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)

D-7: Investment Plan and Fund Raising

June 2022

DHI | Deltares Enabling Delta Life | IWM Water Environment & Climate | CU | Columbia University

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)

D-7: Investment Plan and Fund Raising

June 2022

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

Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone

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

Memo No: CEIP/LTMRA/0722/191 26 July 2022

Project Management Unit
Coastal Embankment Improvement Project, Phase-I (CEIP-I)
Pani Bhaban, Level-10
72, Green Road, Dhaka-1205

Attn: Mr. Syed Hasan Imam, Project Director

Dear Mr Imam,

Subject: Submission of D-7: Investment Plan and Fund Raising

It is our pleasure to submit herewith five copies of the Report ***"D-7: Investment Plan and Fund Raising"***.

This report has a focus on the physical interventions that are required for the different polders and the costs for the necessary investments. Based on the data and model results from the different Components, an investment has been prepared to improve the resilience of the communities living in Bangladesh's 139 polders to hydro-meteorological events.

The report will present the investments for the polders in Bangladesh that have not been included in the CEIP I or CEIP II investment program. The investments are proposed based on the risk profiles that are developed for each of the polders and the insights that have been gained from the more detailed assessment for the 5 pilot polders as described in the deliverable 5A-3; Conceptual Design of 5 Polders (2022).

The report includes 5 chapter and 3 annexes.

Thanking you,

Yours sincerely,

Dr Ranjit Galappatti
Team Leader

Copies: Engineer Fazlur Rashid, Director General, BWDB
Dr. Zia Uddin Baig, ADG (Planning), BWDB
Dr Kim Wium Olesen, Project Manager, DHI
Ms. Sonja Pans, Deltares Project Manager
Mr Zahirul Haque Khan, Deputy Team Leader
Mr AKM Bodruddoza, Procurement Specialist
Swarna Kazi, Sr. Disaster Risk Management Specialist, World Bank

Joint Venture of DHI and Deltares in partnership with
IWM, University of Colorado, Boulder and Columbia University

Contents

1 Introduction 1
1.1 Scope of work 1
1.2 Identification of interventions 1
1.3 Approach 3
1.4 Setup of the report 4

2 Proposed interventions 5
2.1 Embankments 5
2.2 Drainage system rehabilitation 7
2.3 Cyclone shelters 7
2.4 Land reclamation 7
2.5 Drinking water 9
2.6 Benefits from interventions 9
2.6.1 Embankments 9
2.6.2 Khals and drainage structures 10
2.6.3 Cyclone shelters 10

3 Risk Analysis and investments per zone 12
3.1 Western Zone 12
3.1.1 Risk analysis 12
3.1.2 Proposed investments 14
3.2 Southern Zone 14
3.2.1 Risk analysis 15
3.2.2 Proposed investments 17
3.3 Eastern Zone 19
3.3.1 Risk analysis 19
3.3.2 Proposed investments 21
3.4 South-Eastern Zone 21
3.4.1 Risk analysis 22
3.4.2 Proposed investments 24

4 Economic evaluation per zone 25
4.1 Basic principles in the Cost Benefit Analysis 25
4.2 Western Zone 25
4.3 Southern zone 26
4.4 Eastern zone 27
4.5 South-Eastern zone 28

5 Way forward; Planning and funding 29
5.1 Combined investment budget 29

5.2 Key development directions for the polders 29
5.3 Funding 30
5.3.1 National Budget 31
5.3.2 Bangladesh Delta Plan 31
5.3.3 International donors 32
5.3.4 Climate finance 33

References 35

Annex A: Principle design sketches dike improvement Bangladesh 37

Annex B: Risk Calculations; assumptions and damage functions 47

Annex C: Factsheet per polder 48

TABLES

Table 1-1 Key characteristics of the 5 selected polders 2
Table 2-1 Cost of typical embankment designs for polders in Bangladesh 6
Table 2-2 Type of embankment proposed as function of location and loading category 6
Table 2-3 Cost for excavation of Khal and rehabilitation/reconstruction of drainage structures 7
Table 2-4 : Estimated potential accretion as result of cross dams 8
Table 2-5 : Estimated number of RO plants to provide the zones with drinking water 9
Table 2-6 Coverage in Cyclone Shelter to evacuation fraction 10
Table 3-1 Polders belonging to the western zone of Bangladesh 12
Table 3-2 Proposed interventions for the western zone 14
Table 3-3 Investment budget for risk reduction in the western zone 14
Table 3-4 Polders belonging to the southern zone of Bangladesh 15
Table 3-5 Proposed interventions for the southern zone 18
Table 3-6 Investment budget for risk reduction in the southern zone 18
Table 3-7 Polders belonging to the eastern zone of Bangladesh 19
Table 3-8 Proposed interventions for the southern zone 21
Table 3-9 Investment budget for risk reduction in the southern zone 21
Table 3-10 Polders belonging to the south-eastern zone of Bangladesh 21
Table 3-11 Proposed interventions for the southern zone 24
Table 3-12 Investment budget for risk reduction in the southern zone 24
Table 4-1 Economic evaluation of the western zone and its polders 26
Table 4-2 Economic evaluation of the southern zone and its polders 27
Table 4-3 Economic evaluation of the eastern zone and its polders 28
Table 4-4 Economic evaluation of the south-eastern zone and its polders 28
Table 5-1 Combined investments for all polders in Bangladesh 29
Table 5-2 Economic evaluation of the investments in all polders in Bangladesh 29
Table 5-3 Portfolio of coastal projects in the Bangladesh Delta Plan 2100 32
Table 5-4 Main climate change adaptation funds 33
Table 5-5 Typical values for relevance of public expenditures .... **Error! Bookmark not defined.**

FIGURES

Figure 1-1 Map with the 4 main zones and locations of the 5 study polders 2
Figure 1-2 General methodology for identification of investments for polders in Bangladesh 3
Figure 2-1 Conceptual designs for embankments for polders in Bangladesh........ 5
Figure 2-2: Locations of the cross dams in the Meghna estuary as proposed by the MES study........ 8
Figure 3-1: Risk profiles for annual damages for the polders belonging to the western zone of Bangladesh (MUSD) 13
Figure 3-2: Risk profiles for annual mortality for the polders belonging to the western zone of Bangladesh.. 13
Figure 3-3: Risk profiles for annual damages for the polders belonging to the southern zone of Bangladesh (in USD Million) 16
Figure 3-4: Risk profiles for annual mortality for the polders belonging to the southern zone of Bangladesh. 16
Figure 3-5: Risk profiles for annual damages and mortality for the polders 56/57 (Bhola) 17
Figure 3-6: Risk profiles for annual damages for the polders belonging to the eastern zone of Bangladesh (USD million) 20
Figure 3-7: Risk profiles for annual mortality for the polders belonging to the eastern zone of Bangladesh... 20
Figure 3-8: Risk profiles for annual damages for the polders belonging to the south-eastern zone of Bangladesh (USD million) 23
Figure 3-9: Risk profiles for annual mortality for the polders belonging to the south-eastern zone of Bangladesh 23

ACRONYMS AND ABBREVIATIONS

BDP2100- Bangladesh Delta Plan 2100

BDT- Bangladesh Taka

BWDB- Bangladesh Water Development Board

CBA- Coast Benefit Analysis

CC- Concrete Cement

CEGIS- Centre for Environmental and Geographic Information Services

CEIP- Coastal Embankment Improvement Project

CEP- Coastal Embankment Project

DEM- Digital Elevation Model

EIA- Environmental Impact Assessment

FIAT – Flood Impact Assessment Tool

GBM- Ganges Brahmaputra Meghna

GIS- Geographical Information System

IGDCZ- Interactive Geo Database of the Coastal Zone

IPCC- Intergovernmental Panel for Climate Change

IPSWAM- Integrated Planning for Sustainable Water Management

IWM- Institute of Water Modelling

LGED- Local Government Engineering Department

MoWR- Ministry of Water Resources

MSL- Mean Sea Level

ppt- parts per thousand

PV- Present Value

PWD- Public Works Datum

RCP- Representative Concentration Pathways

SFINCS- Super Fast Inundation of Coasts

SLR- Sea Level Rise

SWRM- South West Region Model

TRM- Tidal River Management

ToR- Terms of Reference

USD- United States Dollar

VoSL- Value of a Statistical Life

WL - Water Level

WMA- Water Management Association

WMG- Water Management Group

1 Introduction

1.1 Scope of work

The project ‘Long term monitoring, research and analysis of Bangladesh Zone’ focusses on ’research, monitoring, and analyses of Bangladesh coastal zone towards long term sustainable polder development and management with attention to geo-morphological, environmental, economic and ecological aspects’. As part of this project a large amount of data has been collected and specific studies have been carried out at various time and spatial scales on the impact of climate change and human interventions on salt intrusion, morphological changes, bank erosion, and polder drainage. Based on the understanding of the long term and large scale dynamics of the delta and research into sustainable polder concepts a polder management plan was developed, describing future interventions for the polders so that these polders should provide their inhabitants a safe environment to live in and sufficient opportunities for their livelihoods.

Based on these data and model results from the different Components, the Project has prepared an investment plan to improve the resilience of the communities living in Bangladesh’s 139 polders to hydro-meteorological events. In order to do so, measures and strategies have been defined and evaluated in an economic cost-benefit analysis (CBA) in order to assess the economic rationale of the proposed interventions.

The proposed measures are an outcome of the assessment process that has been done in the Polder Development Plan (Deliverable 5A-3) that outlines the type of interventions that are considered for the polders that are located in the 4 identified coastal zones; West, South, East and South-East.

The selection of the interventions for the polders was done in a stepwise approach. In the first step 5 pilot polders were selected that were used to develop a conceptual design for future polder development. These 5 polders are considered to be representative for the polders in the identified zones of coastal Bangladesh. In the distinction between the polders consideration is given to different aspects for long term sustainability of the polders; climate change, subsidence, elevation of the polder, land use, economic activities, infrastructure needed for water management and water management policy, drinking water facilities (especially in region with current or future increase in salinisation).

This report has a focus on the physical interventions that are required for the different polders and the costs for the necessary investments. Institutional requirements for safeguarding adequate participation by stakeholders from the polder in the planning and design process, or institutional water management issues, are not considered in this report. However, these issues are essential for the long-term sustainability of the polder and should get adequate attention when investments will be taken forward. More information on polder management can be found in the reports of Components 6.2 and 6.3; Polder Management Plan.

The objective of this report is to develop an economically viable investment plan including the economic evaluation of the proposed interventions. A preliminary prioritisation based on the costs, benefits and the recommendations from the Polder Development Plan.

1.2 Identification of interventions

In the identification of the interventions for the polders a methodology was followed that made use of the lessons learned from the interventions proposed for 5 pilot polders and the lessons learned from the implementation from the CEIP I project. This process is described in more detail in the Deliverable 5A-1.

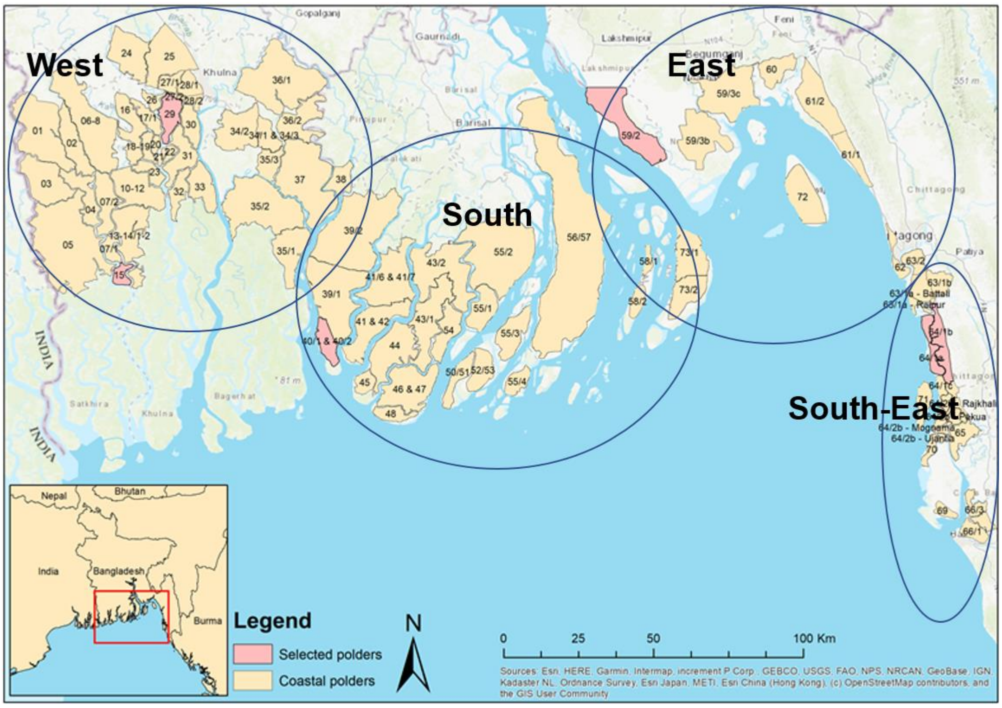


Figure 1-1 Map with the 4 main zones and locations of the 5 study polders

Table 1-1 Key characteristics of the 4 zones

Coastal Region	Key Characteristics
Western region	➢ Very little freshwater flow from upstream river (Ganges) ➢ Influenced by strong tidal action, salinity problem is acute. ➢ Peripheral river sedimentation is a major problem; which creates drainage problems. People inside coastal polder experiencing prolonged water logging. ➢ River bank erosion problem. ➢ Vulnerable to cyclonic storm surges.
Southern region	➢ Polder embankment is facing river erosion problem. ➢ Vulnerable to cyclonic storm surges. ➢ Large mangove forest present
East region	➢ Morphologically active place: land accretion and erosion ➢ Severe river erosion due to thalweg migration. ➢ Vulnerable to cyclonic storm surges. ➢ Some area subjected to prolonged waterlogging due to encroachment and land reclamation by closing of tidal creeks.
South-Eastern region	➢ Vulnerable to cyclonic storm surge. ➢ Prone to flash flood due to steep gradient of river and intense rainfall. ➢ Erosion around Sangu River

1.3 Approach

This report will present the investments for the polders in Bangladesh that have not been included in the CEIP I or CEIP II investment program. The investments are proposed based on the risk profiles that are developed for each of the polders and the insights that have been gained from the more detailed assessment for the 5 pilot polders as described in the deliverable 5A-3; Conceptual Design of 5 Polders (2022). The lessons learned in the formulation of the investment plan for the 5 polders in the current report will form the basis to develop a more general approach that will be used in the formulation of the investment plan for the polders for which only basic data are available. The general methodology for the identifi8cation of the investments for the polders is showed in Figure 1-2.

