**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)

## Baleswar-Bishkhali morphological modelling study



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


February 2019

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University of Colorado, Boulder, USA

Columbia University, USA

# CONTENTS

## TABLES



## FIGURES

# 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

GTPE- Ganges Tidal Plain East

GTPW- Ganges Tidal Plain West

HD- Hydrodynamic

InSAR- Interferometric Synthetic Aperture Radar

IPCC- Intergovernmental Panel for Climate Change

IPSWAM- Integrated Planning for Sustainable Water Management

IWM- Institute of Water Modelling

LCC- Life Cycle Costs

LGED- Local Government Engineering Department

LGI- local Government Institute

LRP- Land Reclamation Project

MCA- Multi Criteria Analysis

MES- Meghna Estuary Study

MoWR- Ministry of Water Resources

MPA- Mongla Port Authority

NAM - Nedbor Afstromnings Model

PPMM- Participatory Polder Management Model

PSD- Particle Size Distribution

RCP- Representative Concentration Pathways

RTK- Real-Time Kinematic

SET-MH- Surface Elevation Tables – Marker Horizons

SLR- Sea Level Rise

SOB- Survey of Bangladesh

SSC- Suspended Sediment Concentration

SWRM- South West Region Model

TBM- Temporary Bench Mark

TRM- Tidal River Management

ToR- Terms of Reference

WARPO- Water Resources Planning Organization

WL - Water Level

# 1 Introduction

This report describes the development, calibration, validation and application of a large-scale morphodynamic model covering the Baleswar-Bishkhali river system.

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

- 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- Tetulia River system (Polder 56/57,55/1,55/2, 55/3 & 59/2)
- Sangu River system (Polder 63/1a, 63/1b & 64/1b)

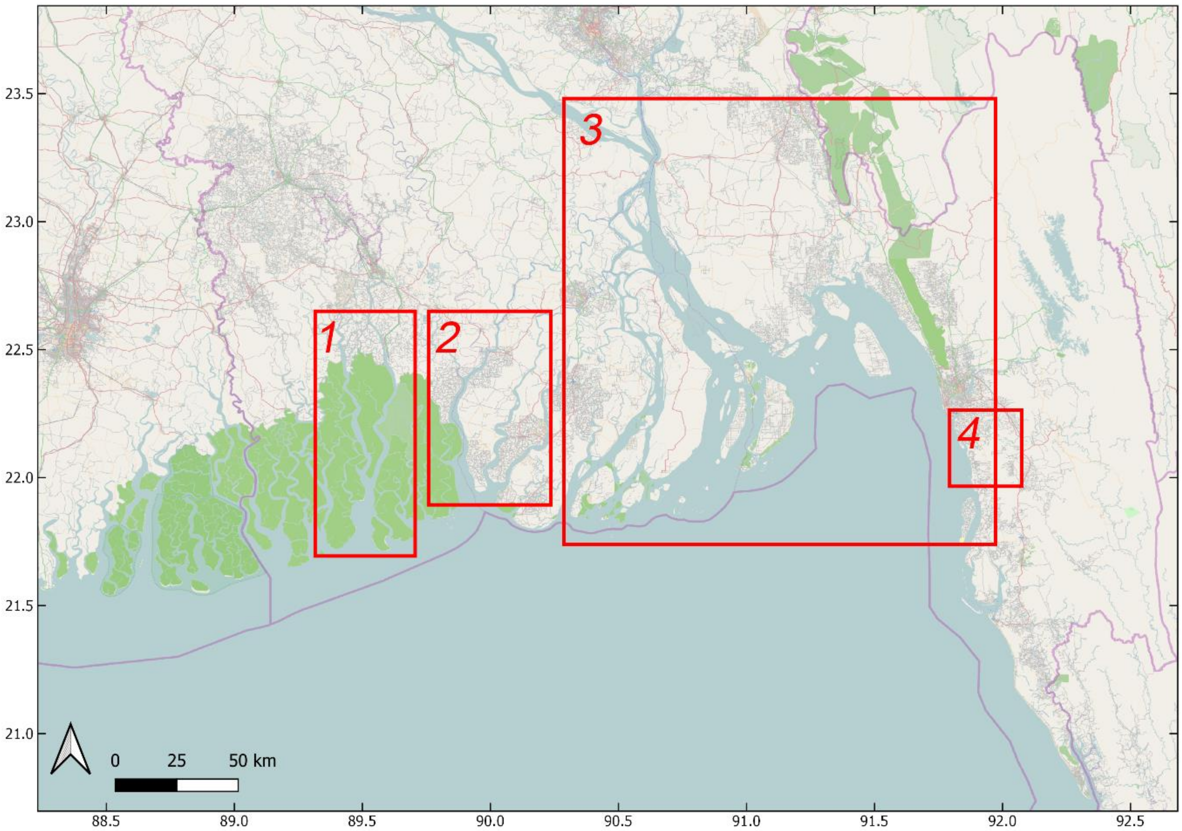


Figure 1.1 Map of meso-scale modelling groups for long-term morphology (1) Pussur-Sibsa; (2) Baleswar-Bishkhali; (3) Lower Meghna-Tetulia; (4) Sangu river

# 2 Objectives and Approach

The objectives of this model are:

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

The approach is as follows:

- Model grid - to construct an unstructured-grid model of the entire Baleswar-Bishkhali river system, with rectangular grid cells except where areas of different resolution are connected by triangles (section 4.1).
- Setup and Calibration – setup, calibrate and validate the model with field measurements (section 4.4).
- Morphological hindcast – reproduce the morphology for the period 2011-2019.
- Scenario runs - study future changes in the morphodynamic processes based on possible scenarios. This will be reported in the next phase.

  Two types of morphodynamic simulations are carried out (section 4.4 and 4.6):

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

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

Calibration of the decadal-scale morphological development is carried out using the accelerated approach (section 4.6.1) in order to have acceptable runtimes, as the available bathymetries to assess model skill are separated by 8 years, making brute-force simulations prohibitively long.

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

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

# 3 Data

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

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

## 3.1 Bathymetry

The river system has been surveyed in previous years, so suitable bathymetry information was readily available. Detailed bathymetry surveys were conducted in 2011, 2015 and 2019 for the

Baleswar river system under different projects as well as a less detailed survey in 2009. For the Bishkhali river system a very limited bathymetry survey was conducted in 2009 and a detailed survey in 2019 within two different projects.

The available bathymetry data and originating projects are summarised in Table 3.1. The bathymetries for the Baleswar and Bishkhali river systems as well as the changes in bathymetry over the years in the Baleswar river (2011, 2015, 2019)2019hare shown in Figure 3.1 and Figure 3.2.

Table 3.1 Bathymetry data for Baleswar-Bishkhali River 2011 and 2019

| Bathymetry data collection year | River | Sources |
|---|---|---|
| 2009 | Baleswar, Bishkhali | IWM (FFWC) |
| 2011 | Baleswar | IWM (GRRP Project) |
| 2015 | Baleswar | IWM (CEIP-I) |
| 2019 | Baleswar, Bishkhali | Primary data (Present Project) |

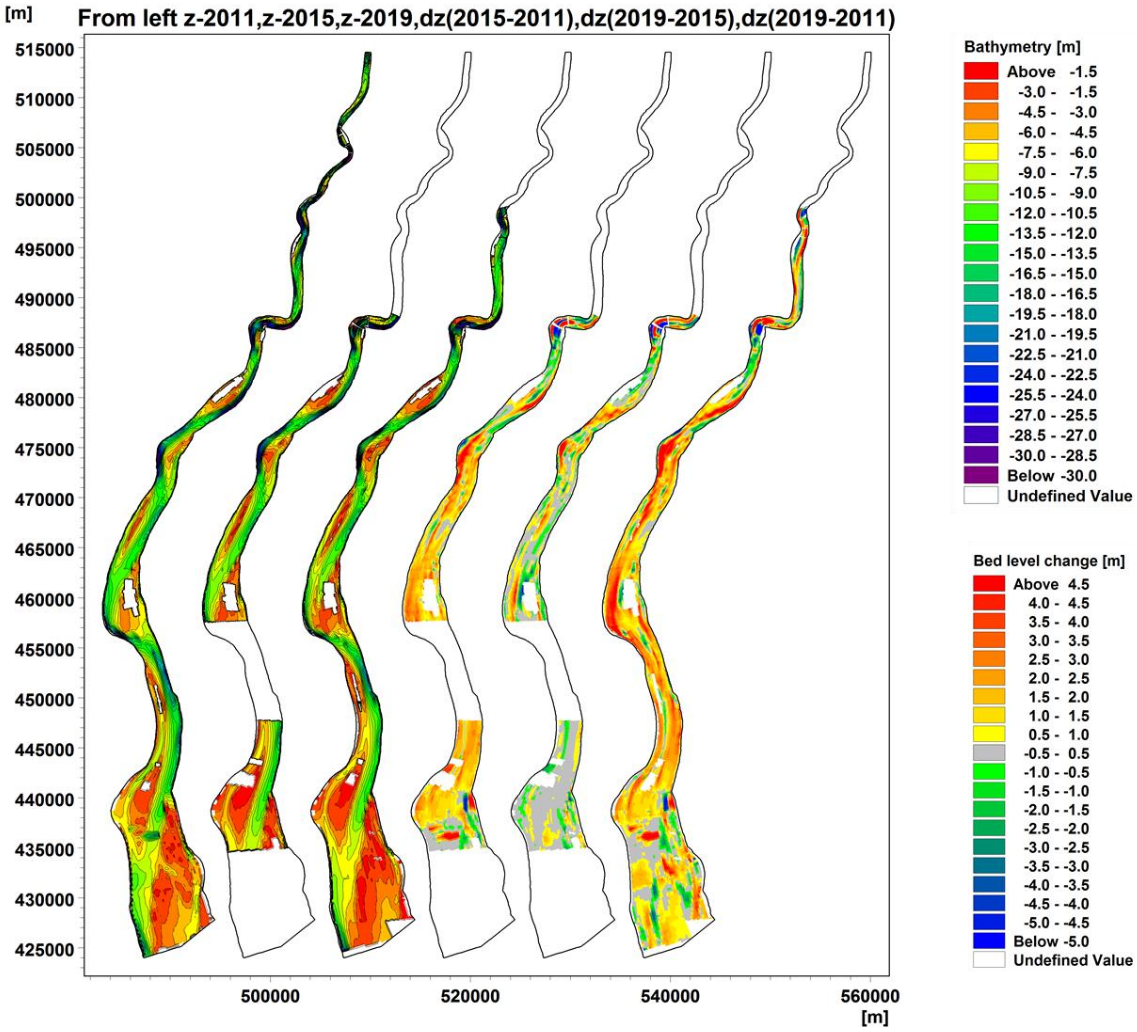


Figure 3.1 Observed bathymetries 2011, 2015, 2019 and corresponding bed level changes 2011-2015, 2015-2019 and 2011-2019 (from left to right)

