BANGLADESH

Coastal Embankment Improvement Project Phase 1

Short TOR on Component C3: Long Term Monitoring, Research and Analysis of Bangladesh

Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics),

Contract Package No. CEIP-I/C3/S4

Bangladesh is situated at the confluence of three great trans-Himalayan rivers — the Ganges, the Brahmaputra or Jamuna, and the Meghna (GBM). While over 90 percent of the GBM catchment lies outside of Bangladesh, approximately 200 rivers and tributaries of the GBM drains through the country via a constantly changing network of estuaries, tidal inlets, and tidal creeks, before emptying out into the Bay of Bengal[1]. Thus, the coastal zone of Bangladesh, the lowest landmass of the country, is continually influenced by these Himalayan drainage ecosystems that join to form one of the largest, youngest, and most active deltas in the world.

The coastal zone[2] of Bangladesh spans over 710 km of coastline and is prone to multiple threats. Sixty-two percent of the coastal land has an elevation of up to 3 meters and eighty-three percent up to 5 meters above mean sea level[3]. The flow of the rivers entering the GBM delta is the third largest in the world and river floods occur regularly, often leading to flooding of one thirds of the country. In 1998, the flooded area covered as much as two thirds of the country. With a sediment supply of 1 billion tons per year, this is the delta with the largest sediment supply in the world. This leads to accretion of the land area in the coastal zone (5-10 km^2/year, mainly in the Meghna Estuary), and to highly unstable river branches and estuaries. The large amounts of sediments also lead to natural subsidence of the soil. This subsidence is increased at several places by anthropogenic factors like drainage and ground water extraction. On top of that there are tectonic movements in the deep subsoil, caused by horizontal plate movements.

The coastal zone constitutes 32 percent of the land area and hosts nearly 28 percent of the population[4] (i.e., nearly 42 million[5]). The coastal population is projected to grow to 61 million by 2050[6]. Coastal districts are characterized by a high pace of population growth[7]. This trend continues to push millions of people to live in the low lying coastal areas which are highly vulnerable to natural hazards. The vulnerability of the coastal population is on the rise due to climate change. Climate variability and change will accentuate the intrinsic risks facing coastal Bangladesh. These risks span: (i) cyclones and storm surges (ii) river bank erosion and vulnerability of islands and chars, (iii) sea level rise, (iv) saline intrusion, and (v) coastal erosion. Much is still to be understood of this dynamic delta.

Background on Polders and CEIP-I

The Government of Bangladesh's commitment to develop a safe and inhabitable coastal zone can be dated back to the 1960s. Compelled by the call for intensive rice cultivation during the green

[1]Yu W. et al., 2010. Climate Change Risks and Food Security in Bangladesh. World Bank.
[2] The delineation of the Coastal Zone, approved by the Ministry of Water Resources in 2003, comprises 19 districts, 147 upazillas and the exclusive economic zone.
[3]Bangladesh Water Development Board. Coastal Embankment Improvement Project, Draft Final Report, Sept 2012.
[4] Islam, M.R., 2004. Where land meets the sea: a profile of the coastal zone of Bangladesh. Dhaka, the University Press Limited. 317 pp.
[5]Based on a total population of 148.7 million in 2010; as per World Bank Open Data.
[6] Ahmad, M. 2005. Living in the coast: urbanization. Dhaka, Program Development Office for Integrated Coastal Zone Management Plan Project, Water Resources Planning Organization.
[7] In 1990s, population growth is estimated to be 2.25% according to Mcgranahan G., D. Balk, and Bridget, A., 2000. The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environment and Urbanization April 2007 vol. 19 no. 1 17-37, doi: 10.1177/0956247807076960.

revolution, the government constructed a series of embankments and polders[8] in order to provide tidal flood protection for coastal population; thereby enabling intensification of crop production and agricultural growth. Coastal embankment projects put in place regulators and other structures to control water intake and drainage of polder areas with the primary principle of improving agriculture productivity.

Primarily, the coastal embankment system brought benefits to the people living along low lying areas. The system was designed originally to protect against the highest tides, without much attention to storm surges. Recent cyclones brought substantial damage to the embankments and further threatened the integrity of the coastal polders. In addition to breaching of the embankment due to cyclones, siltation of peripheral rivers surrounding the embankment caused the coastal polders to suffer from water logging, which lead to large scale environmental, social and economic degradation. Poor maintenance and inadequate management of the polders have also contributed to internal drainage congestion and heavy external siltation. As a result, in some areas soil fertility and good agriculture production are declining because of water logging and salinity increase inside polders.

For the long term, it can even be questioned whether the polder concept, as it is practiced now, will last. Water logging in the peripheral rivers is only one side of a morphological phenomenon. The sediment previously entered the area before it was a polder, thus contributing to maintaining the soil level while, currently, the polders are isolated areas deprived of natural sediment supply. Together with the (artificially reinforced), drainage this will lead to subsidence of the soil, which is similar to the polders in the Netherlands that lie below sea level, due to subsidence. The sinking polders in the Netherlands require ever increasing pumping activities. In the much more dynamic GBM delta, this problem will be even worse. Although the subsidence problem might not yet be so manifest after the few decades that they exist, the water logging is a sign that polders, as they are now, are alien entities in the delta.

Salinity is another problem in the polders. Changing relations between river discharges and tides, aggravated by climate change and sea level rise, can make agricultural activities in the area more and more difficult. In some polders, agriculture is gradually replaced by aquaculture. It is not really clear if this has to do with salinity conditions in the rivers around a polder or with the profitability of the activities, regardless of physical conditions.

The objectives of the Coastal Embankment Improvement Project (CEIP-I) are to:

a) Increase the area protected in selected polders from tidal flooding and frequent storm surges, which are expected to worsen due to climate change

b) Improve agricultural production by reducing saline water intrusion in selected polders; and

c) Improve the Government of Bangladesh's capacity to respond promptly and effectively to an eligible crisis or emergency

As part of the strategic polder assessment, a multi criteria analysis was developed to guide the prioritization process of selection of polders. The analysis relies on the following key criteria: physical condition of the embankment and the drainage system, economic activities in the polders (agriculture, fishery or forestry), population and socio economic conditions, environmental condition and economic efficiency considerations. Based on this assessment a first priority group of 17 polders was selected. Among the seventeen, 4 have been considered for the first package of investment (originally 5, see Figure 1).

[8] The Dutch term "polder" is used to designate areas that are enclosed on all sides by dykes or embankments, separating them hydrologically from the main river system and offering protection against tidal floods, salinity intrusion and sedimentation. Polders are equipped by in- and outlets to control the water inside the embanked area.

CEIP-I Component C3

This ToR addresses the C3 Component of CEIP-I: *Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone* (Sustainable Polders adapted to Coastal Dynamics).