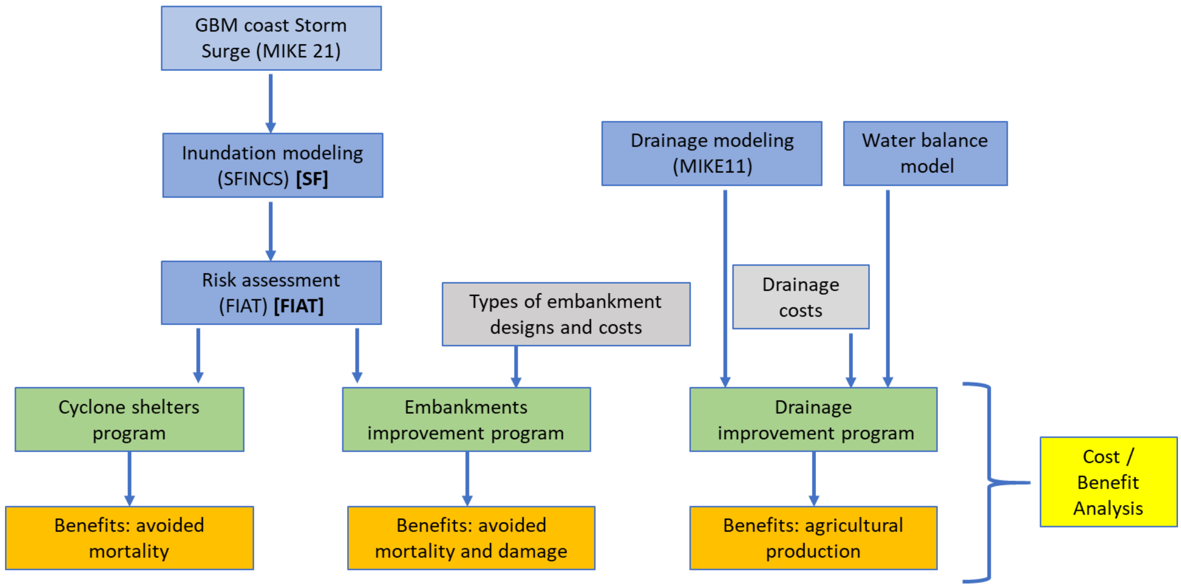


Figure 1-2 General methodology for identification of investments for polders in Bangladesh

The first step in the methodology starts with the storm surge model developed by IWM that defines the boundary conditions for the inundation modelling. In the next step, the SFINCS model is used to calculate inundation maps under different return periods. Storm surge characteristics are taken from the storm surge modelling as previously reported by IWM (IWM, 2018). Based on the inundation maps the FIAT model is used to calculate damages to infrastructure, including loss of production (businesses, agriculture), people affected and mortality. This is also done for different return periods. Based on the FIAT model a risk profile is made for each of the polders. Details used in FIAT calculations can be found in Annex B to this Report. Based on the developed risk profile per polder, the proposed interventions and associated costs, a cost benefit analysis (CBA) is made.

Interventions are not only proposed for reducing storm surge damage, but also for improved drainage, improvements for agriculture and investments to reduce mortality (cyclone shelters). Benefits are calculated based on difference in risk profile between the reference situation and the situation with proposed investments. Additional benefits are calculated based on improvement in agricultural output and reductions in mortality due to the construction of cyclone shelters, that constitute in reduction of mortality from flooding (cyclone shelters are elevated buildings) and reductions in mortality from excessive winds during cyclones. Details on interventions and investments; what, how, when, costs, etc. are provided in chapters 2, 3, and 4.

Based on the risk profile for the different aspects in the risk profile investments are proposed at polder level that will meet the economic requirements as calculated in the Cost Benefit Analysis (CBA). The evaluation in the CBA is made on the Benefit/Cost-ratio (B/C-ratio). Costs and benefits are discounted with a 12% interest rate. Future population growth and economic development are assumed to develop according the Shared Socioeconomic Pathways scenario 2 (SSP2 - middle of the road) (Riahi et al., 2017). Details on benefit calculations are provided in paragraph 2.6.

1.4 Setup of the report

Chapter 2 provides the proposed interventions, as well as a description of the benefits from each intervention. Chapter 3 provides the risk assessment of the polders per zone and the investment plan for the polders. Chapter 4 presents the economic evaluation of different investments. Chapter 5 provides a conclusion in terms of key development directions for the zone with a proposed timing of activities. It concludes with general remarks on the economic evaluation of the development opportunities for these polders.

Annex A provides details on the typical designs for the different types of embankments used in the investment plans. Annex B provides the methods and results of the cyclone risk assessment, while Annex C provides factsheets for all polders.

2 Proposed interventions

This chapter outlines the conceptual designs that are proposed for the different investments that serve to determine the investment costs for the interventions for the polders. The designs are based on the risk profile of the polder and the information that is obtained from the different models. The conceptual designs are developed using the design characteristics that follow from the boundary conditions. However, these designs are a first draft, that need to be further detailed in a full feasibility study and a consequent detailed design. The design presented in this report are a first assessment of what types of interventions are needed for the different polders based on the current boundary conditions. Consequently, also costs for the implementation of the design are a first estimate.

In this chapter the method is also presented in which the benefits from the different interventions are determined. Similar to the costs, also the benefits are a first assessment, based on modelled effects of the interventions.

2.1 Embankments

For the design of the embankments use is made of 6 conceptual designs that are made for the different environments that exist for the polders in Bangladesh. The different designs vary according to storm surge level, typical wave height and the situation on the water (sea, river) side of the embankment, notably the presence of a land in front of the embankment and the presence of protective vegetation to reduce wave energy. Figure 2-1 provides the 6 types of designs proposed in this report. Annex A provides more details on the designs.

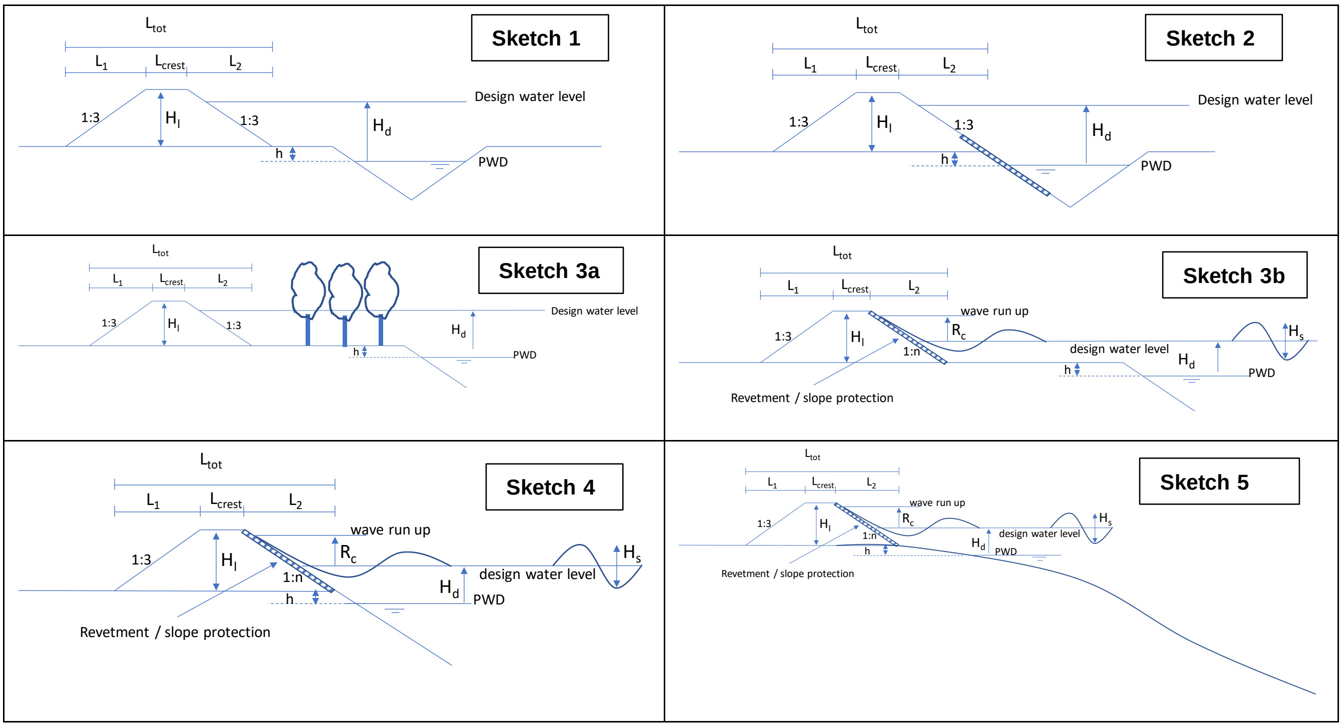


Figure 2-1 Conceptual designs for embankments for polders in Bangladesh

The actual dimensions of the embankments are a function of polder elevation and storm surge level as provided in the IWM storm surge model (IWM, 2018). Based on these dimensions the costs for the different types of embankments per each individual polder are determined. The Table 2-1 provides the costs for embankments for each design type under varying conditions for average polder height, storm surge level and wave action. Costs are based on the designs as presented in Annex A and unit costs as used in the Coastal Resilience study (Deltares, 2020) that are updated to current prices (2020). It is assumed that embankments are constructed at the same locations as current embankments, i.e. new embankments are constructed “on top of” the old embankment. Note that although costs for land acquisitions is part of the cost estimate for the embankments, these costs are found to be very high. At this point the costs for future land acquisition is therefor a point of concern for the overall cost estimate for embankments.

Table 2-1 Cost of typical embankment designs for polders in Bangladesh

Description Embankment	Cost (USD/km)
Sketch 1, Narrow channel with foreland	
Type1_1	337.500
Type1_2	427.500
Sketch 2, Narrow channel without foreland	
Type2_1	1.507.500
Type2_2	1.597.500
Sketch 3a, river bank with foreland, no wave action	
Type3A_1	78.750
Type3A_2	153.750
Sketch 3b, river bank with foreland and wave action	
Type3B_1	315.000
Type3B_2	727.500
Type3B_3	395.000
Type3B_4	821.550
Sketch 4, River bank, no foreland with wave action	
Type4_1	907.500
Type4_2	1.072.500
Type4_3	991.800
Type4_4	1.227.800
Sketch 5, Sea defence, no berm	
Type5A_1	3.387.500
Type5A_2	3.857.500
Type5A_3	3.593.750
Type5A_4	4.233.750
Sketch 5, Sea defence, no berm, high loading	
Type5B_3	6.590.000
Type5B_4	7.400.000
River Bank Protection Work	8.250.000

For the development of the investment plan the type of proposed embankment is based on the location of the polder and the distribution of the embankment over the different types of environment (sea, river or side channel) and the loading category. The loading category is a combination of the storm surge height and the wave action predicted for the polder. The combination of the two aspects, location and loading category, determines the type of embankment proposed in the investment plan according to the matrix in Table 2-2. The costs for the different types of embankment are taken from Table 2-1.

Table 2-2 Type of embankment proposed as function of location and loading category

Embankment location	Loading Category 2	3	4	5	6	7
ID	Type 3A/2	Type 3B/1	Type 1/1	Type 2/1		
ID, MD	Type 3A/2	Type 3B/1	Type 3B/3	Type 1/2		
MD	Type 3A/1	Type 3A/1	Type 3A/2	Type 1/1		
MD, ID	Type 3A/1	Type 3A/1	Type 3B/3	Type 1/2		
SD			Type 5A/1	Type 5A/4	Type 5B/3	Type 5B/4
SD, ID			Type 2/2	Type 5A/4	Type 5B/3	Type 5B/4
SD, ID, MD	Type 1/1	Type 1/2	Type 2/3	Type 5A/4	Type 5B/3	Type 5B/4
SD, MD	Type 1/1	Type 1/1	Type 1/2	Type 5B/2	Type 5B/3	Type 5B/4

SD = Sea dike; ID = Intermediate dike; MD = Marginal dike

2.2 Drainage system rehabilitation

The rehabilitation of the drainage system requires two interventions: excavation of the khals in the polder to improve drainage flows to the drainage structures (sluices) and the reconstruction or rehabilitation of the drainage structures. For reconstruction the design is considered the same as used in the CEIP I project. The costs are taken from the feasibility study for CEIP II. The costs for reconstruction are USD 350,000 per structure (mostly replacement of the gate) and for minor repairs of the concrete an average cost of USD 25,000 is used. For the replacement of the gates it is recommended to use composite gates, which recently have been tested in Bangladesh. The advantage of the composite gates is the reduced need for maintenance and the increased lifespan, especially in conditions with saline water. The excavation of the khals is assumed to be a volume of 3 m^3/m – 5 m^3/m, which at current prices is estimated to be USD 75,000/km, see also Table 2-3.

Table 2-3 Cost for excavation of Khal/km and rehabilitation/reconstruction of drainage structures

Description	Unit Cost (USD)
Khal excavation (km)	75,000
Regulator Rehabilitation (#)	25,000
Regulator Reconstruction (#)	350,000

2.3 Cyclone shelters

Based on the cost estimate that was made within the “Coastal resilience project” (Deltares et al., 2020) the average cost of a multipurpose cyclone shelter with a capacity of 1,250 persons is US$ 600,000 (the report cites several sources from Bangladesh like documents from MDSP[1] and ECRRP[2]). Added to the cost of the cyclone shelter there is a need for an average of 1km of access road, in order to secure easy access during heavy storms, which would cost around US$150,000. This brings the total costs for a cyclone shelter at US$ 750,000.