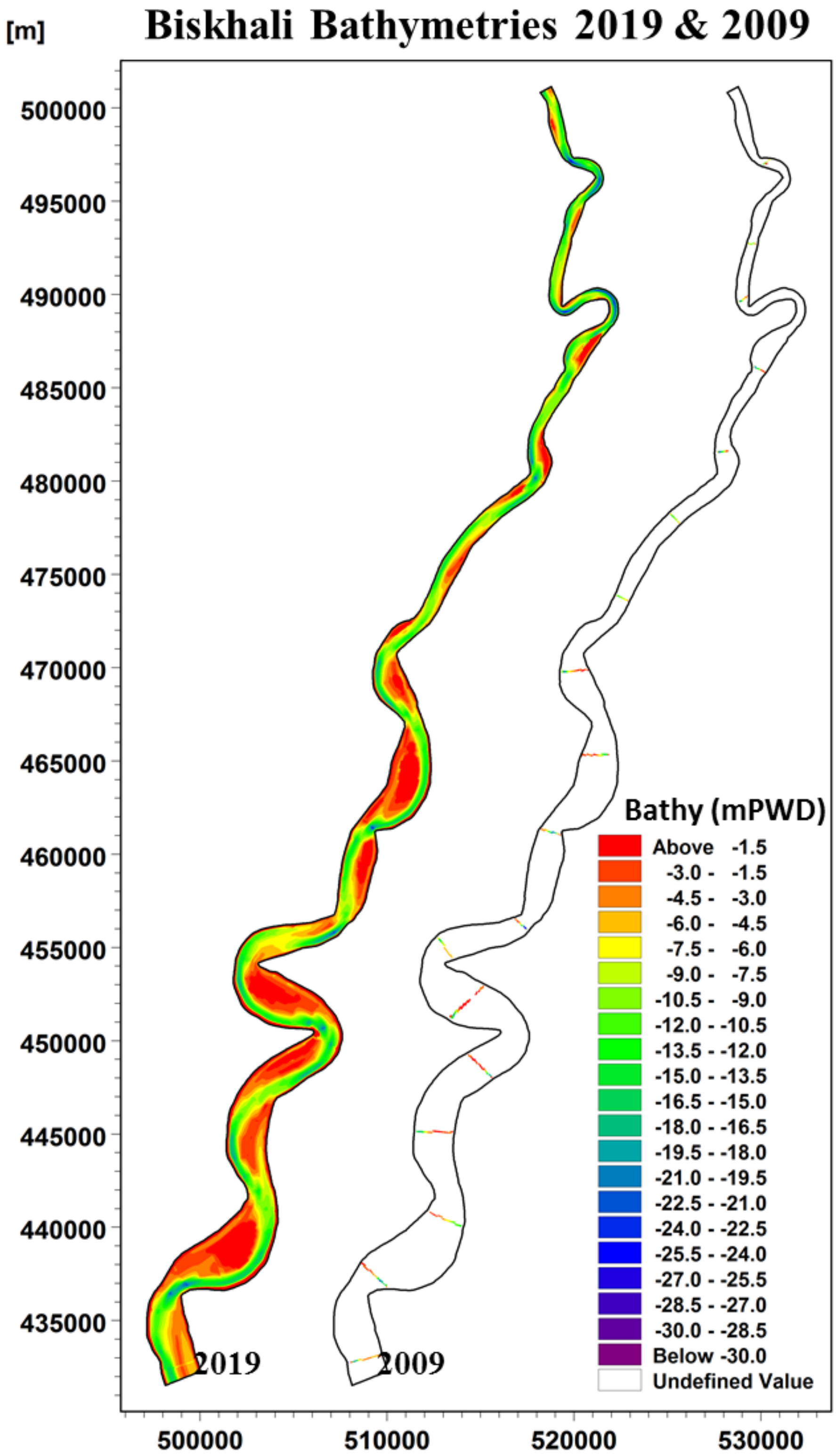


Figure 3.2 Observed bathymetries of Bishkhali river in 2009 and 2019

## 3.2 Digital Elevation Model (DEM)

Baleswar-Bishkhali river system is surrounded by polders. This results in very limited flow exchange between the river and associated floodplains. Therefore, no floodplains have been applied to the Baleswar-Bishkhali river model.

## 3.3 Water level time-series

Observed water levels are available at several stations in the Baleswar-Bishkhali river system. The locations of water level and discharge measurement under the present study are shown in Figure 3.3.

Table 3.2 Available water level observations from Baleswar-Bishkhali river system

| Discharge collection year | River Name | Station Name | Sources |
|---|---|---|---|
| 2011 | Baleswar | Chardoani | IWM (GRRP Project) |
| 2011 | | Umedpur & Sarupkati | BWDB |
| 2015 | | Tafalbari Launchghat & Telekhali Bazar | IWM (CEIP-1 Project) |
| 2019 | | Chardoani | Primary data (Present Project) |
| 2015 | Bishkhali | Patharghata (Bishkhali) | IWM (CEIP-1 Project) |
| 2019 | | Taltoli | Primary data (Present Project) |

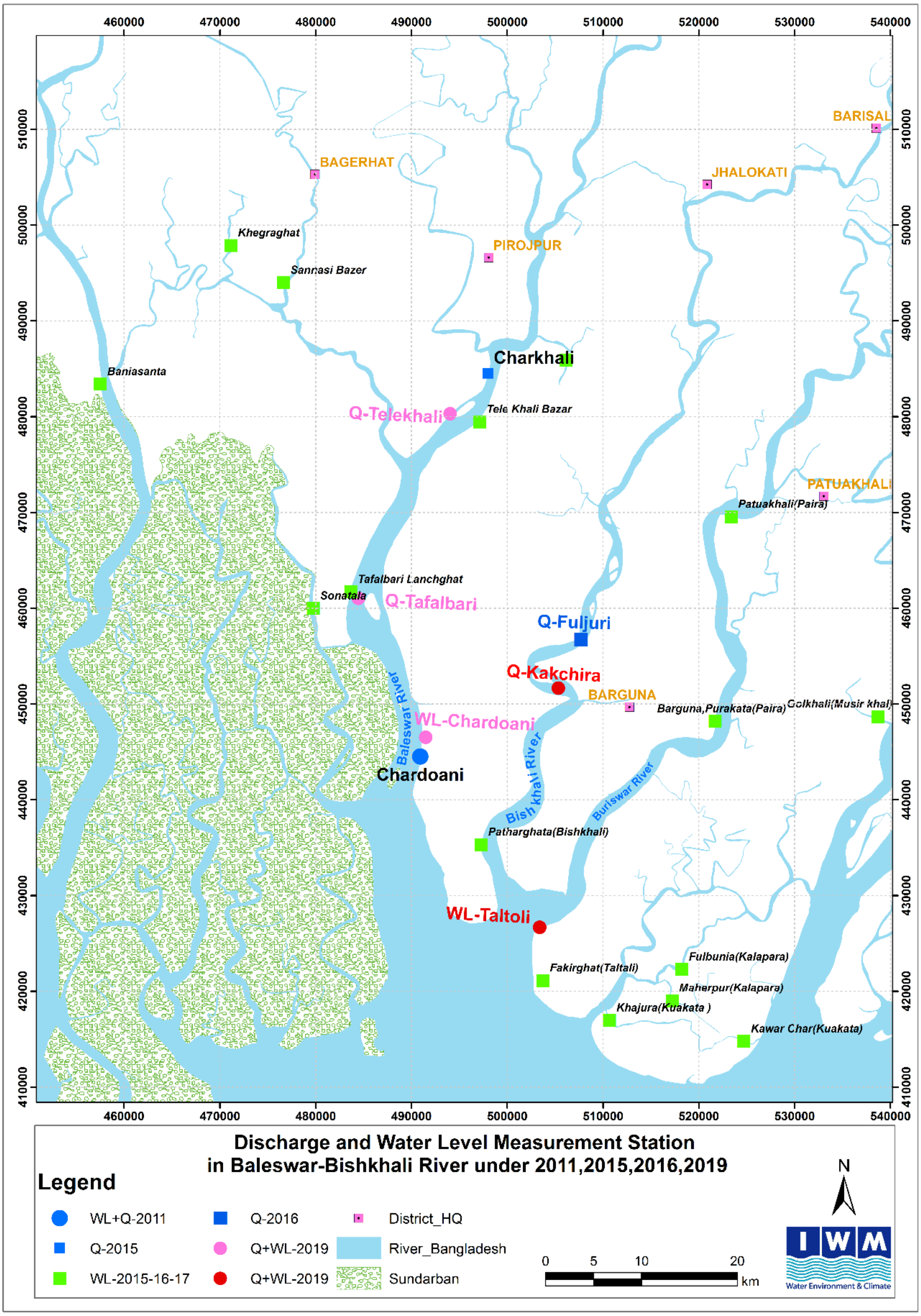


Figure 3.3 Field data collection map of the Baleswar-Bishkhali river system (2011, 2015, 2016 and 2019)

## 3.4 Discharges time-series (IWM)

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

Table 3.3 Available discharge observations from Baleswar-Bishkhali river system

| Discharge collection year | River Name | Station Name | Sources |
|---|---|---|---|
| 2011, 2012 | Baleswar | Chardoani | IWM (GRRP Project) |
| 2015 | | Charkhali | IWM (CEIP-1 Project) |
| 2016 | | Sarmasi (Rayenda) | IWM (CEIP-1 Project) |
| 2019 | | Chardoani | Primary data (Present Project) |
| 2016 | Bishkhali | Fuljuri | IWM (CEIP-1 Project) |
| 2019 | | Kakchira | Primary data (Present Project) |

## 3.5 Sediment bed samples (IWM)

In this section all readily available sediment bed samples for the Baleswar-Bishkhali river system have been combined. Many samples have been collected for various projects, but no report compiling the available data into a comprehensive picture of the sediment bed could be identified. Table 3.4 and Table 3.5 summarise the available data sets, whereas the measurements locations are shown in Figure 3.4.

Table 3.4 Bed samples inventory for Bishkhali river system

| Name | BTM X [m] | BTM Y [m] | Year | $d_{50}$ [mm] | Clay [%] | Silt [%] | 0.125 mm [%] | 0.25 mm [%] | 0.5 mm [%] | Cohesive [%] | Non-cohesive [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bishkhali_LB | 505932 | 452542 | 2019 | 0.03 | 7.37 | 89.66 | 1.49 | 0.97 | 0.50 | 97.03 | 2.97 |
| Bishkhali_CL | 505063 | 451329 | 2019 | 0.12 | 0.00 | 4.04 | 46.76 | 45.47 | 3.72 | 4.04 | 95.96 |
| Bishkhali_RB | 504853 | 450824 | 2019 | 0.06 | 4.08 | 50.57 | 15.40 | 26.76 | 3.19 | 54.65 | 45.35 |

Table 3.5 Bed samples inventory for Baleswar river system

| ID | BTM_X | BTM_Y | Year | Name | D50 | Clay | silt | VFS | FS | MS | SUM | Cohesive | Non-cohesive |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 484936 | 465534 | 2011 | Sharnkhola_RB | 0.015 | 15.4 | 83.4 | 1.12 | 0 | 0 | 100 | 98.88 | 1.12 |
| 2 | 487164 | 464296 | 2011 | Sharnkhola_LB | 0.02 | 11.2 | 88.1 | 0.72 | 0 | 0 | 100 | 99.28 | 0.72 |
| 3 | 490714 | 473165 | 2016 | Sonnasi Left Bank | 0.02 | | | | | | | | |
| 4 | 489646 | 473427 | 2016 | Sonnasi Centre | 0.036 | | | | | | | | |
| 5 | 488556 | 473652 | 2016 | Sonnasi Right Bank | 0.029 | | | | | | | | |
| 6 | 499185 | 486870 | 2017 | Baleswar_01 | 0.05 | 4.88 | 87.9 | 5.55 | 1.39 | 0.2 | 100 | 92.83 | 7.17 |
| 7 | 498794 | 486754 | 2017 | Baleswar_02 | 0.04 | 6.24 | 87.4 | 4.7 | 1.11 | 0.5 | 100 | 93.64 | 6.36 |
| 8 | 498343 | 486597 | 2017 | Baleswar_03 | 0.033 | 8.51 | 89.1 | 2.43 | 0 | 0 | 100 | 97.57 | 2.43 |
| 9 | 489825 | 474698 | 2017 | Baleswar_04 | 0.04 | 5.94 | 79 | 9.1 | 4.46 | 1.5 | 100 | 84.96 | 15.04 |
| 10 | 490291 | 474537 | 2017 | Baleswar_05 | 0.042 | 5.52 | 88.6 | 4.34 | 1.33 | 0.2 | 100 | 94.08 | 5.92 |
| 11 | 490759 | 474426 | 2017 | Baleswar_06 | 0.03 | 5.52 | 92.3 | 2.22 | 0 | 0 | 100 | 97.78 | 2.22 |
| 12 | 483843 | 458345 | 2017 | Baleswar_07 | 0.029 | 12.3 | 76 | 6.82 | 3.77 | 1.1 | 100 | 88.31 | 11.69 |
| 13 | 485418 | 458459 | 2017 | Baleswar_08 | 0.026 | 11.7 | 79.1 | 4.68 | 3.31 | 1.2 | 100 | 90.84 | 9.16 |
| 14 | 487125 | 458624 | 2017 | Baleswar_09 | 0.034 | 8.8 | 89.7 | 1.55 | 0 | 0 | 100 | 98.45 | 1.55 |
| 15 | 486410 | 438424 | 2017 | Baleswar_10 | 0.025 | 15.3 | 82.5 | 2.22 | 0 | 0 | 100 | 97.78 | 2.22 |
| 16 | 488446 | 438583 | 2017 | Baleswar_11 | 0.048 | 4.99 | 80.9 | 9.02 | 3.33 | 1.7 | 100 | 85.93 | 14.07 |
| 17 | 491860 | 430847 | 2017 | Baleswar_13 | 0.113 | 0 | 3.92 | 54.3 | 41.1 | 0.7 | 100 | 3.92 | 96.08 |
| 18 | 499134 | 485341 | 2019 | Baleswar_1B_LB | 0.042 | 8.78 | 89.4 | 0.24 | 1.33 | 0.3 | 100 | 98.13 | 1.87 |
| 19 | 498006 | 485460 | 2019 | Baleswar_1B_RB | 0.048 | 7.62 | 79.3 | 7.41 | 4.66 | 1 | 100 | 86.91 | 13.09 |
| 20 | 486962 | 464017 | 2019 | Baleswar_2B_LB | 0.051 | 14.3 | 81.9 | 2.18 | 1.33 | 0.3 | 100 | 96.17 | 3.83 |
| 21 | 485041 | 464095 | 2019 | Baleswar_2B_RB | 0.037 | 5.73 | 66.6 | 16.2 | 10.8 | 0.7 | 100 | 72.33 | 27.67 |