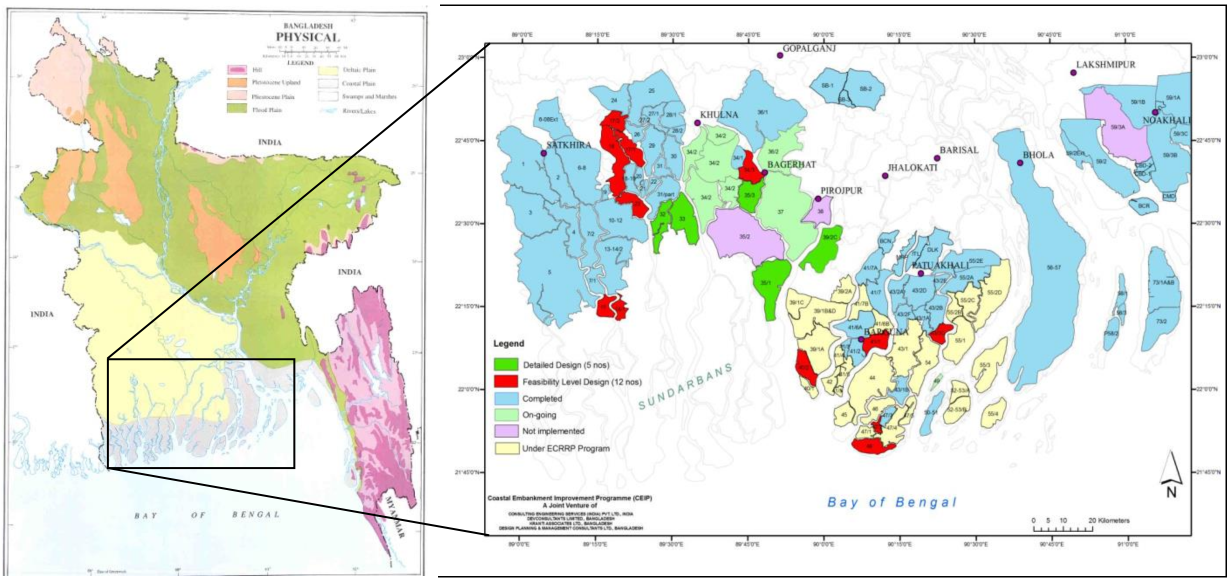

Figure 1: Coastal zone of Bangladesh and polders in CEIP-I project

To improve and manage the polders successfully in the coming decades, it is important to have a clear understanding of the relation between the functioning of polders and the ever changing boundary conditions due to the dynamics of the environment. Annex 1 gives the relation between polders in the coastal zone and the delta dynamics.

On May 5, 2014 a stakeholder consultation workshop was organized in Dhaka, Bangladesh (Annex 2). During this workshop, government officials, researchers and other stakeholders discussed the following issues and questions, in four groups with one issue each:

Issues	Questions
1. (River) floods& storm surges 2.Drought & salinity 3. Erosion & sedimentation (morphology) 4. Compaction & tectonics (subsidence)	1. Where and when are the largest problems with these issues now? How well do we understand these issues? 2. Is there a clear trend and what are the drivers? 3. What will the situation be 25, 50 or 100 years from now?

To answer the last question, the groups were also asked what was needed in terms of:

- Maps (topography, bathymetry, land use, etc.)
- Data collection
- Research
- Capacity building

Based on the outcome of these discussions, the phenomena related to the delta dynamics to be studied were clustered into seven categories, which will be addressed in this ToR.

1. Polder design and management/Land use
2. Morphodynamics of Tidal River & Estuaries
3. Subsidence
4. Meteorology
5. Water levels and salinity
6. Data availability and reliability
7. Capacity building

At first, the focus in the CEIP-C3 component was on the dynamics of the delta to get insight in the changing boundary conditions for polder design, where the design itself focused on embankments and drainage only. During and after the workshop, discussions came up (again) whether Bangladesh should go on like this or that it is time to come with a new approach for the polders in the coastal zone (at that time indicated with the term polder v2.0).

These discussions, including the reasons mentioned in the Background on CEIP-I, have led the Government to re-focus its strategy on the coastal area. The Government has recognized not only the need for a systematic approach to upgrade the coastal embankment system but also wants to come to a sustainable polder concept that is well tuned to the dynamics of the delta.

Objectives of the CEIP-C3 program are:

- Create a framework for polder design, based on understanding of the long term and large scale dynamics of the delta and on sustainable polder concepts. These polders should offer their inhabitants a safe environment to live in and sufficient opportunities for their livelihood. Land use (agriculture, aquaculture, housing etc), ground level, sedimentation balance inside and outside the polder, and salinity in rivers and groundwater are the key parameters in coming to these concepts, taking climate change into account

- Present an overview of values of relevant parameters at locations in the polder area, now and in the future, as boundary conditions for polder design and management

- Develop a long term investment plan for implementation of the proposed design and management improvements

- Build the analytical foundation and technical capacity of BWDB & partners to engage in data driven decision making on tidal flood, storm surges and drought hazards in the coastal region of Bangladesh

The vision is also to expand the analytical capacity and data driven decision making into an “ecosystem” in which professionals cooperate, and exchange knowledge and information in a community of practice, using a common infrastructure, to be housed in BWDB and other organization would have access to data system. Starting with the researchers directly involved in the coastal area and the polders, the future extension will be to bring onboard the whole delta and the Bangladesh water community.

Beside geography and community involved, a third dimension in this movement is quality. With one of the most complicated deltas in the world, understanding and application of this knowledge is of paramount importance. Activities described in this ToR should be carried out in Bangladesh in cooperation with BWDB and related agencies ("training on the job"). Among the deliverables in the ToR, will be workshops and training as elements of capacity building and an explicit indication of future steps for further improvement.

Components

Evidence based decision making to improve coastal region of Bangladesh requires improved monitoring scheme, solid analytical foundation, and up to date technical capacities. The activities envisaged to achieve this goal are structured around the following components:

1. Inception Phase (Polder concepts and coherence in research)
2. Development of input datasets for mathematical models
3. Modeling of the long-term physical processes
4. Completion phase (Polder design and long term management plan)
5. Investment plan for future polder improvements
6. Capacity building and communication of results

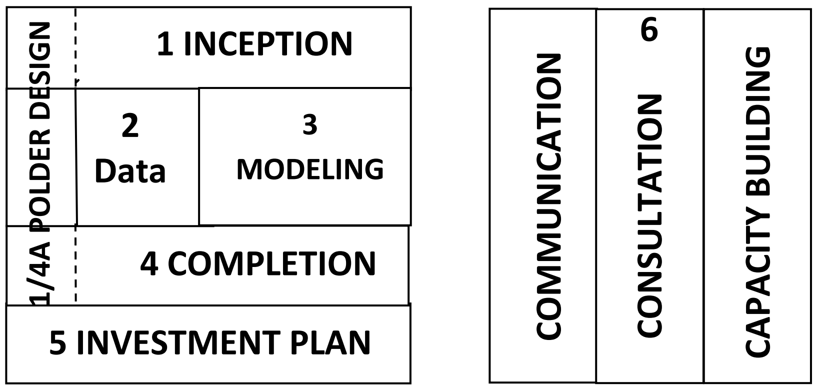

Figure 2: Building blocks of ToR

The Inception phase is, beside fine tuning the activities in the program, about developing new polder concepts, based on available data and what is known of delta dynamics now. In the subsequent phases, this will also focus on developing new knowledge on delta dynamics and use this for elaborating promising polder concepts for the 13 Feasibility Level polders in the CEIP-I project (see Figure 2 in the completion phase).