2.4 Land reclamation

The Meghna River is a sediment-rich river. More than 1 billion tons of sediment flow through the river towards the Bay of Bengal every year. By building cross dams at suitable locations, sediment from the river can be retained, creating land that can be used, for example, for agriculture or nature development. In the Meghna estuary, the dams can be constructed in the southern part, close to the mouth of the Meghna River. The areas are indicated in blue in figure 2-1. The MES Studies[3] conducted between 1995 and 2001 prepared a Master Plan and a Development Plan for the Meghna Estuary under the umbrella of the National Water Management Plan. Under MES, 19 potential sites were identified for cross dams in the coastal zone (see Table 2-4 and Figure 2-2 below).

Cross dams are barrier structures that are used to influence the hydrodynamics of and thus the morphology, initiating natural accretion processes or creating areas with optimal conditions for specific vegetation types to grow, such as mangroves. This in turn will result in speeding up sedimentation with the objective of creating new polders on the former chars. In different studies the potential of these cross dams was assessed, and high potential locations identified. The sites are presented in Table 2-4, the ID numbers in the table refer to the numbers in Figure 2-2.

As a result of the dams listed in Table 2-4, it is estimated that a minimum of 197 km^2 and a maximum of 558 km^2 land can be gained. It should be noted that the accretion due to cross dam ID 4 (Sandwip - Urir char - Noakhali) represents more than half of the total accretion. The feasibility of these plans remains to be explored in more detail. Accreted lands have to undergo land formation processes before it can be called as reclaimed land. The study in the report of the Coastal Resilience project (Deltares, 2020), found an average B/C-ratio of between 0.9 and 1.3 for the combined land reclamation projects, at an estimated total investment cost of 1,3 billion USD.

---

[1] Based on WB Project brief (2019), mentioning 3268 existing shelters plus 552 newly constructed shelters of MDSP.
[2] World Bank, 2018, Implementation completion and results report, Emergency 2007 cyclone recovery and restoration project
[3] Meghna Estuary Studies (MES-I & MES-II), 1995 – 2001, BWDB

Although the intervention is mentioned in the Polder Development Plan, no further detailed economic evaluation will be made for land reclamation, as land reclamation is not considered to be part of the rehabilitation of the existing polders. Furthermore, current data availability is insufficient to improve on the economic evaluation already conducted within the Coastal resilience Project.

Table 2-4 : Estimated potential accretion as result of cross dams

ID	Name cross dam	Estimated cross dam length [m]	Min. potential accretion [km^2]	Max. potential accretion [km^2]	Investment		Benefits based on PV USD 33,810/ha	
					Low	High	Min	Max
5	Char Rustam-Char Haldor	500	2	5	12	26	7	17
13	Char Halim-Choto Baisda	200	5	10	5	11	17	34
15	Choto Baisda-Char Biswas	2,000	10	18	47	106	34	61
17	Char Kajal (Shibar Char)-North Char	200	3	7	5	11	10	24
7	Char Burhan-Bhola	800	3	7	19	42	10	24
8	Char Kukri Mukri-Char Alcha	150	8	12	4	8	27	41
1	Hatia-Nijhum Dwip	2,000	8	12	47	106	27	41
2	Hatia-Damar Char	3,500	20	25	83	185	68	85
4	Sandwip-Urir Char-Noakhali	21,000	100	400	497	1,109	338	1,352
11	Bhola-Kukri Mukri	2,500	30	45	59	132	101	152
18	North Char (Char Nilkamal)-Kasher Char	900	3	7	21	48	10	24
19	Rangabali-Char Kashem	1,000	5	10	24	53	17	34
	Total				**823**	**1,835**	**666**	**1,887**

Figure 2-2: Locations of the cross dams in the Meghna estuary as proposed by the MES study[4]

[4] Meghna Estuary Studies (MES-I & MES-II), 1995 – 2001, BWDB

2.5 Drinking water

As mentioned in the PDP[5], there are polders that have a serious problem with the supply with drinking water of adequate quality. The report outlines different options for improving the situation. Suggested sources and technologies for supply of drinking water include tube wells, pond sand filters, rainwater harvesting, small-piped schemes, managed aquifer recharge, and reverse osmosis systems. However, it is observed that not all of these options are effective in supplying drinking water of sufficient quality. In this plan we only look at the option of small reverse osmosis-based desalination plants (RO plants), that are available in Bangladesh and that can provide drinking water of adequate quality. These plants have a production capacity of about 20–60 m^3 per day and mainly purify brackish shallow groundwater by passing it through a semi-permeable membrane. There are already desalination plants in Satkhira and Khulna districts. The cost for a Reverse Osmosis plant that can serve 250 households[6], is around USD 26,000 (USAID/Pro WASH/World Vision, 2021). The study also proposes a financial evaluation and although this financial evaluation is not very promising with an IRR of 4 %, the economic evaluation should be sufficient, when taking the positive health benefits into consideration. The investments costs for drinking water supply will be included in the investment plan without any further detailed CBA.

A quick inventory to demand, with reference to the PDP report (Deliverable 5A-1), in the different zones provides the demand for the installation for these RO plants at about 4,000 units, see also Table 2-5. With a unit cost of USD 26,000 the total investment for the RO plants in the 4 zones would be USD 104 million.

Table 2-5 : Estimated number of RO plants to provide the zones with drinking water

Zone	Pop. (M)	% req. RO plant	Demand Pop (M)	# RO plants
West	3.6	50%	1.8	1,585
South	4.3	25%	1.1	959
East	3.3	25%	0.8	725
South-East	3.0	25%	0.7	663
Total	14.2		4.4	3,932

2.6 Benefits from interventions

This section will detail the manner in which the benefits of the interventions are assessed and how these benefits will be taken into account in the economic evaluation of the investments that are proposed for the different polders. Only interventions for individual polders are considered. At this point there is insufficient information to be able to assess large scale and systemic interventions (e.g. combination of several polders; rerouting of rivers and sub-branches).

2.6.1 Embankments

The benefits from embankments are formed by the increase in safety level in the polders from protection against storm surges and resulting floods. In order to assess these benefits risk profiles of the polders are made from flood maps based on the current situation for different events with different return periods. Risk profiles are made both for the current situation under current storm surge levels and for storm surge levels in 2050. Storm surge levels are taken from the study by IWM from 2018 (IWM, 2018). The risk profiles of all polders are considered to currently have a safety level of 1/10 years. New investments are considered to bring the safety level of the polders to 1/50, gradually declining to 1/25 in 2050 due to subsidence and climate change. The reduction in damages from the increased safety level are considered to be the benefits from the embankments. In the calculation of the risk profile the coverage with cyclone shelters in the polder plays a role in the definition of the "evacuation fraction", the percentage of the population in the polder that is considered to find refuge in a cyclone shelter from floods, as cyclone shelter are elevated buildings. The evacuation fraction is divided into 3 classes 25%, 50% and 75%, meaning that with increasing shelter coverage the calculated mortality in a polder will be

[5] Deliverable 5A-1: Long Term Polder Development Plan

[6] Assuming the average number of persons in a household in Bangladesh is 4.5 and RO plant can supply drinking water to 1125 persons

decreased with the evacuation fraction. Coverage in cyclone shelters is calculated by dividing the total shelter capacity by the total polder population and corresponding evacuation factions are provided in Table 2-6. For instance, a polder that has a modelled mortality risk of 10 persons a year and a coverage of cyclone shelters with 60%, will be assigned an evacuation fraction of 50% which will lead to a risk of 5 persons a year. However, changes in evacuation fraction are attributed to the cyclone shelters, not to the embankments.

Table 2-6 Coverage in Cyclone Shelter to evacuation fraction

Coverage in CS	Evacuation fraction
0 – 25%	25%
25% - 75%	50%
> 75%	75%

2.6.2 Khals and drainage structures

The excavation of khals and the rehabilitation, or reconstruction, of drainage sluices have the objective to improve the drainage and water management in general of the polders. Improved drainage and water management will contribute to improved agricultural yields. Improved yields are translated into increased income for the agricultural sector. In order to determine the benefits of khal excavation and sluice rehabilitation a certain increase in income from the increase in yields is assigned to these works. Currently the average yield for a rice crop in the polders is below 2 T/ha paddy. Based on expert judgement improved agricultural practices could increase the yield with an average of 1 T/ha. However, although improved drainage will contribute to the increase in yield, more aspects are required. Drainage is a very important factor in the effectiveness of fertilizer application. However, next to drainage also the correct timing and the quantity of fertiliser applied is very important in the overall effect on crop yields. In order not to over-estimate the effect of the drainage a 25 % increase in crop yield has been assumed. Therefore 25% is used as a fraction of the increase in yield that is attributed to the investments. The increase in valued through the price of paddy of BDT 24,000 per ton (2020 prices), over a period of 30 years, equalling USD 855/ha. This is used as the overall benefit from the improvements in drainage systems per hectare for all polders.

2.6.3 Cyclone shelters

The benefits from cyclone shelters consist of three parts; firstly, they provide shelter from the wind and flying debris caused by cyclonic winds, and secondly, they provide a place of refuge in case of inundations due to their elevated positions and multi-story construction. Additionally, cyclone shelters in Bangladesh have a double function as schools. Also, the schooling function is valued as a benefit. All services provided by the cyclone shelter are attributed to the number of new shelters. When additional cyclone shelters are constructed in a polder that already has a coverage of more than 75% of the population it is assumed that no additional benefits are attributed to the service as a refuge in the case of flooding. Furthermore, it is assumed that in time the quality of housing in a polder will improve, resulting in a smaller fraction of the population being dependent on cyclone shelters. For this reason the required number of cyclone shelters is determined by 33% of the population needing access to a cyclone shelter, while in 2050 only 25% of the population is assumed to be in need of shelter in a cyclone shelter. The value of the different services is determined through the reduction in mortality and the Value of Statistical Life (VoSL). Reduction in mortality in the flood risk calculations are based on the results from the FIAT model and the possible change in evacuation fractions as illustrated in Table 2-6. Reduction in mortality due to the service of refuge from cyclonic winds is taken from the "Coastal Resilience study" (Deltares et al., 2020), that determine the overall reduction of mortality from cyclone shelters to be from 1% of the exposed population to 0.05% of the exposed population. In this study we assume the protection against cyclonic winds to be 1/3 of the improvement[7], i.e. 0.0167% of the additionally protected population.

[7] Consequently 2/3 of the effect of the cyclone shelters is in the form of protection from mortality in a flood event, which is taken into consideration in the increased evacuation fraction in the mortality in the risk profile based on the FIAT calculations

The benefits from education services are taken from the PAD document of the World Bank (WB, 2014) in which a grade 5 education is valued at in increased annual income of US$ 172/year. Assuming 236 pupils per shelter and 5 year in education this would provide an annual benefit of US$ 8,152.

3 Risk Analysis and investments per zone

In the risk assessment for the polder a list of basic data was used that in general is available for all polders. The list contains the following data; Population, surface, embankment length (including embankment type(s), available breaches, erosion and need for bank protection works), length of khals, number and type of structures, number of cyclone shelters. Furthermore, in order to be able to make a flood map the boundary conditions for storm surge height and wave height is required. In case there are gaps in the available data risk profiles can not be determined. In the next paragraphs for the polders in the four identified zones are presented.

3.1 Western Zone

The polders that are situated in the western zone are listed in Table 3-1. The polders that are situated in the zone, but have severe data limitations either from missing basic data or the lack of boundary conditions are not included in the investment plan (missing data) or in the benefit calculations (missing boundary conditions). The risk profiling and the economic evaluation is only performed for polders that have sufficient data.

Table 3-1 Polders belonging to the western zone of Bangladesh

Polders Western zone	1, 2, 3, 4, 5, 6-8, 7/1, 7/2, 9, 10-12, 13-14/2, 14/1, 15, 16, 17/1, 17/2, 18-19, 20-20/1, 21, 22, 23, 24, 25, 26, 27/1-27/2, 28/1, 28/2, 29, 30, 31, 31/Part, 32, 33, 34/1&34/3, 34/2, 34/2/Part, 34/3, 35/1, 35/2, 35/3, 36/1, 36/2, 37, 38,
Missing Basic data	34/2, 34/2/Part, 35/2, 36/2, 37, 38
No risk profile	1, 2, 3, 6-8, 24, 25, 26, 27/1-27/2, 34/2/Part, 34/3, 36/1, 36/2,

3.1.1 Risk analysis

In the Figure 3-1 the annual expected damages (AED) for assets (buildings, houses, agriculture, businesses) and production losses (business, agriculture) are provided for the western zone. The Figure 3-2 presents the annual expected mortality from flood risk. These two figures provide insight into the overall risk profile of each individual polder. The risk profile is provided for four different situations;

- Risk under current conditions of the embankment in the present situation
- Risk under the present situation with improved embankments (safety level of 1/50)
- Risk under current conditions of the embankment in 2050 (including Climate change and subsidence)
- Risk in 2050 (including Climate change and subsidence) with improved embankments (remaining safety level of 1/25)

The reduction of the risk that obtained by the implementation of the embankments are considered the benefits of the investment in the embankments. The increase in risk in 2050 stems from two drivers. On the one hand there is an economic growth in Bangladesh that will both increase the number as the value of the assets. Secondly there is an increase in population between 2020 and 2050. In the benefit calculations these changes are considered to be linear.

From the figures it is clear that current risk is limited for most polders, but polders towards the eastern part of the zone have significant AED, as these polders are closer to the Baleshwar river and are more exposed to storm surge. For all polders the risk towards 2050 increases considerably, both through increase in storm surge as through increased economic value of the assets. Furthermore, as can be seen from the figures the AED in 2050 in the situation with the improved embankments is lower than in the current situation without the improved embankments. For the expected mortality it shows that although expected mortality is reduced, the reduction is much smaller than for the AED. As mortality is especially high for return periods of 1/50 and 1/100, against which the embankment do not protect, the reduction is small compared with the damages to the assets, where damages start already at low return periods. Furthermore, it should be noted that the polder 37 and 38 currently do not have a formal status as polders, while the modelled risk is substantial. It is recommended that these should be further research in order for these areas to be formally included as polders.