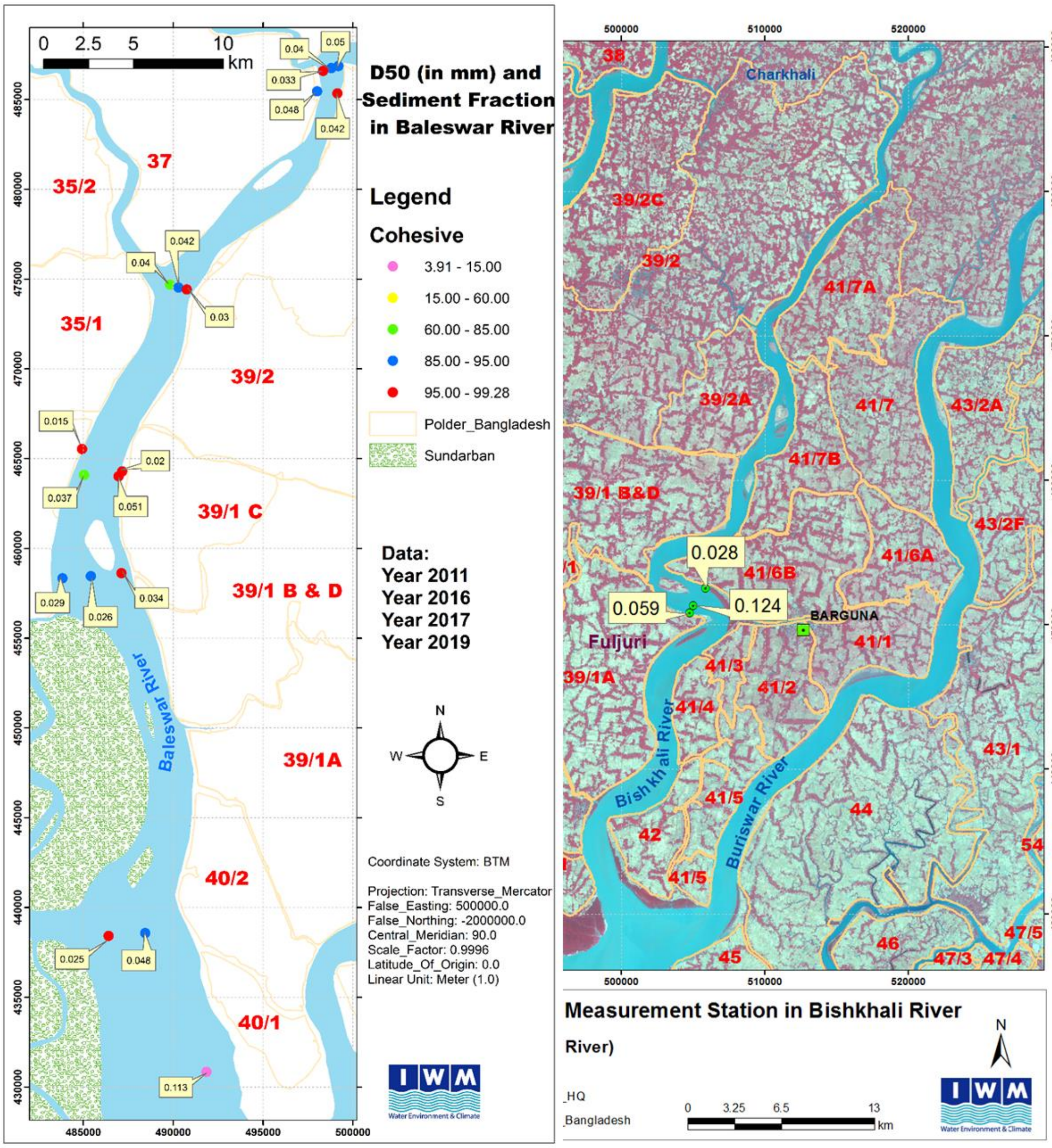


Figure 3.4 Measured sediment fraction of bed sample for the Baleswar-Bishkhali river system. The colours indicate the cohesive sediment content

Figure 3.5 and Figure 3.6 show particle size distribution curves based on measurements taken. The following can be noted:

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

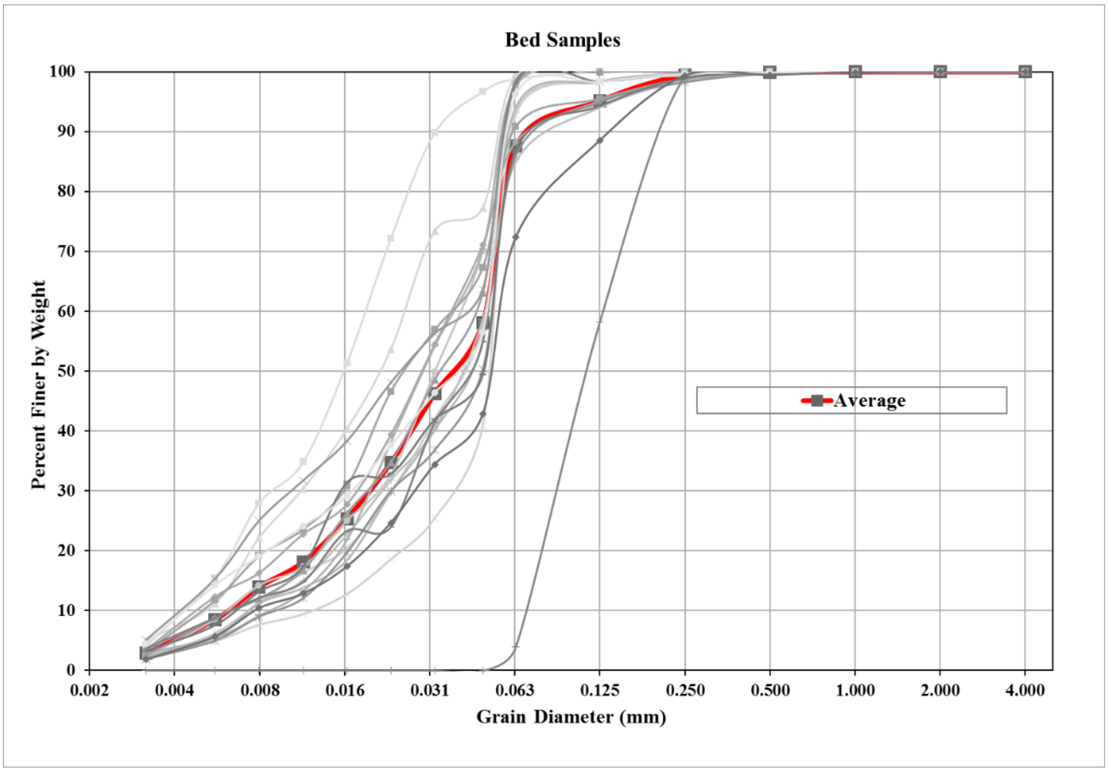


Figure 3.5 Particle size distribution of bed sediment in the Baleswar river systems. IWM data, 2011, 2017, 2019

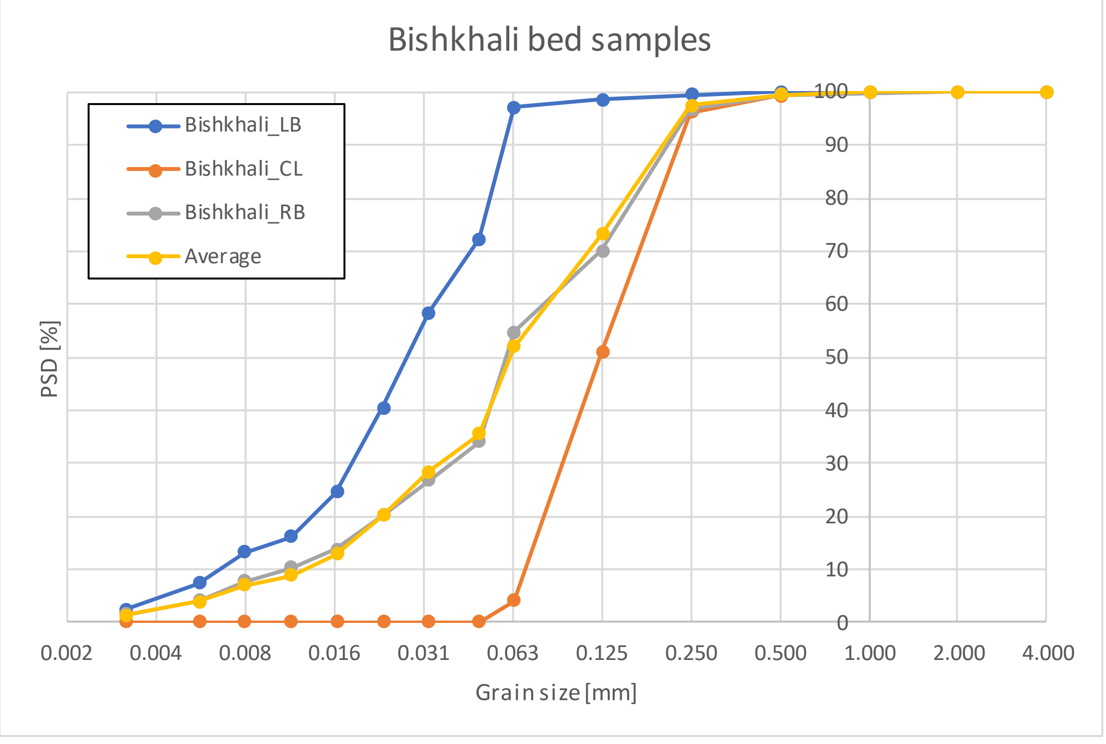


Figure 3.6 Particle size distribution of bed sediment in the Bishkhali river for 2019

## 3.6 Suspended sediment data

For the purpose of the present project no specific samples were collected in the Baleswar and Bishkhali river, but use has been made of samples collected by IWM most recently in 2019 in 2 locations: Chardoani and Kakchira as well as older samples (Table 3.6).

Table 3.6 Suspended sediment concentrations in the Baliswar and Bishkhali river system

| SL | Station | Vertical | River Name | BTM X | BTM Y | Year |
|---|---|---|---|---|---|---|
| 1 | Chardoani | V-1 | Baleswar | 489239 | 446613 | 2011 |
| 2 | Chardoani | V-2 | Baleswar | 490958 | 446638 | 2011 |
| 3 | Charkhali | | Baleswar | 497992 | 484543 | 2015 |
| 4 | Sormasi | | Baleswar | 489306 | 473497 | 2016 |
| 5 | Chardoani | V1 | Baleswar | 486880 | 460988 | 2019 |
| 6 | Chardoani | V2 | Baleswar | 483709 | 461398 | 2019 |
| 7 | Chardoani | LB | Baleswar | 486880 | 460988 | 2019 |
| 8 | Chardoani | RB | Baleswar | 483709 | 461398 | 2019 |
| 9 | Chardoani | V1LB | Baleswar | 486261 | 460934 | 2019 |
| 10 | Chardoani | V2RB | Baleswar | 483674 | 461405 | 2019 |
| 11 | Chardoani | V1CL | Baleswar | 486795 | 460492 | 2019 |
| 12 | Chardoani | V2LB | Baleswar | 485156 | 460944 | 2019 |
| 13 | Chardoani | V2RB | Baleswar | 483844 | 460964 | 2019 |
| 14 | Fujjuri | | Bishkhali | 507447 | 457003 | 2016 |
| 15 | Fujjuri | | Bishkhali | 507900 | 456394 | 2016 |
| 16 | Kakchira | | Bishkhali | 505253 | 452434 | 2019 |
| 17 | Kakchira | | Bishkhali | 505041 | 452899 | 2019 |
| 18 | Kakchira | | Bishkhali | 503597 | 451312 | 2019 |

# 4 Model development

## 4.1 Grid and bathymetry

The long term meso scale model for the Baleswar-Bishkhali river system was developed using the Delft3D FM modelling system. The Baleswar-Bishkhali river system is modelled in one numerical grid, combining both Baleswar and Bishkhali river systems in a single model. The available 2011 bathymetry data was interpolated on the unstructured curvilinear grid system using triangular interpolation. The grid size varies between 1600 m and 100 m. Figure 4.1 shows the grid and bathymetry for the Baleswar-Bishkhali river system.