This ToR requests for expert input required to successfully execute along with the Ministry of Water Resources (MWR) and the Bangladesh Water Development Board (BWDB) the tasks/components mentioned above. All activities described in this ToR are to be carried out in cooperation with MoWR and BWDB to ensure knowledge transfer. In addition, among the deliverables in the ToR will be workshops and training to relevant government officials.

To adapt to local situations and using the available knowledge, a national Research Firm/Institute, experienced and active in Water Modeling in Bangladesh, could be involved in carrying out the services, particularly of the Components 2, 3 & 4 above. National modeling Institute in cooperation with International Research Institute will also support expatriate research in other areas.

Component 1: Inception Phase

The inception phase is meant to review the overall approach of the program and to align strengths and capacities between consultant and MoWR/BWDB to come to a common view on its implementation. The focus is on how to come to the concept of sustainable polders and the coherence between the physical processes in the coastal zone of the delta to be studied in the program.

1A: Sustainable polders

The rationale behind the new polder concepts is that the drainage in the polder, together with the lack of sediment supply, lowers the soil level inside the polder, eventually leading to very low lying polders with increasing problems to drain into the rivers and estuaries, while the sediment that used to cover the land, now settles in these rivers, giving water-logging, making drainage even more difficult. This is further exacerbated by sea level rise and possibly by increased storm surges, river discharges and local extreme rainfall.

The idea to come to sustainable polders in the coastal zone of the GBM delta is not completely new but there are no concrete options until now. In hydraulic engineering, 'Building with nature'[9] is becoming more and more an option, but until now the focus there is predominantly on shore protection. In the Netherlands some ideas exist on 'polders wrapping' where sediment (and salt water) is allowed for some years after which, on the raised bottom, agriculture is carried out again. In fact, the wheel has to be invented here, but necessary elements of knowledge are present around the world.

Sediment management will be an important issue, where both subsidence of the polder soil and water logging in the peripheral rivers is to be avoided, either in a natural or artificial way. "Natural" does not mean without technical means: an intelligent system of gates, to be opened or closed at will, can play an important role to manage the sediment balance. "Artificial" means actively taking up sediment with mechanical (dredging) equipment.

Another issue is how to deal with salinity, either by fighting it as much as possible by means of water management or by embracing it through changing livelihood from agriculture to aquaculture. The idea is to develop concepts that fit well in the dynamic environment, where salt or fresh is not a prerequisite. Rice cultivation, aquaculture, salt tolerant crops are possibilities for livelihood, depending on the salinity situation. In the inception phase it should become clear what options will be taken into account, which will be worked on parallel with the research on delta dynamics.

1B: Coherence

There are complex relationships between all the physical processes and the polders. Hence, the modeling and design work should incorporate the interdependency of the processes of the built and natural environments. Figure-3 visualizes these relations. Meteorology influences polders via local rainfall and water levels via rainfall in the Himalaya and via wind in the coastal area. Of course, climate change is an important element in the meteorological component of the program. Meteorology influences morphology indirectly via water levels and discharges in the rivers, while conversely, morphology influences water levels in the rivers and estuaries. Water levels, storm surges level and salinity are boundary conditions for polder design and management. Subsidence can influence morphology (via tectonics) and, conversely, soil compaction depends on the thickness and composition of sediment layers. Subsidence will influence polder (embankment) levels and, conversely, polder management influences the soil compaction inside the polders. Tidal river morphology can erode polder embankments through meandering channels and can cause water-logging which is again influenced by polder management where sediment is allowed to enter the polder area or not.

[9] For more information on Building with nature, see e.g. www.ecoshape.nl, www.wageningenur.nl

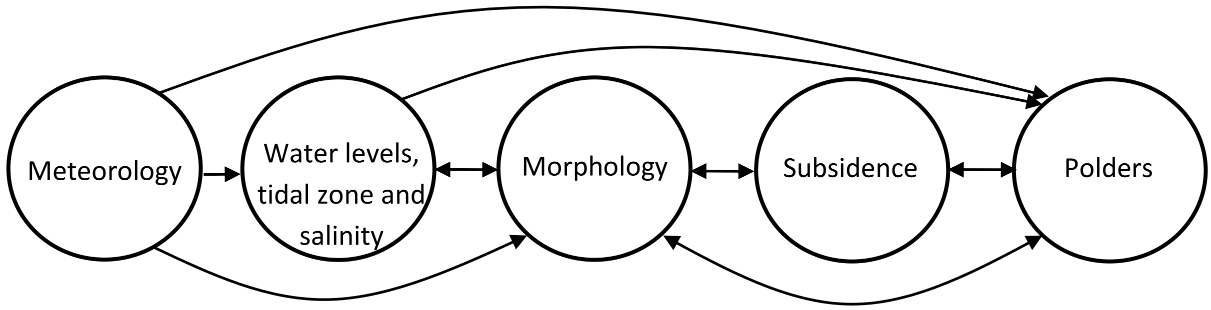

Figure 3 Relations between physical processes and polders

Objectives

- Come with promising options for sustainable polders in terms of dealing with physical factors like sediment and salinity taking into account the socio-economic factors such as the choice between agriculture and aquaculture or combinations in space or time

- Specify the modeling approach taking into account the interdependencies between the physical processes, built and natural environment; asses initial data needs for each approach, specify the required computational framework including mechanism for filling potential data gaps, and set up an overall work plan

Activities

1) ***Inventory present situation***: Description of the polders as they function now and their relation with the environment. The relevant physical, social, economic and environmental characteristics of the polders and the coastal environment will be identified, including upstream hydraulic infrastructure and current polder management and operation. Field visits will be made to the polders and weaknesses in functioning will be inventoried from the responsible (local level) authorities. All previous studies and development plans will be collected and studied. Stakeholders will be identified and consultations will be organized. This inventory will be described, mapped and summarized in e.g. tables, index cards in order to make the findings comparable.

2) ***Range of boundary conditions for polder management*:** Description of tides, salinity and sediment in the waters around polders, including best estimates for possible climate change based on available data and knowledge. Description of seasonal variations of these parameters and the implications for irrigation, drainage, sediment input of polders. This overview will be leading for the data collection in component 2 (Development of input data sets ...)

3) ***Possible polder concepts*:** Brainstorm on possible polder designs with safe and profitable living conditions and feasible with the environmental boundary conditions as derived in activity 2 i.e. salinity conditions varying from fresh water year round to salt water year round and variations in between, possibilities for sediment balance between polder and adjacent rivers year round. Spatial planning in polder areas to locate essential functions such as housing on higher ground above normal high water, where other parts of the polder can be inundated. Derive at least three basic concepts, one for a fresh water area, one for a salt water area and one for alternating conditions, all three with a sediment balance that is in equilibrium with the environment. These concepts are on ‘feasibility level’, meaning that they offer acceptable socio-economic conditions within the physical boundary conditions.

4) ***Modeling approach*:** Based on the problem identification and activities 1) and 2),an overall modelling approach shall be set up, including the review of component 3 of this ToR. It is imperative that the models developed capture the interdependencies among the physical processes, the built and natural environments in the coastal areas. The proposed models should be agreed

upon with the Client and should be flexible in such a way to run with the available data and subsequently be calibrated and verified with additional acquired data at any time interval.