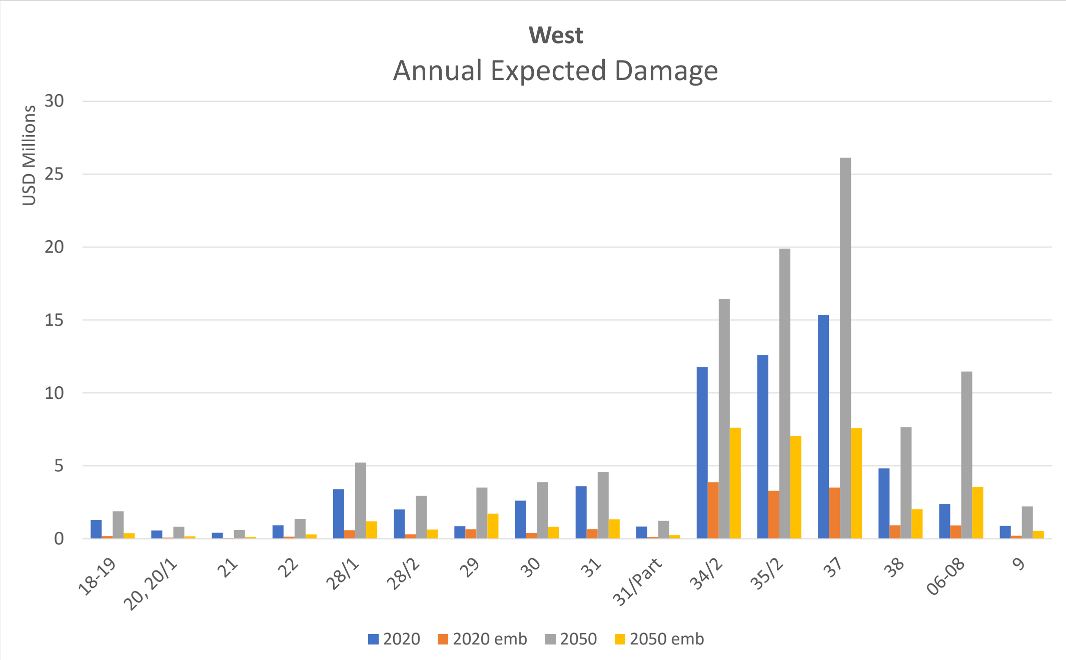


Figure 3-1: Risk profiles for annual damages for the polders belonging to the western zone of Bangladesh (USD million)

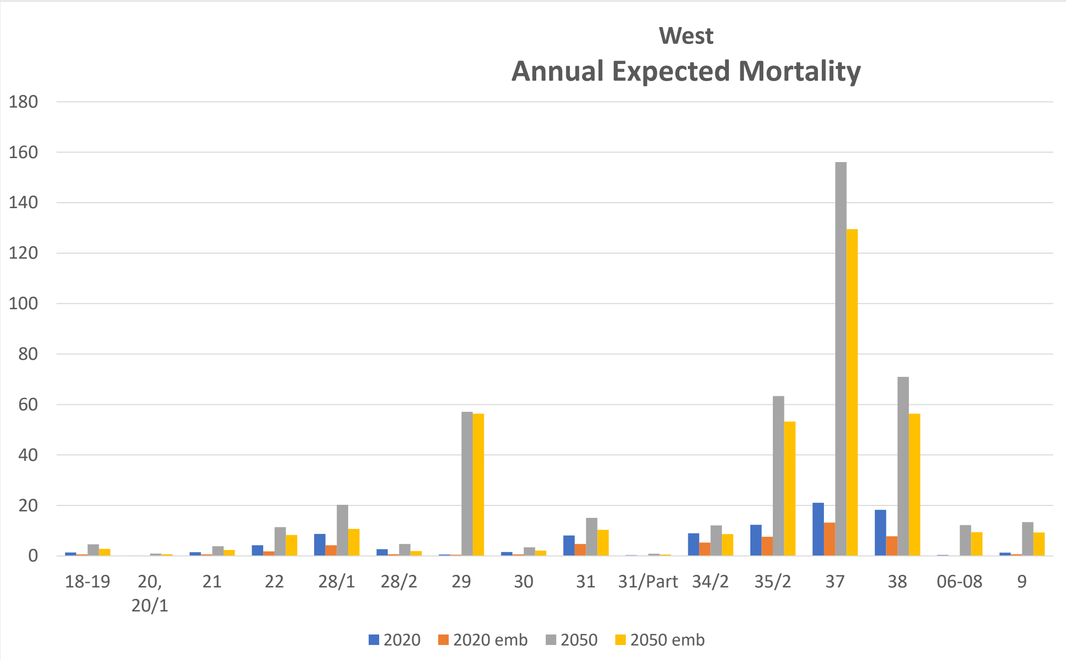


Figure 3-2: Risk profiles for annual mortality for the polders belonging to the western zone of Bangladesh

3.1.2 Proposed investments

Based on the characteristics of the polder and the risk profiles in the western zone the Table 3-2 proposes the different interventions that are planned for reducing the risk in the polders. Furthermore, the Table 3-3 presents the investment budget for risk reduction in the western zone. The investments for the western zone are relatively modest with a total of USD 335 million in total investments. Investments are relatively low as the storm surge levels in this zone are relatively low, resulting in modest investments for embankment. In order to reduce mortality a relatively large part of the investment budget is geared towards the construction of additional cyclone shelters.

Table 3-2 Proposed interventions for the western zone

Polder No	Zone	Gross Polder Area (Ha)	Population 2022	Population 2050	Embankment Length (Km)	Breach of Embankment (Km)	Erosion (Km)	Requirement of BPW (Km)	Khal Length (km)	Regulators (#)		# new CS
										Const.	Rehab	
06-08	West	18,450	286,762	337,741	53	1.0	10.00	-	182	30	6	72
9	West	1,255	9,412	11,085	8	-	5.70	-	5	3	0	2
18-19	West	3,380	9,775	11,513	32	-	9.00	-	13	19	2	3
20, 20/1	West	1,600	5,239	6,170	23	-	5.00	-	25	5	9	1
21	West	1,417	3,989	4,698	17	-	5.00	-	7	0	3	1
22	West	1,630	10,026	11,808	20	-	10.00	-	0	20	3	3
28/1	West	5,600	51,073	60,153	23	-	-	-	12	6	2	13
28/2	West	2,590	27,420	32,295	20	-	-	-	19	1	5	7
29	West	8,218	66,038	77,778	49	1.8	13.00	-	93	30	12	17
30	West	6,396	45,248	53,292	40	-	-	-	24	21	10	11
31	West	7,288	34,841	41,035	47	-	4.00	3.5	28	17	14	9
31/Part	West	4,848	21,690	25,546	29	-	9.00	-	45	8	4	-
					19							
	Total	62,672	571,512	673,113	361	2.8	70.70	3.5	453	160	70	139

Table 3-3 Investment budget (in USD million) for risk reduction in the western zone

Zone	West		
	Number of units	Average Unit costs	Investments (million USD)
Polder area (ha)	62,672		
Population	571,512		
Embankment Length (km)	361	199,820	72
Bank protection Works (km)	11	8,250,000	90
Khal Length (km)	453	25,000	11
# Regulators (new)	160	350,000	56
# Regulators (repair)	70	25,000	2
# New Cyclone Shelters	139	750,000	104
Total			335

3.2 Southern Zone

The polders that are situated in the southern zone are listed in Table 3-4. The polders that are situated in the zone, but have severe data limitations either from missing basic data or the lack of boundary conditions are not included in the investment plan (missing data) or in the benefit calculations (missing boundary conditions). The risk profiling and the economic evaluation is only performed for polders that have sufficient data.

Table 3-4 Polders belonging to the southern zone of Bangladesh

Polders Southern zone	39/1, 39/1A, 39/1B, 39/1C, 39/2, 39/2A, 39/2C, 40/1, 40/2, 41/1, 41/2, 41/3, 41/4, 41/5, 41/6A, 41/6B, 41/7, 41/7A, 41/7B, 42, 43/1, 43/1A, 43/1B, 43/2A, 43/2B, 43/2C, 43/2D, 43/2E, 43/2F, 44, 45, 46, 47/1, 47/2, 47/3, 47/4, 47/5, 48, 49, 50/51, 52/53A, 52/53B, 54, 55/1, 55/2A, 55/2B, 55/2C, 55/2D, 55/2E, 55/3, 55/4, 56/57, 58/1, 58/2, 58/3
Missing Basic data	39/1, 39/2
No risk profile	39/1, 39/2, 54, 55/1
"New" polders	Bibichini, Dumki Laukathi, Itbaria Labukhali, Mirzagonj Rampura, Satla Bagda-1, Satla Bagda-2, Satla Bagda-3

3.2.1 Risk analysis

In the Figure 3-3 the annual expected damages (AED) for assets (buildings, houses, agriculture, businesses) and production losses (business, agriculture) are provided for the western zone. The Figure 3-4 presents the annual expected mortality from flood risk. These two figures provide insight into the overall risk profile of each individual polder. The risk profile is provided for four different situations;

- Risk under current conditions of the embankment in the present situation
- Risk under the present situation with improved embankments (safety level of 1/50)
- Risk under current conditions of the embankment in 2050 (including Climate change and subsidence)
- Risk in 2050 (including Climate change and subsidence) with improved embankments (remaining safety level of 1/25)

The reduction of the risk that obtained by the implementation of the embankments are considered the benefits of the investment in the embankments. The increase in risk in 2050 stems from two drivers. On the one hand there is an economic growth in Bangladesh that will both increase the number as well as the value of the assets. Additionally, there is an increase in population between 2020 and 2050. In the benefit calculations these changes are considered to be linear.

From the figures it is clear that the current risk in the southern zone in general is similar to the western zone, although the southern zone is more exposed to the Bay of Bengal (BoB). For all polders the risk towards 2050 increases considerably, both through increase in storm surge and through increased economic value of the assets. Furthermore, as can be seen from the figures the AED in 2050 in the situation with the improved embankments is lower than in the current situation without the improved embankments. For the expected mortality is shows that although expected mortality is reduced, the reduction is much smaller than for the AED. As mortality is especially high for return periods of 1/50 and 1/100, against which the embankment does not protect, the reduction is small compared with the damages to the assets, where damages start already at low return periods. A special case is the polder 56/57 (Bhola island), which through its exposure has both high annual AED and expected mortality from its exposure to the BoB. Due to the differences in scale as compared to the other polders in the southern zone the polders 56/57 are presented separately in Figure 3-5.

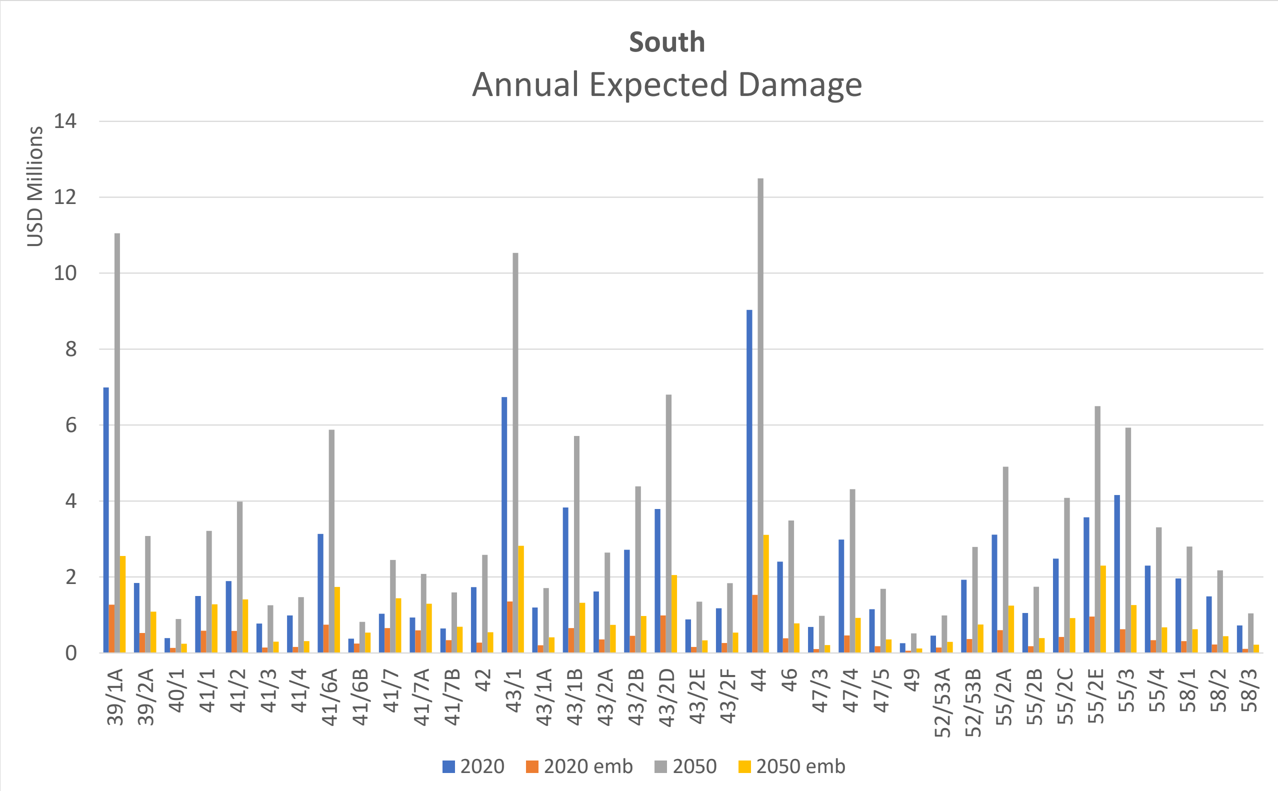


Figure 3-3: Risk profiles for annual damages for the polders belonging to the southern zone of Bangladesh (in USD Million)

