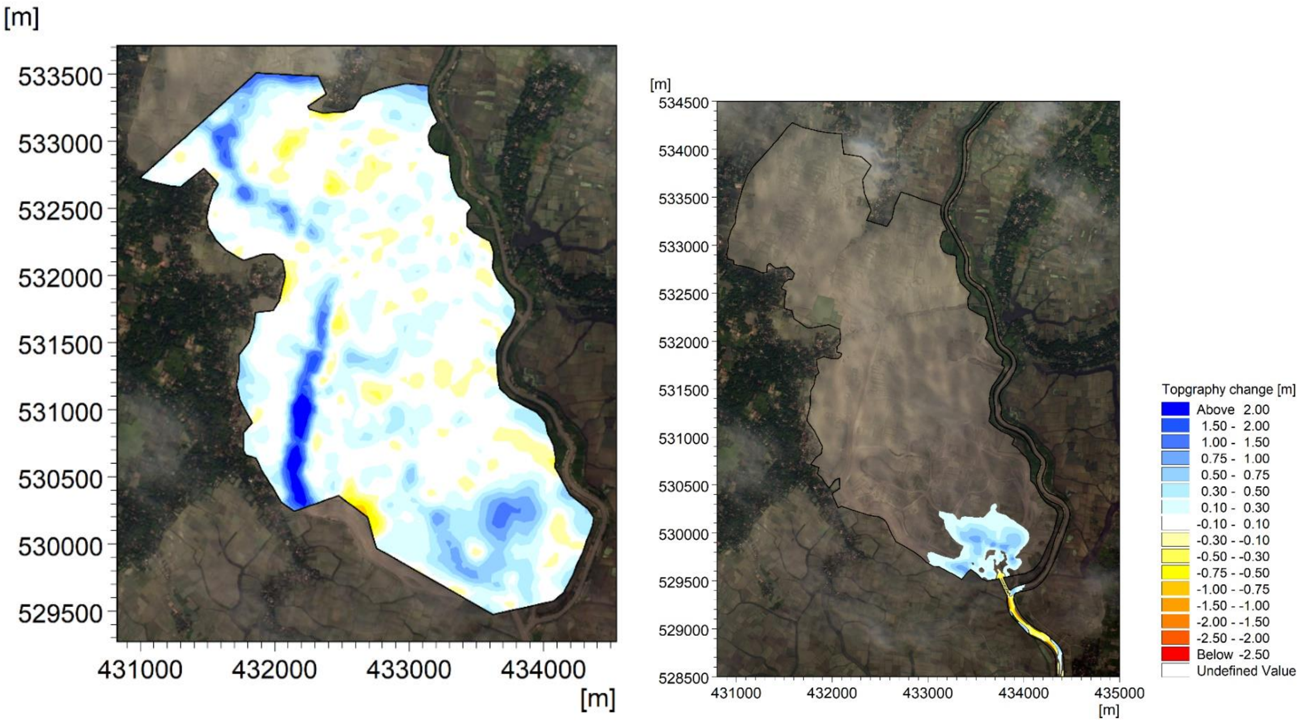


Figure 4-28: Observed and modelled deposition pattern inside the beel during the period from February 2007 to May 2007.

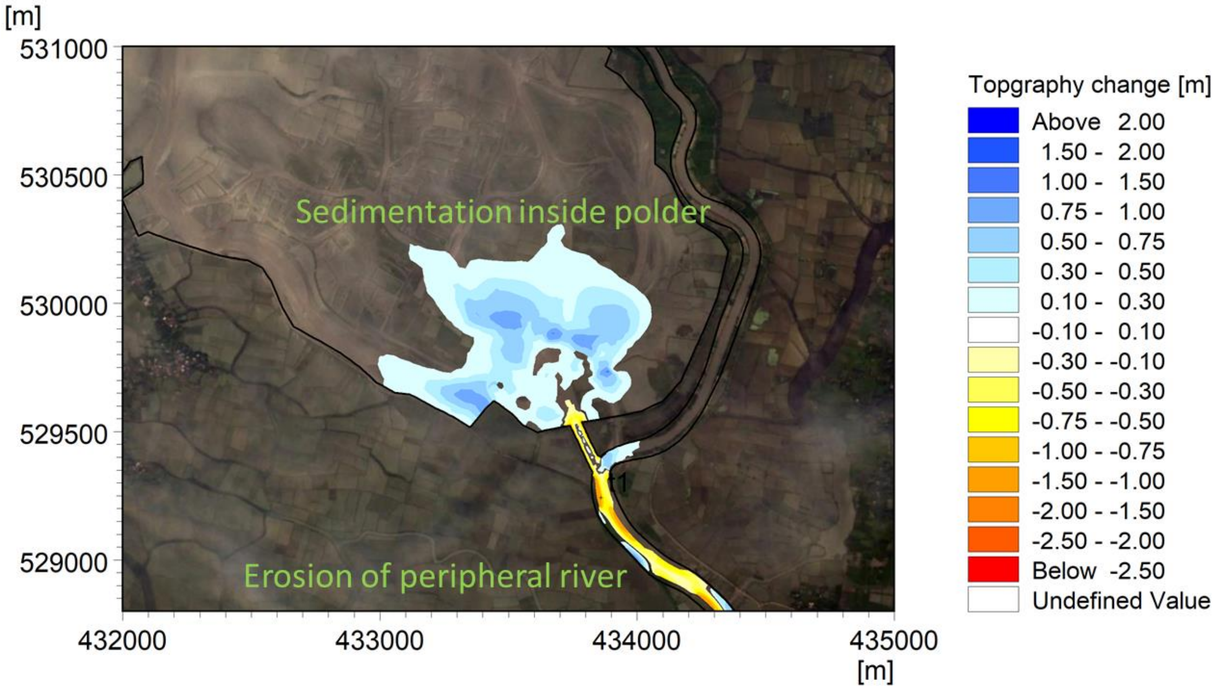


Figure 4-29: Closeup of the deposition pattern inside the polder and the erosion of the peripheral river

4.5.3 Further TRM Modelling

A 1D (Mike 11) model was setup to simulate TRM operation at East Beel Khuksia (Polder 24). The TRM operation implemented for East Beel Khuksia will be used as pilot case because ample data are available from this particular TRM operation. The objective of TRM modelling in general is to establish a modelling approach that can be used to test alternative TRM operations and identify the most effective operations. The purpose of the 1D modelling 1D is to explore what will be required in terms of modelling to optimise TRM operation.

TRM has for many years been considered a viable way to maintain the drainage capacity of the peripheral rivers and for compensating the impact of subsidence by increasing land level inside the polders through deposition of silt. The key problem with TRM is that the area inside the polders which are subjected to tidal flooding cannot be used for the intended purpose of the polders (viz. agriculture) while TRM is ongoing hence the population of the polders must be compensated and alternative livelihood created. An issue with TRM operation is also that deposition inside the polders is highly non-uniform, hence not the entire area inside the polders may benefit from deposition. There is thus much to win if TRM operation can be optimised, i.e. accelerate erosion in the peripheral rivers, accelerated deposition within the polders and by ensuring a more uniform deposition pattern

The model used simulates hydrodynamics and advection-dispersion of suspended sediment represented by one (representative) size fraction only. Erosion and deposition are as sources and sinks in the advection-dispersion model and calculated as simple/standard functions of the cross-sectional average bed shear stress (thus a standard cohesive sediment modelling approach). There are thus no 2D representation, which is likely to be important in the polders/beels, nor morphological feedback (impacts from erosion and deposition on the flow pattern), which may be important in the peripheral rivers.

The model was developed from a curtailed version of the South-West Regional Model (SWRM). The layout of the curtailed model is shown in Figure 4.30. East Beel Khuksia is part of Polder 24. Polder 29 is one of the selected polders in this study. The model boundary conditions are the corresponding simulated values from the full SWRM.

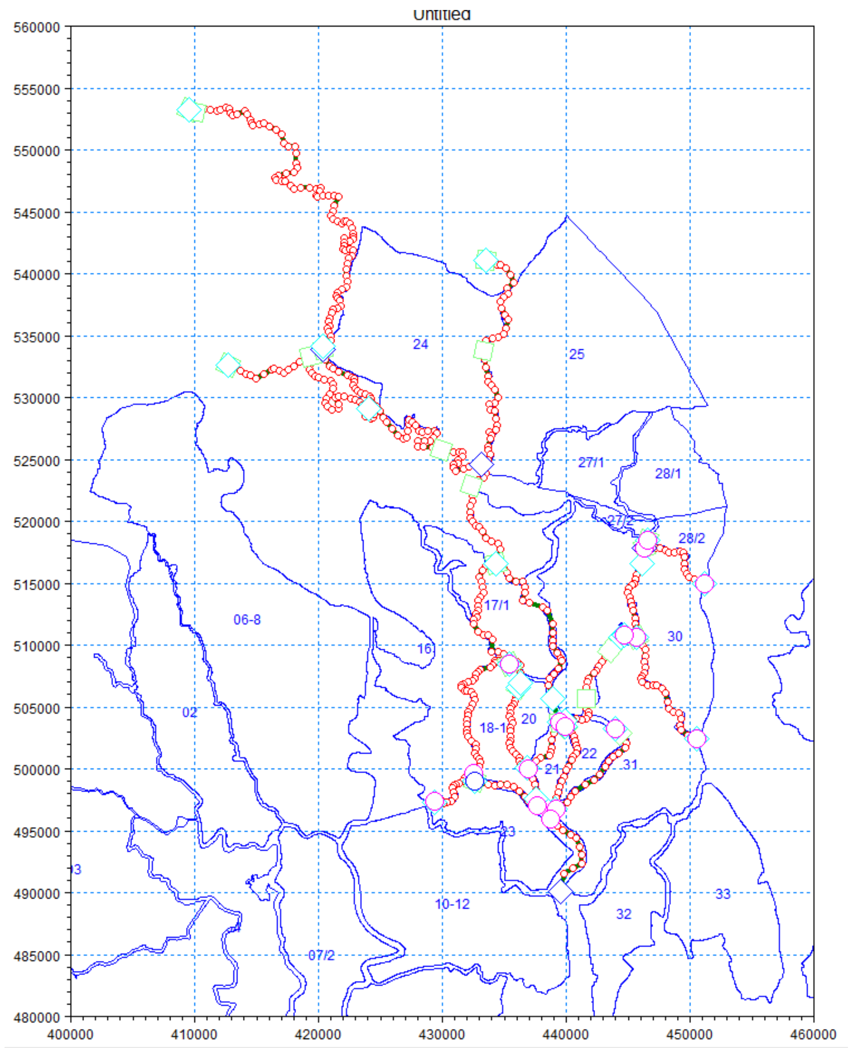


Figure 4-30: Curtailed SWRM setup with polder map.

The model was calibrated on observed water level variation and sediment concentration as well as observed siltation and re-erosion for a 3 months period.. Sample results are shown below in Figure 4.31 and 4.32.   .

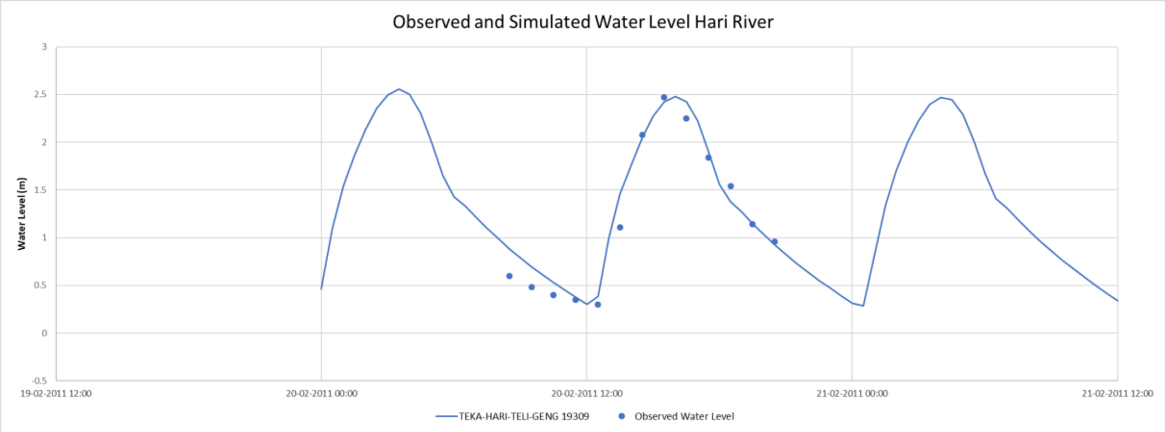


Figure 4-31: Simulated water level in Hari River compared to measured water depth assuming a bed elevation of -3.2 PWD.

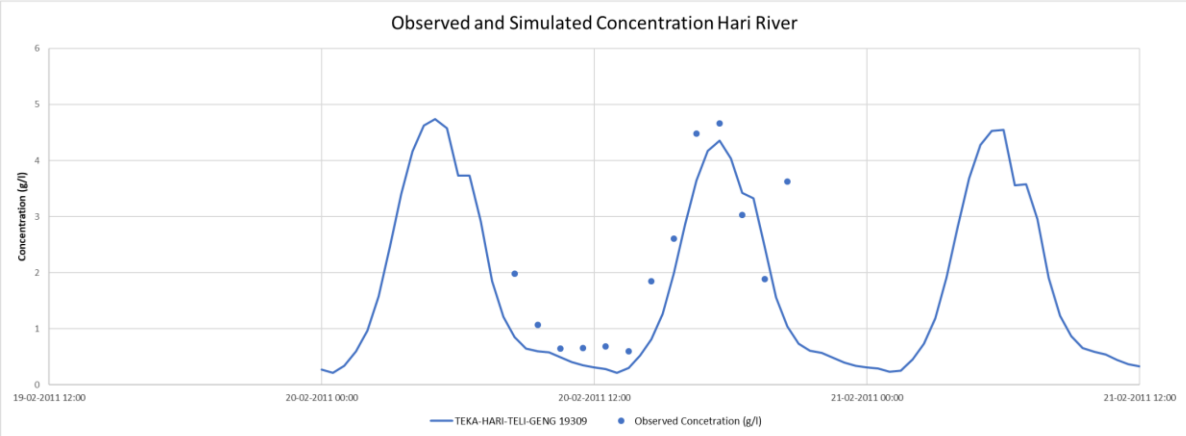


Figure 4-32: Simulated and observed sediment concentration in Hari River – calibrated sediment parameters.

4.6 Bay of Bengal Model

4.6.1 Bathymetry and Mesh generation

a) Cross Sections of River and Estuary

The bathymetry of the Bay of Bengal (BoB) hydrodynamic model has been updated under different studies including the LongTerm Research and Monitoring Program over the recent years. The bathymetry of Pussur-Shibsha River network, Baleswar, Lower Meghna and Sangu River systems have been surveyed under the Long-Term Research and Monitoring program and most of the major river systems bathymetry have been updated with very recent cross sections data. Error! Reference source not found. shows an overview of recently collected bathymetry data.