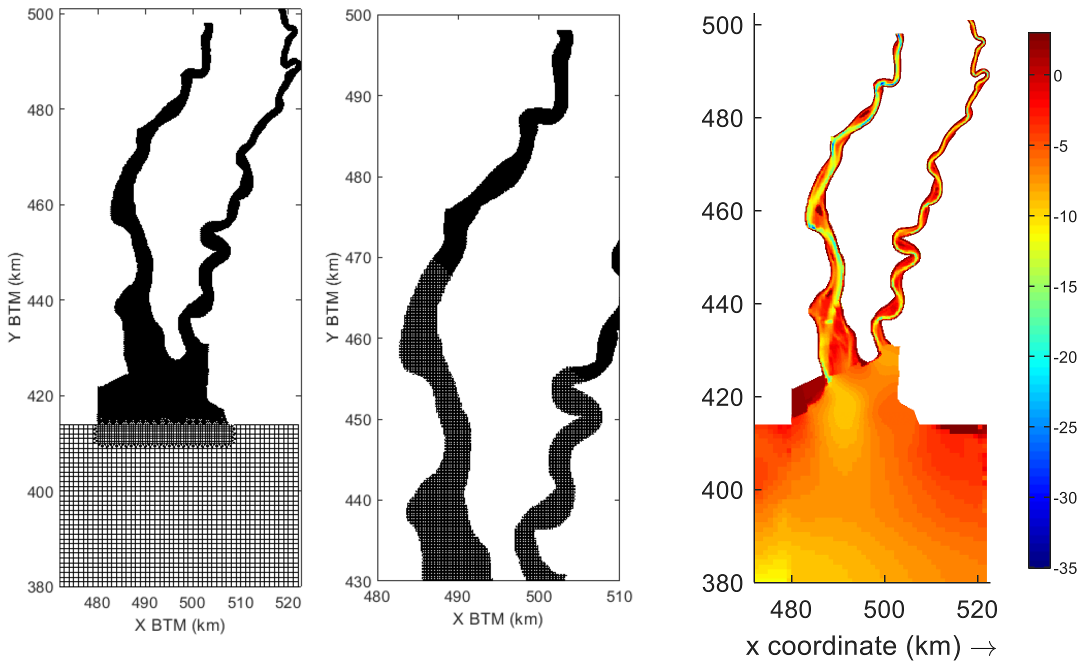


Figure 4.1 Computational mesh and interpolated bathymetry for the Baleswar-Bishkhali river system

## 4.2 Boundary conditions (hydrodynamic model)

The Baleswar-Bishkhali river system model has two upstream boundary, three downstream boundary and several source points representing side channels. Upstream boundaries and sources were collected from the calibrated and validated South West Regional Model for year 2011 and 2015. The three southern boundaries have been generated from the Bay of Bengal Model for the year 2011 and 2015.

The side channels are important to include in the hydrodynamic model, as the flow exchanges with these side channels are not insignificant. Without the side channels it becomes difficult to get the correct discharges in the Baleswar River model. Figure 4.2 shows all boundaries locations in both rivers.

Time series of discharges imposed on the model for 2015 are shown in Figure 4.3; the time series of water levels imposed on the seaward boundaries are shown in Figure 4.4.

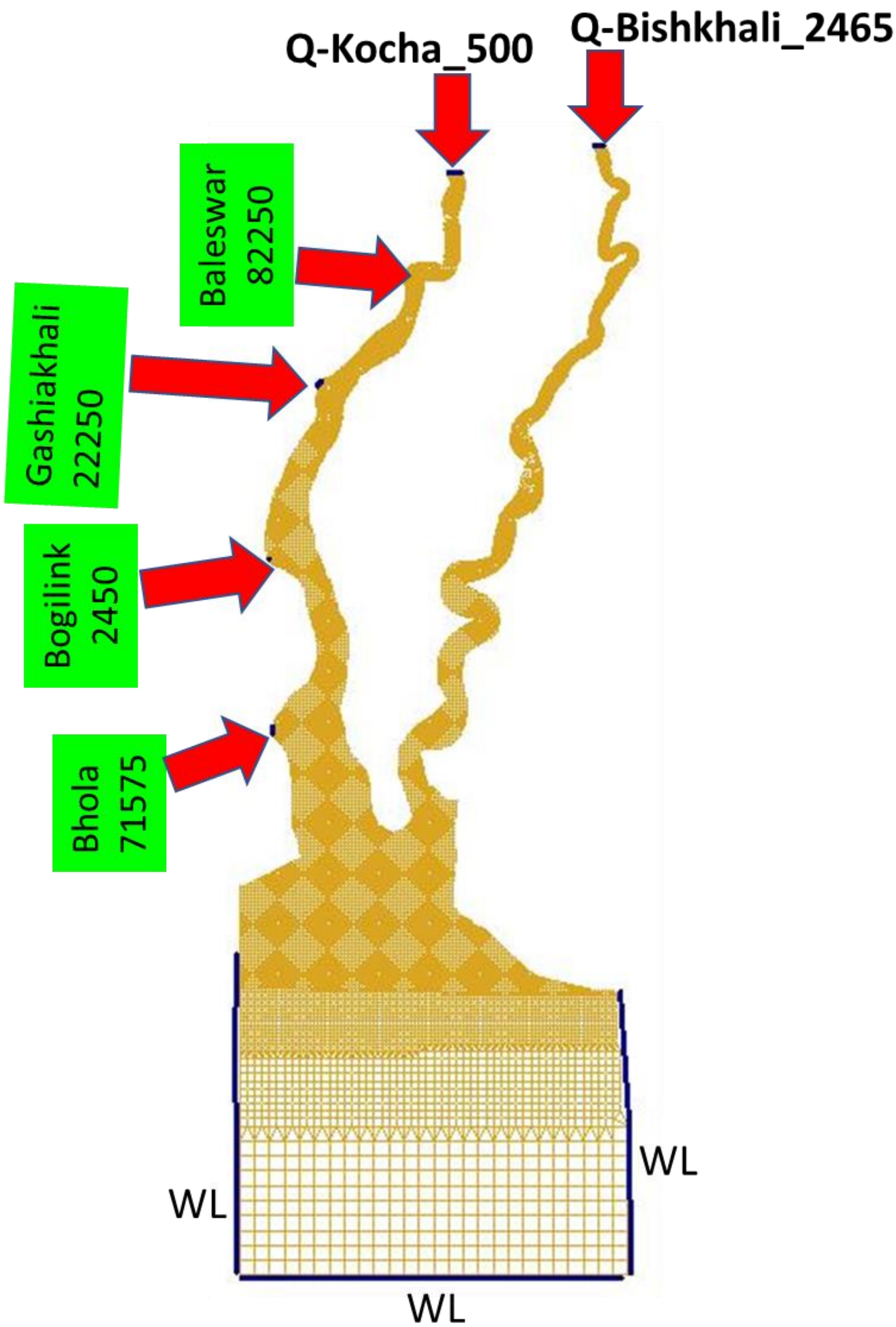


Figure 4.2 Boundaries location map in the Baleswar-Bishkhali river system indicated in dark blue. Thegreen boxes indicate discharges from side channels from SWRM model chainage

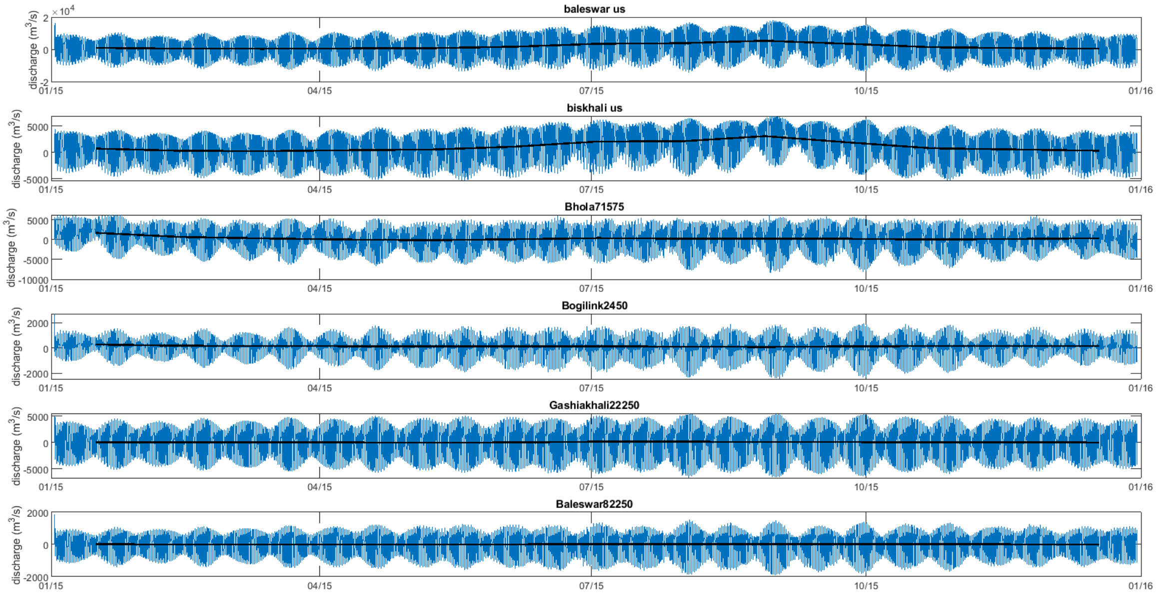


Figure 4.3 Discharge boundary conditions and monthly mean discharges Baleswar-Bishkhali river system for the year 2015.

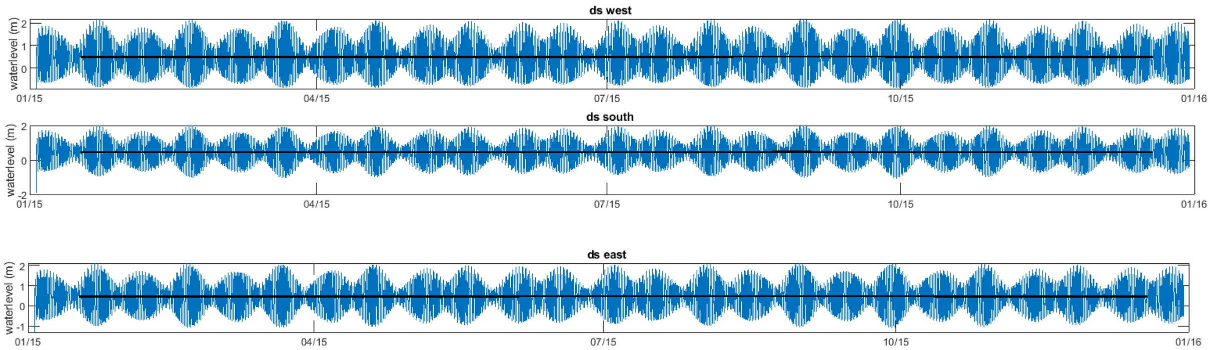


Figure 4.4 Water level boundary conditions Baleswar-Bishkhali river system for the year 2015

## 4.3 Bed resistance

From the bed sediment samples, it can be derived that the Baleswar-Bishkhali river system is cohesive in nature. After extensive calibration, here we used a constant manning's number (n=0.017) for the whole model domain.

## 4.4 Hydrodynamic calibration and validation

The Delft3D FM sediment transport model calculates transport rates on a flexible mesh (unstructured grid) covering the area of interest based on hydrodynamic data obtained from a simulation with the Hydrodynamic Module (HD) as well as with information about the characteristics of the bed material. This means that a well calibrated and validated hydrodynamic model is needed to develop a reliable sediment transport model. The hydrodynamic model was calibrated with field data from a measurement campaign in 2011 both during dry and monsoon season for the Baleswar river and during 2015 for the Baleswar-Bishkhali river system. The locations of the field data sampling points are shown in Figure 3.3.

### 4.4.1 Calibration for water levels during 2011

The hydrodynamic model of the Baleswar-Bishkhali river system was calibrated with the field data collected in 2011 and 2015 (Figure 3.3) during both dry and monsoon season to achieve satisfactory model performance. The water level calibration plots at Chardoani are shown in Figure 4.5 for the 2011 monsoon season. The computed water level is underpredicted especially during flood tide, but during ebb tide, the water level matches quite well. This discrepancy may occur due to the adopted upstream boundary conditions and a lack of tidal prism during flood tide.