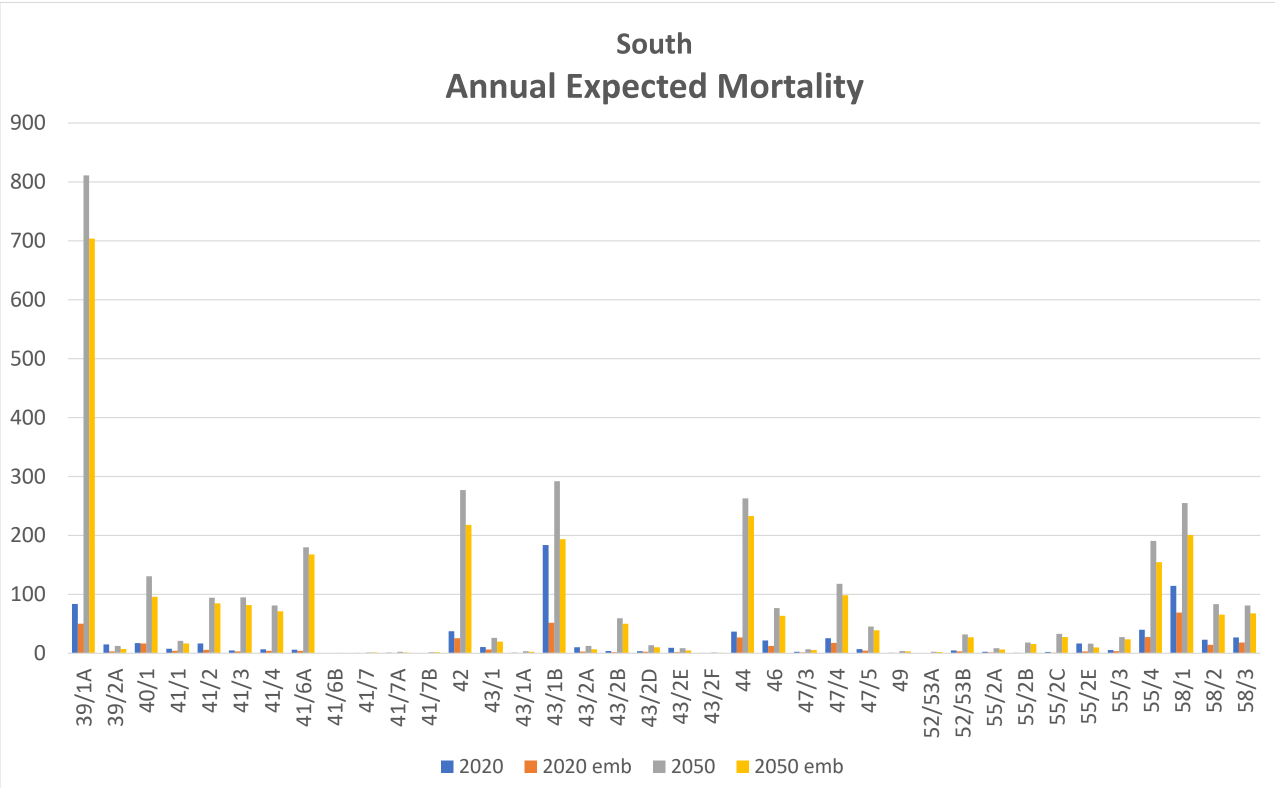


Figure 3-4: Risk profiles for annual mortality for the polders belonging to the southern zone of Bangladesh

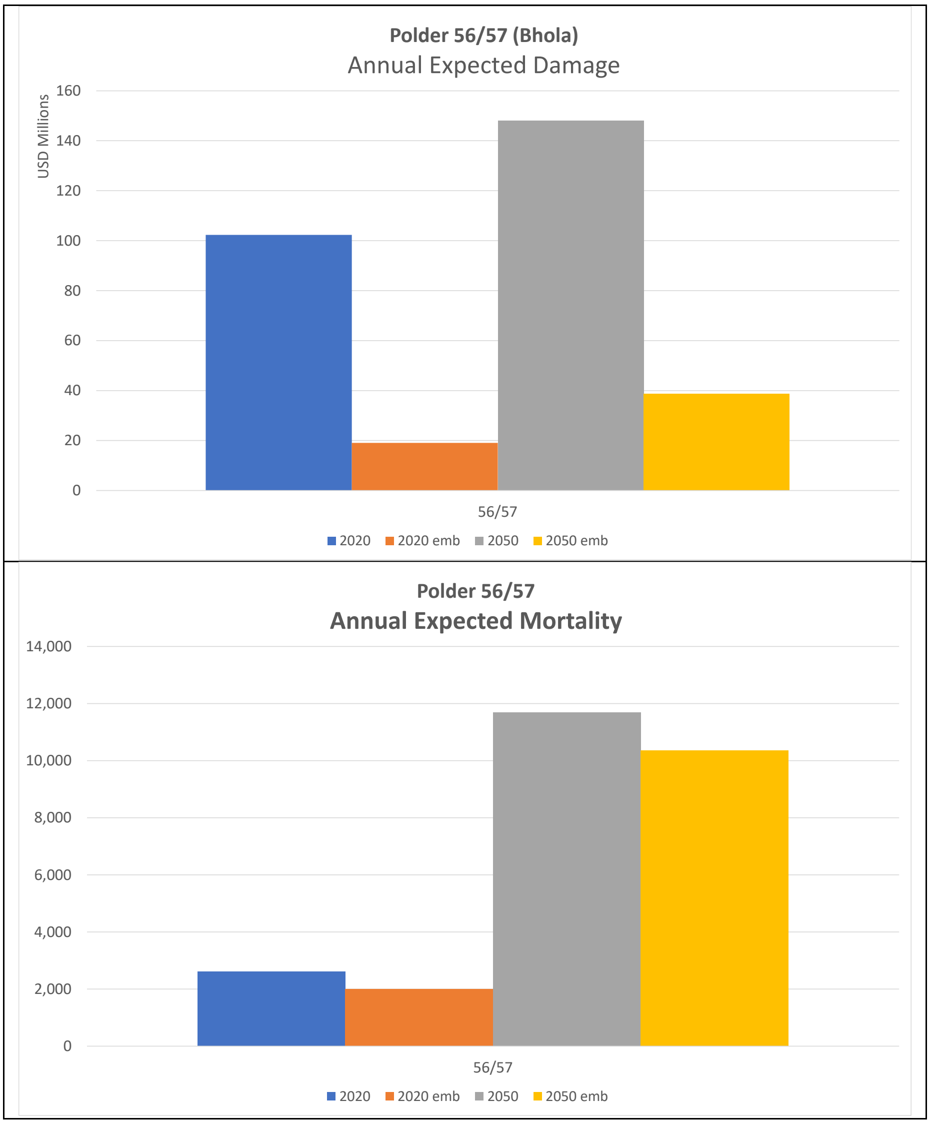


Figure 3-5: Risk profiles for annual damages (USD million) and mortality for the polder 56/57 (Bhola)

3.2.2 Proposed investments

Based on the characteristics of the polder and the risk profiles in the southern zone the Table 3-5 proposes the different interventions that are planned for reducing the risk in the polders. Furthermore, the Table 3-6 presents the investment budget for risk reduction in the southern zone. Because of the higher exposure, and with that the higher storm surge levels, and the high number of polders in the southern zone the investments for this zone are 10-fold of those in the western zone, mainly due to higher embankments and required slope protection works. Note that the average costs for embankment in the western zone, is much lower than in the southern zone (USD 200,000 and USD 1.4 million per km, respectively), explaining a large part of the additional investments. Also bank protection works to the amount of USD 600 million are a substantial part of the investments.

Table 3-5 Proposed interventions for the southern zone

Polder No	Zone	Gross Polder Area (Ha)	Population 2022	Population 2050	Embankment Length (Km)	Breach of Embankment (Km)	Erosion (Km)	Requirement of BPW (Km)	Khal Length (km)	Regulators (#)		# new CS
										Const.	Rehab	
39/1A	South	11,740	92,647	109,117	58	-	-	0	104	45	7	3
39/2A	South	5,080	57,877	68,166	32	-	-	3.5	0	54	4	10
40/1	South	2,105	13,639	16,063	23	-	-	0	15	30	0	-
41/1	South	4,048	49,748	58,591	34	-	-	0.75	84	33	6	10
41/2	South	3,644	46,348	54,587	39	-	-	0.75	98	30	6	9
41/3	South	1,053	10,933	12,877	20	-	-	0	25	21	3	3
41/4	South	1,741	12,745	15,011	19	-	-	0	60	16	7	-
41/6A	South	3,850	33,719	39,713	33	-	-	0	47	18	6	5
41/6B	South	7,280	73,530	86,602	44	1.50	6.00	4.5	68	14	9	19
41/7	South	6,984	62,658	73,798	51	6.00	1.50	3	0	7	9	15
41/7A	South	6,220	59,292	69,833	39	-	-	0	0	45	6	1
41/7B	South	6,150	31,523	37,127	29	0	0	0	0	19	7	4
42	South	2,794	15,352	18,082	28	-	3.00	2.1	80	21	3	-
43/1	South	10,600	144,555	170,254	65	1.50	1.00	0	98	28	10	34
43/1A	South	2,675	17,305	20,382	27	0.40	-	1.5	98	23	3	3
43/1B	South	3,000	39,253	46,231	21	0	0	0	98	11	6	4
43/2A	South	5,182	42,630	50,208	39	2.00	-	2	0	41	8	11
43/2B	South	5,460	38,150	44,932	42	-	-	0	0	44	6	6
43/2D	South	6,500	64,188	75,599	43	-	-	0	0	83	9	17
43/2E	South	1,650	11,540	13,592	20	-	-	6	0	46	1	3
43/2F	South	4,453	31,359	36,934	32	-	-	0	53	57	4	7
44	South	17,530	95,997	113,063	82	-	-	0	109	40	7	10
46	South	4,697	31,694	37,329	40	4.50	3.00	0	0	12	10	-
47/3	South	2,025	7,479	8,808	20	-	-	0	0	11	6	2
47/4	South	6,600	34,161	40,235	57	0.10	-	0	0	23	13	1
47/5	South	7,500	11,071	13,039	33	2.00	7.00	5	0	11	6	-
49	South	-	5,381	6,338	27	0	0	0	0	10	3	1
52/53A	South	3,663	28,546	33,621	25	-	-	0	1	0	4	-
52/53B	South	4,064	13,354	15,728	34	-	-	0	1	5	5	-
55/2A	South	7,166	54,748	64,481	43	-	-	0	0	17	4	12
55/2B	South	2,600	22,712	26,749	30	1.50	0.60	1.95	0	11	4	1
55/2C	South	6,275	44,062	51,895	48	-	-	2.5	4	25	7	7
55/2E	South	10,535	106,795	125,781	84	-	-	0	0	0	0	24
55/3	South	9,845	52,730	62,104	56	-	-	4.6	0	22	9	6
55/4	South	5,142	13,216	15,566	33	-	-	3.5	0	19	5	1
56/57	South	123,800	1,693,609	1,994,692	250	4.50	15.00	14.5	895	0	0	146
58/1	South	4,200	29,179	34,366	32	0.50	2.00	0	25	1	4	-
58/2	South	4,312	28,595	33,679	28	-	6.50	4	43	0	5	-
58/3	South	1,308	8,601	10,130	17	-	7.47	4.85	27	0	2	-
	Total	**323,471**	**3,230,922**	**3,805,302**	**1,677**	**24.5**	**53.07**	**65.0**	**2,033**	**893**	**214**	**375**

Table 3-6 Investment budget for risk reduction in the southern zone

Zone	South		
	Number of units	Average Unit costs	Investments (USD million)
Polder area (ha)	323,471		
Population	3,230,922		
Embankment Length (km)	1,677	1,401,003	2,350
Bank protection Works (km)	73	8,250,000	600
Khal Length (km)	2,033	25,000	51
# Regulators (new)	893	350,000	313
# Regulators (repair)	214	25,000	5
# New Cyclone Shelters	375	750,000	281
Total			3,600

3.3 Eastern Zone

The polders that are situated in the eastern zone are listed in Table 3-7. The polders that are situated in the zone, but have severe data limitations either from missing basic data or the lack of boundary conditions are not included in the investment plan (missing data) or in the benefit calculations (missing boundary conditions). The risk profiling and the economic evaluation is only performed for polders that have sufficient data.

Table 3-7 Polders belonging to the eastern zone of Bangladesh

Polders Eastern zone	59/1A, 59/1B, 59/2, 59/2 Ext., 59/3A, 59/3B, 59/3C, 60, 61/1, 61/2, 72, 73/1 (A & B), 73/2	
Missing Basic data	59/3A	
No risk profile	59/1A, 59/1B, 59/2 Ext., 59/3A, 59/3B, 59/3C, 60	
"New" polders	Boychar, CDSP-II, Char Bagardona-1, Char Bagardona-2, Char Mojid, Kumiriya to Sonaichari Flood Control Project	Basic data available, no risk profiles (no shapefiles for embankments available)

3.3.1 Risk analysis

In the Table 3-6 the annual expected damages (AED) for assets (buildings, houses, agriculture, businesses) and production losses (business, agriculture) are provided for the eastern zone. The Table 3-7 presents the annual expected mortality from flood risk. These two figures provide insight into the overall risk profile of each individual polder. The risk profile is provided for four different situations;

- Risk under current conditions of the embankment in the present situation
- Risk under the present situation with improved embankments (safety level of 1/50)
- Risk under current conditions of the embankment in 2050 (including Climate change and subsidence)
- Risk in 2050 (including Climate change and subsidence) with improved embankments (remaining safety level of 1/25)

The reduction of the risk that obtained by the implementation of the embankments are considered the benefits of the investment in the embankments. The increase in risk in 2050 stems from two drivers. On the one hand there is an economic growth in Bangladesh that will both increase the number as well as the value of the assets. Additionally, there is an increase in population between 2020 and 2050. In the benefit calculations these changes are considered to be linear.