5) ***Data needs and availability*:** An initial scoping of the availability and quality of data required for the agreed analysis approach will be made. This preliminary overview of the data availability will in part form a selection of the analysis approach. At an early stage additional data needs shall be identified, including the review of component 2 of this ToR. The necessary measurements and equipment shall be specified and scheduled for implementation and execution in due course

6) ***Work plan:*** An overall Project Work Plan shall be made, detailing and scheduling the activities for under each component

7) ***Staffing and Collaboration*:** MoWR and BWDB will provide a counterpart team. The nominated staff will be bound to stay in the Project for its duration. The consultant, MoWR and BWDB should decide and agree upon on the terms of collaboration.

   Note: *Lead International Research Institute/Consortium shall be responsible for overall activities of Component -1. National Research Firm/Institute, experienced and active in Water Modelling of rivers and estuaries in Bangladesh, shall carry out the activities (1) Inventory present situation and (2) Range of boundary conditions for polder management and support the Lead Research Institute substantially providing data, map, information and sharing knowledge, past experiences, lessons learned and new and innovative ideas for conducting activities 3, 4 and 5.*

Deliverables

1) Inception Report and Inception Workshop: The findings during the Inception Phase including problem identification, promising polder options, a final scheme of the activities in component 2 for data needs and availability, a final scheme of the activities in component 3 for further research to be included. Staffing, capacity building and work plan to be submitted. The approach and preliminary conclusions will be presented and discussed in stakeholder workshops.

Component 2: Development of input datasets for modeling the physical processes in the coastal zone of Bangladesh

This project will not invest in equipment and in situ data collection on a large scale. However, some specific equipment as needed will be installed and this will be mentioned explicitly in the relevant part of the ToR. Large efforts are being made to improve the availability of measuring equipment through other projects. For example, a World Bank supported Water Management Improvement Project will install 29 new automatic water level recorders of which about one third will be in the coastal zone[10]; a network of groundwater salinity stations has been installed[11] under the Climate Change Resilience Trust Fund; the BWDB has plans for upgrading its existing network.

During the stakeholder consultations in May 2014, limited organizational capacity was mentioned as the main shortcoming, limiting quantity and quality in data collection. However, required data on bathymetry, sediment, water flow, tide, subsidence needs to be collected with available capacity, state-of-art survey technology and equipments. In addition to data collection and processing, there will be a focus on improving organizational capacity and technical capacity to improve quantity and quality of data collection, and on evaluating the results of adding the new data collection stations in other projects.

[10] See Annex 3 for a list with the planned locations of these 29 new automatic water level recorders
[11] Annex 4 shows maps of the nested and line wells installed within the framework of the Climate Change Resilience Trust Fund.

Objectives

- Collect all input datasets, undertake Quality Assurance / Quality Checking (QA/QC) and update/modify datasets as necessary for use in the modeling of the physical processes in the coastal zone of Bangladesh

- Improve the processes of data collection, QA/QC and data dissemination and sharing among the government agencies

Activities

1) *Data collection* for model development, calibration, validation and application, including but not limited to (and to be reviewed during the Inception phase):

   a) Digitized maps (GIS)[12]
      - High resolution DEM for the coastal zone *based on available Topographic maps of IDMS project of SoB,*
      - Soil maps
      - Geological maps based on compaction measurement data
      - Land-use maps, including historical changes in land-use, based on remote sensing and census data

   b) Bathymetry surveys of river branches and estuaries covered by the hydraulic and morphological models. Consultants shall specify the locations of the cross sections, critically validate the results of the survey and the connections with the DEM used in the modeling. The results shall be referenced to the Survey Datum. Data collection on sediment and flow of major river system to assess the annual sediment load to coastal area

   c) Monitoring of cross sections in the selected peripheral rivers of polders to see the sedimentation/ erosion rate for examining the change in drainage conveyance over the years and river dynamics

   d) Details of monitoring networks for rainfall, cyclone intensity, hydrometric, salinity, ground water, sediment concentration, soil, subsidence etc.and their operation history (see also Annex 3, 4 and 5)
   e) Aquifer parameters, pump test data, and well characteristics

   f) Salinity measurement data in surface and ground water

   g) Time series of rainfall data: daily series covering at least the period of 1980-2014 to estimate current conditions and to assess the changes in rainfall patterns, including annual rainfall, monsoon rainfall, and temporal and spatial distributions

   h) Time series of cyclonic data to estimate current conditions and assess the changes in frequency and intensity of cyclones.
   i) Time series of surface and ground water levels, including tidal levels, based on measurements and historical flood marks

   j) Time series of discharges upstream of the coastal zone in the Ganges, the Brahmaputra and the Meghna rivers at least at the borders of Bangladesh, in addition to the Jessore-Chandpur line in relevant rivers inter alia Lower Meghna and Gorai

[12]All spatial data should meet OGC standards http://www.opengeospatial.org/standards. See also *Data Standards, Transfer Media and Licensing* in chapter *Further information about the Consultancy Data Standards, Transfer Media and Licensing*.

k) Relative Mean Sea Level rise estimations, based on the 5th Assessment Report of IPCC and considering the local effects for the Bay of Bengal. Consultant shall put these sea level rise estimations in a local context

l) Estimation of precipitation projections in the coastal area for the climate change scenario of the 5th Assessment Report (RCP2.6,RCP4.5,RCP6 and RCP 8.5)

m) Field measurements of flood plain sedimentation applying Surface Elevation Tables (SETs) along with sedimentation plots and marker horizons to understand elevation changes and compaction rates

n) Sediment concentration in the river branches, estuaries and along the coast, sediment transportation through the delta and sedimentation measurements in the delta and estuaries. If necessary, execute additional field measurements to create additional data for the validation of the morphological models

o) Quantification of sediment load of Ganges, Brahmaputra, Meghna and Padma rivers to the Bay of Bengal

p) Land erosion and accretion using remote sensing or in situ measurements

q) Measure vertical movement due to compaction at statistically relevant and representative points, in addition to already available information, and extrapolate to the polder area in the coastal zone. Install extra equipment if necessary

r) Estimate the vertical movement due to tectonics (neo)in the polder area of the coastal zone based on literature review

s) Measure the annual subsidence rate for the area either by means of installing stationary GPS or by methods that employ Interferometry Synthetic Aperture Radar (In SAR). For identification of historic subsidence trends, the use of In SAR is advised. Compare both methods and choose the appropriate (one or both) in consultation with BWDB taking into account the technical feasibility and cost implications. Elaborate on the costs for the different options and the technical advantages and disadvantages. Install equipment where necessary

t) Land-use data, focusing on agriculture versus aquaculture; historical spatial and temporal distribution of land-use classifications using remote sensing and census data; demands on fresh water for different land-use classifications. Elaborate on the methods to be used

u) Analyze the current procedures of data collection within the Government of Bangladesh (GoB) for all types of data. The consultant will make recommendation to optimize the data collection within the GoB, including but not limited to recommendations on organizational and technical capacity, automating of measurement stations, data collection schemes etc.

2) ***Data processing, validation and completion***

a) Consultant will process and validate all collected data in consultation with the Government counterparts

b) Organize and store data in appropriate format to be used as input to the model

c) Where necessary and possible the consultant will complete and/or digitize data. Consultant shall specify completion procedures

d) Analyze the current data processing and validation procedures within the GoB and recommend data processing and validation improvements, including but not limited to recommendation on organizational and technical capacity (also taking into account the time horizons as used in component 3: 25, 50 and 100 years).