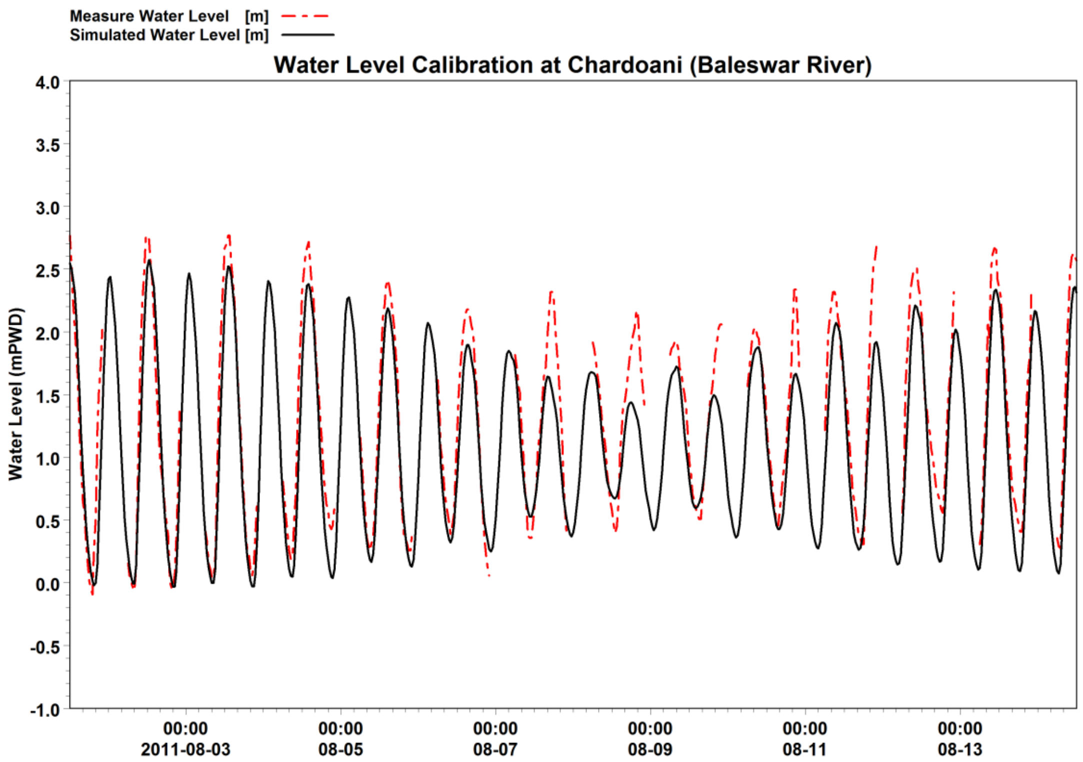


Figure 4.5 Comparison between observed and computed water level at Chardoani during monsoon season (August 2011)

## 4.4.2 Calibration for discharge during 2011

Figure 4.6 and Figure 4.7 show the discharge calibration at Chardoani during monsoon and dry season. The computed discharge is underpredicted especially during flood flow. This discrepancy may in the flood plain which could have retained more water volume during the flood flow.

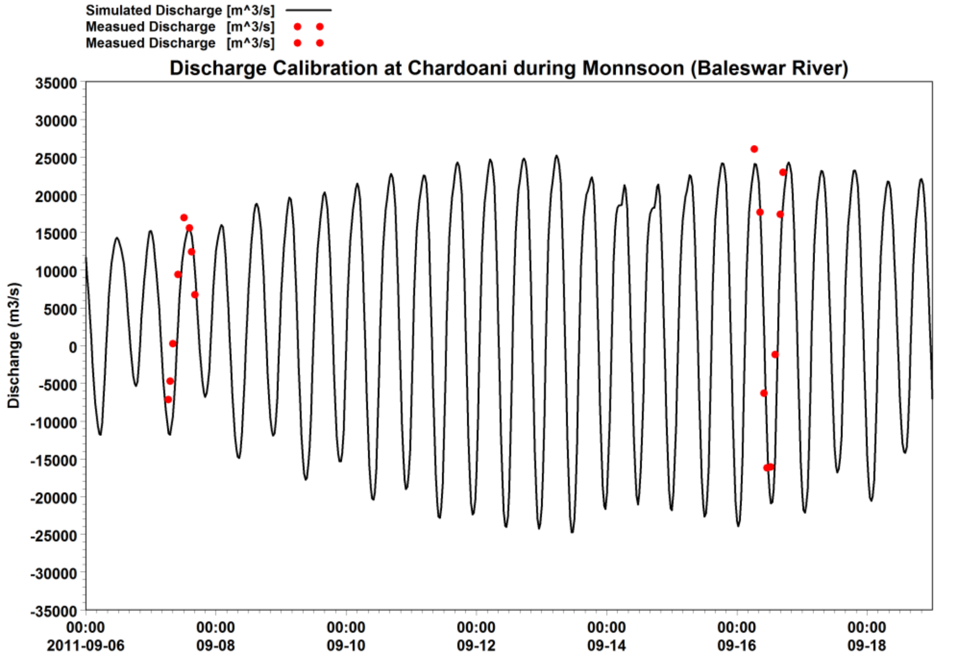


Figure 4.6 Discharge calibration at Chardoani during Monsoon September 2011 (ebb is positive, and flood is negative)

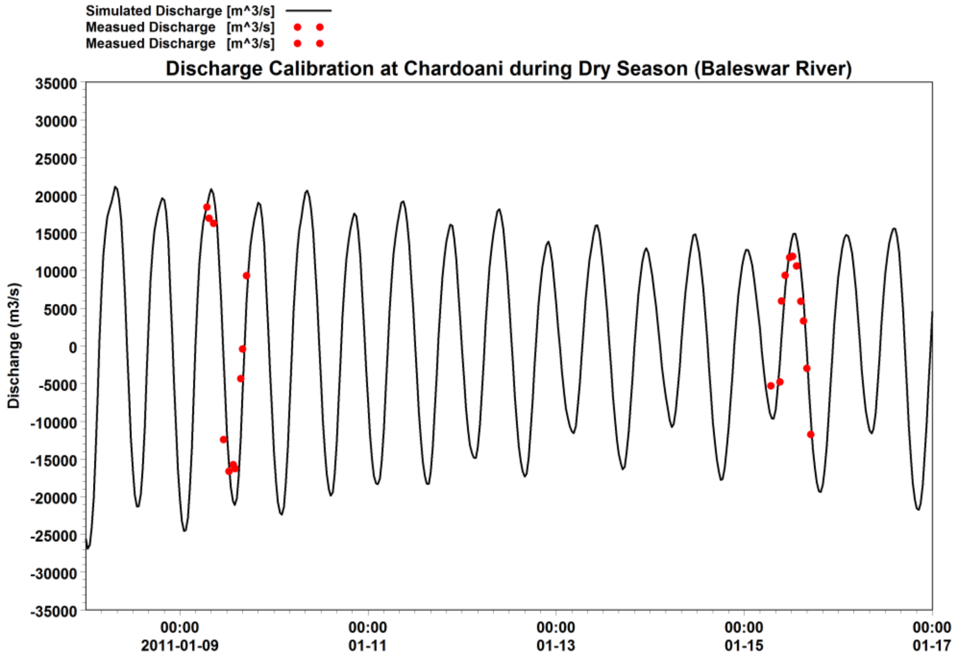


Figure 4.7 Discharge calibration at Chardoani Port during the dry season (January 2009)

### 4.4.3 Validation for water levels during 2015

Water levels were validated at Pathorgata and Fakirghat during Monsoon of 2015, as shown in Figure 4.8 and Figure 4.9, respectively and generally showed a good agreement, in spite of some longer-period fluctuations in the measurements, likely due to atmospheric conditions.

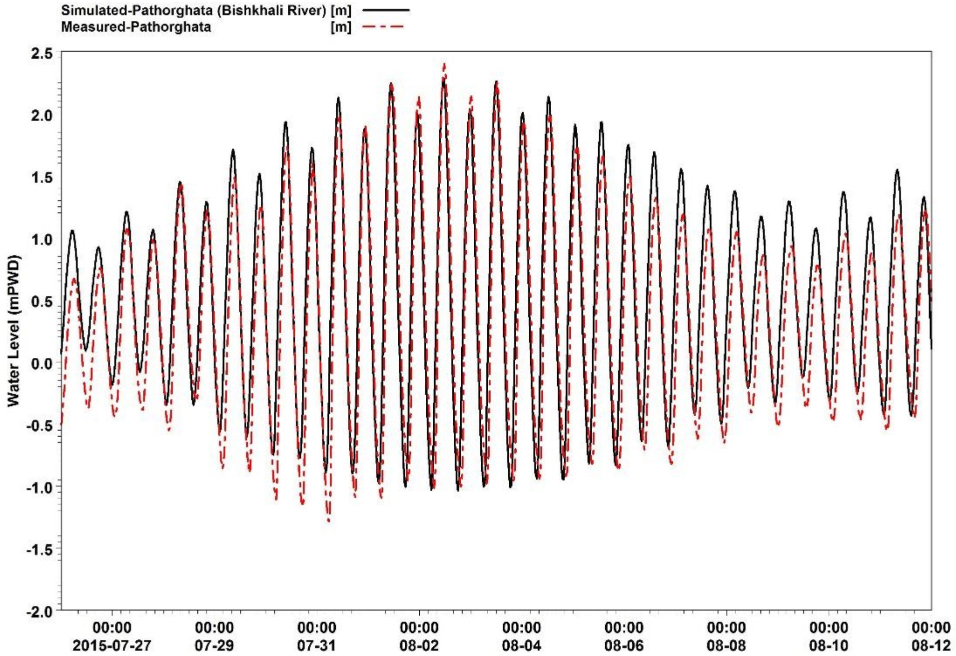


Figure 4.8 Comparison between observed and computed water level at Pathorghata (Bishkhali River) during Monsoon (July/August 2015)

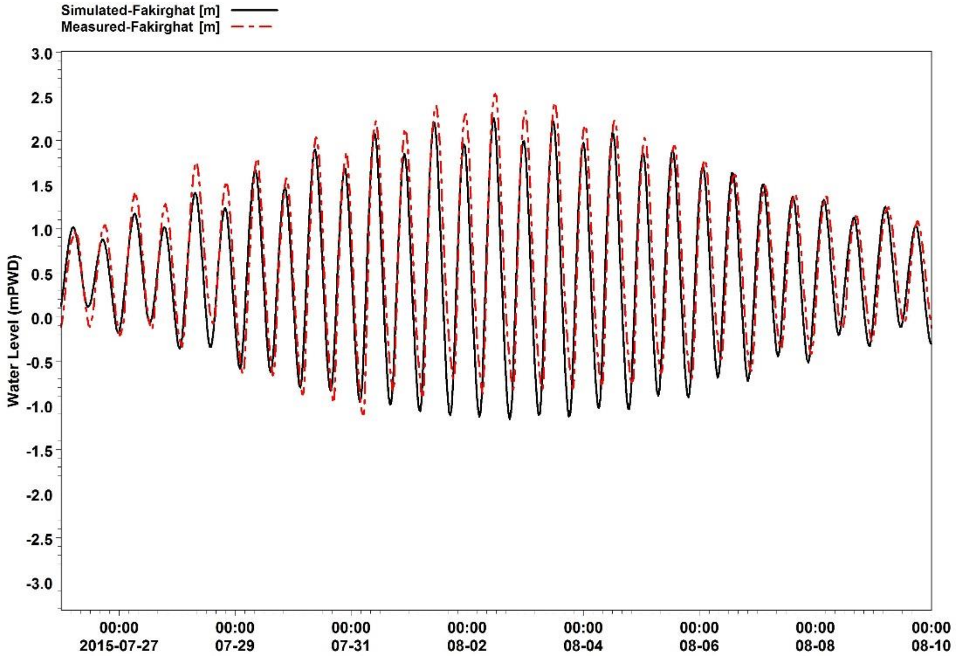


Figure 4.9 Comparison between observed and computed water level at Fakirghat during Monsoon (July/August 2015)

### 4.4.4 Validation for Discharge during 2015

Figure 4.10 and Figure 4.11 show the discharge calibration at Charkhali in the Baleswar river during monsoon for spring and neap tide. The computed discharge is well calibrated with the measurement and shows good correlation between measured and simulated discharge for both spring and neap tide.