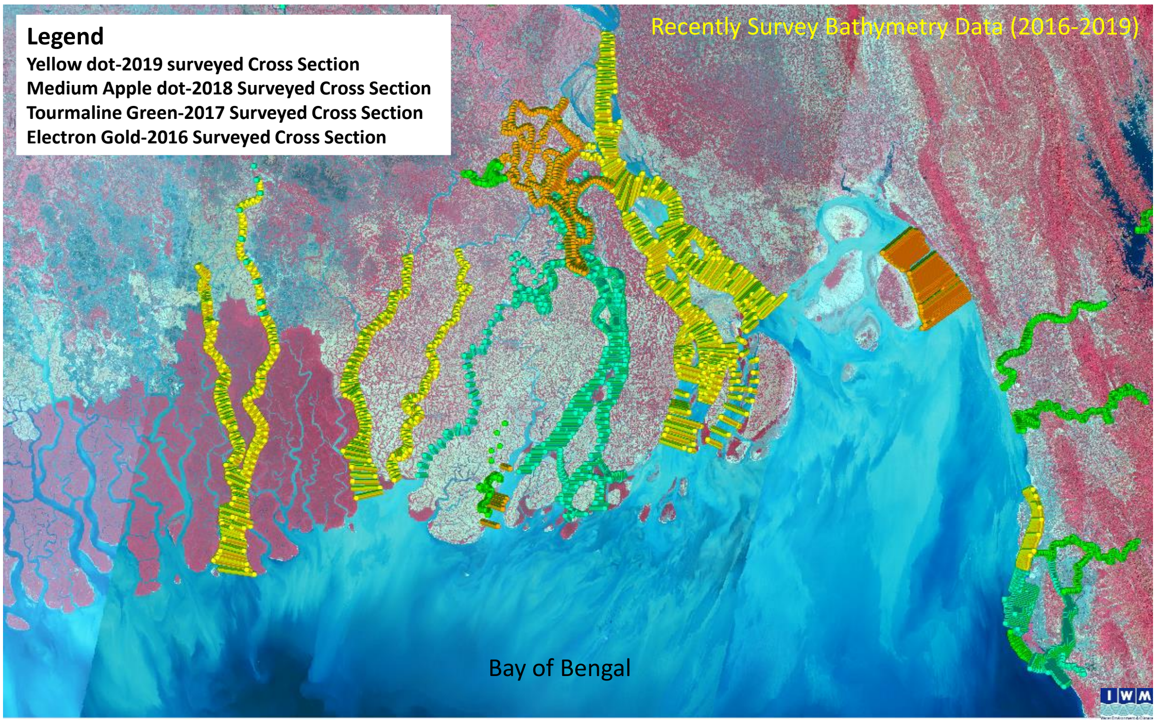


Figure 4-33: Recently collected bathymetry data in different river systems

b) Mesh Generation

Riverbank lines, islands and shorelines have been delineated based on recent Google Images 2019. The dry season (Feb. 2019) image has been selected to identify the bank lines properly. Later, digitized bank lines have been converted into .xyz file format for inclusion in the Mike Zero Mesh Generator. Based on the alignment of the bank lines a proper mesh system has been selected to define the channel properly. Both triangular and quadrangular elements have been generated with different mesh resolution to ensure a correct geometry of the channels and estuary. A highest-level accuracy has been used to define the river system because a suitable mesh is essential for obtaining reliable model results. Figure 4-34 presents the mesh system for the whole Bay of Bengal and coastal area of Bangladesh. The mesh file is an ASCII file (. mesh extension) that includes information of the geographical position and water depth at each node point in the mesh. The file also includes information about the node connectivity of the triangular and quadrangular elements.

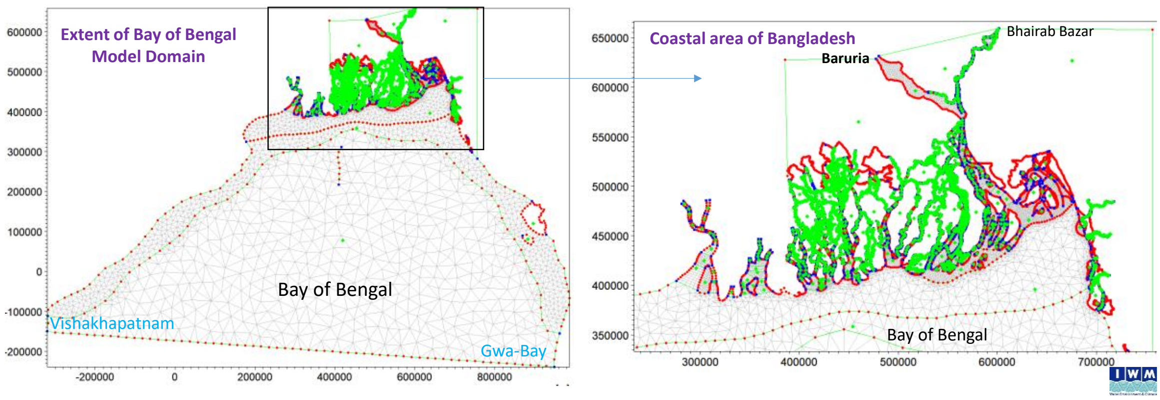


Figure 4-34: Flexible mesh system for the Bay of Bengal and the coastal area of Bangladesh

During the mesh development, most of the river systems have been developed by quadrangular elements. Only confluences of different river systems and sharp bends have been defined by triangular elements. The purpose of this is to reduce the number elements and thereby simulation run time. As an example part of the upgraded mesh using a combination of triangular and quadrangular elements is presented in Figure 4-35.

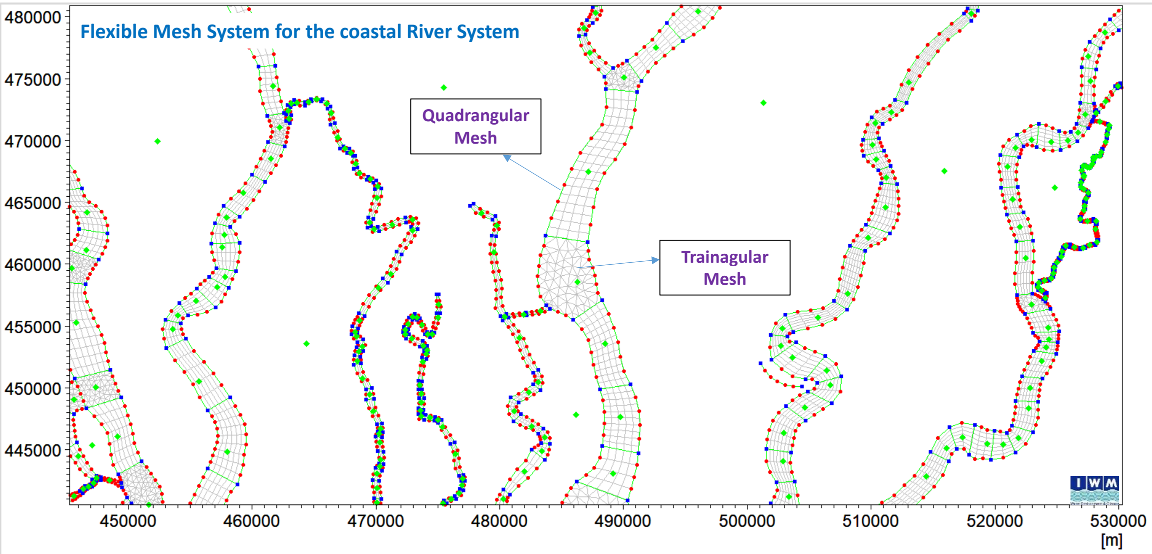


Figure 4-35: Combination of quadrangular and triangular elements of different resolution in the model mesh

a) Development of the Bathymetry

Surveyed cross section data from 2015 to 2019 has been collected by the IWM Survey and Data Division. The data was processed, and quality checked for the generation of the bathymetry according to new digitized land boundaries. A few rivers have been surveyed under the Long Term Research project and the rest of the rivers surveyed under different other projects. Figure 4-36 shows the bathymetry data used in the Bay of Bengal model mesh.

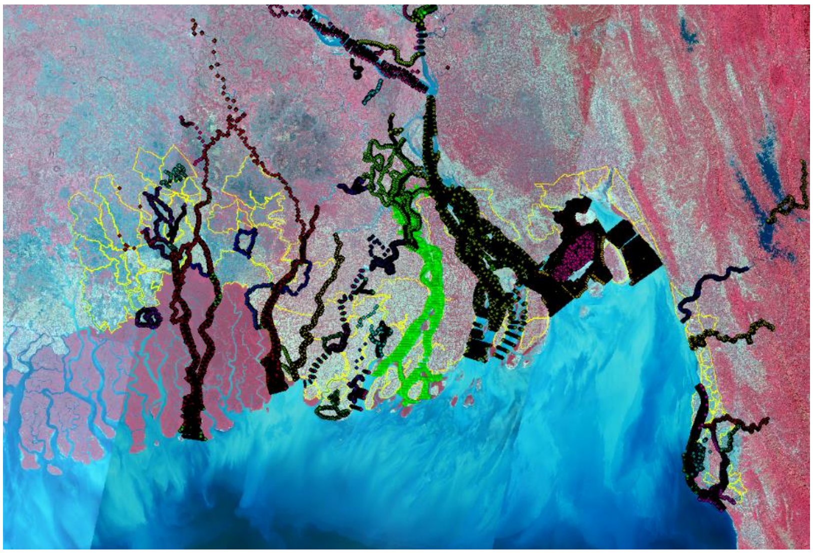


Figure 4-36: Surveyed bathymetry data from 2015 to 2019

For rivers with a meandering shape it is difficult to represent the thalweg or connectivity of the bathymetry in a satisfactory way in the applied Mesh Generator software. In this project, therefore, the Delft 3D FM software has been used as a tool to develop parts of the finer resolution mesh and to interpolate the cross-section depth data (script developed by Professor Dano Roelvink, IHE, Delft). Figure 4-37 illustrates the processed bathymetry of the Kobadak River system.

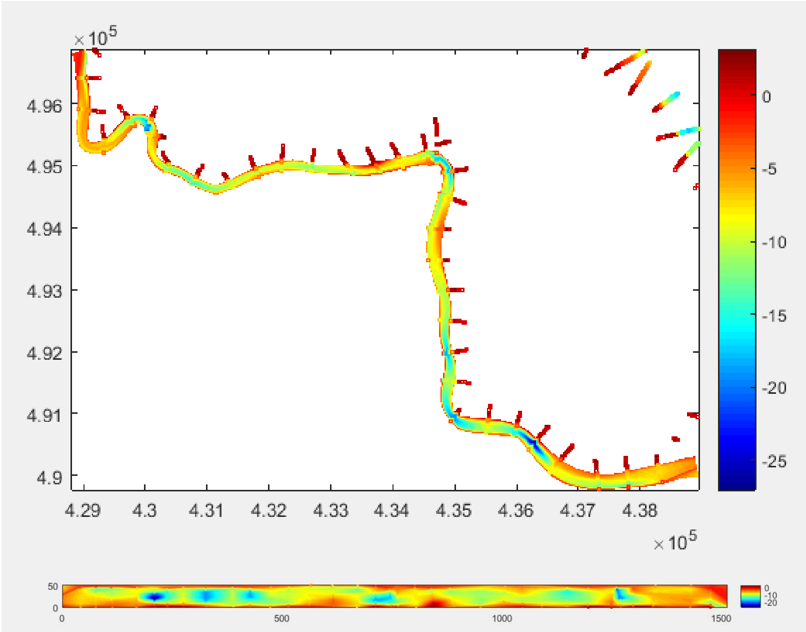


Figure 4-37: New bathymetry generation technique using the Delft 3D Flexible Mesh System

Similar procedure has been applied for all of the river systems in this study. The new bathymetry development concept has been described below for a river reach. The measured bathymetry data are normally spaced by 500-1,000m, in some places 2,000 m. In a meandering river, such large spacing between cross sectional data does not produce good bathy using simple interpolation, especially around the bends. The applied script helps to solve this problem by producing a very fine resolution of cross sectional data based on the original cross section data and as a result connectivity in the river is maintained. The steps are as follows (see also **Error! Reference source not found.**).

- Step 1: Generation of splines from digitized Bankline using quickplot;
- Step 2: Generation of grid (10 m x 10 m) using Delft software;
- Step 3: Run script to generate the fine resolution bathymetry data using MATLAB and open earth tools.

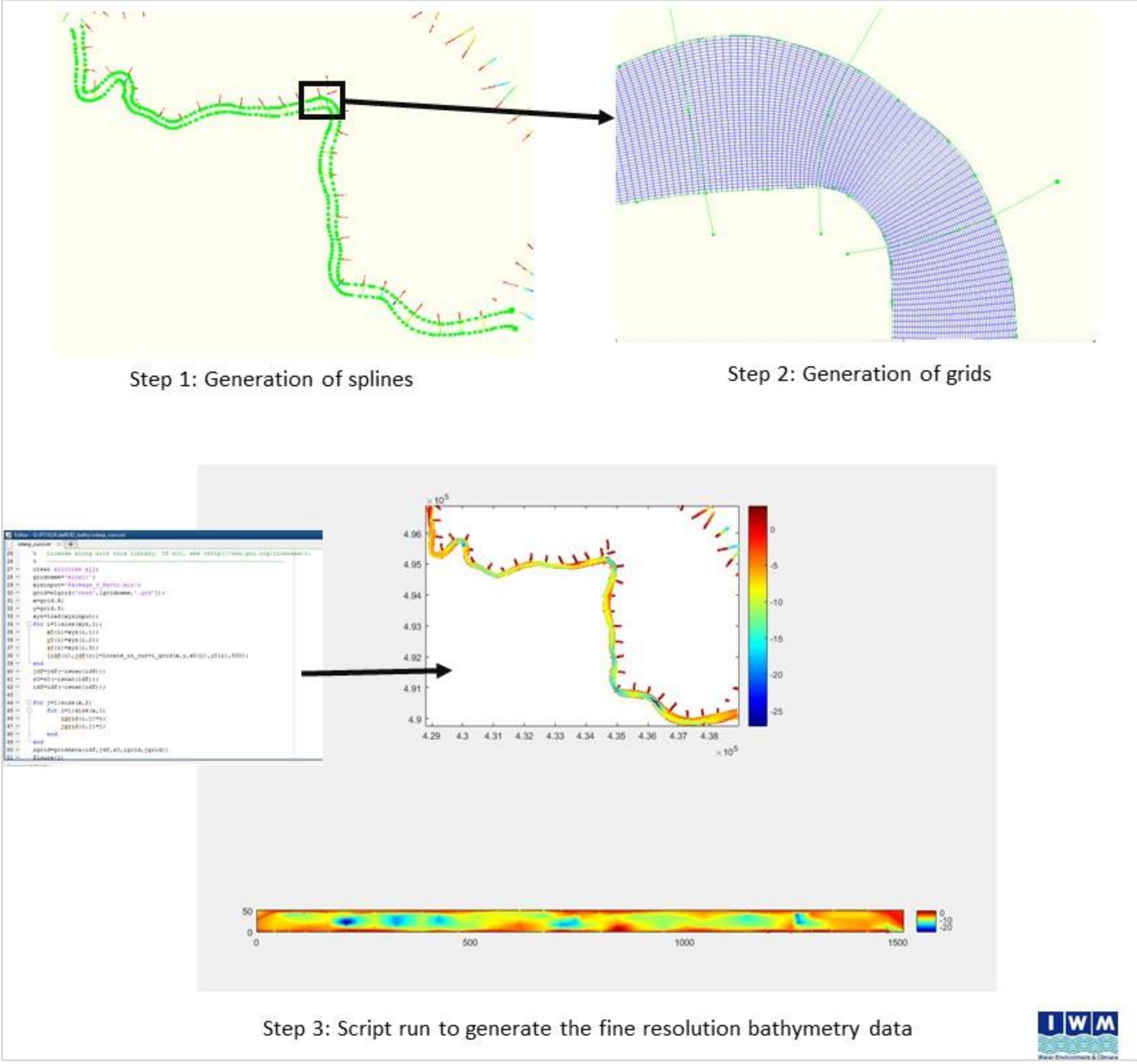


Figure 4-38: Explanation of the steps used for generation of fine resolution bathymetry

The processed bathymetry data has been imported to the MIKE Zero mesh generator as .xyz file format. The imported bathymetry in the MIKE Zero mesh generator is presented in Figure 4-39.