3) *Data dissemination.*

a) Store all the collected primary data including meta-data GIS based Database in BWDB

b) Analyze the procedures of data dissemination within the GoB for all type of data, including mandates for disseminating the data and recommend data dissemination improvements within the water community of Bangladesh,

c) Develop interactive database for archiving, analyzing, updating and retrieval of time series and spatial data including a national coastal polder database and to be housed in BWDB

d) Analytical results, graphs, tables will be shared in GeoNode[13]

Deliverables

1) Map of the location of all the current field measurement stations, by type, stored in Database of BWDB

2) Raw datasets of all type of data, including meta-data, stored in Database of BWDB

3) Completed and validated including meta-data, stored in Database of BWDB

4) GIS based National Coastal Polder Database/Management Information System/Database

5) Boundary conditions and data for calibration and validation of models

6) Monitoring results on sedimentation rate in rivers and floodplain

7) Annual and seasonal sediment load of major rivers and to Bay of Bengal

8) Technical memorandum describing the validation and completion procedures that have been used by the consultant for all type of data; for reproducibility purposes and to be stored in Database of BWDB
9) Memorandum with recommendations to improve the data collection, processing, validation and dissemination within the GoB.

Note: *Lead International Research Institute shall engage an experienced, equipped and skilled national institution in consultation with the Project Director to carry out the all activities under component 2 i.e. (1) Data collection for model development, calibration, validation and application; (2) Data processing, validation and completion; and (3) Data dissemination*

Component 3: Modeling of the long-term physical processes in the coastal zone of Bangladesh

The objective of this component is to develop mathematical models and datasets that describe the long-term physical processes in the coastal zone of Bangladesh, taking into account climate change.
In relation to polder management and design, the following long-term physical processes are important, and will subsequently be discussed in this component:

- Tidal River and Coastal Morphology, on macro, meso and micro scale
- Subsidence

- Meteorology
- The effect of climate change on the tidal zone and salinity intrusion

Component 3A: Morphology

The dynamics of the delta are most visible in the morphology. Coastal accretion (mainly in the lower Meghna area), shifting of river branches and siltation in peripheral branches are some of the phenomena that need more clarification. The overall objective of morphological analysis is to understand the phenomena and quantify of present and future erosion and sedimentation.

The morphology component is divided into three studies on different length scale and with different scope. See also Figure 4 :

A. Macro scale Sediment balance sheet GBM delta

B. Meso scale River and estuary dynamics

C. Micro scale Water logging and polder management

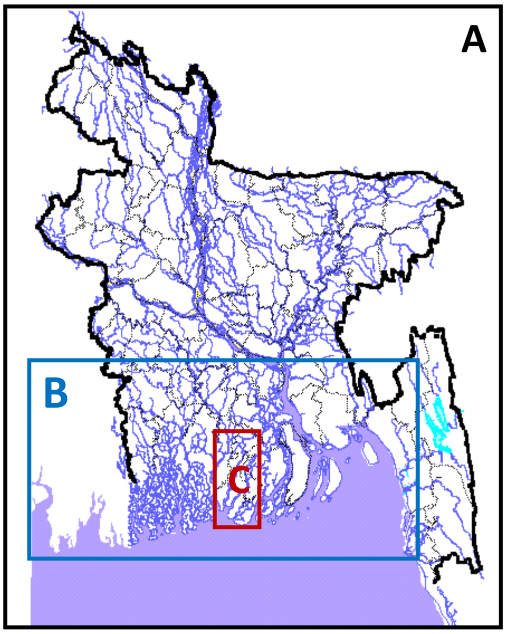

Figure 5 Three scales for morphological research

Component 3A-1: Morphology on a macro scale (Sediment balance sheet GBM delta**)**

Natural influx of sediment from the Himalaya may change in the future due to natural causes (changes in the erosion pattern in the mountains, earthquakes and landslides, etc.) or due to human interference (e.g. construction of dams upstream of Bangladesh). The abundance of sediment input leads to increase of the land area in the coastal zone.
Another issue is the amount of sediment that enters the Bay of Bengal and remains in suspension or is easily mobilized by waves and currents in the area. These sediments can play a role in the so-called tidal pumping phenomenon, in which the sediment in the estuaries is moving to and fro with the tides. Therefore, the amount of sediment should be considered as a boundary condition for erosion and sedimentation on a meso scale.

Finally, sediment will settle in the delta, on floodplains, in river branches, etc. Hence, this study should give the overall picture of the current and future total sediment balance which will serve as the base for all other morphological processes.

Objectives

- Understand sediment dynamics of the GBM delta

- Selection and prioritization of drivers of change and development of future scenarios (example: change in transboundary flow through dams, river linking, land use change, infrastructure development)

- Estimate future changes, using possible scenarios for future(natural and anthropogenic) developments

Activities

1) Use available and proven mathematical model to describe the sediment processes (transport, deposition, re-suspension by river flow, waves and tides, etc.)

2) Calibrate and validate the model with field measurements and remote sensing data.

3) Make a description, using this model, of the sediment processes during a year (monsoon, dry season, wind along the coast, etc.) and give yearly averages

4) Study future changes (up to 25, 50 and 100 years from present), both natural and anthropogenic, such as but not limited to:

   a) expected erosion in Himalaya
   b) tectonic activities causing changes in sediment supply (such as an event like the 1950 landslide), including their probability. This should be done on a 'what if 'level, since tectonics in the Himalayas are outside the scope of this ToR.
   c) sensitivity analysis of the sediment processes to changes in discharges in the upper regions of the river (due to for example the construction of dams in the upstream basin)

Note: *National Research Firm/Institute, experienced and active in Water Modeling in Bangladesh, shall carry out these activities under the guidance and supervision of the lead International Research institute/consortium*

Deliverables

1) The software newly developed under this project with all source code and accompanying technical document with detailed explanation of the methodology and assumptions

2) Geospatial datasets of main sources and deposits of sediment at present, including full meta-data a restored and archived in Database of BWDB

3) Geospatial datasets of main sources and deposits of sediment for 100 years from present, including full meta-data are published on archived in Database of BWDB

4) Peer reviewed paper with description and explanation of geospatial analysis of sediment deposits at present and for 50 and 100 years from present, including a description of seasonal variations, accretion in the Bay of Bengal, tidal pumping (quantity and seasonal variation), used models, indication of more and less likely scenarios, and full metadata. This peer reviewed paper may be combined with the paper for Component 3A_2: *Morphology on a meso scale*

Component 3A-2: Morphology on a meso scale (river and estuary dynamics)

Several processes play a role in the dynamics of the lower reaches of the rivers in the delta. One is the ever changing course of river branches and estuaries due to meandering and other natural changes in morphology. Another issue is the influence of polders on the hydrodynamics of the region and its consequences for sediment transport. In general, with polders the sediment coming from upstream will be transported more directly to the sea, while in areas without polders (e.g. the Sundarbans) the sediment will remain (longer or permanently) in the area. With the help of measurements and model computations, more knowledge on the dynamics of the complicated network of SW-Bangladesh (including the coastline) should lead to a better insight in future developments in the area.