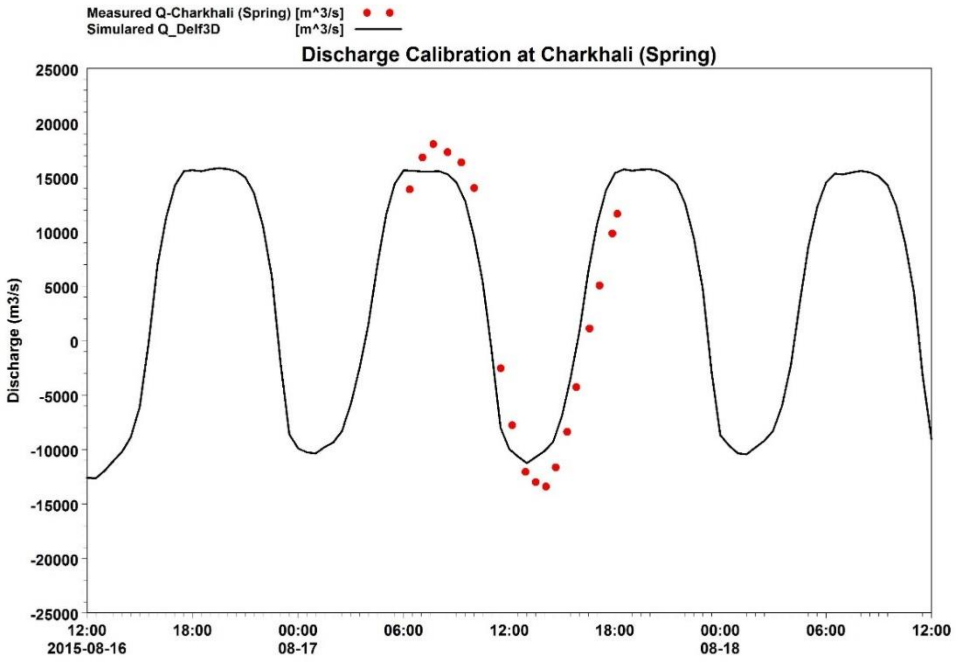


Figure 4.10 Discharge calibration at Charkhali in Baleswar river during the Monsoon season (Spring tide)

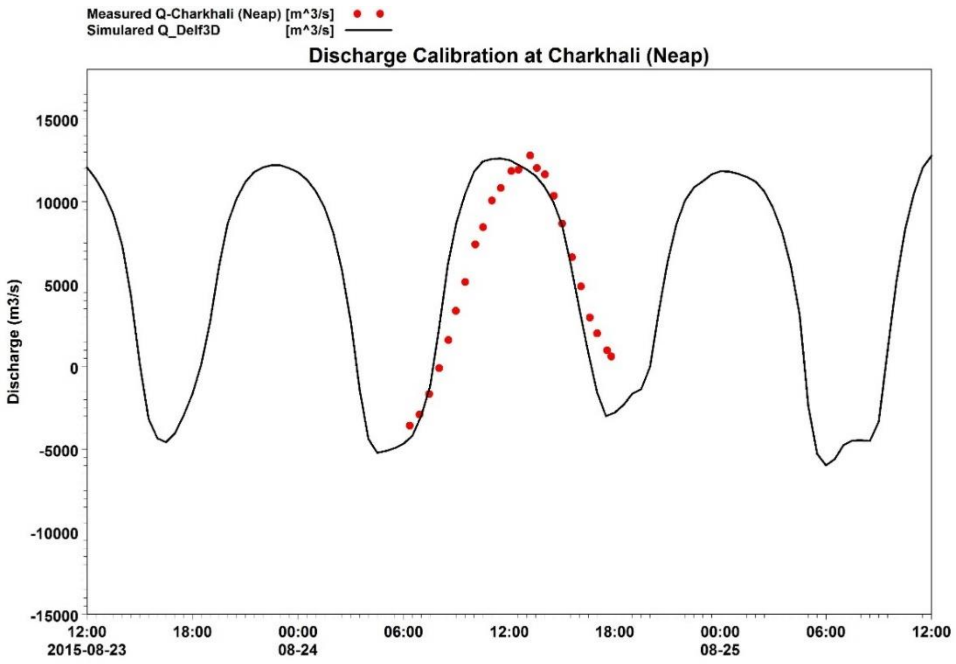


Figure 4.11 Discharge calibration at Charkhali in Baleswar river during the Monsoon season (Neap tide) in August 2015

## 4.5 Sediment transport boundary conditions

The first attempts at modelling observed suspended concentrations were done using constant concentration boundary conditions with mud concentrations as shown in Table 4.1. The side channel boundaries were set to 0.20 (kg/m$^{3}$). However, the definition of the boundary conditions will be improved in future by applying information from the 1D macro scale model, which will be available later. This will provide a more realistic boundary condition for this model. At present, that model has not been completed.

Table 4.1 Sediment concentration boundaries for the morphological model

| **Boundary** | **Mud (kg/m$^3$)** |
|---|---|
| Bishkhali (u/s) | 0.20 |
| Baleswar (u/s) | 0.20 |
| All Side Channel | 0.20 |
| (d/s) Boundaries | 0.04 |

## 4.6 Morphodynamic model

### 4.6.1 Method

The method applied for the long-term simulations is the same as applied in the macro-scale model, as described in section 6.8.1 of the report on the current situation (Deltares, 2020a). Here the procedure is repeated for readability. The computational time for simulating a single year of hydrodynamics and morphology with a model such as this is in the order of 12-24 hours on a heavy computational cluster; therefore, 'brute-force' simulations of the morphological evolution over decades would be extremely cumbersome. Therefore, the well-established approach of 'morphological acceleration' or MorFac method (Roelvink 2006, Ranasinghe et al, 2011) has been applied. This works as follows: in Delft3D the model solves hydrodynamics, sediment transport and bottom updating at every timestep; however, the morphological changes are multiplied by the MorFac (the Morphological Acceleration Factor), effectively accelerating the morphological evolution. Thus, after one tidal cycle, the effect on the morphology is as if a number of cycles equal to MorFac had been run. This approach is acceptable as long as the changes within one tidal cycle, even accelerated, are small relative to the water depth.

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

## 4.6.2 Domain and initial bathymetry

The domain and initial bathymetry are described in Section 4.1.

## 4.6.3 Boundary conditions

For the macro-scale model (Deltares, 2020a) and the Lower Meghna meso-scale model (Deltares, 2020b), the schematization of the upstream discharge is relatively simple as the tide there is negligible. However, in the Baleswar-Bishkhali model the upstream boundaries are well within the tidal limit and therefore a more sophisticated approach was required. This consisted of taking the discharges from the entire year of 2015 and analysing the monthly variation of the mean discharge and the main tidal constituents; from these, a continuous timeseries was created where the mean discharge was 'squeezed' in time and the amplitudes of the M2 and M4 components varied seasonally. The time variation of the tidal components is left unchanged in the 'squeezed' timeframe, so the tidal dynamics are preserved. Hence in the morphological timeframe the tide is 'elongated' by the same morphological factor of 26. This was executed by the script analyse_and_squeeze_timeseries_morfodischarge.m. The same procedure was applied for all discharge and water level boundaries of the Baleswar-Bishkhali model.

In Figure 4.12, as an example, the original and schematized time series of discharge for the Baleswar upstream boundary are shown. With these boundary conditions, it is assured that the mean discharge variation throughout the year is preserved and the morphologically representative tide is represented correctly.

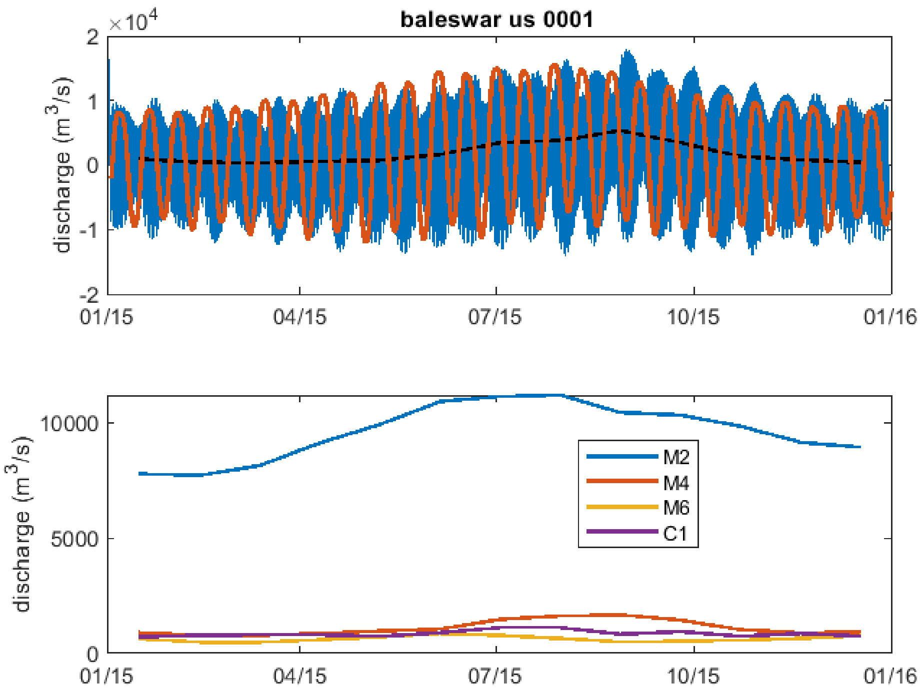


Figure 4.12 Squeezed timeseries for Bishkhali upstream (us) discharge. Top panel: observed discharge 2015 (thin blue line), monthly mean discharge (dashed black line) and total schematized discharge (red line). Bottom panel: monthly mean tidal amplitudes. Note that morphological time is denoted on the time axis.

Alternative methods for driving this mesoscale model have been tested and may be useful in future:

1. Directly deriving the discharge and water level boundaries from a macro-scale model hydrodynamic or morphodynamic run with schematized boundary conditions. The advantage of this approach would be that the effects of, for instance, upstream scenarios, would be automatically transferred to the nested model domain. A prerequisite, however, is that the discharges passing through the Baleswar-Bishkhali system need to be well calibrated and validated. With the current macro-scale model (Deltares, 2020a) this has not been a specific target of validation and as it turned out, discharge amplitudes were in fact overestimated. Further attention needs to be paid to all branches of possible interest. At this stage, the macro-scale model has been refined to 250m resolution in order to better resolve all branches in the area, but a further inspection of how all channels are resolved and check on all possible discharge measurements needs to be carried out first. Furthermore, nesting in morphologically active areas is far from ideal and can easily lead to instabilities near the boundaries.

2. A promising alternative to nesting is to *incorporate* the local grid(s) in the overall network so that they become a part of it. Still, the overall network needs to reproduce the correct flow distribution and tidal propagation over the different branches, but the transition between the refined domains and the overall model is smooth and does not create problems. Of course, in such an approach the entire model domain has to be run for every simulation, which creates an overhead; first experiments indicate nevertheless that this does not lead to insurmountable problems.

### 4.6.4 Sediment settings

The morphological model development for the Baleswar-Bishkhali river system was carried out for 2011. The Baleswar-Bishkhali river is mostly cohesive in nature whereas some bed samples at the middle of the channel show non-cohesive sediment. Therefore, a mud and sand fraction were added for the sediment calibration, similar to the settings in the macro-scale model (Deltares, 2020a) and the meso-scale model of the Lower Meghna (Deltares, 2020b). The detailed parameters used for the sediment model are illustrated in Table 4.2. For the sand fraction the same sediment thickness of 5 m was taken and a D50 grain size of 0.15 mm.

Table 4.2 Sediment model parameters for sand and mud fraction

| [Sediment] Fraction (Mud) | | |
|---|---|---|
| Name | #mud# | Name |
| SedTyp | mud | Must be "sand", "mud" or "bedload" |
| IniSedThick | 5 | [m] |
| FacDss | 1 | Factor |
| RhoSol | 2650 | [kg/m³] |
| TraFrm | -3 | Integer |
| CDryB | 850 | [kg/m³] |
| SalMax | 31 | [ppt] |
| WS0 | 0.001 | [m/s] |
| WSM | 0.001 | [m/s] |
| EroPar | 0.001 | [kg/m²s] |
| TcrSed | 1000 | [N/m²] |
| TcrEro | 0.35 | [N/m²] |

### 4.6.5 Sediment transport calibration

As is also apparent from the MIKE21 simulations of the Baleswar River (see DHI, 2020), the exact replication of sediment concentrations is not feasible in a morphodynamic model, given the sparse data on sediment types and the fact that the concentration will change as soon as the bottom starts to evolve. For the measurements of sediment concentration reported in the bank erosion report (DHI, 2020), not repeated here, the majority of data lies between 0 and 1000 mg/l, with values around 200 mg/l being the most common.

For the morphodynamics model simulations it suffices to ensure that the sediment concentrations are in the right order of magnitude and evolve towards a reasonable longer-term variation. In Figure 4.13 and Figure 4.14 the timeseries of sediment concentration is shown for Tafalbani and Chardoani stations. It can be clearly seen that after a short period of adaptation to boundary conditions and initial bed level changes the sediment concentration stabilizes to a seasonal variation, with values in a reasonable range of 50-300 mg/l for Tafalbani and 40-200 mg/l for Chardoani.