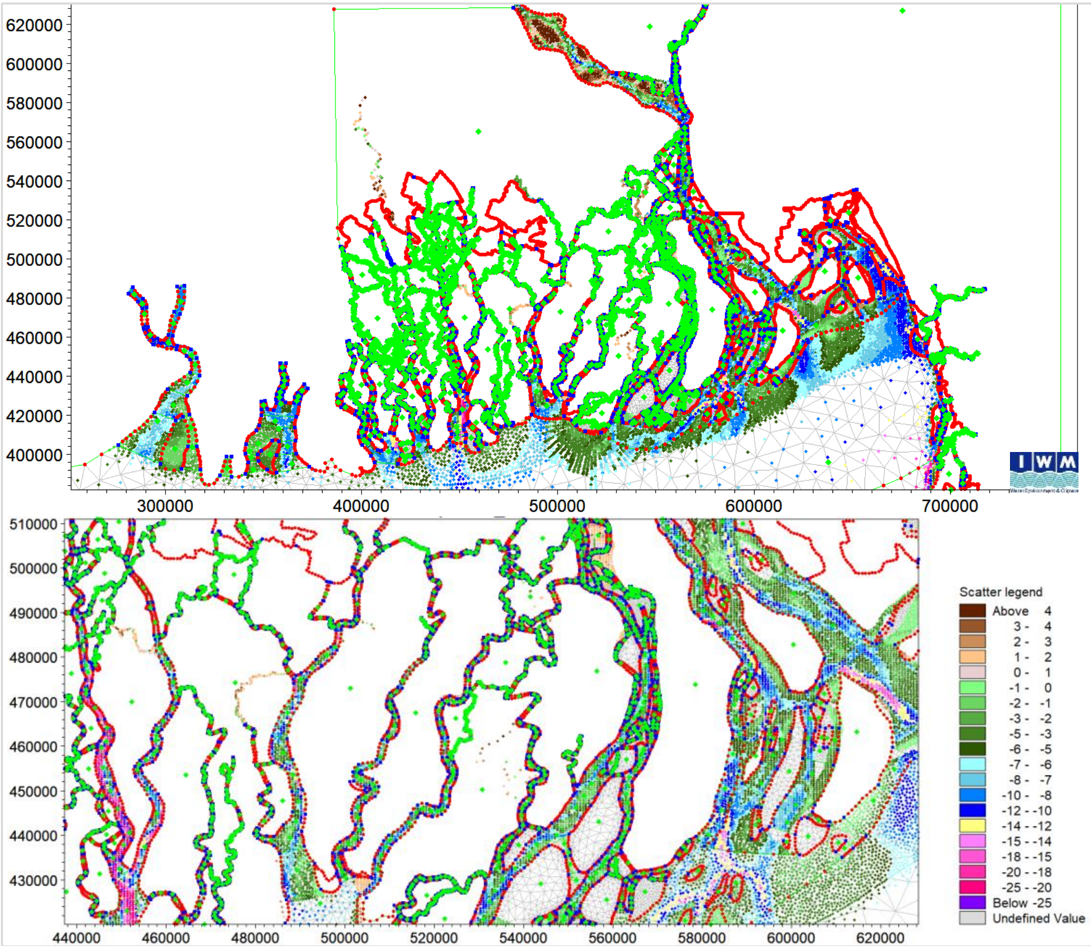


Figure 4-39: Imported bathymetry in the Mike Zero Mesh Generator

i. Inclusion of Polder and Island Land Level

Polder and Sea island land level has been added in the modelling system to assess the effects of tide and cyclones. The land level has been collected from Survey of Bangladesh (SOB). **Error! Reference source not found.** presents the land data density inside the polders. The shown land level resolution is 50m x 50m. However, these are interpolated data from 300m x 300m resolution data sets.

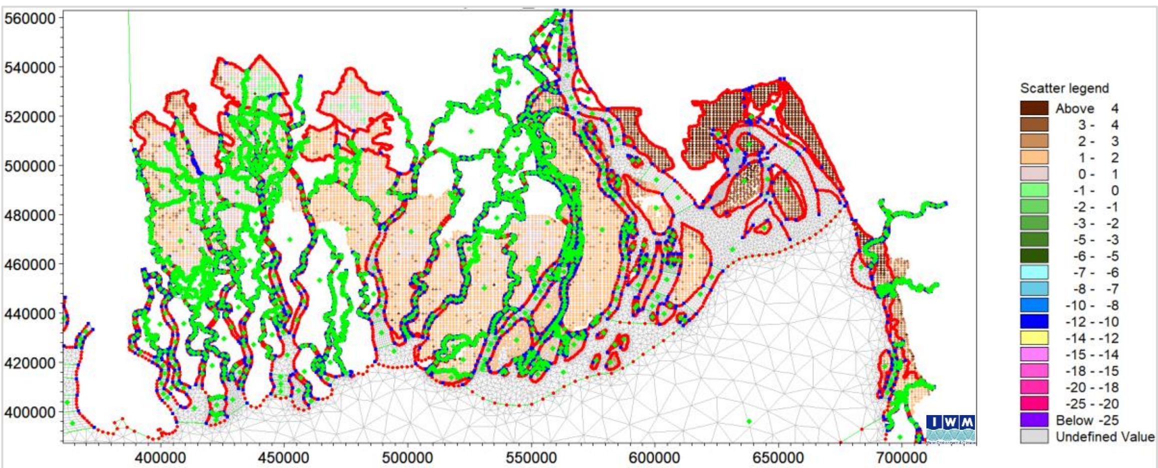


Figure 4-40: Inclusion of land level data in the developed Bay of Bengal model mesh

4.6.2 Hydrodynamic Modelling

(a) Extent and Boundaries of Bay of Bengal Model

Three main open boundaries are defined in the updated Bay of Bengal model. Two open boundaries are located to the north in the Upper Meghna River at Bhairab and in the Padma River at Baruria and one open boundary is located in the southern Bay of Bengal at 16º latitude. The maximum depth along the southern open boundary of the model area is more than 2,000 m.

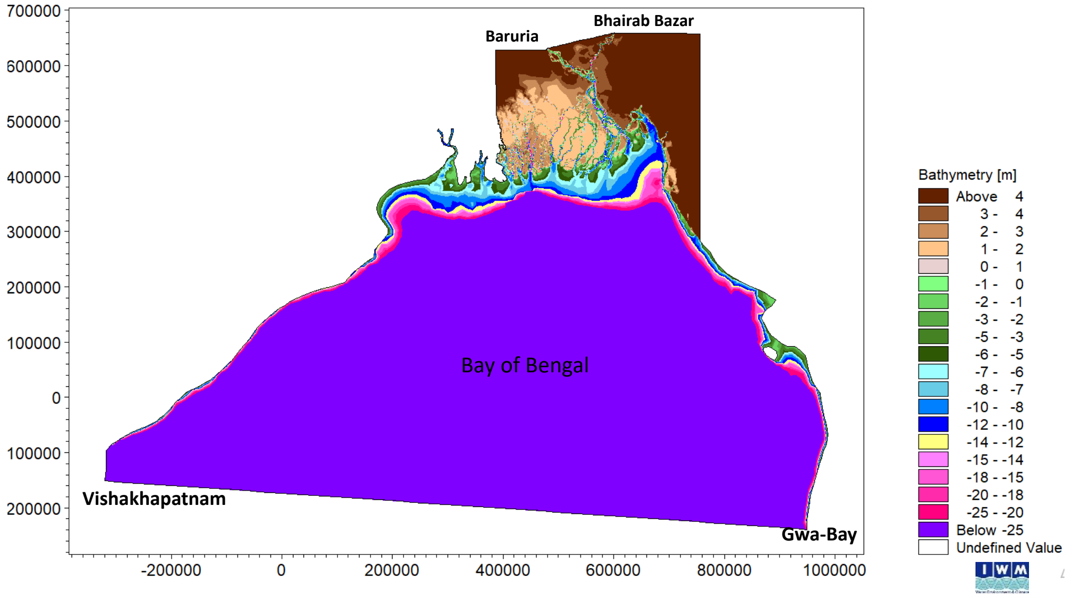


Figure 4-41: Geographic extent of the updated of Bay of Bengal model

The northern boundaries are located in the non-tidal zone where time series of daily discharge is prescribed. Along the southern boundary astronomical tides generated from the Global Tide Model is prescribed. There are additionally 26 minor upstream open boundaries in the Bay of Bengal model. Discharges at these boundaries have been extracted from the IWM regional model (South-West and Eastern Hilly Regional Model).

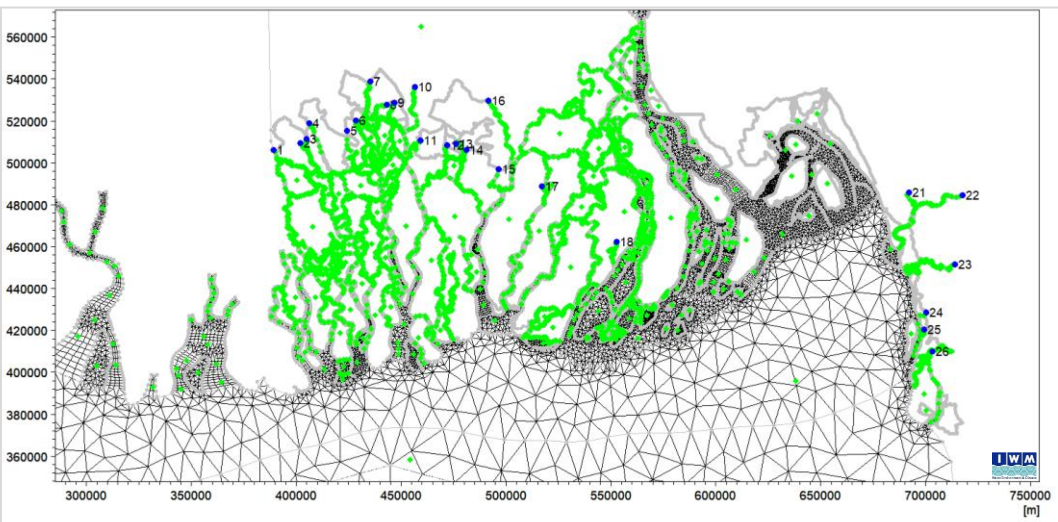


Figure 4-42: Upstream open boundaries in the Bay of Bengal Model

(b) Bed Resistance

To calibrate the model, it is necessary to adjust the bed resistance. In this study a map with different bed resistance has been used. The relation between Manning number (M) and bed roughness length, Ks can be estimated using the following formula:

$$M = \frac{25.4}{Ks^{1/6}}$$

The Manning number (M) is the reciprocal value of Manning's n. Initially a Manning map was prepared based on the local water depth, however, further corrections have been made during the calibration process of the model. The initial Manning number distribution is presented in Table 4-7 and in Figure 4-44.

Table 4-7: Manning number distribution

Areas with depths	Manning number ($m^{1/3}/s$)
Below -20 m	32
-20 to -15 m	60
-15 to -10 m	65
-10 to -5 m	90
Above -5 m	100
Mangrove Forrest	15
Settlement & Rice field	25

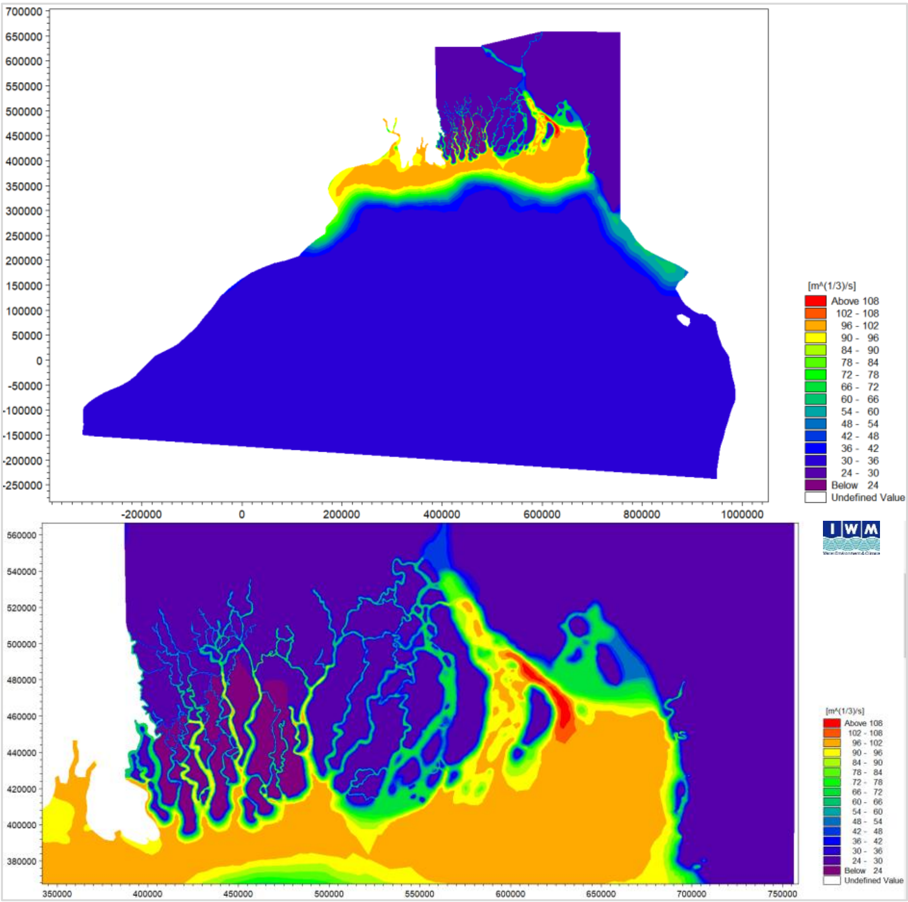


Figure 4-43: Spatial variation of roughness (M) in the Bay of Bengal Model

(i) Calibration and Validation of Hydrodynamic Model

The updated two-dimensional hydrodynamic model of the Bay of Bengal will be calibrated against IWM observed water level, currents and discharge at different locations comparing the model results with field measurement. The calibration will be carried out during different conditions like dry season, wet season and during spring tide and neap tide depending on data availability. Figure 4-44: shows the most important stations with data available for the model calibration. Among them few stations have very recent data, few have data during 2015-2016 and some have only older data. The priority is to calibrate the model against the most recent data and validate the model against the 2015-2016 data.

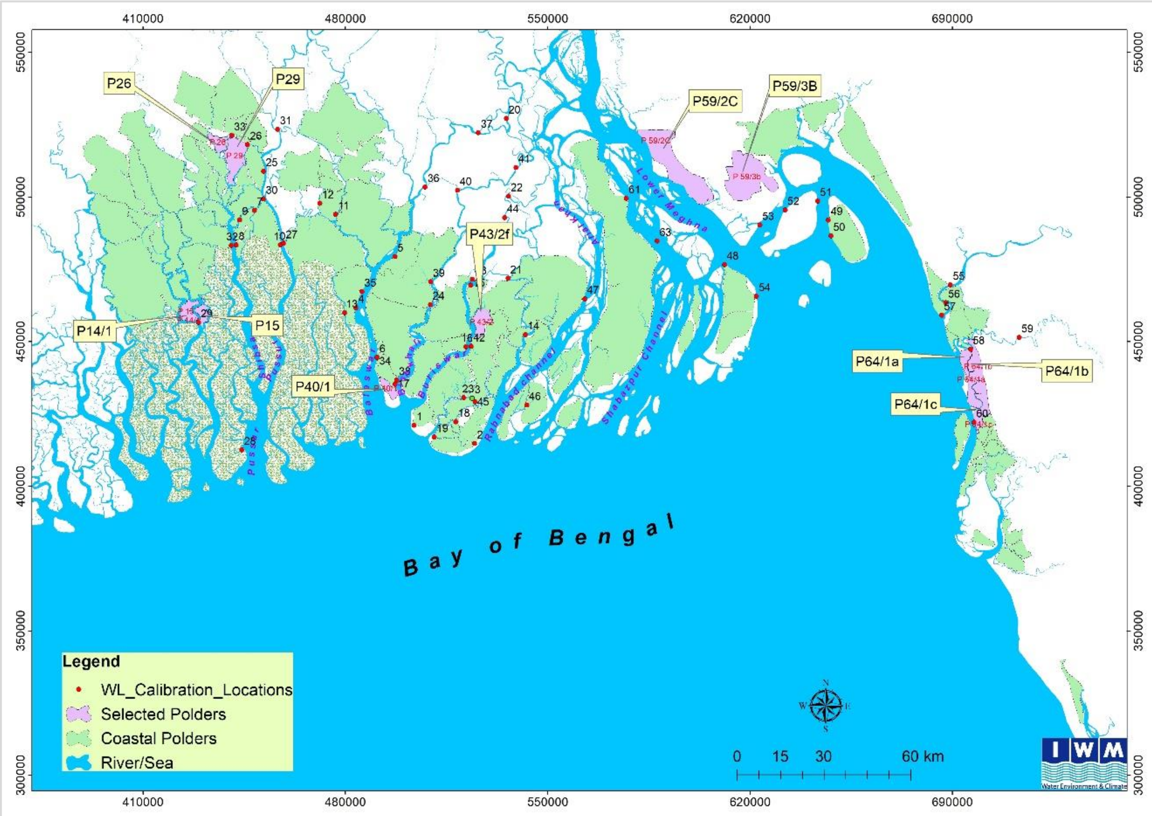


Figure 4-44: Locations with data available for model calibration

(ii) Cyclone Wind Model

The description of a cyclone is based on a few parameters related to the pressure field, which is imposed to the water surface, and a wind field which is acting as a drag force on the water body through a wind shear stress description. The pressure field creates a local water level setup close to the eye of the cyclone, whereas the wind shear contributes more to the surge giving a level setup on the right side of the eye and a level set down on the left side.