From the figures it is clear that the current risk in the eastern zone in general is much higher than in the western or southern zones. This because the eastern zone is more exposed to the Bay of Bengal (BoB) and the predominant direction of waves in case of a cyclonic storm. For all polders the risk towards 2050 increases considerably, both through increase in storm surge as through increased economic value of the assets. Furthermore, as can be seen from the figures the AED in 2050 in the situation with the improved embankments is lower than in the current situation without the improved embankments. For the expected mortality is shows that although expected mortality is reduced, the reduction is much smaller than for the AED. As mortality is especially high for return periods of 1/50 and 1/100, for which the embankment does not protect, the reduction is small compared with the damages to the assets, where damages start already at low return periods.

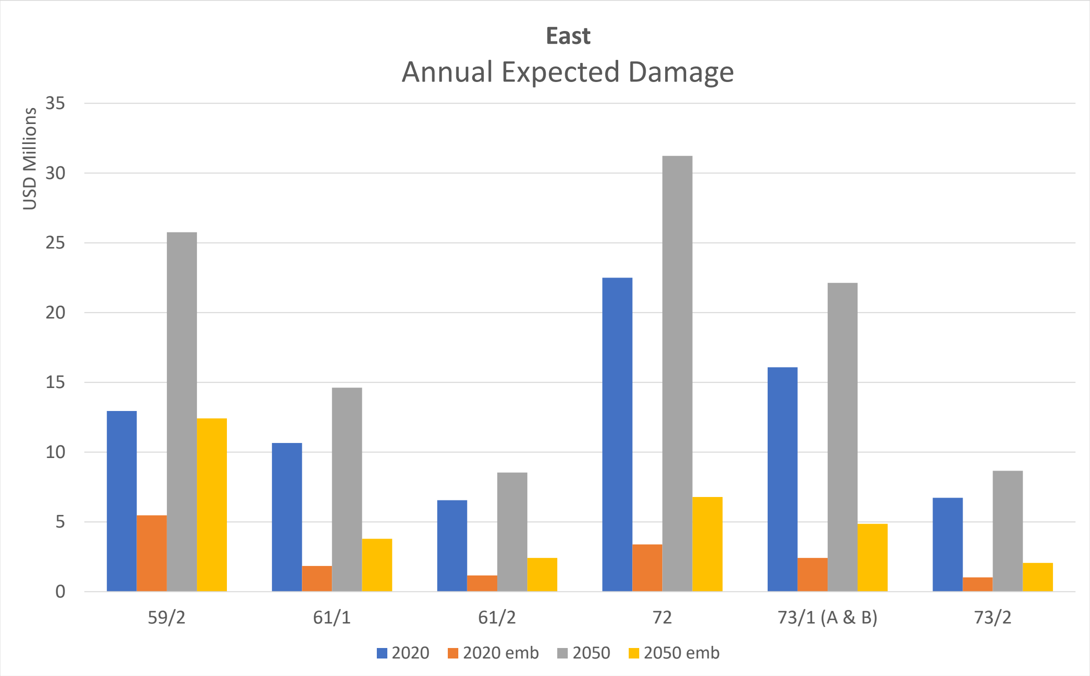


Figure 3-6: Risk profiles for annual damages for the polders belonging to the eastern zone of Bangladesh (USD million)

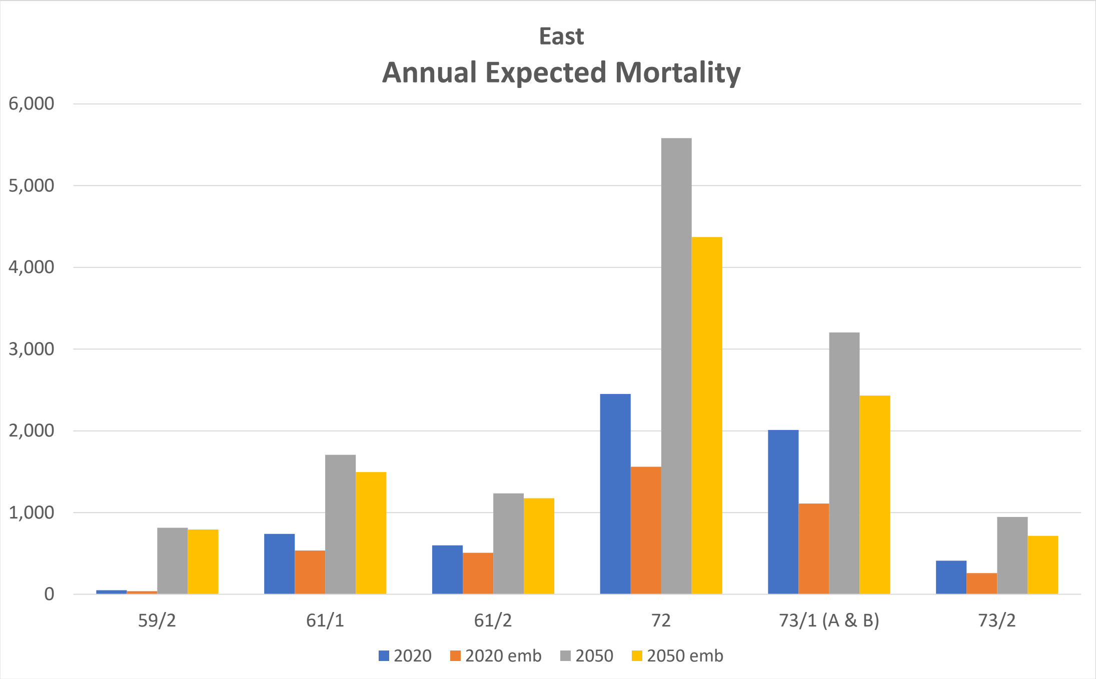


Figure 3-7: Risk profiles for annual mortality for the polders belonging to the eastern zone of Bangladesh

3.3.2 Proposed investments

Based on the characteristics of the polder and the risk profiles in the eastern zone the Table 3-5 proposes the different interventions that are planned for reducing the risk in the polders. Furthermore, the Table 3-6 presents the investment budget for risk reduction in the eastern zone. Investments for the eastern zone stand at USD 932 million, and are very high per polder. This is mostly explained by the very high average cost for embankments, USD 2.4 million per km, which is twice that from the southern zone. Next to the investment in embankments, there is also a substantial cost for bank protection works, to the sum of USD 126 million.

Table 3-8 Proposed interventions for the southern zone

Polder No	Zone	Gross Polder Area (Ha)	Population 2022	Population 2050	Embankment Length (Km)	Breach of Embankment (Km)	Erosion (Km)	Requirement of BPW (Km)	Khal Length (km)	Regulators (#)		# new CS
										Const.	Rehab	
59/2	East	21,255	415,890	489,826	31	5.50	3.95	10	131	16	5	52
61/1	East	8,769	153,378	180,645	27	1.35	-	0	77	12	12	-
61/2	East	19,855	284,537	335,121	10	0.11	-	0	84	6	7	38
72	East	22,700	294,866	347,287	58	9.40	-	0	142	3	23	-
73/1 (A & B)	East	21,377	139,985	164,871	80	3.53	28.00	0	136	30	0	-
73/2	East	11,134	86,842	102,281	48	-	0.40	0	85	2	27	-
	Total	**105,090**	**1,375,499**	**1,620,029**	**253**	**19.9**	**32.35**	**10.0**	**655**	**69**	**74**	**90**

Table 3-9 Investment budget for risk reduction in the southern zone

Zone	East		
	Number of units	Average Unit costs	Investments (USD million)
Polder area (ha)	105,090		
Population	1,375,499		
Embankment Length (km)	253	2,753,997	697
Bank protection Works (km)	15	8,250,000	126
Khal Length (km)	655	25,000	16
# Regulators (new)	69	350,000	24
# Regulators (repair)	74	25,000	2
# New Cyclone Shelters	90	750,000	68
Total			932

3.4 South-Eastern Zone

The polders that are situated in the south-eastern zone are listed in Table 3-10. The polders that are situated in the zone, but have severe data limitations either from missing basic data or the lack of boundary conditions are not included in the investment plan (missing data) or in the benefit calculations (missing boundary conditions). The risk profiling and the economic evaluation is only performed for polders that have sufficient data.

Table 3-10 Polders belonging to the south-eastern zone of Bangladesh

Polders South-Eastern zone	62, 63/1A, 63/1B, 63/2, 64/1A, 64/1B, 64/1C, 64/2A, 64/2B, 65, 65/A, 65/A1, 65/A3, 66/1, 66/2, 66/3, 66/4, 67, 67/A, 67/B, 68, 69/NE, 69/P1, 70, 71	
Missing Basic data	63/2	
No risk profile	65/A, 65/A1, 65/A3, 67, 67/A, 67/B, 68, 69/P1	
"New" polders		

3.4.1 Risk analysis

In the Figure 3-8 the annual expected damages (AED) for assets (buildings, houses, agriculture, businesses) and production losses (business, agriculture) are provided for the western zone. The Figure 3-9 presents the annual expected mortality from flood risk. These two figures provide insight into the overall risk profile of each individual polder. The risk profile is provided for four different situations;

- Risk under current conditions of the embankment in the present situation
- Risk under the present situation with improved embankments (safety level of 1/50)
- Risk under current conditions of the embankment in 2050 (including Climate change and subsidence)
- Risk in 2050 (including Climate change and subsidence) with improved embankments (remaining safety level of 1/25)

The reduction of the risk that obtained by the implementation of the embankments are considered the benefits of the investment in the embankments. The increase in risk in 2050 stems from two drivers. On the one hand there is an economic growth in Bangladesh that will both increase the number as well as the value of the assets. Additionally, there is an expected increase in population between 2020 and 2050. In the benefit calculations these changes are considered to be linear.

From the figures it is clear that current risk in the south-eastern zone in general is also much higher similar to the eastern zone. This because, as the eastern zone, the polders in the south-east are more exposed to the Bay of Bengal (BoB) and the predominant direction of waves in case of a cyclonic storm. For all polders the risk towards 2050 increases considerably, both through increase in storm surge as through increased economic value of the assets. Furthermore, as can be seen from the figures the AED in 2050 in the situation with the improved embankments is lower than in the current situation without the improved embankments. For the expected mortality it shows that although expected mortality is reduced, the reduction is much smaller than for the AED. As mortality is especially high for return periods of 1/50 and 1/100, for which the embankment does not protect, the reduction is small compared to the damages to the assets, where damages start already at low return periods. However, the mortality risks in the south-eastern zone for some polders are extremely high. This will need further research to see whether this is indeed a correct interpretation of reality, or that there are some inaccuracies in either the boundary conditions or in the way these are interpreted in the SFINCS model. In any case the risks in the south-eastern polders are so high that substantial investments are needed to reduce the risk to acceptable levels.

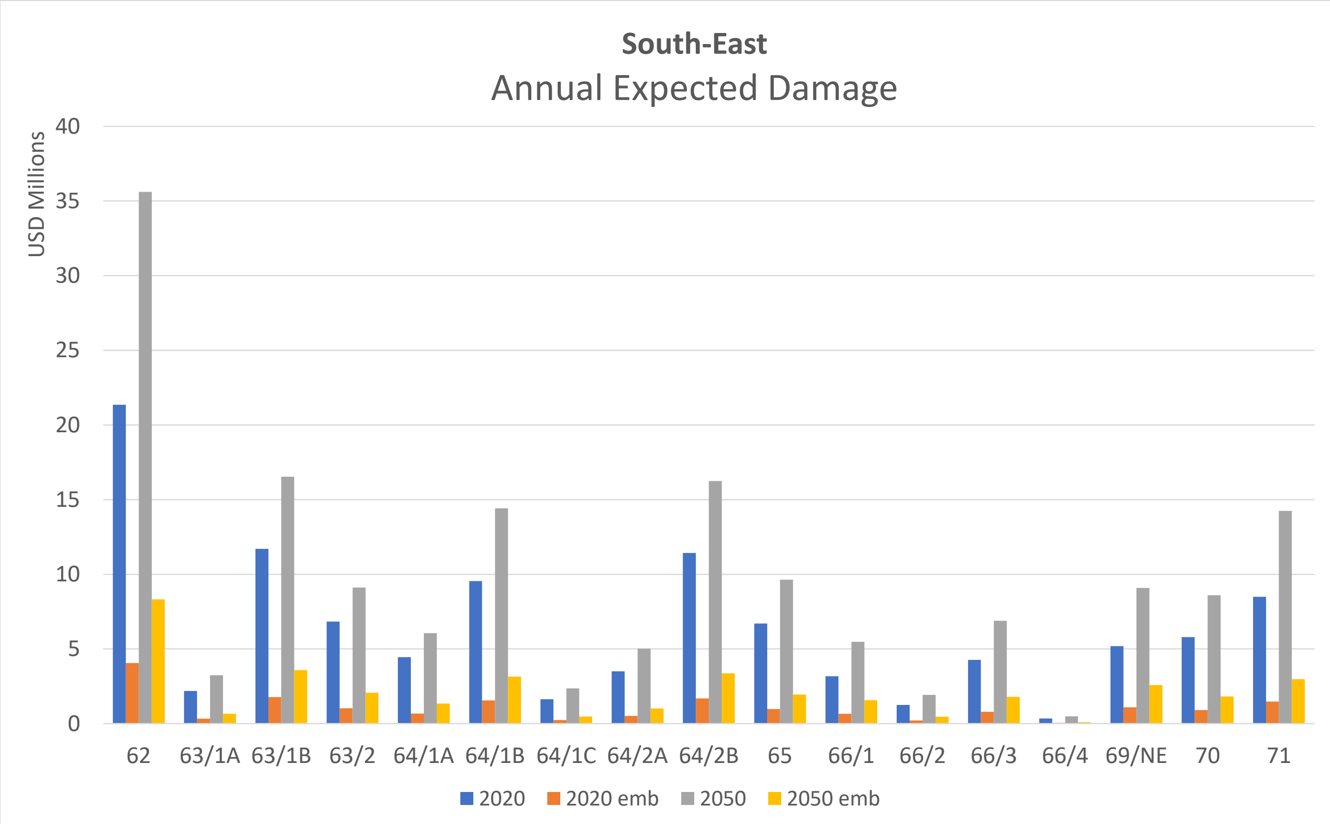


Figure 3-8: Risk profiles for annual damages for the polders belonging to the south-eastern zone of Bangladesh (USD million)