Objectives

- Understanding the dynamics of the river branches and estuaries in the coastal zone of the GBM delta, channel switching and bank erosion both in the fluvial—dominated parts of the delta as well as in the tidally—influenced river delta (i.e. Sundarbans)

- Estimate future changes, predicting erosion and sedimentation in the area

Activities

1) Use available and proven mathematical model to describe the relevant morphological processes in three dimensions, including river flow, tidal flow and wave action

2) Calibrate and validate the model with field measurements and remote sensing data

3) Assess the effects of past interventions such as polderization in the coastal area on tidal prism, amplitude, morphological conditions using numerical modeling technology

4) Quantify river, tide and storm surge flooding and associated sedimentation rates in the natural and human-impacted coastal zone

5) Improve estuarine modeling to assess the impact of polders on estuarine flow, sediment budgets and morpho-dynamics and the future impact of sea level rise

6) Study future changes in the morphological processes based on possible scenarios coming from the macro scale approach such as (but not limited to) possible dam construction, probable natural changes etc

7) Interpret these changes in terms of drainage and irrigation in polders, and erosion of embankments.

   Note: *National Research Firm/Institute, experienced and active in Water Modeling in Bangladesh, shall carry out these activities under the guidance and supervision of the lead research institute/consortium*

Deliverables

1) The available model will be further upgraded &updated under this project and accompanying technical document with detailed explanation of the methodology and assumptions

2) Geospatial datasets of erosion and sedimentation in the coastal zone at present for various seasons and circumstances if relevant (average river flow, extreme discharge, average tide, extreme spring

tide, storm surges and cyclone). These geospatial datasets should include full meta-data and be stored and archived in Data base of BWDB.

3) Geospatial datasets of erosion and sedimentation in the coastal zone for possible scenarios 25, 50 and 100 years from now, for various seasons and circumstances if relevant (average river flow, extreme discharge, average tide, extreme spring tide, storm surges, cyclone). These geospatial datasets should include full meta-data and be stored and archived in Data base of BWDB.

4) Peer reviewed paper with description and explanation of geospatial analysis of erosion and sedimentation in the coastal zone at present and for 25, 50 &100 years from present, including description of relevant seasonal variations, used models, indication of more and less likely scenarios, and full metadata. The Research Team will indicate what the consequences of future scenarios are for drainage and irrigation in the polders, and for erosion of the embankments. This peer reviewed paper may be combined with the paper for Component 2A_1: *Morphology on a macro scale*

Component 3A-3: Morphology on a micro scale (water-logging and polder management)

Before polders were constructed, the tides inundated large areas in the coastal zone. This had two effects: sedimentation on the land (up to a level of approximately HW) while the flow velocity in the adjacent river branches remained high due to the deep penetration of tides. After the construction of polder embankments, the flow in the river branches diminished (before embanking, the whole area was filled and emptied through the river branches, while after embankment this happens only in the river area itself, giving a much smaller tidal flow), leading to sedimentation in these branches. Of course, sedimentation in the polder areas stopped completely and the sediment now settles in the adjacent peripheral river branches. Water drains from the polder into the rivers and estuaries through sluice gates under the influence of gravity. The sedimentation in the branches hampers the free flow of water from the polders into the estuaries. This phenomenon is called water-logging.

Over the past 15 years, experiments have shown the possibility to reduce water-logging by creating openings in the low lying areas of the polders (“beels”) that allow tidal flow to occur (Tidal River Management-TRM). The idea is to extend this approach to the polders as a whole. In the Inception phase and in component 4 of this ToR, possibilities to allow sedimentation in the polder areas will be studied. This component 3A-3 is the direct link between polder management and morphology in the river branches.

Objectives

- Understand the dynamics of water-logging in the polder and tidal river system and develop measures to reduce water-logging in combination with restoring natural sedimentation processes within polder area sand adjacent tidal rivers.

Activities

1) Provide analysis and an overview of existing methods and experiences that reduce water-logging (e.g. TRM) in the coastal zone of Bangladesh

2) Use available and proven mathematical model to study tidal flow and sedimentation/erosion in peripheral river branches, "beels" and polder areas, including deposition of silt. Area C shown in Figure 45 is only indicative of the scale of geographical coverage of the area that is expected to be looked at for this component. The model should contain at least one river branch together with some (polder) areas that can be inundated. This model is to be used in the Completion phase for the conceptual design of polders. The final decision of the study area will be made in consultation with BWDB

3) Recommend techniques to reduce water-logging and polder subsidence, including possibilities to use seasonal fluctuations in sediment content and land-use in polders based on findings and use of the mathematical model.

Deliverables

1) The model setup developed will be updated under this project with all accompanying technical document with detailed explanation of the methodology and assumptions

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

   Note*: National Research Firm/Institute, experienced and active in Water Modeling in Bangladesh, shall carry out these activities under the guidance and supervision of the Lead International Research Institute/consortium*

Component 3B: Subsidence

The land level with regard to the sea level is an important parameter in the design and management of polders. This parameter determines, to a certain extent, the height of embankments, drainage conditions, sustainability of sluice gates, etc.

Figure 6 shows the key elements of the phenomena behind this parameter. Subsidence is the total movement downwards of the soil level and consists of two components: compaction of the upper sediment layers (Holocene and Pleistocene deposits of river sediment) and tectonic movements[13] (caused mainly by movements of the Indian plate and the Burma arc). Compaction can have natural (gravity, organic) or anthropogenic causes (groundwater extraction, drainage). Sea level rise is due to temperature changes causing melting of glaciers and expansion of the ocean volume.

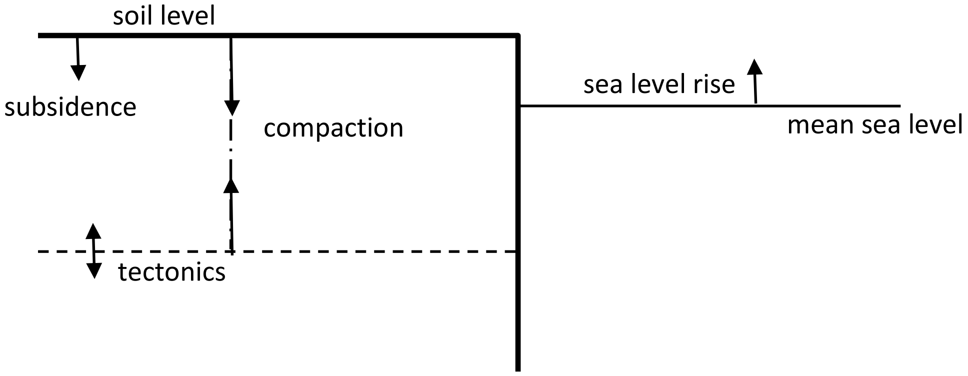

Figure 6: Key elements of subsidence

Measuring and determining absolute values for these parameters is often difficult. Sea level rise derived from very long term water level recordings always contains the subsidence of the soil on which the gauge is founded. Subsidence derived from GPS devices on buildings (as is the case in Bangladesh) contains the settlement of the building in the subsoil. Figures on SLR and subsidence, therefore, are often relative, while absolute figures are necessary in understanding the processes.