To generate the wind field, Holland Single Vortex theory will be applied. The cyclone model needs the following information for the description of the pressure and wind field:

- Radius of maximum winds, R_m,
- Maximum wind speed, V_m and
- Cyclone track forward speed V_f and direction.
- Central pressure, P_c
- Neutral pressure, P_n
- Holland Parameter, $B= 2.0-(P_c-90)/160$

In order to obtain surface winds, a boundary layer wind speed correction is applied to the gradient wind. The near-surface wind is usually obtained by the following relation (Harper et al., 2001):

$V_{10\ r}$ = Km. (r)

where Vg is the rotational wind gradient speed at a distance r from the center of the cyclone. As mentioned by Harper et al, (2001) different values for the parameter K_m are available in the literature.

As mentioned by Harper et al, (2001) different values for the parameter K_m are available in the literature. These values can be entered in the Cyclone Wind Generation Tool using a constant type of geostrophic correction.

A speed-dependent formulation for K_m is also proposed by Harper et al. (2001) and seems widely used in Australia. This has been implemented in the Cyclone Wind Generation Tool as the “Harper et al.” Geostrophic correction type where the K_m factor is computed as:

$$K_m = \begin{cases} 0.81 & for V_g < 6\ m/s \\ 0.81 - 2.96\ 10{-3}\ (Vg - 6) & for\ 6 \le V_g < 19.5 \\ 0.77 - 4.31\ 10{-3}\ V_g - 19.5) & for\ 19.5 \le V_g < 45 \\ 0.66 & for V_g > 45\ m/s \end{cases}$$

For this study 0.75 is used as the geotropic correction factor. As an example, the pressure and wind field for cyclone SIDR is presented below (Figure 4-45).

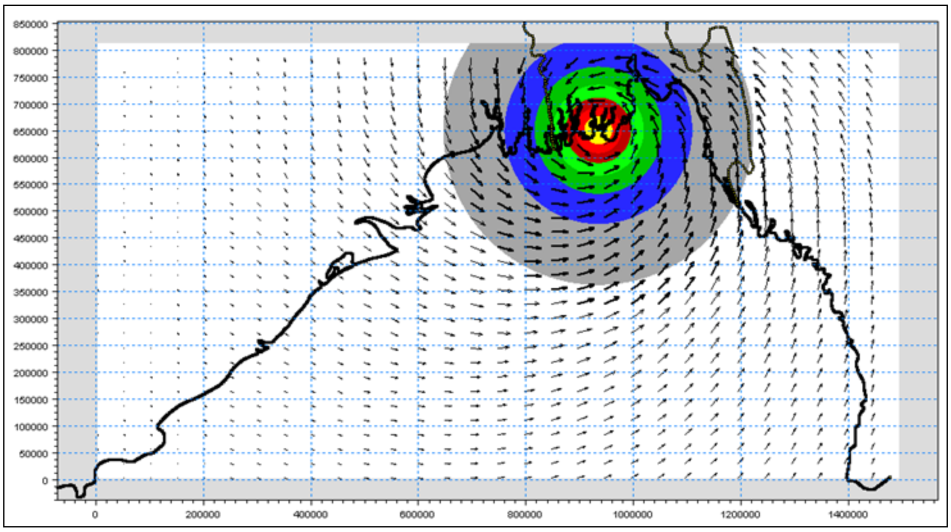


Figure 4-45: Pressure and wind field of cyclone SIDR

(iii) Calibration of Cyclone Wind Model

The Bangladesh Metrological Department (BMD) collects wind data at different locations. Historical wind data from BMD has already been collected and data from the 9 measuring stations: Mongla, Barisal, Khepupara, Hatiya, Chandpur, Sandwip, Chittagong, Kutubdia and Teknaf is available for verification of applied modelled wind during the cyclone periods.

(iv) Storm Surge Model

The developed Bay of Bengal Model will be used for modelling of tidal propagation and storm surges. The storm surge model is based on the MIKE 21 FM HD hydrodynamic modelling system.

The MIKE 21 FM HD 21 modelling system includes dynamic simulation of flooding and drying processes, which are very important for a realistic simulation of flooding in the coastal area and inundation.

Wind and pressure fields generated by the cyclone wind model will be used as forcing of the model together with the astronomical tides and river flows at the open model boundaries.

(v) Calibration and Validation of Storm Surge Model

The developed storm surge model will be calibrated against observed water levels during historical storms. The aim is to calibrate the storm surge model under two conditions: during a weak storm (depression) and during a strong storm, cyclone (e.g. during the SIDR cyclone). The exact storm conditions that will be used depend on the availability of data.

4.6.3 Development of the Wave Model

IWM already maintains a wind wave model which has been developed using the Mike 21 SW (Spectral Waves) Flexible Mesh software. To correctly model waves generated by the historical cyclones the model extent (model mesh) was extended further south (to 4 degrees latitude) as compared to the hydrodynamical model extent.

For the present study the model extent will remain unchanged. However, the local coastal mesh system will be updated with the developments described above for the hydrodynamic model. This also includes that a finer resolution bathymetry will be used near the coast compared to the deep sea.

Figure 4.46 shows the extent of the wave model mesh that will be linked to the above described mesh developed for the hydrodynamic Bay of Bengal model.

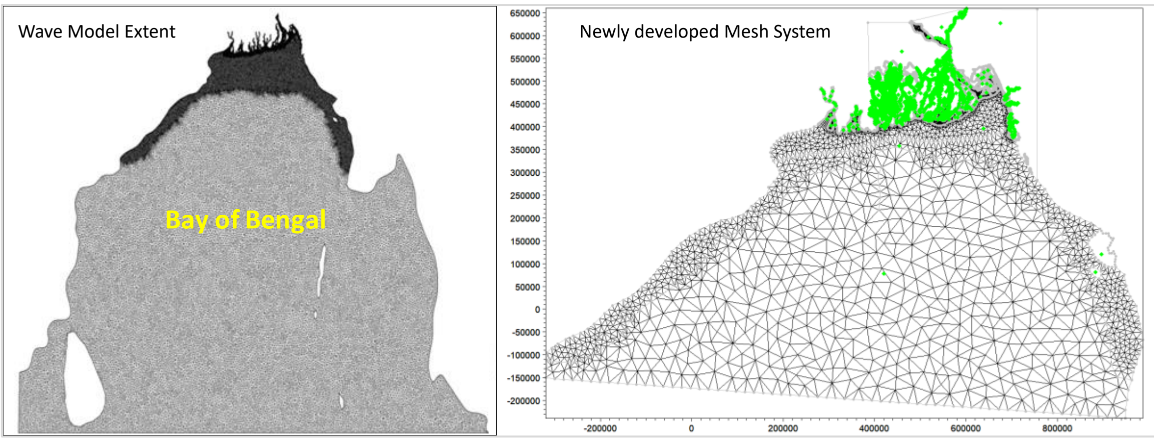


Figure 4-46: The new wave model mesh will be developed as a combination of the existing wave model (left) and the new developed hydrodynamic model mesh (right).

Calibration of Wave Model

Very little wave data is available for calibration of the wave model. However, wave data is available from two locations (Kuakata and Cox's Bazar/Kutubdia) and these data will be used for comparison with the wave mode results.

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 Climate Change Effects (analysis of historical data)

5.2.1 Rainfall

Time series of 32 rainfall stations were available to the project, see Figure 5-1 and Table 5.1. Figure 5-2 shows the data availability for these stations; gaps in the lines represent missing data. It shows there is substantial variation in data availability for the various stations. Years with more than 5% missing data were excluded from the analysis.

Figure 5-3 shows the annual average rainfall as derived from this data set. For verification purposes, a comparison is made with an annual average rainfall map from Shahid et al (2011). It shows these results are in very good accordance. This seems logical as the same data is likely to be the basis of both figures, but nevertheless a useful verification/validation for both studies.

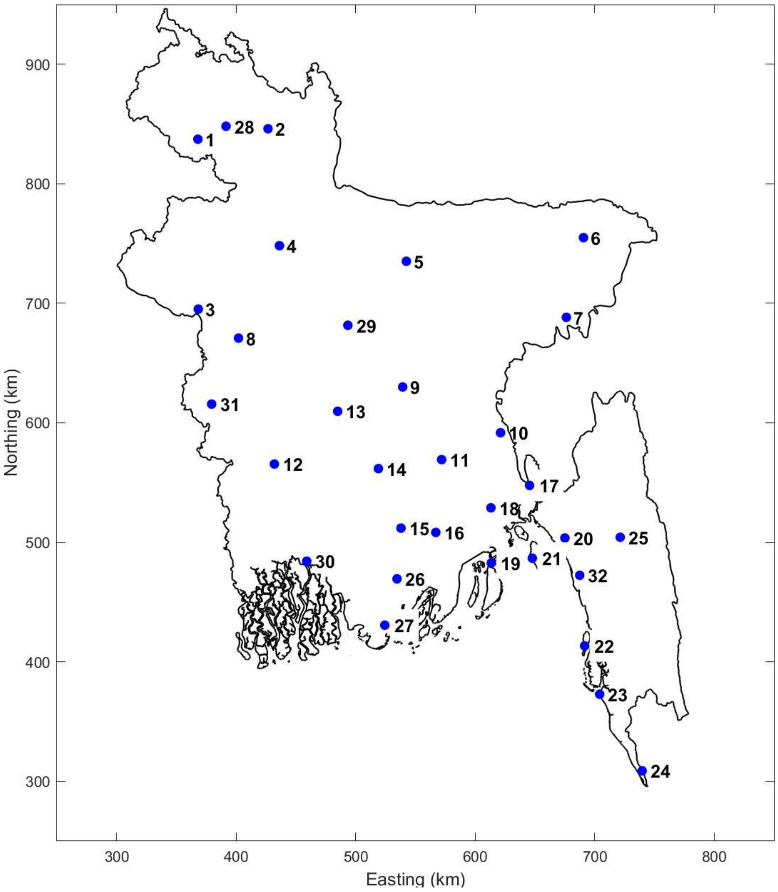


Figure 5-1: Rainfall stations (32 in total) for which data was available to this project.

Table 5.1: Names and coordinates of the 32 rainfall stations of Figure 5-1.

no	station	lat	lon		no	station	lat	lon
1	Dinajpur	25.65	88.68		17	Feni	23.03	91.42
2	Rangpur	25.73	89.27		18	Maijdee Court	22.87	91.10
3	Rajshahi	24.37	88.70		19	Hatiya	22.45	91.10
4	Bogra	24.85	89.37		20	Sitakunda	22.63	91.70
5	Mymensingh	24.73	90.42		21	Sandwip	22.48	91.43
6	Sylhet	24.90	91.88		22	Kutubdia	21.82	91.85
7	Srimangal	24.30	91.73		23	Coxs Bazar	21.45	91.97
8	Ishwardi	24.15	89.03		24	Teknaf	20.87	92.30
9	Dhaka	23.78	90.38		25	Rangamati	22.63	92.15
10	Comilla	23.43	91.18		26	Patuakhali	22.33	90.33
11	Chandpur	23.23	90.70		27	Khepupara	21.98	90.23
12	Jessore	23.20	89.33		28	Syedpur	25.75	88.92
13	Faridpur	23.60	89.85		29	Tangail	24.25	89.93
14	Madaripur	23.17	90.18		30	Mongla	22.47	89.60
15	Barisal	22.72	90.37		31	Chuadanga	23.65	88.82
16	Bhola	22.68	90.65		32	Chittagong (City)	22.35	91.82

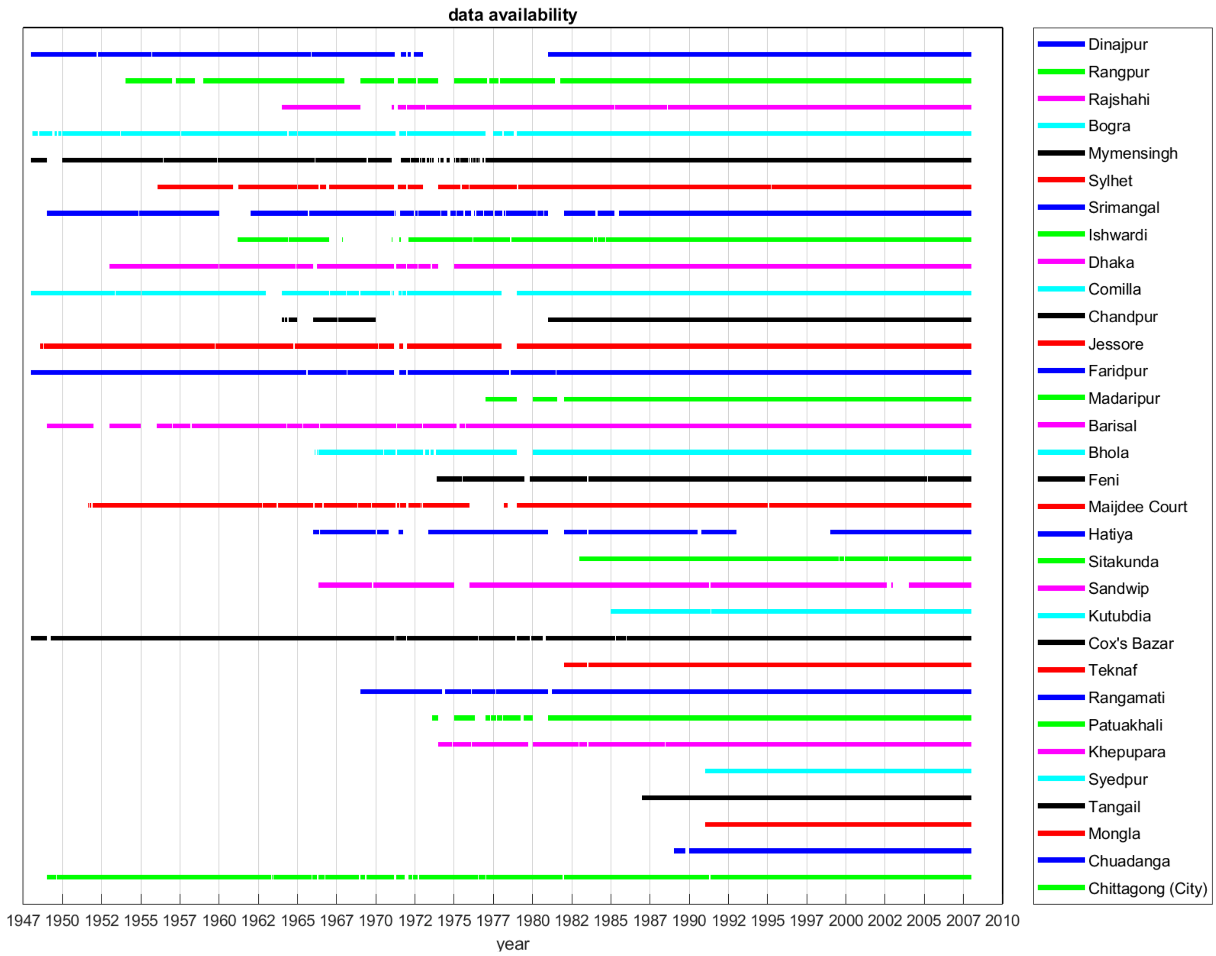


Figure 5-2: Data availability for the 32 rainfall stations. Gaps in the line indicate missing data.