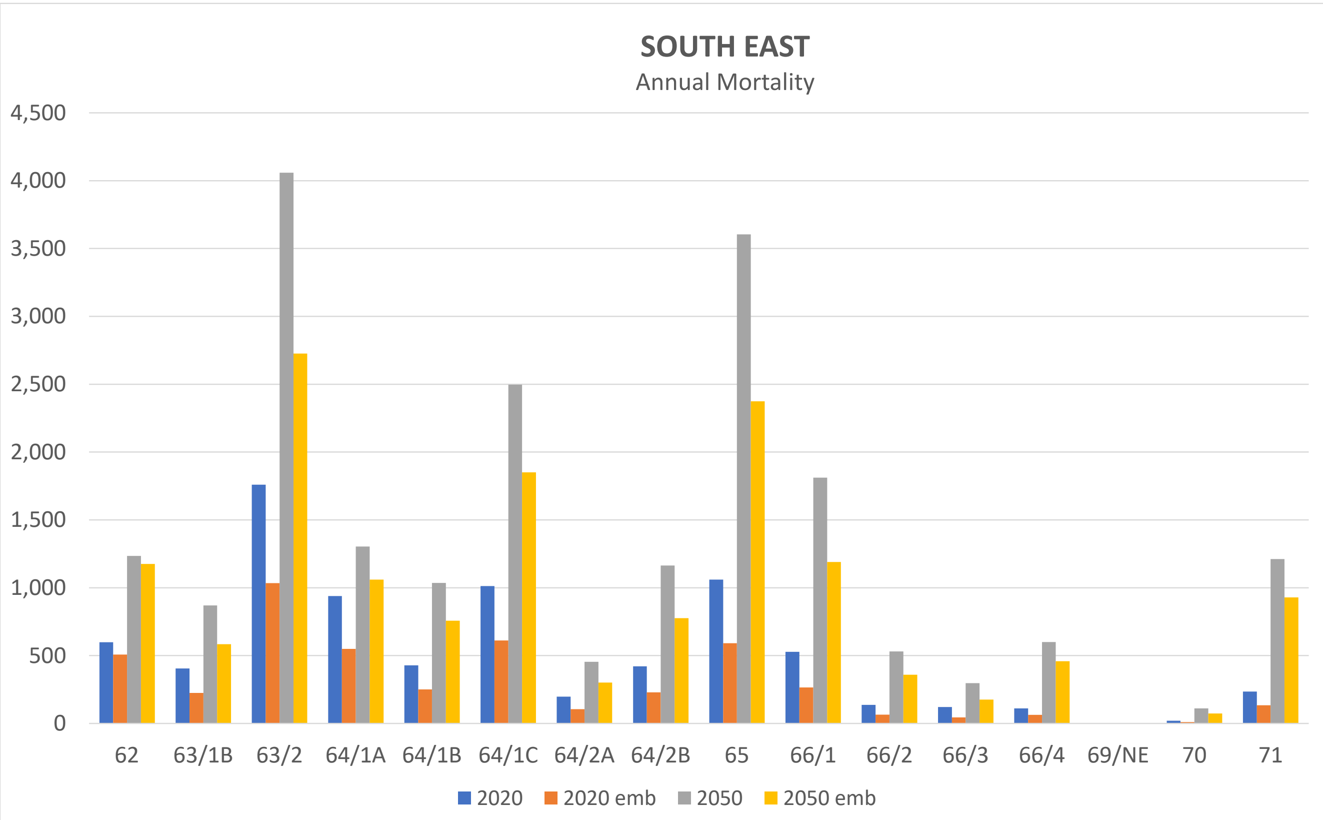


Figure 3-9: Risk profiles for annual mortality for the polders belonging to the south-eastern zone of Bangladesh

3.4.2 Proposed investments

Based on the characteristics of the polder and the risk profiles in the south-eastern zone the Table 3-11 proposes the different interventions that are planned for reducing the risk in the polders. Furthermore, the Table 3-12 presents the investment budget for risk reduction in the zone. Investments for the south-eastern zone stand at USD 2,166 million, and are very high per polder. This is mostly explained by the very high average cost for embankments, with USD 2.5 million per km, even surpassing the average embankment costs per km of the eastern zone.

Table 3-11 Proposed interventions for the southern zone

Polder No	Zone	Gross Polder Area (Ha)	Population 2022	Population 2050	Embankment Length (Km)	Breach of Embankment (Km)	Erosion (Km)	Requirement of BPW (Km)	Khal Length (km)	Regulators (#)		# new CS
										Const.	Rehab	
62	South-East	5,600	1,234,923	1,454,463	22	-	4.50	0	0	1	13	290
63/1A	South-East	7,500	196,287	231,182	48	7.00	17.00	10	50	10	14	39
63/1B	South-East	7,300	93,809	110,486	33	-	-	0	50	1	7	-
64/1A	South-East	5,750	101,306	119,316	58	0.50	2.00	3	36	10	15	-
64/1B	South-East	8,000	199,314	234,748	53	4.50	-	0	78	15	21	9
64/1C	South-East	2,151	31,988	37,675	23	0.70	10.75	0	15	12	14	-
64/2A	South-East	3,750	44,760	52,718	34	-	-	0	38	1	1	-
64/2B	South-East	7,736	116,796	137,560	96	4.50	15.50	0	123	22	14	-
65	South-East	6,649	115,380	135,891	48	-	15.56	2.05	41	7	21	-
66/1	South-East	4,930	78,282	92,199	20	0.50	0.85	1.05	10	6	9	-
66/2	South-East	2,621	45,675	53,795	20	-	5.10	0	9	14	13	2
66/3	South-East	4,832	123,621	145,598	52	-	11.37	0	0	23	8	7
66/4	South-East	3,324	295	348	24	9.42	5.06	0	36	1	15	-
69/NE	South-East	2,226	6,336	7,463	16	2.40	8.25	0	0	6	0	-
70	South-East	3,025	60,969	71,808	32	-	5.00	0	0	11	3	-
71	South-East	5,116	136,810	161,132	40	0.20	20.00	0	36	9	1	-
	Total	**80,510**	**2,586,553**	**3,046,380**	**619**	**29.7**	**120.94**	**16.1**	**522**	**149**	**169**	**347**

Table 3-12 Investment budget for risk reduction in the southern zone

Zone	**South-East**		
	Number of units	Average Unit costs	Investments (USD million)
Polder area (ha)	80,510		
Population	2,586,553		
Embankment Length (km)	619	2,551,334	1,579
Bank protection Works (km)	31	8,250,000	257
Khal Length (km)	522	25,000	13
# Regulators (new)	149	350,000	52
# Regulators (repair)	169	25,000	4
# New Cyclone Shelters	347	750,000	260
Total			2,166

4 Economic evaluation per zone

4.1 Basic principles in the Cost Benefit Analysis

In this section the basic principles that are used in this CBA are explained. The general approach within the CBA is that investments are compared with the discounted benefits over the anticipated lifespan of the investments, which for all investments is put at 30 years, which is the estimated technical lifespan of the investments. Furthermore, it is estimated that a new round of improvements is required after 2050, due to increasing risks caused by continuing sea level rise, subsidence and economic growth. The investments and discounted benefits are compared in a Benefit / Cost ratio (B/C-ratio). Because of the uncertainties in the assessment of the investment costs and the determination of the benefits (at this point not all benefits are known, nor can these be accurately calculated), investments are judged economically feasible when the B/C-ratio is between 0.8 – 1.2. Below a B/C-ratio of 0.8 investments are not considered to be economically feasible and investments should be reconsidered. Redesign of investments could be done by only investing in economically feasible components, e.g. constructing embankments at a lower safety level, only construction of cyclone shelters, or only rehabilitation of the drainage system. Investments that have a B/C-ratio of more than 1.2 are considered to be very economically feasible, e.g. because current risk profile is very high. Investment in these polders should receive priority in programming of investments, as the significant benefits can be obtained from interventions in these polders. As budget in Bangladesh is a constraint, a discount rate of 12 % is used. This discount rate, in combination with the used SSP2 scenario for economic and population growth results in a net discount rate of around 6 %. This rate is adequate to substantiate economic viability of investments when B/C-ratio is above the threshold.

In summary, in the CBA the following points of departure have been used;

- Discount rate of 12%
- Economic evaluation of technical lifespan of investments of 30 years
- All investments are considered to be done in year 0
- Full benefits are assumed to occur from year 1
- Economic and demographic developments are considered to follow the SSP2 scenario (Riahi et al., 2017)
- Effects of climate change and subsidence are considered to occur linear over time between current and 2050
- Value of a statistical life (VoSL) is US$ 205,000 (Viscusi and Masterman, 2017)

Based on these points of departure an economic evaluation has been conducted for the investments as proposed in the chapter 3. As in that chapter the economic evaluation will be presented per zone. Details on individual polders can be found in the Annex C.

4.2 Western Zone

In Table 4-1 the economic evaluation of the western zone is presented and the individual polders that are located in this zone. The overall B/C-ratio for the zone is 1.5, which is good from an economic perspective. As risks were assessed to be relatively low, investments were also relatively modest. All polders have a positive B/C ratio, with the exception of polder 29. However in the 5 polder report (Deliverable 5A-3) it was noted that the embankments for polder 29 are relatively high, so investments for this polder will be lower than the standard calculation used in this report. The relatively modest investments and the systemic problems that exist in the western zone make this zone very suitable to be implemented with priority. When the zone as a whole is considered, there will be a number of systemics interventions, e.g. the Sibsa – Pussur changes, that could be incorporated in the investment plan. Also possible intervention for the Gorai will significantly benefit the western zone. However, the systemic interventions for the western zone should be further researched before a design can be made. The different models that are developed under the current Long Term Monitoring, Research and Analysis project are very suitable to investigate the effects of proposed systemic interventions before a choice for a specific solution can be made.

Table 4-1 Economic evaluation of the western zone and its polders

		Economic Calculations					
Polder No	Zone	Costs	Benefits (flood risk reduction)	Benefits CS	Benefits Agr. Prod	Total Benefits	B/C Ratio
06-08	West	95	77	59	16	151	1.6
9	West	10	19	2	1	22	2.2
18-19	West	27	20	2	3	25	0.9
20, 20/1	West	9	8	1	1	11	1.2
21	West	6	7	1	1	9	1.3
22	West	19	15	2	1	18	1.0
28/1	West	19	53	11	5	69	3.6
28/2	West	13	31	6	2	39	3.1
29	West	54	17	14	7	37	0.7
30	West	20	41	9	5	55	2.8
31	West	50	50	8	6	64	1.3
31/Part	West	14	13	0	4	17	1.2
	Total	**335**	**349**	**114**	**54**	**516**	1.5

4.3 Southern zone

In Table 4-2 the economic evaluation of the southern zone is presented and the individual polders that are located in this zone. The overall B/C-ratio for the zone is 1.3, which is good from an economic perspective. However, there is a large difference between individual polders in the southern zone, with B/C ratios between 0.1 and 21.5. The large variations in B/C-ratio seem to stem from discrepancy between the investments and the benefits from risk reduction. The most likely cause is the fact that polders with low asset values are over protected at a 1/50 safety level. The southern zone should be further analysed and an approach with risk-based safety standards should be applied. This will improve the economic viability of the proposed investments.

Table 4-2 Economic evaluation of the southern zone and its polders

		Economic Calculations					
Polder No	Zone	Costs	Benefits (flood risk reduction)	Benefits CS	Benefits Agr. Prod	Total Benefits	B/C Ratio
39/1A	South	157	132	3	10	145	0.9
39/2A	South	63	36	9	4	49	0.8
40/1	South	19	11	-	2	13	0.7
41/1	South	107	27	9	3	40	0.4
41/2	South	105	41	8	3	52	0.5
41/3	South	19	14	2	1	17	0.9
41/4	South	46	17	-	1	18	0.4
41/6A	South	89	54	5	3	61	0.7
41/6B	South	82	3	16	6	25	0.3
41/7	South	66	11	12	6	29	0.4
41/7A	South	33	9	1	5	15	0.5
41/7B	South	10	10	3	5	18	1.8
42	South	86	37	-	2	40	0.5
43/1	South	172	104	28	9	141	0.8
43/1A	South	37	17	2	2	22	0.6
43/1B	South	9	187	14	3	203	21.5
43/2A	South	57	35	10	4	49	0.9
43/2B	South	37	46	5	5	56	1.5
43/2D	South	60	57	14	6	77	1.3
43/2E	South	76	16	2	1	20	0.3
43/2F	South	40	17	6	4	26	0.7
44	South	191	138	10	15	162	0.8
46	South	71	40	0	4	44	0.6
47/3	South	14	10	2	2	14	1.0
47/4	South	125	49	1	6	55	0.4
47/5	South	120	19	-	6	25	0.2
49	South	4	5	1	-	6	1.4
52/53A	South	51	8	-	3	11	0.2
52/53B	South	71	28	-	3	31	0.4
55/2A	South	33	47	10	6	63	1.9
55/2B	South	35	17	1	2	20	0.6
55/2C	South	55	41	6	5	52	1.0
55/2E	South	53	71	22	9	101	1.9
55/3	South	214	63	5	8	76	0.4
55/4	South	176	51	3	4	59	0.3
56/57	South	644	2,134	252	106	2,492	3.9
58/1	South	96	50	-	4	53	0.6
58/2	South	158	27	-	4	31	0.2
58/3	South	119	15	0	1	16	0.1
		3,600	**3,694**	**458**	**277**	**4,429**	1.3

4.4 Eastern zone

In Table 4-3 the economic evaluation of the eastern zone is presented and the individual polders that are located in this zone. The overall B/C-ratio for the zone is 2.4, which is very good from an economic perspective, value of the benefits is more than twice the investment costs. Furthermore, all the polders have a positive B/C-ratio. However, the interventions for the polders in the eastern zone are large and complicated, especially interventions for polder 59/2 require further study before the technical feasibility of the proposed investments are validated. These technical complications and the high costs of investments make that the investments for this zone should not receive first priority but should be scheduled when technical performance and technical feasibility is proven.