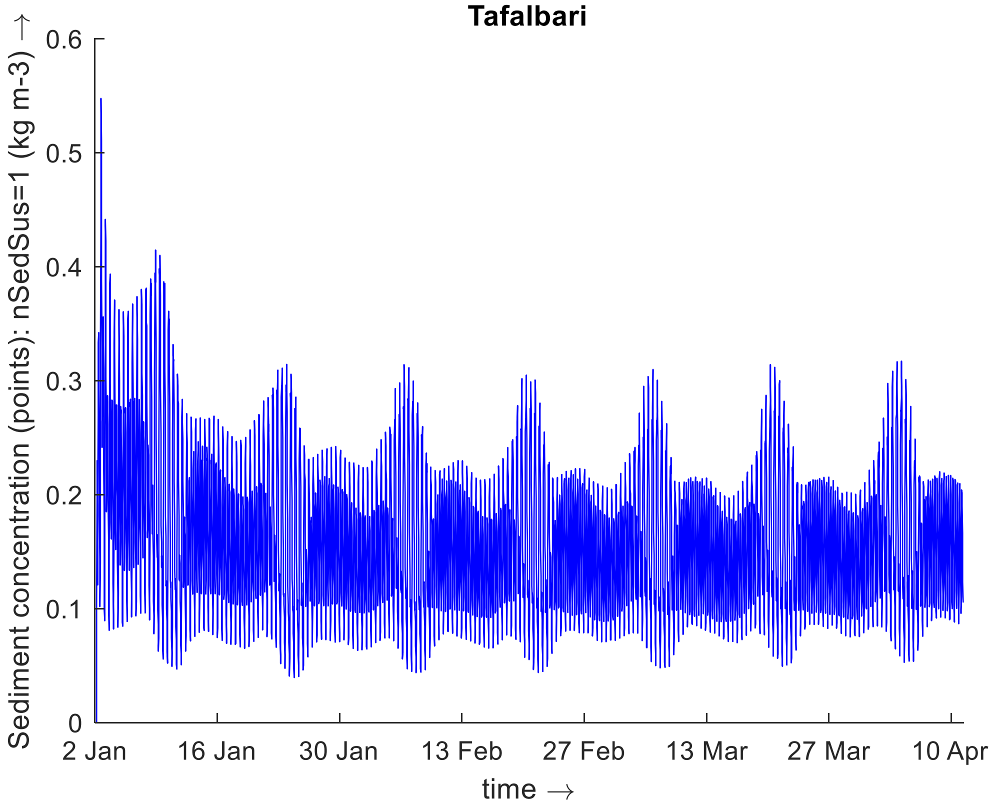


Figure 4.13 Sediment (mud) concentrations over (hydrodynamic) time, Tafalbari station

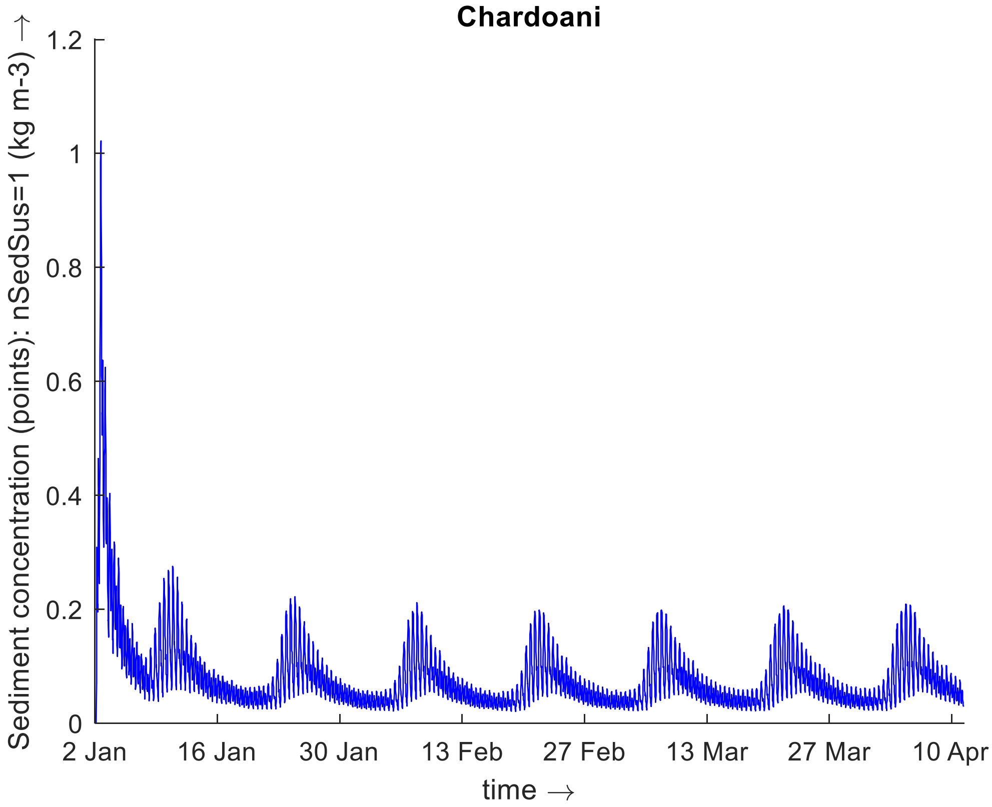


Figure 4.14 Sediment (mud) concentration over (hydrodynamic) time, Chardoani station

## 4.6.6 Morphological settings

For the settings for the morphological parameters the same parameters as in the macro-scale model have been used with the following two small exceptions: the Alfabn smoothing factor has been set to 100 instead of 200 because of the finer grid. Due to the same reason the Wetslope of 1/20 has been set to 1/50. An overview of all parameters is shown in Table 4.3.

Table 4.3 Overview of morphological parameters for the model

| **Morphology** | | | |
|---|---|---|---|
| MorFac | 26 | [-] | Morphological scale factor |
| MorStt | 1209600 | [s] | Spin-up interval from TStart till start of morphological changes (14 d) |
| Thresh | 0.05 | [m] | Threshold sediment thickness for transport and erosion reduction |
| MorUpd | true | [-] | Update bathymetry during FLOW simulation |
| NeuBCMud | false | [-] | Neumann condition for upstream mud boundary |
| NeuBCSand | true | [-] | Neumann condition for upstream sand boundary |
| AksFac | 1 | [-] | van Rijn's reference height = AksFac* ks |
| RWave | 2 | [-] | Wave related roughness = RWAVE * estimated ripple height. |
| AlfaBs | 1 | [-] | Streamwise bed gradient factor for bed load transport |
| AlfaBn | 100 | [-] | Transverse bed gradient factor for bed load transport |
| Sus | 1 | [-] | Multiplication factor for suspended sediment reference concentration |
| Bed | 1 | [-] | Multiplication factor for bed-load transport vector magnitude |
| SusW | 0 | [-] | Wave-related suspended sed. transport factor |
| BedW | 0 | [-] | Wave-related bed load sed. transport factor |
| SedThr | 0.2 | [m] | Minimum water depth for sediment computations |
| ThetSD | 0 | [-] | Factor for erosion of adjacent dry cells |
| Wetslope | 0.05 | [-] | Threshold bed slope for avalanching |
| **Underlayer** | | | |
| IUnderLyr | 2 | [-] | Flag for underlayer concept 1 = one well mixed layer 2 = multiple layers |
| ExchLyr | false | [-] | True/false separate exchange layer |
| TTLForm | 1 | [-] | Transport layer thickness formulation |
| ThTrLyr | 0.25 | [m] | Thickness of the transport layer |
| MxNULyr | 2 | [-] | Number of underlayers (excluding final well mixed layer) |
| ThUnLyr | 0.25 | [m] | Thickness of each underlayer |

### 4.6.7 Calibration

The calibration of the morphodynamic model was carried out for the period from 2011 to 2019 as suitable bathymetry data were available for the Baleswar. Unfortunately, no data of sufficient quality was available for Bishkhali before 2019, so this area could not be evaluated.

Several sediment transport settings have been tried, in combination with different alternative approaches to create boundary conditions, as indicated in Section 4.6.3. However, since the discharge amplitudes following these approaches were overestimated, the schematized, locally validated discharges were applied here. As for the sediment settings, the settings derived in the macro-scale model, as described in Section 4.6.4, clearly gave the best results; therefore, only results for these settings are discussed below.

The overall sedimentation/erosion pattern over the period from 2011 to2019 shows predominantly an accreting trend, although particularly along some of the banks erosion can be seen. This is even more pronounced in in the measurements. A possible explanation may be due to the model resolution of 100 m in the northern part and 200 m in the southern part. This resolution may be on the coarse side in order to resolve these erosion patterns. Therefore, it is recommended that the 100 m resolution will be applied throughout the Baleswar river system.

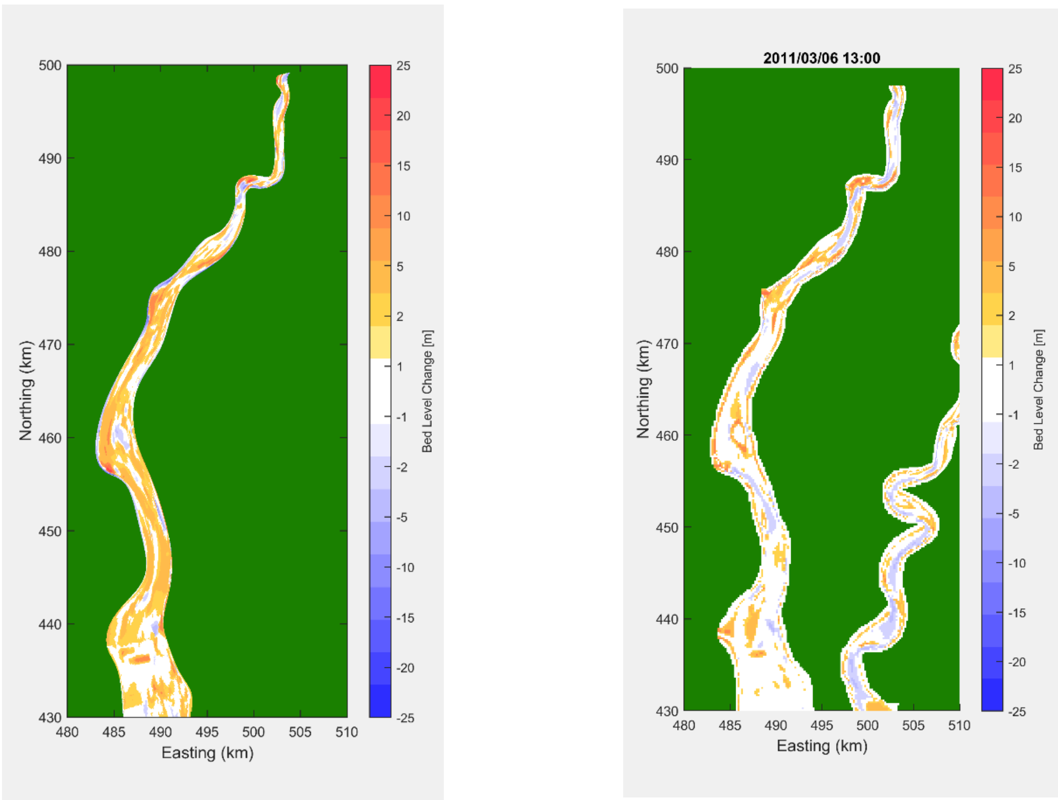


Figure 4.15 Sedimentation/erosion Baleswar River, 2011-2019. Left panel: observations; right panel: simulated with morphological factor of 26 and squeezed, schematized boundaries.

In Figure 4.16 the sedimentation-erosion patterns are plotted in a linear colour scale and five areas were classified that are used for the analysis of volume changes and changes in the hypsometry, which are given in Figure 4.17 to Figure 4.19.

In the overall sedimentation-erosion pattern, clear boundary effects are seen in Area 1 resulting in slightly different, more erosive patterns, although model results and observations are within the same order of magnitude. A lack of sedimentation there may be the result of the imposed sediment concentration of 200 mg/l at the upstream end, which may be on the low side.

In Area 2, the patterns of sedimentation and erosion are quite similar, as are the negative, positive and net volume changes, where the dots at the end of the volume change series indicate the volume changes derived from the observed bathymetry change over 2011-2019.

Areas 3 and 4 also show reasonable agreement in patterns, and quite good agreement in net and gross volume changes.

Finally, Area 5 is close to the area where no data were available in 2011 and may have been hindered by this fact; the seaward boundaries are relatively far away but may still have an effect on the sedimentation as a relatively low concentration was imposed there.