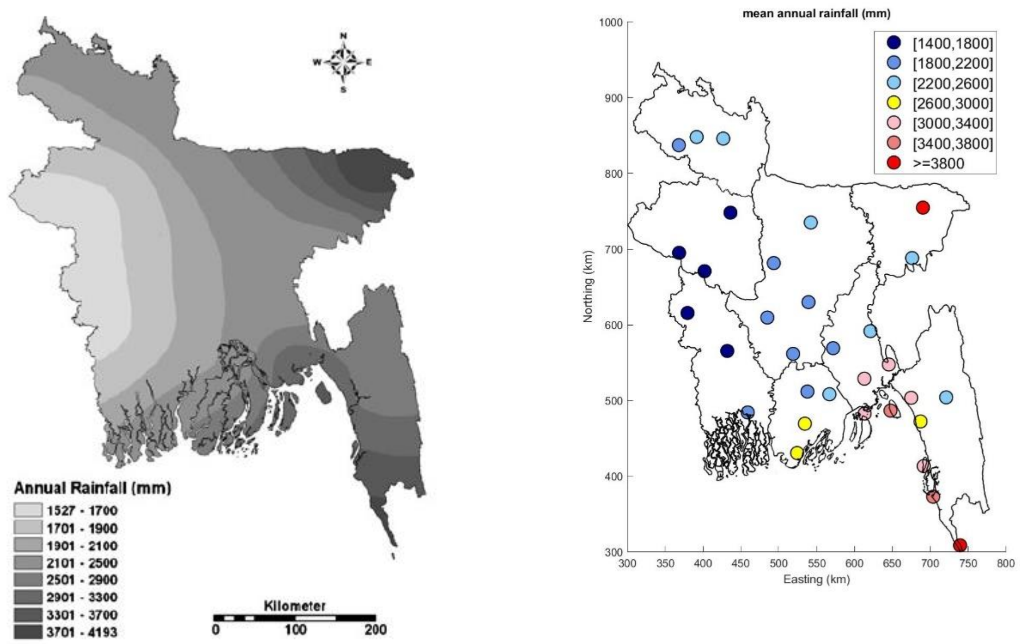


Figure 5-3: Annual average rainfall: comparison between results from Shahid et al [2011] (left) and this report (right).

Figure 5-4 shows derived trend classes based on the measured data presented for the annual total (sum) rainfall, analyzed using the Mann-Kendall test (right subplot). The results are compared to the results of Shahid (2009) (left plot). It shows no major trends over the entire Bangladesh as both, darkest red to darkest blue colors are observed. Overall, there are more locations with an increasing trend than locations with a decreasing trend, therefore suggesting an overall increase in total rainfall. In particular, in the northwest and along the coastline there are several locations with an increasing trend.

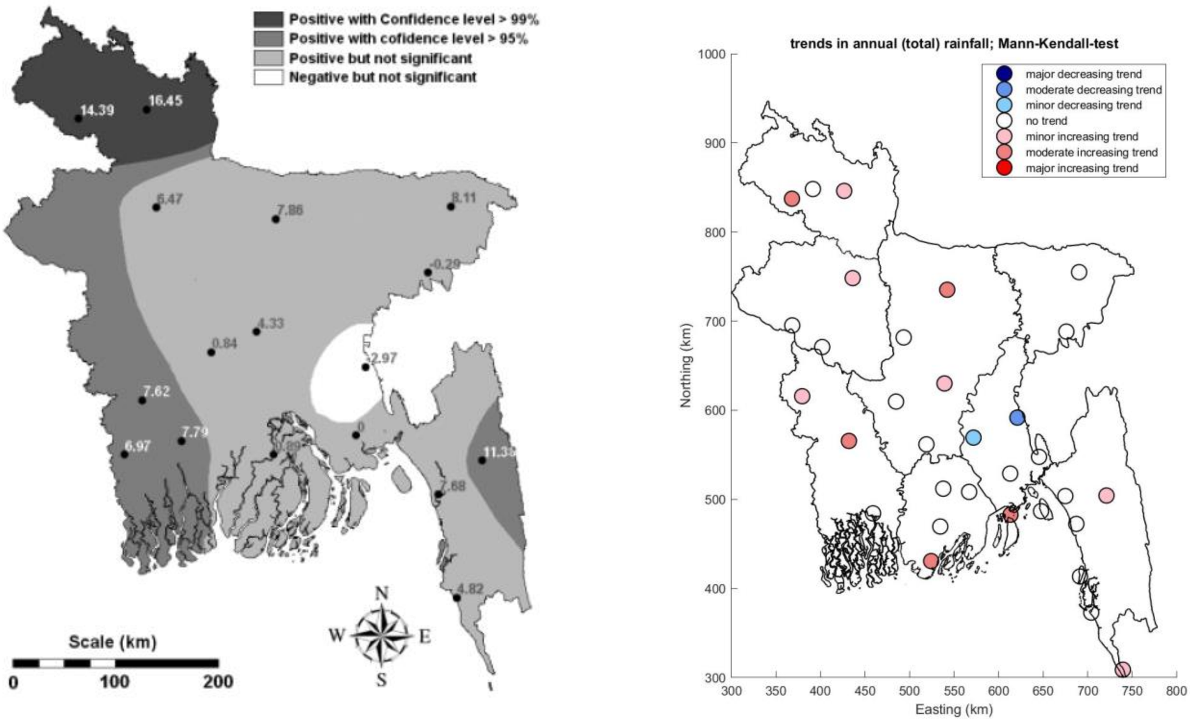


Figure 5-4: Trends in annual total rainfall: comparison between the results from Shahid (2009) (left) and this report (right).

The trend classes for the annual total rainfall as derived with other three statistical tests are very similar to the one shown for the Mann-Kendall test in Figure 5-4; as such confirming the seemingly apparent increasing trend in the Northwest and along the coastline.

Table 5.2 shows the resulting trend classes when all 32 stations are combined. Several tests indicate that the winter season has an overall negative trend, whereas the post-monsoon season and the whole year have an increasing trend.

Table 5.2: Derived trend classes for rainfall for the combination of all stations. Results are shown for two indicators, four statistical tests and five different seasons (including the whole year).

Indicator:	**Total rainfall (sum)**				**Maximum daily rainfall**			
test:	**PS**	**MK**	**SM**	**WMW**	**PS**	**MK**	**SM**	**WMW**
Year	1	1	1	0	0	0	0	0
Pre-monsoon	0	0	0	0	0	0	0	0
Monsoon	0	0	0	0	1	0	0	0
Post-monsoon	1	0	1	0	0	1	0	0
Winter	0	-1	-1	0	-1	-1	-2	0

5.2.2 Temperature

Time series of 34 temperature stations were available to the project, see Figure 5-5. Figure 5-6 shows the data availability for these stations; gaps in the lines represent missing data. It shows there is substantial variation in data availability for the various stations. Years with more than 5% missing data were excluded from the analysis. Figure 5-7 shows derived annual average temperatures (right) and compares them with corresponding results from MOEF (2005) (left). Both figures show a clear temperature gradient from east to west. The values from MOEF (2005) are higher, though, this is most likely the difference between mean daily rainfall (our data) and daily maximum temperature (MOEF, 2005).

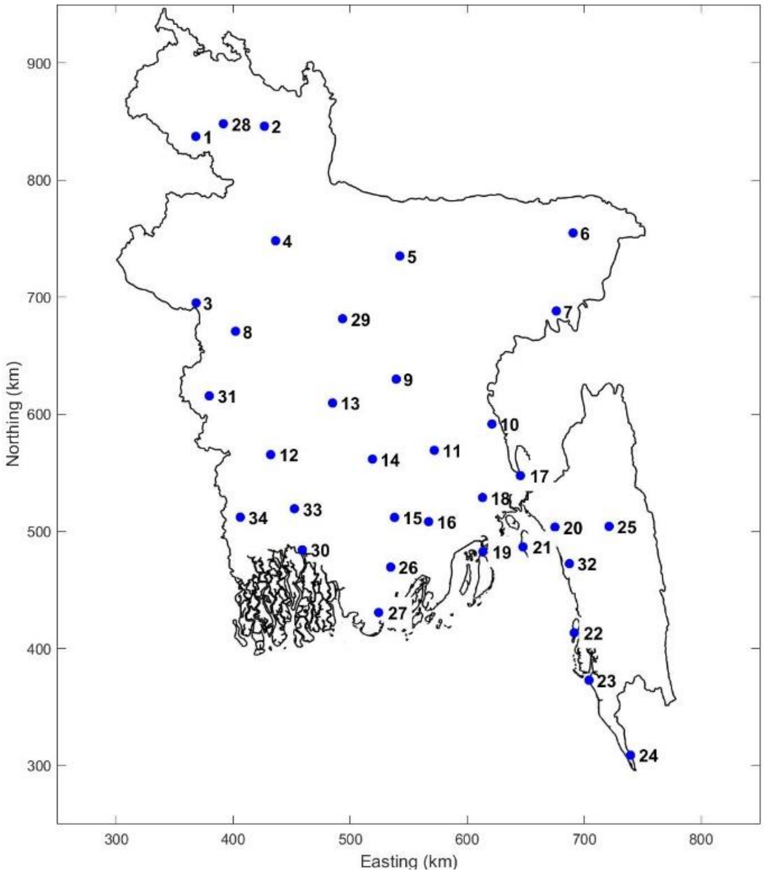


Figure 5.5: Temperature stations (34 in total) for which data was available to this project.

Table 5.3: Names and coordinates of the 34 rainfall stations of Figure 5-5

no	station	lat	lon		no	station	lat	lon
1	Dinajpur	25.65	88.68		18	Bhola	22.68	90.65
2	Rangpur	25.73	89.27		19	Feni	23.03	91.42
3	Rajshahi	24.37	88.70		20	Maijdee Court	22.87	91.10
4	Bogra	24.85	89.37		21	Hatiya	22.45	91.10
5	Mymensingh	24.73	90.42		22	Sitakunda	22.63	91.70
6	Sylhet	24.90	91.88		23	Sandwip	22.48	91.43
7	Srimangal	24.30	91.73		24	Kutubdia	21.82	91.85
8	Ishwardi	24.15	89.03		25	Coxs Bazar	21.45	91.97
9	Dhaka	23.78	90.38		26	Teknaf	20.87	92.30
10	Comilla	23.43	91.18		27	Rangamati	22.63	92.15
11	Chandpur	23.23	90.70		28	Patuakhali	22.33	90.33
12	Jessore	23.20	89.33		29	Khepupara	21.98	90.23
13	Faridpur	23.60	89.85		30	Syedpur	25.75	88.92
14	Madaripur	23.17	90.18		31	Tangail	24.25	89.93
15	Khulna	22.78	89.53		32	Mongla	22.47	89.60
16	Satkhira	22.72	89.08		33	Chuadanga	23.65	88.82
17	Barisal	22.72	90.37		34	Chittagong (City)	22.35	91.82

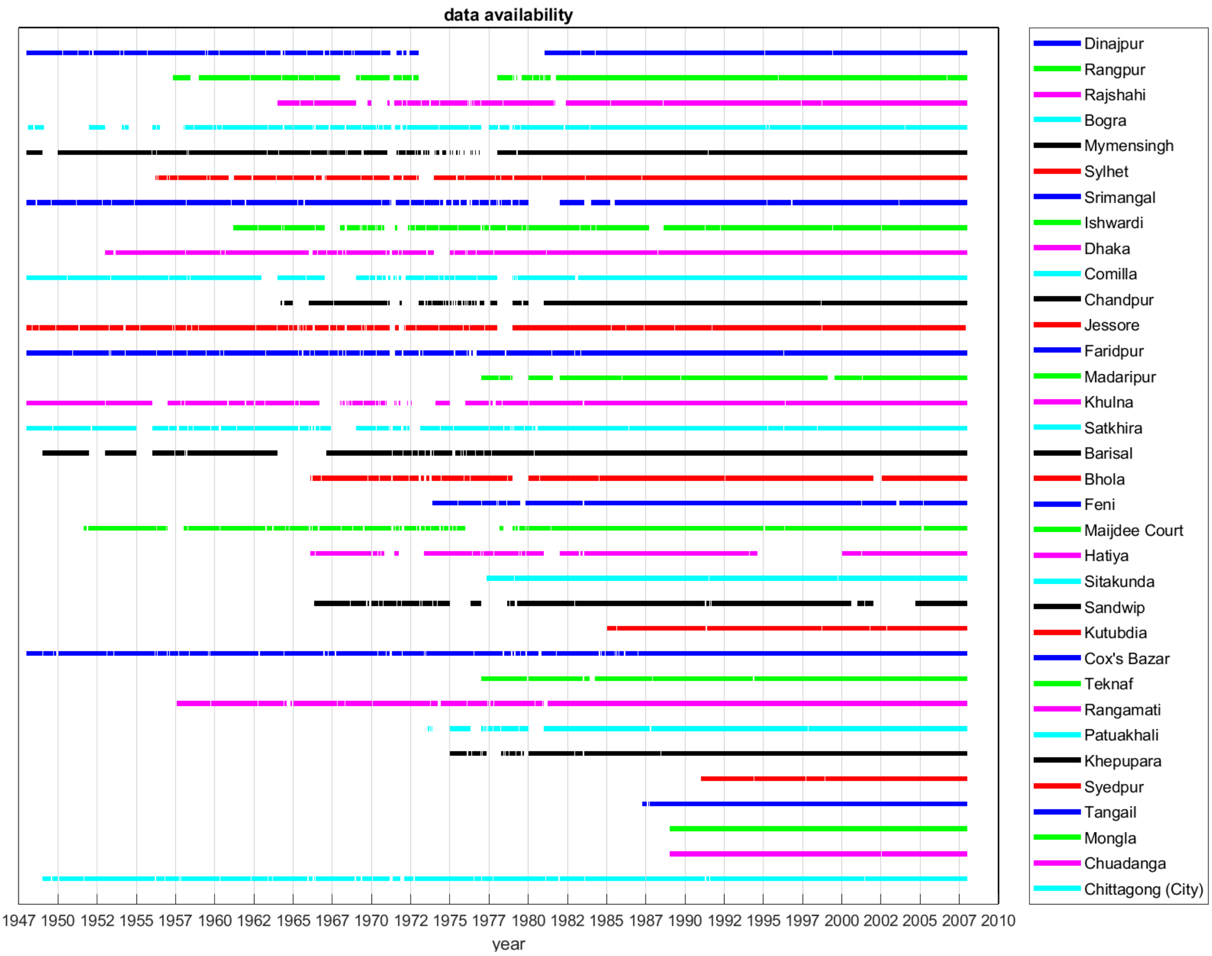


Figure 5-6: Data availability for the 34 temperature stations. Gaps in the line indicate missing data.