[13] Tectonic movements can of course also cause uplifting.

In the research as covered by this ToR, sea level rise will not be studied separately. The 5th Assessment Report of IPCC contains information on (absolute) SLR in the Bay of Bengal. The results of IPCC 5 will be used in downscaling and considering local effect & regional circulation in this project as the estimate for the sea level rise due to climate change.

Objectives

- Estimate the annual rate of subsidence of the polder area in the coastal zone for three regions: southwest zone, south central zone and south east zone

- Estimate the annual rate of subsidence of specific polders, due to drainage or other anthropogenic causes and its effect on the defense structures

Activities

1) Literature survey on subsidence in the polder area of the coastal zone, more specific on the (neo)tectonics and compaction

2) Make an inventory of natural and anthropogenic causes of compaction, estimate the rate of compaction due to these causes and indicate their contribution to the total subsidence in the regions of the polder area of the coastal zone at present and for over 25, 50 and 100 years

3) Use a subsidence model to estimate the subsidence in specific polders (to be designated by BWDB) at present and for 25, 50 and 100 years from now. The Research Team shall collect &use subsidence and compaction data to validate the subsidence model. Information on soil type, drainage practice, natural and anthropogenic causes of compactions can be used as input parameters for the model

Deliverables

1) 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

2) Technical memorandum with description and explanation of geospatial analysis of the total subsidence in the three 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 (natural/anthropogenic compaction, tectonic movement), full metadata, and stored in Database of BWDB

3) Report on the total subsidence in representative polders (designated by BWDB) in 25, 50 and100 years from now when no sediment is supplied to the polder, including the amount of sediment needed to counteract this subsidence. This report should be combined with the report for Component 3: *Polder management and design*

Component 3C: Meteorology

During the stakeholder consultations it was repeatedly mentioned that rainfall figures are changing, such as more "erratic" rainfall and a possible shift from four to three seasons (monsoon and post monsoon are more or less one). At this moment, there is no real drought problem in the coastal area but due to changing rainfall figures, this could change when periods without rain lengthen. Statistical processing of data can shed light on these processes. For the future, expectations could be derived based on climate models and scenarios. The same can be done for rainfall figures in the Himalaya (important for river floods in the coastal zone), and for cyclone frequency and intensity.

Objectives

- Identify current trends in rainfall and temperature, in Bangladesh and the catchment area of the rivers, and in cyclone frequency and intensity
- Estimate future changes in rainfall and cyclone frequency and intensity

Activities

1) Assess the changes in rainfall patterns, including annual rainfall, monsoon rainfall, and temporal and spatial distributions in the polder area of the coastal zone, based on historical data

2) Assess the changes in frequency and intensity of cyclones based on historical data

3) Compute future scenarios for rainfall and cyclone frequency and intensity for the next 10, 50 and 100 years by downscaling global climate models

   Note: *National Research Firm/Institute, experienced and active in Water Modeling in Bangladesh, shall carry out these activities in consultation with the lead research institute/consortium*

Deliverables

1) Report describing current trends and future scenarios in rainfall in the polder area (including estimation of rainfall distribution over the year) and cyclone frequency and intensity for the next 10, 50 and 100 years from now, including meta-data of the datasets used for the trend analyses and stored and archived in Database of BWDB. The Research Team shall include a description of the statistical and downscaling methods used for reproducibility reasons.

Component 3D: The effect of climate change on water levels, salinity intrusion and storm surges

Under a changing climate, droughts and fresh water availability can become problematic. Fresh water availability in a delta depends largely on the salinity intrusion from salt water. Sea level rise and river discharges will influence both the extent of the tidal zone and salt intrusion (in surface water as well as in ground water). When tidal water levels increase, due to sea level rise, the tidal zone will shift land inwards and the salinity intrusion will increase. Higher river discharges have a counter effect; they push the tidal zone and the salinity intrusion seawards. Salinity intrusion will have major impacts on the freshwater ecosystem, irrigation and drinking water availability. Higher storm surges will lead to a larger wave run-up at the embankments of the polders, possibly causing overtopping or breaches, which will lead to major salinization of the flooded polders. Higher storm surges may also damage the polder infrastructure and can cause morphological changes in the river.

Sea level rise and changes in discharge levels will also influence the tidal water levels in the delta. Higher tidal water levels mean less opportunity to drain water from the polders to the rivers and estuaries through sluice gates under gravity. The higher tidal water levels combined with a larger wave run-up at the embankment, caused by an increase in storm surge, will lead to higher design levels for the embankments. The objective of CEIP-I is to increase the area protected in selected polders from tidal flooding and frequent storm surges, under a changing climate. Therefore, it is important to quantify the change in water levels due to climate change.

Objectives

- To have an overview of extreme water levels due to storm surges and cyclones
- To have an overview of tidal water levels and salinity in the river, estuary and groundwater system in the coastal zone at present and in the future

- To devise scenarios and strategies to optimize salinity levels in the coastal zone

Activities

1) Estimate changes in storm surges and discharge levels using the future scenarios on rainfall in the catchment area and cyclone frequency and intensity (coming from component 3C, Meteorology) as input for computational models

2) Compile available measurements and model results on tides and water levels, including monsoonal variations, extreme high water due to river discharges and storm surges/cyclones at present and for 25, 50 and 100 years from now. The Research Team will use the changes in storm surges and river discharges, as well as estimations for sea level rise, as input for their hydraulic models

3) Compile available measurements and model results on salinity in the river and estuary system and in the groundwater system of the coastal zone at present and for 25, 50 and 100 years from now. The Research Team will use the changes in storm surges, river discharges and local rainfall, as well as estimations for sea level rise, as input for their salinity models

4) Develop reasonable alternatives of redistribution of river water in the delta (more water from the Ganges or Brahmaputra to river branches in the South West) and determine the effect on salinity in the river system, applying the available tested numerical models.

   Note: *National Research Firm/Institute, experienced and active in Water Modeling in Bangladesh, shall carry out these activities in consultation with the Lead International Research Institute/consortium*

Deliverables

1) 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 50 and 100 years from now, including full metadata and stored and archived in Database of BWDB
2) 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

3) 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

4) Exceedance frequency curves for water levels in the same 20 stations at present, and at 50 and 100 years from now

5) 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 consultant will also discuss the effect of at least two relevant options of redistribution of river water in the South West delta on salt intrusion.

Component 4: Completion phase

4A: Polder design

The purpose of this Component is to refine concepts for polder design and management to see in which of the remaining polders in the CEIP-I project these concepts could be applied. Based on the boundary conditions around the polders, that were derived in component 3, the promising polder options from the Inception Phase are translated into conceptual polder designs. 'Conceptual' means up to the level of spatial planning inside the polder and seasonal management of gates (where 'Detailed design' means ready for tendering and implementation). After the Inception phase, the work on elaborating the polder concepts will be continued parallel to the research on the delta dynamics.

Objectives

- Design the recommended polder improvement measures and develop long term management plans for the 13 remaining polders in the CEIP-I project, with due consideration to; opportunities for livelihood, spatial planning, water management and operation, subsidence, raising of low lying area and future climate change scenarios.