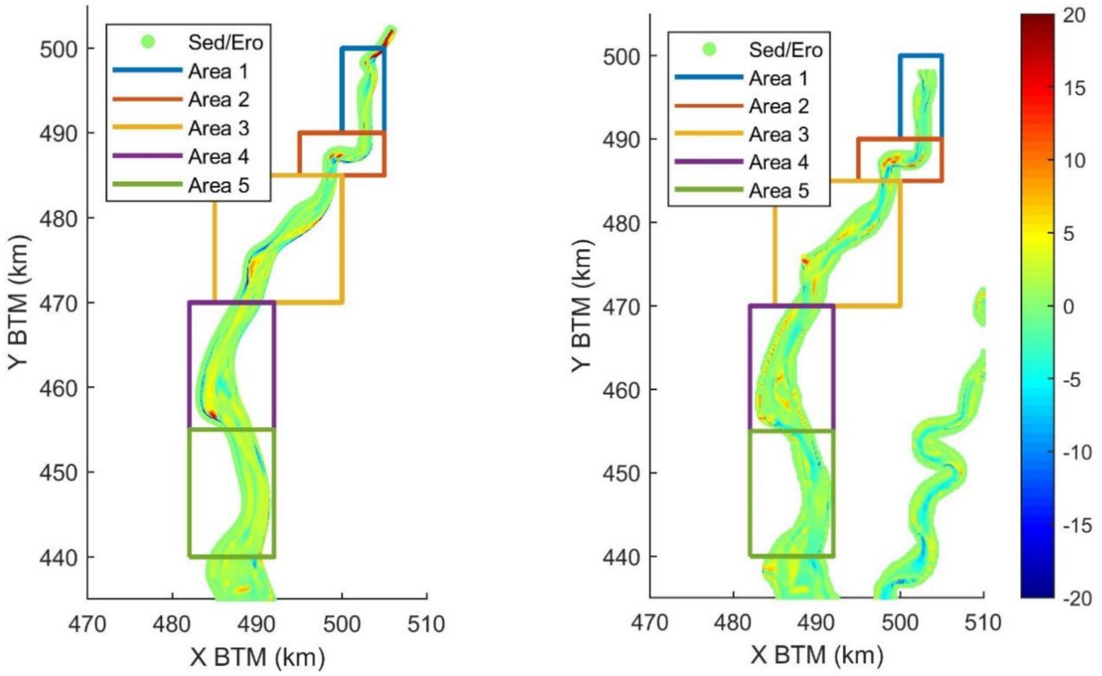


Figure 4.16 Sedimentation/erosion Baleswar River, 2011-2019. Left panel: observations; right panel: simulated with morphological factor of 26 and squeezed, schematized boundaries.

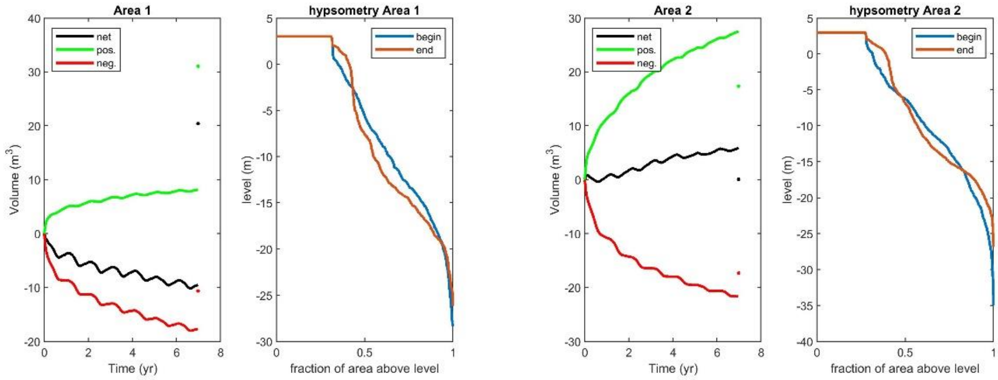


Figure 4.17 Positive, negative and net change in volume and change in hypsometry, 2011-2019, Baleswar Area 1 (left panels) and Area 2 (right panels). Dots in volume plot indicate actual observations.

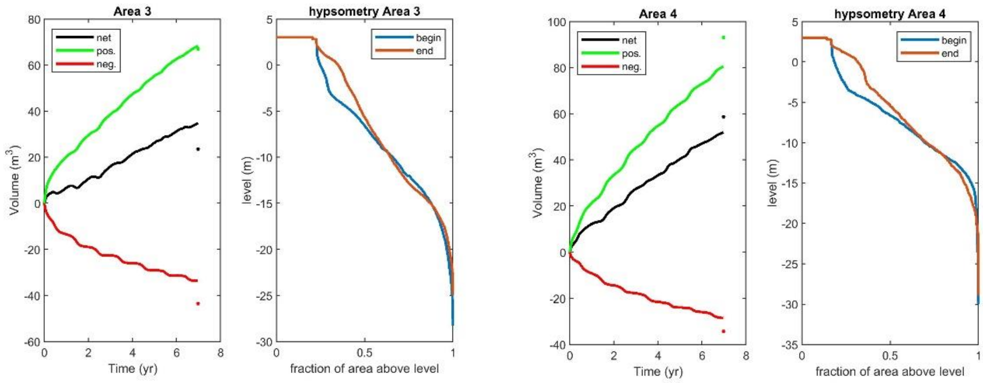


Figure 4.18 Positive, negative and net change in volume and change in hypsometry, 2011-2019, Baleswar Area 3 (left panels) and Area 4 (right panels). Dots in volume plot indicate actual observations

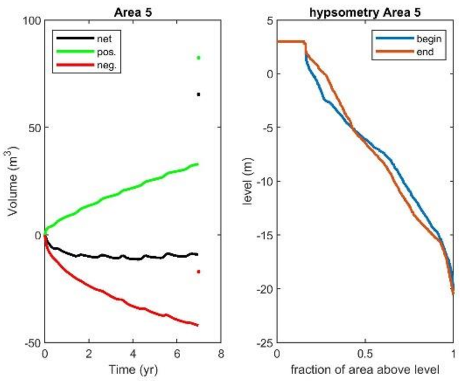


Figure 4.19 Positive, negative and net change in volume and change in hypsometry, 2011-2019, Baleswar Area 5. Dots in volume plot indicate actual observations

In Figure 4.20 and Table 4.4 the observed and modelled volume changes in the five control areas are compared. The level of agreement is rather good, given the paucity of data in the area and the relative simplicity and coarseness of the model. Especially the middle areas 2, 3 and 4 perform well; however closer to the boundaries, uncertainties in boundary conditions and adjacent bathymetries increase and results are less accurate.

From the statistics in Table 4.5 it can be seen that the trend in the erosion is roughly right but with quite some scatter, whereas the sedimentation has less scatter (and better correlation) but underestimates the trend by a modest 25%; the resulting net sedimentation is then underestimated by a little over a factor 2. If concentrating on the areas well away from the boundary, the overall performance would be better.

It seems that, given a reasonably accurate description of the discharges, the model settings derived for the macro-scale 2D model and confirmed for the Lower Meghna – Tetulia meso-scale model again produce relatively good results; various sensitivity runs did not improve on this. This is a strong point from a perspective of predictability and though refinements are certainly possible and desirable, provides a good starting point for further validation and simulation of scenarios.

As was mentioned before in Section 4.6.3, given accurate distribution of discharges and tidal propagation over all branches of the macro-scale model, it should be relatively straightforward to directly incorporate meso-scale models into the macro-scale model; the extra computational cost is offset by a simpler specification of boundary condition and avoidance of boundary problems in highly dynamic areas. This does, however, require some additional effort in calibrating discharge distributions in the macro-scale model.

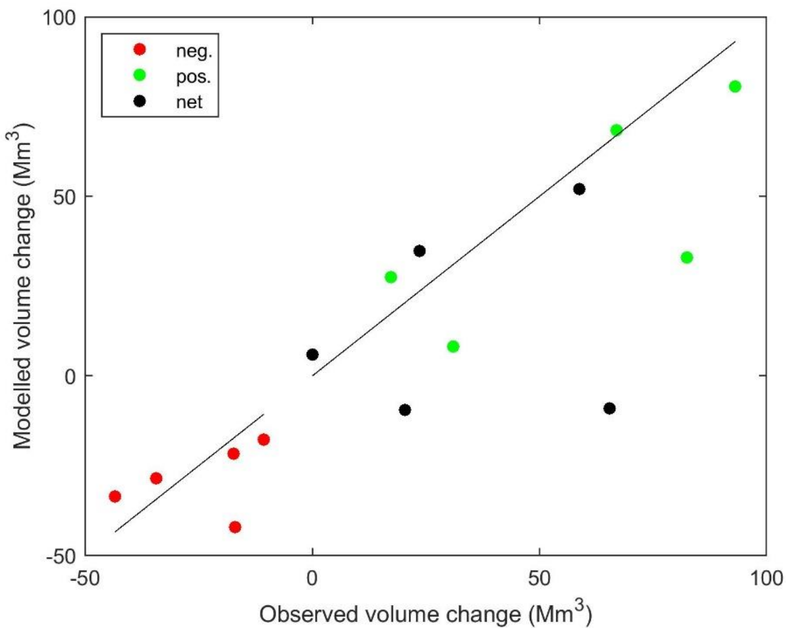


Figure 4.20 Modelled vs. observed negative, positive and net volume changes 2011-2019, Baleswar River, all areas

Table 4.4 Observed and modelled volumetric changes

| Area | Observed volume change (Mm3) | | | Modelled volume change (Mm3) | | |
|---|---|---|---|---|---|---|
| | Neg. | Pos. | Net | Neg. | Pos. | Net |
| 1 | -11 | 31 | 20 | -18 | 8 | -9 |
| 2 | -17 | 17 | 0 | -22 | 28 | 6 |
| 3 | -43 | 67 | 24 | -34 | 68 | 35 |
| 4 | -34 | 93 | 59 | -29 | 81 | 52 |
| 5 | -17 | 82 | 65 | -42 | 33 | -9 |
| ***Total*** | ***-123*** | ***291*** | ***168*** | ***-143*** | ***218*** | ***74*** |

Table 4.5 Statistics of the observed and modelled volumetric changes

| Parameter | Neg. | Pos. | Net |
|---|---|---|---|
| RMSE | 14 | 23 | 35 |
| BIAS | -4 | -15 | -19 |
| MAE | 10 | 19 | 26 |
| SLOPE | 1.17 | 0.75 | 0.44 |
| CORR | 0.37 | 0.73 | 0.20 |

# 5 Model applications

The meso-scale Baleswar-Bishkhali model has proven to give reasonably accurate predictions of gross and net volume changes over a period of almost a decade, especially in areas somewhat away from the boundaries. The main uncertainty in this prediction lies in the forcing by discharges and the sediment concentration, both of which have to be specified in a highly dynamic area. Sediment parameters do play a role, but a relatively robust setting has been found that appears to function in several areas of the delta system.

In the current setup, different large-scale scenarios, including upstream regime changes and sea level rise, will have to be run through the macro-scale model to update the boundary conditions. A setup wherein the current model is integrated within the macro-scale network would eliminate the coupling steps and potentially could be more robust, given that discharge distributions everywhere in the system can be trusted.

The current model could well be used to investigate the effects of certain measures (TRM, dredging, relocating embankments, etc.) on a local scale, and to investigate the sedimentation or erosion close to polder drainage outlets.

# 6 Conclusions

The Baleswar-Bishkhali meso-scale model is set within a highly dynamic area for which setting adequate boundary conditions is far from trivial. A workable solution has been found in schematizing boundary conditions based on validated timeseries of discharges for a given configuration of the delta. Such boundary conditions can be assumed to be constant during a decade but possibly not much longer.

For multi-decade simulations the interaction with the larger system are ideally considered. A workable solution appears to be to incorporate the more detailed meso-scale models within the unstructured macro-scale model. For this to be feasible, the macro-scale model has to be trained to reproduce the distribution and amplitude of discharges over the many branches to a high extent. The discharges in the Pussur-Sibsa and Lower Meghna system were reproduced well in the macro-scale model, allowing the force the subsequent meso-scale models. However, less data was available, and therefore less attention was given to the Baleswar-Bishkhali system. Therefore, discharges from the macro-scale model were not accurate enough to force the meso-scale model to improve multi-decade simulations.

In spite of this, with the current schematized boundary conditions a fairly accurate reproduction of the morphological developments over the period 2000-2009 was made. Therefore, the Baleswar-Bishkhali meso-scale model presented here can be a useful tool to study local erosion and sedimentation problems and effects of possible management scenarios over periods of years to decades.

# 7 References

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