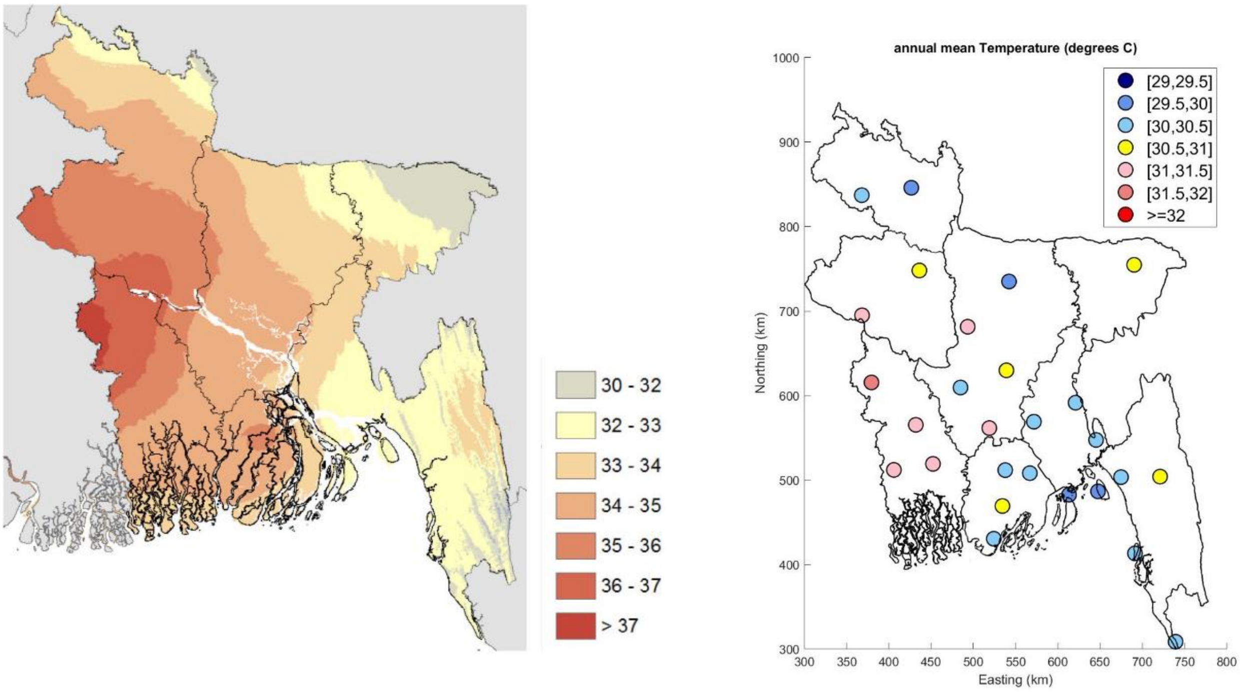


Figure 5.7: Annual average temperature: comparison between MOEF [2005] (left) and the results from our analyses (right).

Figure 5-8 shows the trend classes for the annual mean temperature, as derived with the Mann-Kendall test. Nearly all locations have an increasing trend, about half even have a major increasing trend. In the northwest there are a few locations with a decreasing trend. But generally, the trend is increasing, therefore suggesting a clear variation towards warmer conditions.

The trend classes for the annual mean temperature for the other three statistical tests are very similar to the one shown for the Mann-Kendall test in Figure 5-4, as such confirming the seemingly apparent increasing trend in the Northwest and along the coastline. The increase in mean temperature is mainly happening in the monsoon and post-monsoon season. In these seasons, almost all stations have an increasing trend and no stations have a decreasing trend. In the winter and pre-monsoon season the results are more mixed. In these two seasons, the stations in the south have an increasing trend, while the stations in the north have a decreasing trend.

Error! Reference source not found. shows the resulting trend classes when all 34 stations are combined. This shows significant overall increasing trends in mean temperature are observed in the monsoon and post-monsoon season and, consequently, also increasing trends in the annual mean temperature. The winter season has negative trends for maximum and annual minimum temperatures.

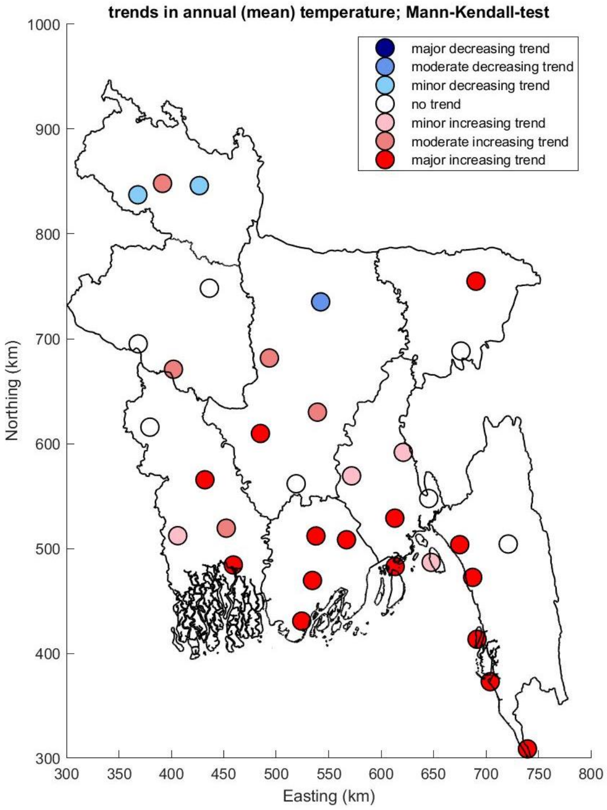


Figure 5-8: Trends in annual mean temperature; Mann-Kendal test.

Table 5.4: Derived trend classes for temperature the combination of all stations. Results are shown for three indicators, four statistical tests and five different seasons (including the whole year).

Indicator:	Mean temperature				Maximum daily temperature				Minimum daily temperature			
test:	PS	MK	SM	WMW	PS	MK	SM	WMW	PS	MK	SM	WMW
Year	3	3	3	2	0	0	-1	0	-1	0	-1	0
Pre-monsoon	0	0	0	0	0	0	-1	0	0	0	-1	0
Monsoon	3	3	3	3	3	3	1	2	1	1	0	2
Post-monsoon	3	3	3	3	3	3	2	3	0	0	0	0
Winter	0	0	0	0	0	0	-1	-1	-1	-1	-2	0

5.2.3 Tropical cyclones

Bangladesh is a global hotspot for tropical cyclones and its 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, tropical cyclones (TC) generate in the Bay of Bengal, propagate northwards and make landfall in a southwest / northeast direction at Bangladesh (see **Error! Reference source not found.**). Once on land, the intensity of the TCs decrease due to lack of warm water supplying energy to the TC and increase in land roughness. Generation occurs both during the early summer time period (April, May, June, July) as in the late rainy season period (September, October, November, December; see for more information Dasgupta et al., 2016).

In this study, information on TC events derived from the IBTrACS database (Knapp et al., 2010; Knapp et al. 2018) and specifically from the subset by the Joint Typhoon Warning Center (JTWC) were used as a basis to assess possible historical changes in TC frequency and intensity. In particular, the most recent data starting from 1972 and based on satellite detection, provides more accurate information on both historical tracks and cyclone intensity for the North Indian Ocean (see e.g. Singh (2010)).

At first, we have analysed the probability of TC genesis (**Error! Reference source not found.** 5-9a) and termination (**Error! Reference source not found.**b). The probability is in this case estimated as number of events within a 200 km radius and divided by the total number of events. **Error! Reference source not found.**a shows that most TC are generated in the middle of the Bay of Bengal (BoB), west of the Andaman and Nicobar Islands. Once generated, the TCs propagate through the BoB and they make landfall in eastern India, with a hotspot in Andhra Pradesh, and in Bangladesh, with a hotspot in the South East region and Eastern Hill (**Error! Reference source not found.**b). This is consistent with the finding of the literature study by Alam and Dominey-Howes (2015).

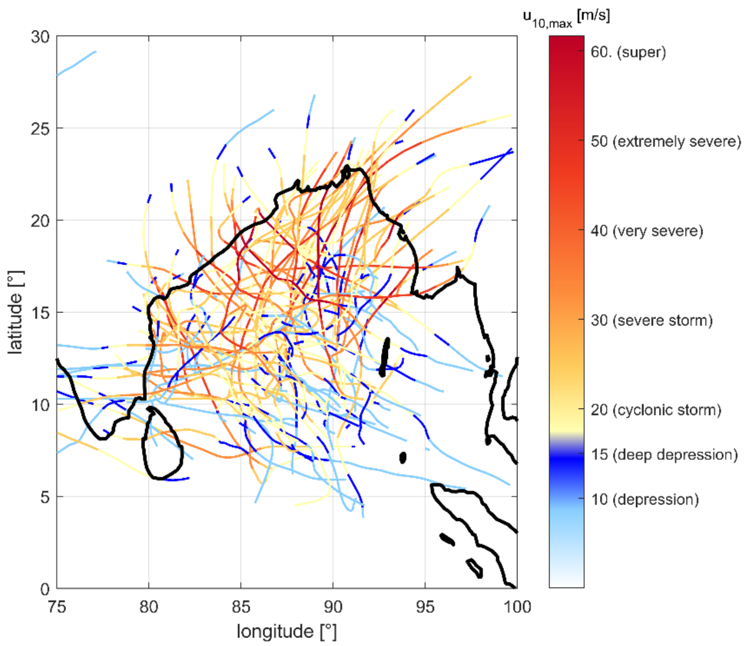


Figure 5-9: Historical tropical cyclone tracks since 1972 as reported in the JTWC database. Indication of the wind speed and severity is provided according to the classification by the India Meteorological Department (IMD) for the North Indian Ocean.

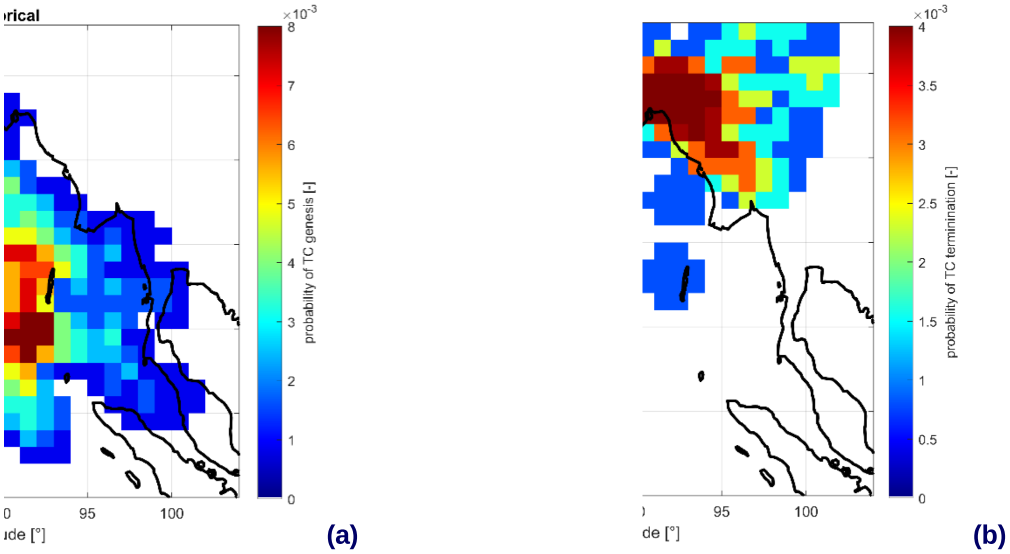


Figure 5-9: Probabilities of genesis (a) and termination (b) for historical tropical cyclones since 1972. Data retrieved from the JTWC database.

Based on the historical tracks, the yearly probability of TC activity was also determined per grid cell (**Error! Reference source not found.**). In this case, the probability was estimated by adding the number of TCs within a 200 km radius and diving by the number of years of observation. The figure shows how, in general, the yearly probability is below one, meaning that it is unlikely that a cell is hit by a cyclone more than once per year. In fact, the value is approximately once in three years in the region of Bangladesh (value of ≈ 0.3).

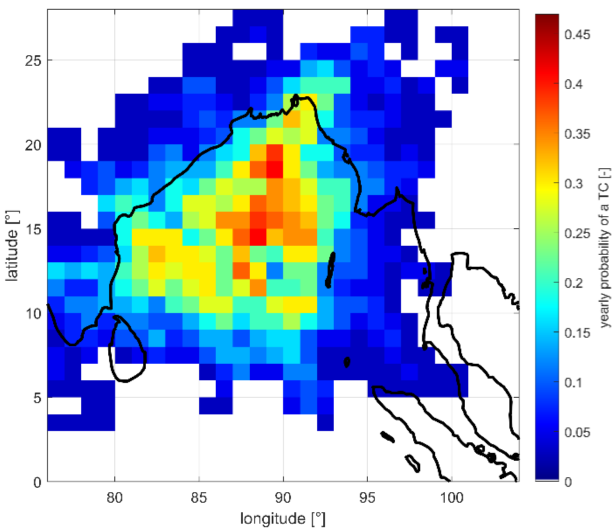


Figure 5-10: Yearly probability of historical TC since 1972. Data retrieved from the JTWC database.

Following the same methodology, the probability of TC generation per month was also plotted in Figure 5-11. The Figure shows how TCs are mostly generated in the pre-monsoon period (May) and post-monsoon period (November), which is consistent to literature (see e.g. Alam et al. (2003), Islam et al. (2009) and Dasgupta et al. (2016)).

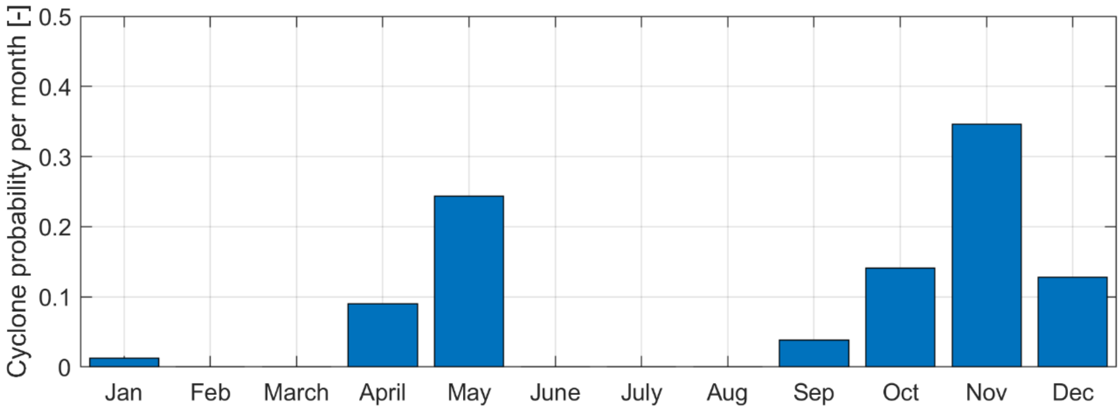


Figure 5-11: Monthly probability of TC generation in the Bay of Bengal based on historical cyclones since 1972. Data retrieved from the JTWC database.

Based on the information from these historical TC from 1972, possible changes in frequency were analysed for the entire Indian Ocean (Figure 5-12a), the Bay of Bengal (Figure 5-12b) and the Bangladesh coastal zone (Figure 5-12c). The three regions are visualized in Figure 5-13. Different colours in the figure indicate the TC occurrence when taking into account all cyclone events (blue bars) and most extreme TC only, characterized by a maximum wind speed larger than 40 m/s. Trend lines have also been added to depict possible trends for both cases. However, it is important to stress that it is hard to define actual trend lines due to the very limited number of years of observations. For example, these trend lines are very sensitive to one additional year characterized by a larger or lower number of TC.

Figure 5-12a suggests that the number of cyclone events and most extreme cyclone events has been slowly increasing through time during the last 5 decades in the North Indian Ocean. Very remarkable has been the year 2019, which was characterized by 6 TCs, all of them in the “severe” category. The increase has been roughly equal to +0.6% and +4.5% per year, respectively for all the TC events and the most extreme ones only. This finding is consistent for example with Singh et al (2000) and Deo et al (2011), which have shown an intensification of the most extreme TCs.