Activities

1) Make an inventory of the present situation in 139 polders in general and details of 17 polders under CEIP-I with regards to; land use, population, economic activities, social organization, infrastructure, functioning of flood protection and water management system
2) List the boundary conditions for each polder, based on available data and outcomes of the research of component 3A to D, including influence of climate change

3) Make a match between the promising polder options from the Inception phase and the outcomes of activity 1 and 2. Where necessary, the work on the polder concepts of the Inception phase is extended to come to realistic options

4) Establish design for 3 to 5 polders as pilot program considering 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.

5) Make a cost estimate for the redesign of the polders and estimate the benefits and beneficiaries in the new situation

Deliverables

1) Overall report on the design process as a whole and summary of results for 3-5 selected polders

2) Report for each of the 3-5 polders with a description of;

   - Present situation
   - Boundary conditions
   - Matching with polder options
   - Establish design, including management plan
   - Costs and benefits

4B: Coherence and overall picture delta

One of the main objectives of the C3 program is to create a framework for polder design, or as the subtitle of the program says: sustainable polders adapted to the coastal dynamics. Therefore, to complete the picture, an overview of the delta dynamics in the future is useful, also to see where future investments can be most favorable in terms of economical, physical and societal aspects. Besides that, after having done all the studies in component 3 and the overview of data as obtained in component 2, it is good to see where the interdependencies lie and where future research would be most useful. Basis for these interdependencies is shown in Figure 3.

Objectives

- Obtain an overall picture of the delta dynamics in the future

- Obtain a picture of (the need for) possible large scale interference in the coastal zone of the delta to reach optimal living conditions

- Quantify the mutual effects of physical processes and obtain an indication where more research is wanted

Activities

1) Describe the interdependencies and mutual effects in detail, also based on the outcome of the studies in component 3

2) Quantify these for the future (the same 25, 50 and 100 year horizons to be used but more as a framework than as exact figure) and indicate possible consequences for the boundary conditions for the polders (water levels, salinity, erosion and sedimentation patterns, subsidence, etc.)

3) Based on the results of activity 2, component 4A (polder design) and the possibilities to influence the salinity situation in the delta (activity in component 3D), investigate the need or desirability of large scale changes in the coastal zone (river diversions, damming river mouths, etc.).

Deliverables

1) Report describing the
   - interdependencies and relations between the processes and parameters
   - the consequences for the boundary conditions
   - recommendations for further research (white spots, inexplicable phenomena)
   - potential large scale interventions

Component 5: Investment plans for future polder improvement

Based on the data gathered and analyzed in component 2, the modeling completed in Component 3, and the polder improvement design and management plan developed in Component 4A, the Research Team, in consultation with the client, will prioritize and define an investment plan to improve the resilience of the communities living in Bangladesh’s 139 polders to hydro-meteorological events. This will be completed in two phases. The first phase will assess the elaboration of the design of the final 13 polders under CEIP, and a second phase will define the investment plan for the remaining 122 polders (139-13-4). Once the investment plan is designed, the Research Team will work with the Government of Bangladesh to define a fundraising rationale for the international community to raise the grant resources necessary to enable the Government to finance a revamping of the coastal protection system that is necessary.

Objectives

- Develop a programmatic investment plan to sustainably improve the resilience of communities in 139 polders

Activities

1) Develop a macro-level multi-phased investment plan for the construction of the selected polder improvement measures based on priorities agreed with the client

2) Develop an investment plan for long term management of the polders and the their effective operation

3) Develop a plan for fundraising and technical collaboration with the international community

Deliverables

1) An investment plan describing a phased polder improvement roadmap and required budget

2) An investment plan for long term management of the polders, including the expansion of monitoring systems, and the required maintenance and operations cost

3) An execution plan including financing and fundraising strategies and plans; and technical collaboration plan

Component 6: Communication, consultation and capacity building

6A: Communication

Objectives

The objective of this task is to ensure that all analysis and results of the study, the data collected and generated, cost-benefit analysis are able to be updated, interactively communicated and understood by a wide range of stakeholders

Activities

1) Upload and store all collected and generated data in the Database of BWDB,
2) Share all analysis and results from this study with all stakeholders
3) Communicate the results of the project and benefit-cost analysis through a series of stakeholder workshops. This should include production of dissemination material such as brochures with results and illustrative material that will inform various stakeholders

Deliverables

1) All datasets will stored in Database of BWDB for use in a variety of ministries, with illustrative material

2) Communication materials such as brochures, animations etc. that will help communicate the proposed improvements

6B: Consultation

Objective

To ensure that the client and stakeholders participate and are well informed of the developments and results of the project

Activities

Organize the following workshops with selected group and plenary session:

1) At the beginning of the Inception Phase to discuss the polder problems and identify and assess the current condition

2) Upon finalizing the Inception Phase: to discuss the initial findings and proposed basin approaches

3) At the end of data collection phase: to discuss extent of existing data, identify gaps and propose improvement methods

4) At the end of the modelling phase: to discuss the findings of the analyses and its implications

5) At the end of development of design and implementation phase: to discuss the effectiveness of the selected interventions and their social, environmental and economic implications

6) At the end of the development of investment plan phase: to select the most promising alternative and discuss risk reduction investment strategy

Consultants shall actively participate in the workshops, in their development, in the discussions and in drafting the conclusions.

Deliverables

1) Report at each stage of the consultation including the summary of the discussions, list of participants and the conclusion reached

6C: Capacity Building

Objective

To build the capacity of the BWDB and related agencies/institute responsible for designing and managing the built as well as the natural environment in coastal Bangladesh and strengthen the university level curriculum in water resources/coastal engineering and management.

Activities

1) Provide on the job training to technical and relevant government counterparts on a regular basis and conduct a number of specialized training courses. The training on the job will include but not limited to;

    a) Feasibility study of alternative plans including mutli- criteria analysis
    b) Quality assurance / quality checking of data
    c) Statistical analysis of trends in data
    d) Development and calibration of models
    e) Design of polder improvements and the development of management plans
    f) Development of investment plans and financing strategies
    g) Provide overseas training mainly of BWDB Engineers on coastal hydraulics, morphology, salinity intrusion, storm surges modeling under changing climate.
    h) Sharing Experiences of BWDB Engineers and policy makers through overseas seminars and workshop.

2) In collaboration with BUET and Dhaka University, strengthen the curriculum in water resources/coastal engineering and management to develop a solid scientific cadre in Bangladesh

Deliverables

1) On the job technical training plan for each of the sections described

2) Report detailing the results of the on job training, list of participants and measure of success

3) The Research Team shall organize a 3-day International workshop on understanding the dynamical processes in the coastal zone of Bangladesh, including morphology, subsidence, meteorological changes due to climate change, salinity intrusion, water levels, and the effect on polder management and design

3) The Research Team shall provide training on the job for the technical and scientific counterpart staff on a regular basis, by carrying out the activities in the ToR in Bangladesh in cooperation with the counterpart staff or by giving specialized trainings. The training on the job will include – at minimum – the quality assurance / quality checking of data, the statistical analysis of trends in data, the development and calibration of new models, and the use of new techniques and analyses

4) Teach the teacher: students at universities are the future members of the Bangladeshi water community. New and advanced techniques used in the execution of this ToR should be taught at universities. Develop new curriculum materials in cooperation with BUET and Dhaka University

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