When we focus on the Bay of Bengal only (Figure 5-12b), one can see that the number of TCs has been decreasing, however the number of most extreme TCs has been increasing through time. The estimated changes have been equal to -0.4% per year and +1.7% respectively for all the TC events and the most extreme ones only.

Finally, Figure 3.13c focuses on the Bangladesh coastal zone only. The figure suggests that in the Bangladesh coastal area, both number of cyclones and number of extreme cyclone events have decreased over time. However, as the number of events is so limited, it could be sufficient that, for example, the year 2020 will be characterized by a larger number of TCs that this will result in a change in slope of these trend lines. Therefore, we have decided not to add a trend line in this last figure.

The yearly number of TC is also dependent by additional multi-year processes such as El Niño-Southern Oscillation (ENSO) (Singh et al., 2000; Hoarau et al. 2012).

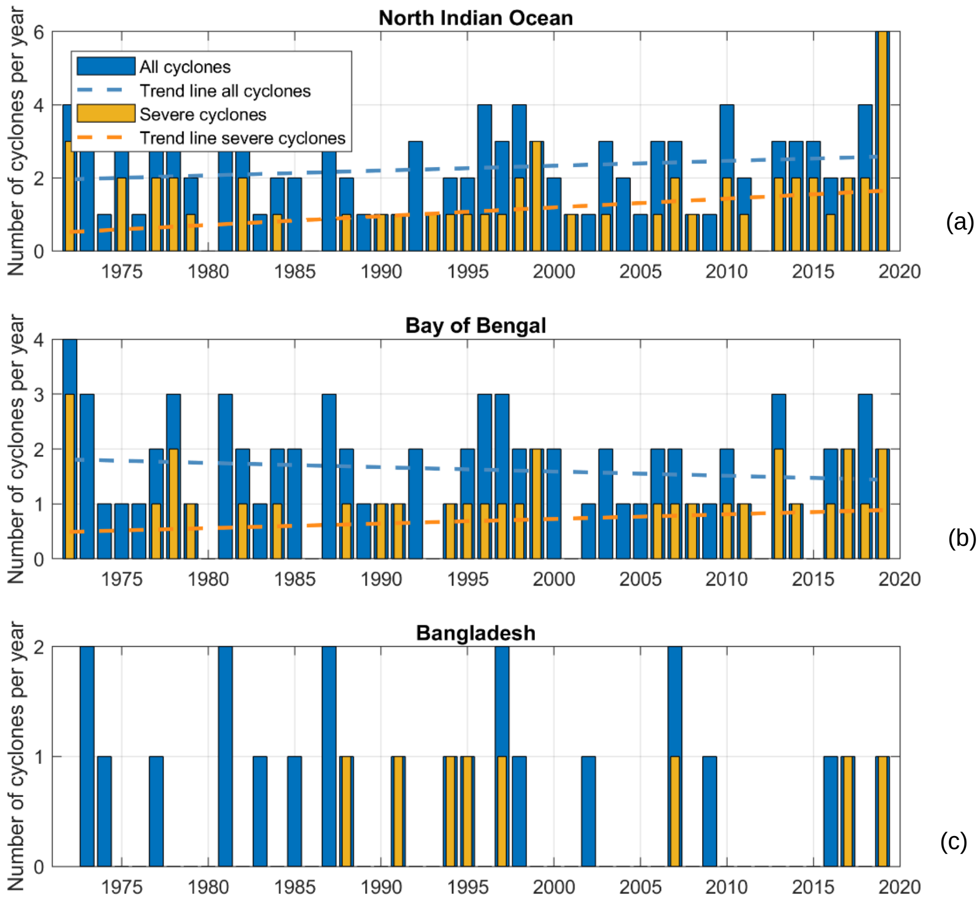


Figure 5-12 Number of cyclones per year since 1972 as retrieved from the JTWC database for: (a) the North Indian Ocean, (b) the Bay of Bengal and (c) the Bangladesh coastal zone. Plots are made for all cyclones (in blue) and only the severe cyclones (maximum wind speed larger than 40 m/s) (in orange). Linear trend lines have been added to show estimated changes in cyclone frequency over the time period.

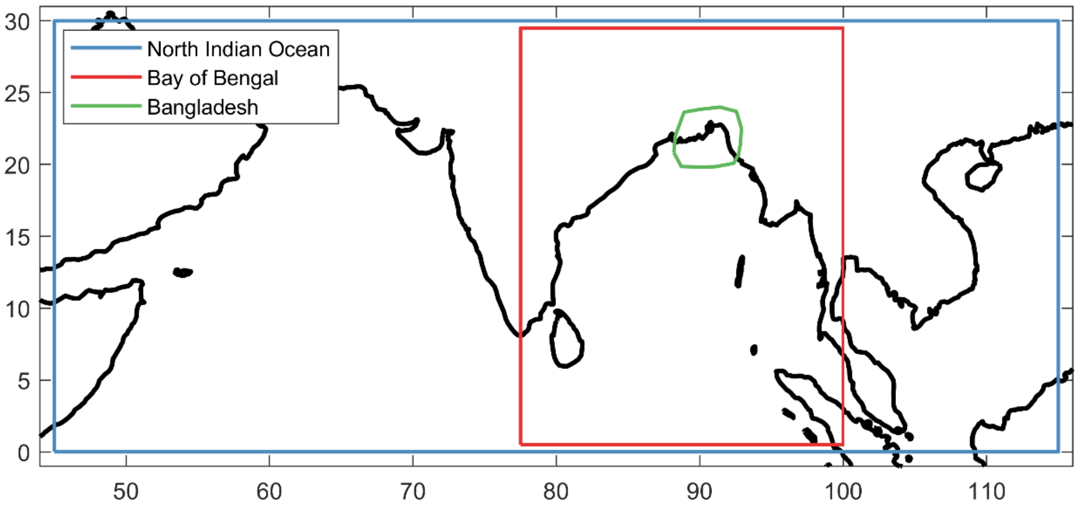


Figure 5-13 Boundaries of the three regions: North Indian Ocean, Bay of Bengal and Bangladesh.

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6 POLDER RECONSTRUCTION PROGRAMME (5A)

6.1 Background

The TOR specifies 3 deliverables of Component 5A, each on a different scale level, i.e. i) on the scale of the entire coastal zone of Bangladesh with special reference to the polders, ii) on the scale of the polders under CEIP-1 (17 polders) and iii) on the scale of single polders (3-5 selected polders). The polder reconstruction at each of these three scale levels requires interaction with the other packages of the project. This includes the modelling work at macro/meso and micro scale, that provide the boundary conditions for the polder development. It also includes interaction with the economic and financial aspects at different stages of design. A summary of interactions is provided in the figure below (Figure 6-1).

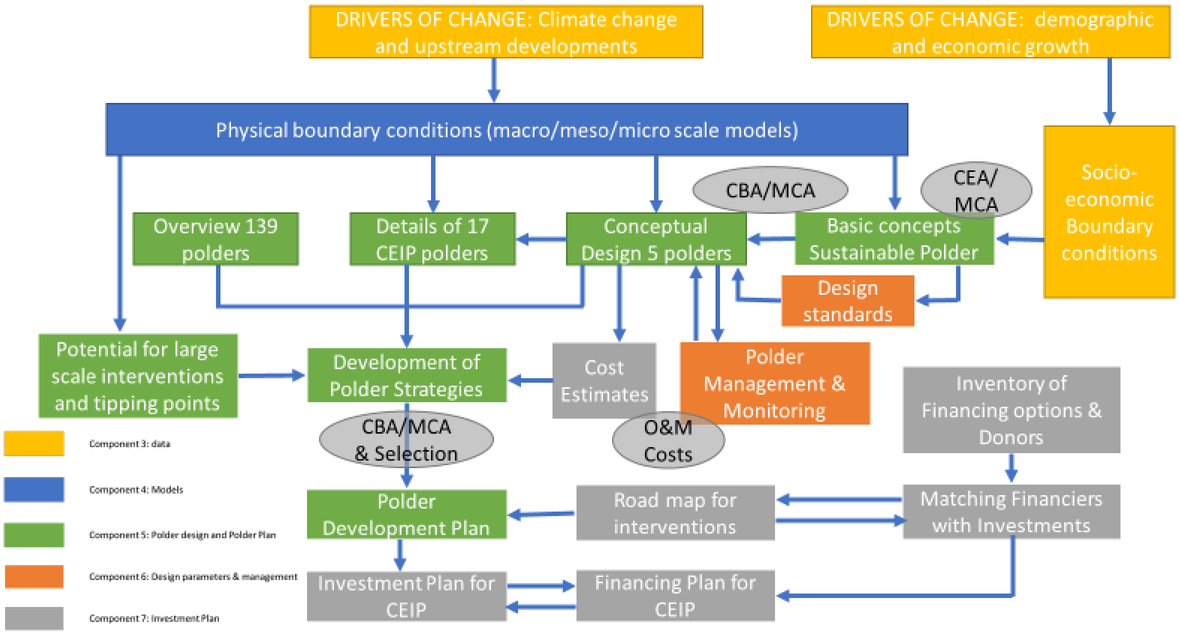

Figure 6-1: Flow chart Polder Development Plan and Investment Plan

The work plan for the deliverables under Component 5A is as follows.

Conceptual design for 5 polders

The Conceptual design will be a spatial plan for each polder including seasonal water management of gates. It will consider climate change, subsidence, possible land heights, land use, economic activities, infrastructure needed for water management and water management policy, drinking water facilities (especially in salt water conditions) for long term stability. Also, a cost estimate for the redesign of the polders and estimate of the benefits and beneficiaries in the new situation will be prepared.

Five polders have been selected for preparing conceptual designs. These polders are chosen in such a way that they are more or less representative for the other polders. Each polder is situated in a different coastal zone, i.e.: Ganges Tidal Plain West (GTPW), Ganges Tidal Plain East (GTWE), Meghna Delta Plain (MDP) and Chittagong Coastal Plain (CCP).

For each polder a detailed study will be made of the problems facing these polders now and in the near future. A summary of the main problems is pictured in Figure 6-2 below.

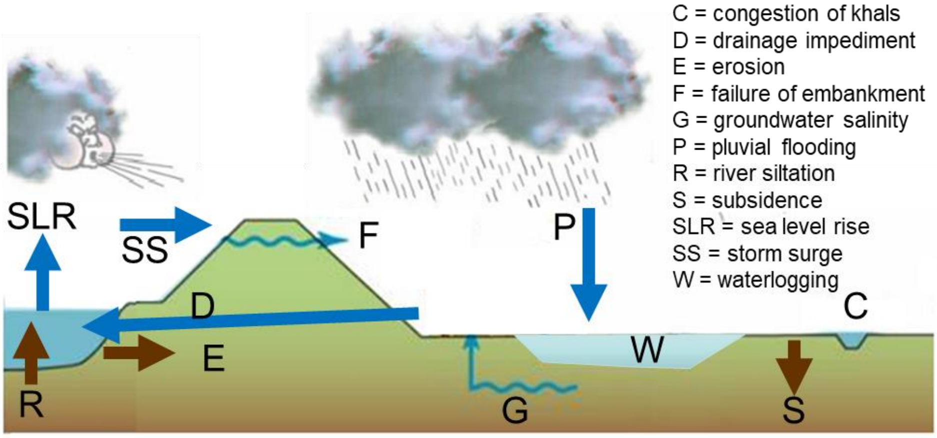

Figure 6-2: Summary of water-related problems in a polder

This Problem Analysis includes:

- A risk profile for cyclonic storm surge, fluvial and pluvial floods (using Delft-FIAT tool)
- Bank erosion study for Polder 40/1 and 59/2.
- Waterlogging / drainage problem analysis (Polder 15, 59/2)
- TRM study for Polder 24
- Future changes in boundary conditions: esp. sea level, tidal amplitude, storm surge conditions, salinity intrusion.

For the strategy development guidelines will be used from existing coastal policies and planning, such as the *Coastal Zone Policy* and *BDP2100*.

The actual conceptual design will be done in three steps:

a) Preparation of material, concepts and boundary conditions
b) Design workshop (charette or hackaton)
c) Evaluation of designs and high-level workshop (with BWDB etc.)

After the workshops the conceptual design will be finalized, and a cost estimate and benefits will be prepared.

All results will be written up in a report (Deliverable 5A-3) that includes the design for each polder with a description of i) Present situation; ii) Boundary conditions (scenarios); iii) Matching with polder options; iv) Establish design, including management plan; v) Costs and benefits.

Review / improvement of 17 CEIP Polders

Each of the 16 remaining polders (Polder 15 is a CEIP-1 polder) will be matched with one of the pilot polders. Besides the nearest location and coastal region also the specific conditions, such as soil salinity, risk profile and other conditions will be used to choose the most relevant pilot polder for each CEIP-I polder. Using the conceptual designs of the 5 polders, improvement measures will be assigned to each CEIP-I polder, considering the detailed designs and feasibility studies of these polders which have been prepared under CEIP-I project. Naturally, these improvement measures will be derived at a lower resolution than the 5 pilot polders. Nevertheless, using unit lengths, unit costs etc. a good indication can be given of the (additional) investments proposed.

The result will be a Report on Polder Improvement measures (Deliverable 5A-2) with a description of opportunities for livelihood, spatial planning, water, management and operation, subsidence, raising of low lying area and future climate change scenarios.

Polder Development Plan

A Polder Development Plan for all 139 coastal polders will be prepared in a holistic and integrated approach. Key inputs to this Plan are the conceptual designs of the pilot polders, but also considering the longer planning horizon (50-100 year). The approach is as follows:

a) Classify all 139 polders to match with the 5 pilot polders using similarities in boundary conditions and land use (analogue to the 17 CEIP polders).
b) Prepare scenarios for macro-economic developments, climate change tipping points and possible large-scale interventions (output from 5B).
c) Develop Alternative Polder Development Strategies for the long term and large scale.
d) Test the analysis results with a high-level workshop.

The result will be a Technical Report on Long term Polder Improvement measures and Polder Development Plan (PDP, Deliverable 5A-1). This will form the input to the Investment and Financing Plan (Component 7).

6.2 Progress

- During the reporting period, the polder management and investment 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.

- The polder management and investment team had a meeting with the Blue Gold team on Monday 10 February during which we discussed the problems in the polder management. Further collaboration was agreed, especially to exchange experiences regarding in-polder water management. Especially the idea of doing collaborative design workshops in one of the Blue Gold polders (polder 29) was proposed, as part of the conceptual designs for the 5 pilot polders. This would assess the feasibility of measures within the polder for improving water management and increasing agricultural output.

- The data collection campaign to collect the most up-to-date dataset of the 139 polders is ongoing. Data is ingested in the Interactive Geo-Database for the Coastal Zone (IGDCZ) (see figure below) and is at the disposal of the polder management and investment team. At this moment the data is not yet completed for doing all the necessary analyses.

- Risk analysis for the 5 selected pilot polders using the Delft-FIAT tool is underway. Results are expected in the next reporting period.

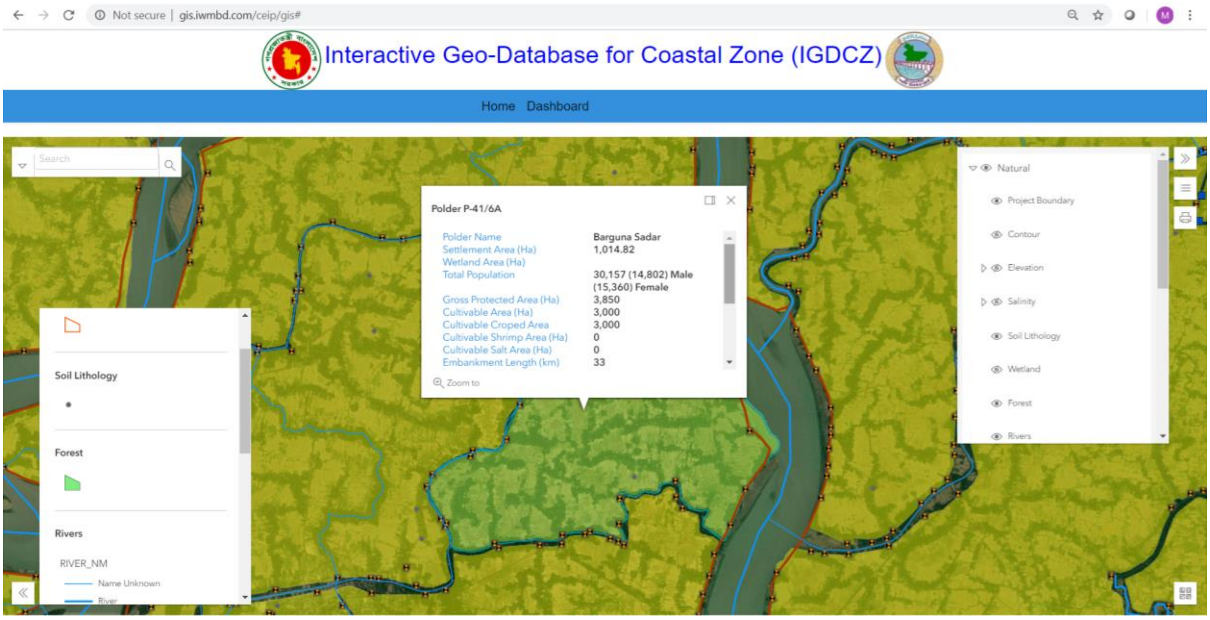

Figure 6-3: example of the IGDCZ showing data for Polder 4.1/6A

6.3 Plan for next Quarter

Activities during the next quarter (from 1 April till 30 June) are seriously hampered by the travel restrictions due to the COVID-19 crisis. Some desk study work is expected to be completed (esp. the FIAT-calculations for the 5 polders).

6.4 Investment Plan for the Entire CEIP

6.4.1 Description of activities

The polder development plan will be developed to an investment and financing plan (IFP). To this end a start was made in contacting potential donors that could be involved in the set-up of the investment plan and could make funds available for financing of different aspects of the investment plan. During the visit to Bangladesh discussion were held at the World Bank offices on further detailing the input for the development of the IFP. Furthermore, visits were made to the Royal Netherlands Embassy and representatives of the Bangladesh Delta Plan. The CEIP investment and financing plan should be developed in close cooperation with the BDP, as this sets the agenda of future investments for activities under the CEIP investment plan. When the IFP will become available in more detail the planned interventions should be presented and discussed with potential financiers in order to identify potential funding sources for the planned investments.

During the reporting period data was collected in unison with the data for the PDP. The data should yield a more detailed intervention strategy and more accurate description of the required investment costs for the different activities. However, to date there are no project designs available nor costs estimates for different interventions. At first outlook will be developed on types of interventions that are deemed necessary for improvement of polder management, including investment costs and costs for operation and management. Lessons learned from the development of interventions for the

5 example polders will be used to establish general criteria that will be used in the definition of interventions for the remaining 122 polders. Furthermore, possible additional intervention for the 17 CEIP polders will be assessed.

6.4.2 Planning for next quarter

The plan for the second quarter of 2020 was to continue data collection and analysis for the development and selection criteria for interventions in the different polders. Furthermore, additional visits to possible financiers were planned. However, due to the COVID-19 crisis it was not possible to visit Bangladesh. Additionally, all work was stopped from mid-April by the client. This will cause a considerable delay in the development of activities for the Deliverable 7, the Investment and Financing Plan. If potential financiers are to be consulted for potential financing of the interventions of the polders, it is essential for a rational intervention strategy, with investment selected based on clear and transparent criteria. Under the current conditions such a planning of activities can not be made pending the ongoing COVID-19 crisis and suspension of project activities.

7 DESIGN PARAMETERS, CONSTRUCTION MANAGEMENT & MONITORING

It is the intention of the Terms of Reference that the design parameters used in the 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:

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

b) Ground subsidence: A more detailed knowledge of local subsidence levels are no 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:

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. 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

The conceptual design of the 5 specially selected polders (see Figure 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

APPENDIX A – FIELD DATA ACQUISITION AND SUBMISSION (Soft Copy Data in USB Pen Drive)

A Field Data Acquisition and Submission

A large field data collection campaign has been undertaken under this project applying state of the art survey technology. These field data are utilized to characterize the hydrological and morphological characterization of river system, assessing sediment transport rate, establishment of baseline conditions, model setup, calibration and validation of macro, meso and micro models. The field data includes-bathymetry data, discharge observation, sediment sampling for total concentration & particle size distribution, bed sample collection for particle size distribution, monitoring sections along the 13 rivers surrounding the polders and salinity observation. The detail of the field data collection has been given in Table A-1 to Table A-7. It may be noted that field survey data for the selected 5 polders are not included here and this will be submitted after completion of field survey and post processing.

The collected field data has been archived after post processing in a certain structure providing item of data, location name and date. The soft copy of surveyed data has been submitted in USB pen drive accordingly.

Table A- 1: List of Bathymetry survey

SL	River Name	escription/Specificatio	Duration of survey	Unit	Target		Progress upto 30th March 2020	Remarks
					TOR	Planned		
1	Shibsa	From Haborkhali to Akrampoint 70 Km length(out of this 50 km @ 1000m interval & 20km @ 500 m interval	18-23/03/2019	Km-transect	0	168	168	As per consultation with client, expatriate and national consultants- and for the requirement of model setup and calibration bathymetry survey of Sibsha, Pusur, Baleswar and Bishkhali river has been added.
2	Pussur	From Rupsha to Outerbar of 133 km length @ 1000m interval	12-24/03/2019	Km-transect	0	353	353	
3	Baleswar	From Hularhat to outfall of 82 km length @ 1000m Interval	01-10/03/2019	Km-transect	0	196	196	
4	Bishkhali	From Gabkhan khal to Badurtala of 92 Km length @ 1000m interval	28-31/03/2019	Km-transect	0	97	97	
5	Lower Meghna	From Chandpur to Tajumuddin of 100 km @ 1000m interval	26/03/19-09/04/19	Km-transect	1306	1068	1068	
Total				Km-transect	**1306**	**1882**	**1882**	
SL	River Name	escription/Specificatio	Duration of survey	Unit	Target		Progress upto 30th March 2020	Remarks
					TOR	Modified		
1	Sangu River	95Km @ 500m interval		Nos.	141	141	141	At 500m interval for 70 km, a total of 141 transects

Table A- 2: List of discharge observation

<table>
<tr><th rowspan="2">SL no.</th><th rowspan="2">Location/ River Name</th><th colspan="2">Target (Number)</th><th rowspan="2">Progress upto Mar-2020</th><th rowspan="2">Remarks</th></tr>
<tr><th>TOR</th><th>Planned</th></tr>
<tr><td>A</td><td>3 main rivers</td><td></td><td></td><td></td><td></td></tr>
<tr><td>1</td><td>Bahadurabad, Brahmaputra</td><td>18</td><td>48</td><td>19</td><td rowspan="3">Additional data are being collected for assessing reliable sediment transport in the Brahmaputra and Ganges rivers</td></tr>
<tr><td>2</td><td>Hardinge Bridge, Ganges</td><td>18</td><td>48</td><td>20</td></tr>
<tr><td>3</td><td>Bhairab Bazar, Upper Meghna</td><td>18</td><td>48</td><td>23</td></tr>
<tr><td colspan="2">Total of A</td><td>54</td><td>144</td><td>62</td><td></td></tr>
<tr><td>B</td><td colspan="5">Lower Meghna</td></tr>
<tr><td>4</td><td>Chandpur, Lower Meghna</td><td>3</td><td>5</td><td>5</td><td>2 spring+ 1 neap during monsoon and 2 nos. 1 Spring +1 Neap for dry season</td></tr>
<tr><td>C</td><td colspan="4">5 nos. Tidal rivers surrounding the Polders.</td><td></td></tr>
<tr><td>5</td><td>U/S of Mongla port, Pusur</td><td rowspan="5">44</td><td>8</td><td>8</td><td rowspan="5">For each location 8 measurement: 1 spring in every two months and -1 neap in every six months for the periods of one year.</td></tr>
<tr><td>6</td><td>Nalian, Shibsha</td><td>8</td><td>8</td></tr>
<tr><td>7</td><td>Charduani, Baleswar</td><td>8</td><td>8</td></tr>
<tr><td>8</td><td>Bhandaria, Baleswar</td><td>8</td><td>8</td></tr>
<tr><td>9</td><td>Polder-17/2, Gangril</td><td>8</td><td>8</td></tr>
<tr><td colspan="2">Total of C</td><td>44</td><td>40</td><td>40</td><td></td></tr>
<tr><td>D</td><td colspan="5">Additional 3 tidal River</td></tr>
<tr><td>10</td><td>Dasmina, Tetulia</td><td>0</td><td>2</td><td>4</td><td>2 nos. measurement during June-Oct-19, 1 Spring+ 1 Neap</td></tr>
<tr><td>11</td><td>Kakchira, Bishkhali</td><td>0</td><td>3</td><td>3</td><td>Total 3 nos. -1 spring in dry season and 1-Neap+1-Spring for monsoon</td></tr>
<tr><td>12</td><td>Taliar dwip,Shangu</td><td>0</td><td>2</td><td>2</td><td>2 nos. measurement during June-Oct-19, 1 Spring+ 1 Neap</td></tr>
<tr><td colspan="2">Total of D</td><td>0</td><td>7</td><td>9</td><td></td></tr>
</table>

Table A- 3: List of suspended sediment sampling for total concentration

SL no.	Location/ River Name	Discharge observation		Suspended Sediment Sampling for Total concentration	
		As per TOR	Planned	As per TOR	Progress upto Mar-2020
A	3 main rivers				
1	Bahadurabad, Brahmaputra	18	48	1056	1673
2	Hardinge Bridge, Ganges	18	48		
3	Bhairab Bazar, Upper Meghna	18	48		
B	Lower Meghna				
4	Chandpur, Lower Meghna	3	5	234	149
C	5 nos. Tidal rivers surrounding the Polders.				
5	U/S of Mongla port, Pusur	44	40	3432	2736
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	633
11	Kakchira, Bishkhali	0	3		
12	Taliar dwip,Shangu	0	2		

Table A- 4: List of suspended sediment and bed sampling for grain size distribution

SL no.	Item	Sediment Sampling		Remarks
		As per TOR	Achieved upto Mar-2020	
1	Suspended Sediment sampling	33	23	More sample will be collected during June-Sep 2020.
2	Collection of Bed Sample	55	63	Collection of five bed samples from each river discharge observation

Table A- 5: List of water level data collection

SL. No.	Name of Location/River	Installation Date	Quantity as per TOR	Planned Target (stat^n-month)	Progress up to Mar 2020 (statn-month)	Remarks
A	Recording of Water level at Hironpoint, Pusur/Kaikhali, Ichamoti					
1	Kaikhali, Ichamoti	15-Feb-19	12	12	13	As per revised plan 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	13	
2	Taltoli, outfall of Biskhali /Baleswar	17-Feb-19		12	13	
3	Chandpur, Lower Meghna	1-Feb-19		4	4.5	Closed at June30, 2019
4	Dasmina(Hajir hat), Tetulia	8-Apr-19		4	4.5	Closed at 22/08/2019
5	Joymuni, Pusur	14-Mar-19		4	5	Closed at 22/08/2019
6	Nalian, Shibsha	15-Mar-19		4	5	Closed at 22/08/2019
7	Charduani, Baleswar	31-Mar-19		4	4	Closed at 22/08/2019
Total				44	49	

Table A- 6: List of Salinity Data Collection

Stat^{n} ID	Station Name	River_Name	Easting (m)	Northing (m)	Start date	Cumulative Progress upto Mar-2020
1	Bashantapur	Isamoti	706840	2486285	12-Feb-19	13.5
2	Kaikhali	Modan Gauga	714395	2455144	13-Feb-19	13.5
3	Kobadak	Kobadak	738053	2459252	15-Mar-19	12.5
4	Nalian	Shibsha	749190	2486655	13-Feb-19	13.5
5	Gangrail	shundor mohol	746284	2509461	10-Mar-19	12.5
6	Khulna	Rupsha	764985	2523883	8-Mar-19	12.5
7	Bardia/ Nabaganga	Noboganga	773750	2555764	19-Feb-19	13.0
8	Chapailghat	Modhumati	786778	2544530	13-Feb-19	13.0
9	Patgati	Modhumati	797052	2533438	16-Mar-19	12.5
10	Mongla	MonglaNala	767846	2487421	10-Mar-19	12.5
11	Joymoni	Pussur	770059	2478036	9-Mar-19	12.5
12	Gasiakhali	Gasiakhali	796021	2484687	22-Mar-19	12.3
13	Char Doani	Baleswar	800083	2449931	13-Feb-19	13.5
14	Bishkhali DS	Bishkhali River	808483	2439742	6-Mar-19	12.5
15	Hiron Point	Pusur	756533	2412633	10-Mar-19	12.5
16	Mohipur	Shibbaria Khal	200814	2419537	25-Feb-19	13.0
17	Khepupara Kol	Adhanmanik	214449	2431880	13-Feb-19	13.5
18	Madhupara	Andharmanik	222130	2433381	13-Feb-19	13.5
19	Amtali	Burisuar	213580	2450306	5-Mar-19	12.8
20	Patuakhali	Buriswar	217267	2473096	15-Mar-19	12.5
21	Burhanuddin	Tetulia	257606	2494785	3-Mar-19	13.0
22	Daulatkhan	Meghna	264409	2504558	13-Feb-19	13.5
23	Hilsha	Ganeshpura	255886	2524418	13-Feb-19	13.5
24	Moju Chowdurir	Lower Meghna	271573	2524453	13-Feb-19	13.5
25	Ramgati	Lower Meghna	296451	2496925	2-Mar-19	13.0
26	Char Elahi	Outfall of Noakhali Khal	316468	2512380	13-Feb-19	13.5
27	Musapur	Little Feni outfall	334907	2517844	1-Mar-19	13.0
28	Kalurghat Brid	Karnafuly	379618	2469046	27-Feb-19	13.0
29	Patenga	Karnafuly	378241	2459360	13-Feb-19	13.5
30	Sangu Outfall	Sangu	380988	2449507	28-Feb-19	13.0
Total (station-month)						390

Table A- 7: List of Monitoring Section

SL no.	River name	Left bankPosition in UTM		Target as per TOR (event)	Cumulative Progress up to Mar-2020	Remarks
		Easting (m)	Northing (m)			
1	Pusur	762273	2501059	4	3	Monitoring section is being carried out at two locations and at each location 3nos. Section is being taken for each survey campaign. In between Jan-2020 to Mar-2020, a total of 3 field campaign are conducted in 13 rivers at 26 locations and a total of 78 nos. section are carried out.
		765884	2494718			
2	Sibsha	751161	2487806	4	3	
		751557	2482153			
3	Kobadak	734559	2474997	4	3	
		735522	2468624			
4	Chunkuri	759390	2500705	4	3	
		758092	2498287			
5	Badurgacha	753417	2504229	4	3	
		749232	2499644			
6	Dhaki	755788	2498307	4	3	
		751834	2493821			
7	Gangril	739773	2522911	4	3	
		746214	2515543			
8	Gashikhali	772383	2496263	4	3	
		769190	2489629			
9	Andharmanik	206871	2432616	4	3	
		214473	2433381			
10	Galachipa	233074	2451448	4	3	
		232892	2462016			
11	Baleswar	808406	2488650	4	3	
		796650	2467005			
12	Lower Meghna	259138	2565429	4	3	
		261237	2543677			
13	Shangu			4	2	
Total				52	38	