Table 4-3 Economic evaluation of the eastern zone and its polders

		Economic Calculations					
Polder No	Zone	Costs	Benefits (flood risk reduction)	Benefits CS	Benefits Agr. Prod	Total Benefits	B/C Ratio
59/2	East	184	170	45	18	232	1.3
61/1	East	184	234	-	7	241	1.3
61/2	East	96	155	62	17	233	2.4
72	East	149	749	-	19	768	5.2
73/1 (A & B)	East	203	604	-	18	622	3.1
73/2	East	116	165	-	10	175	1.5
	Total	**932**	**2,076**	**106**	**90**	**2,272**	2.4

4.5 South-Eastern zone

In Table 4-4 the economic evaluation of the eastern zone is presented and the individual polders that are located in this zone. The overall B/C-ratio for the zone is 3.7, which is extremely positive from an economic perspective, value of the benefits is more than three times the investment costs. Furthermore, most of the polders have a positive B/C-ratio. However, the interventions for the polders in the south-eastern zone are very substantial and require further study before the technical feasibility of the proposed investments is validated. However, technical complexity is less than the eastern zone, giving the south-western zone priority above the eastern zone. Similat to the eastern zone more research will be required to validate the boundary conditions and starting points used in the investment plan to validate the proposed embankment designs used for this region. Because of the exposed location and the significant storm surge for this zone, careful consideration should be given to make designs for embankments that will provide adequate safety to the zone.

Table 4-4 Economic evaluation of the south-eastern zone and its polders

		Economic Calculations					
Polder No	Zone	Costs	Benefits (flood risk reduction)	Benefits CS	Benefits Agr. Prod	Total Benefits	B/C Ratio
62	South-East	367	3,995	730	5	4,730	12.9
63/1A	South-East	385	221	52	6	280	0.7
63/1B	South-East	15	561	-	6	567	37.0
64/1A	South-East	201	152	-	5	157	0.8
64/1B	South-East	40	350	7	7	364	9.1
64/1C	South-East	83	74	-	2	75	0.9
64/2A	South-East	15	164	-	3	167	10.9
64/2B	South-East	383	472	-	7	479	1.3
65	South-East	106	269	-	6	274	2.6
66/1	South-East	53	95	-	4	99	1.9
66/2	South-East	41	62	1	2	66	1.6
66/3	South-East	129	97	6	4	107	0.8
66/4	South-East	50	5	-	3	8	0.2
69/NE	South-East	34	94	-	2	96	2.8
70	South-East	74	157	-	3	160	2.2
71	South-East	191	410	-	4	415	2.2
	Total	**2,166**	**7,179**	**796**	**69**	**8,044**	3.7

5 Way forward; Planning and funding

5.1 Combined investment budget

There are 73 polders for which both a risk analysis is carried out and which have sufficient basic data and do not belong to either the CEIP I or CEIP II project (30 polders), as these polders are already funded.

Of the 109 polder that are not in CEIP I or II, there are 10 polders with insufficient basic information (sometimes polders like 37 or 38 are not yet constructed), while 26 do not have a risk profile, making it impossible to make an economic evaluation. However, for all polders there is a factsheet in Annex C in which the available basic information is presented, as well as the proposed investments for all polder that have adequate basic information. The factsheet includes the different benefit categories when a risk profile is available. These factsheets can serve as a quick access to the data and information for any specific polder. The total investments for the 109 polders is USD 10.5 billion.

Table 5-1 Combined investments for all polders in Bangladesh

	Total investments		
	Number of units	Average Unit costs	Investments (USD million)
Polder area (ha)	571,743		
Population	7,764,486		
Embankment Length (km)	2,910	1,614,309	4,698
Bank protection Works (km)	130	8,250,000	1,072
Khal Length (km)	3,663	25,000	92
# Regulators (new)	1,271	350,000	445
# Regulators (repair)	527	25,000	13
# New Cyclone Shelters	951	750,000	713
RO plants	4,000	26,000	104
Cross dams			1,325
Missing polders			2,000
Total			10,462

Table 5-2 Economic evaluation of the investments (USD million) in all polders in Bangladesh

		Economic Calculations (USD million)					
Polder No	Zone	Costs	Benefits (flood risk reduction)	Benefits CS	Benefits Agr. Prod	Total Benefits	B/C Ratio
59/2	East	184	170	45	18	232	1.3
61/1	East	184	234	-	7	241	1.3
61/2	East	96	155	62	17	233	2.4
72	East	149	749	-	19	768	5.2
73/1 (A & B)	East	203	604	-	18	622	3.1
73/2	East	116	165	-	10	175	1.5
	Total	**932**	**2,076**	**106**	**90**	**2,272**	2.4

5.2 Key development directions for the polders

For each of the polders in the coastal zone of Bangladesh a risk profiles is developed that gives potential damages to infrastructure and the population due to the increasing exposure to sea level rise, increasing cyclonic storms and land subsidence. Based on these risk profiles of the polders an investment program is proposed to reduce the risk to an acceptable level. For the polders this means a protection to floods from storm surge to a return period of 1/50 years under current conditions. Under pressure of climate change and subsidence the protection levels is predicted to change to 1/25 years in 2050.

Based on the current knowledge on storm surge and sediment flows it was only possible to design an intervention for the individual polders. However, with the models as developed by the project interventions should be assessed into more detail. This assessment should look into a more diverse approach in which a differentiation between protection levels between polders is introduced based on the risk profile and the required investment costs. For some polders that have low risk profiles (e.g. from low exposure, or low value of assets) lower protection levels could have higher economic returns. Furthermore, more tailor made solutions for polders, including participation by local stakeholders, can increase ownership of the investments, which in turn can be positive for operation and management.

Another type of investments that is not proposed in this document are “systemic interventions”. This type of intervention, like the combining of polders, need more research, as this type of interventions can have important effects on the functioning of the polder/river -system as a whole. One of these interventions is the remediation of the tidal connection that has formed between the Pussur and Sibsa rivers, causing significant erosion for certain polders and the ongoing sedimentation of the access of Mongla port. Any intervention for this problem should be carefully modelled before a mitigation investment program is proposed.

The planning of the implementation of the investments is currently not detailed. Although the general plan is to complete the investments for the polders before 2050, the current rate of implementation is not fast enough. When the remaining 100 + polders need to be completed well before 2050 the rate of implementation should be at least 5 polders per year.

5.3 Funding

In order to be able to implement the investments for the polders there is a need for adequate funding of the required works. This chapter provides some insight into the different financial resources that can be used in order to finance the proposed investments identified for the different polders. Because the investments for the polders are varied and range between typical disaster reduction measures (such as cyclone shelters), infrastructure improvements and nature-based solutions, also the financing options are diverse and should be appropriate for the different interventions. However, as measures could contribute to different goals altogether (such as improving agriculture *and* reducing risks), it is often not easy to find the right financial source. And it also could be a mixture of sources. Indeed, there is much added value in creating synergies between climate adaptation expenditure and development budgets (Resch et al., 2017).

In this study we focus on two major sources: funding for DRR and climate change adaptation. Basically, there are three types of sources that focus on these (Hirsch et al., 2019):

- Domestic sources: To finance climate adaptation and risk reduction, governments usually create own budget lines (e.g. for a ministry for disaster management) or set up national climate change funds (e.g. the Bangladesh Climate Change Trust Fund – BCCTF). Eventually, these come from general tax revenues, while also location-specific taxes, surcharges or fees are important, as these revenues can typically be used for O&M of infrastructure.
- Bilateral donor assistance (ODA): Grants or concessional loans, e.g. for financing coastal protection, water conservation (e.g. German International Climate Initiative – ICI).
- Multilateral climate funds: Grants or concessional loans (e.g. Green Climate Fund)

For the domestic sources, the investments should fall within the Bangladesh Delta Plan 2100, as currently this is the overarching policy that also includes investments for the polders. For the bi- and multilateral financial sources, section 5.3.3 will provide additional information.

5.3.1 National Budget

Labelling funding for disaster management is complex as these funds are spread across various ministries and governmental institutions. Investments for the polders is generally funded through central government and BWDB. However, tax collection is not very high in Bangladesh, resulting in a below average share of the GDP of below 15 % for the governmental budget. The National Budget for 2017 – 2020 amounts to BDT 3,16,612 crore (USD 36 billion; of which 89 % contributed by tax and the remainder through borrowing and grants), while the GDP amounted to 22,50,479 crore (USD 274 billion) (MinFin[8], BBS, 2019[9]). The low percentage of GDP for the governmental budget makes that large investments from the state are problematic.

Expanding the tax base of the government would increase the availability of funds considerably. Currently Bangladesh has one of the lowest government expenditures compared to GDP. In middle income countries often the government budget is around 20 – 25 % of GDP, while for western European countries expenditures can be as much as 40 – 50 % of GDP. In addition, investments through public-private partnerships (PPP) could be considered, especially in the case of cross dams as land reclamation can generate substantial revenues through the sale or lease of new land, or taxes on increased economic activities, thus offsetting public adaptation investments (Bisaro et al., 2019). For instance, in the Bangladesh Delta Plan, also private financing is targeted. Annual private inflows peak in 2021 at USD 72 million, which is a modest amount to start with, but will gradually increase after pioneer PPP projects show success, and after institutional reforms are implemented.

5.3.2 Bangladesh Delta Plan

In the Bangladesh Delta Plan 2100 (BDP2100[10]) the government has committed to spend a considerable part of GDP on projects to adapt to climate change and provide the country with adequate infrastructure for public services and reduction of disaster risks. It is expected that 99% of total expenditures on the plan will be publicly financed. The government is expected to finance the BDP2100 projects at a level of 0.8% of GDP which would grow to 1.3% of GDP by FY2025. Given current GDP projections, this suggests that by 2020, BDT270 billion (USD 3 billion) in public sector funds should be available, rising to BDT450 billion (USD 6 billion) in 2025, and growing from there with GDP. This would provide a significant national budget that could be used to finance a substantial part of the investment agenda for coastal resilience. The Delta Plan also envisages private finance of Delta projects (GoB, 2018). Table 5-3 shows a number of coastal projects identified in the BDP2100 with a total of around US$ 10 billion and identifies potential linkages with the Strategic Agenda. It is good to note that the order of magnitude of investment is about the same as the Strategic Agenda, which gives confidence as both have been developed through different methods. Some categories come to more or less similar investment budget (such as cyclone shelters and embankment improvements), while land reclamation in the BDP is being allocated one order of magnitude less than in the Strategic Agenda (USD 89 versus 799 – 1782 million, respectively). Because of differences in category or project definition it is difficult to make more accurate comparisons. For instance, mangrove afforestation is not a separate project within the BDP portfolio but is probably part of several projects.

---

[8] https://mof.gov.bd/site/view/budget_moff

[9] BBS, 2019, Statistical Year Book Bangladesh 2018

[10] Bangladesh Delta Plan 2100, Volume 2, Investment Plan Part 1, The Plan

Table 5-3 Portfolio of coastal projects in the Bangladesh Delta Plan 2100

BDP2100 portfolio	US$ million	Embankment improvement	Tidal River Management	Hybrid solutions	Cross dams and land reclamation	Mangrove afforestation	Cyclone shelters	Institutional Strengthening
CZ 1.3 Char Development and Settlement Project- V	14				✓	✓		
CZ1.39 Morphological Dynamics of Meghna Estuary for Sustainable Char Development	1				✓	✓		
CZ1.52 Land beyond Land, Efforts to Reclaim lands at near Coast; Preparatory Surveys and Studies	12				✓	✓		
CZ 1.6 Integrated Land Reclamation Project of Hatiya-Dhamar Char-Nijhum Dwip (Cat. 1 project)	7				✓	✓		
CZ1.7 Urirchar-Noakhali Cross Dam Project (Cat. 1 project)	55				✓	✓		
CZ 1.26 Development of Water Management Infrastructure in Bhola Island	185	✓						
CZ1.30 Rehabilitation of Water Management Infrastructure in Bhola District	295	✓						
CZ1.44 Rationalization of Polders in Baleswar – Tentulia Basin	1,997	✓				✓		
CZ1.45 Program for Implementation of Rationalized Water Related Interventions in Baleswar-Tentulia Basin	111	✓				✓		
CZ1.47 Rationalization of Polders in Gumti - Muhuri Basin	811	✓						
CZ1.48 Program for Implementation of Rationalized Water Related Interventions in Gumti - Muhuri Basin	176	✓						
CH1.10 Rationalization of polders in Chittagong coastal plain	534	✓						
CZ1.40 Rationalization of Polders in Gorai-Passur Basin	1,343	✓				✓		
CZ1.41 Program for Implementation of Rationalized Water Related Interventions in Gorai-Passur Basin	184	✓				✓		
CZ 1.11 Improved Drainage in the Bhabadha Area	20		✓					
CZ12.6 Integrated Coastal Zone Land use Planning in Bangladesh using GIS and RS Technology	11							✓
CZ1.53 Structural interventions for managing sea level rise: preparatory surveys & studies	13			✓				✓
CZ4.1 Development of Climate Smart Integrated Coastal Resources Database (CSICRD)	2							✓
CZ 1.5 Study on Tidal River Management	16		✓					✓
CZ12.8 Southern Agricultural Improvement Project (SAIP)	494		✓					
CZ17.1 Exploration of the Production Potential of Coastal Saline Soils of Bangladesh	1							✓
CC1.4 Development/Improvement of Multi-purpose Disaster Shelters and its Management Information System	3,876						✓	
	10,158	5,636	530	13	89		3,876	27

5.3.3 International donors

International donors can invest directly in coastal projects, both directly at the local, regional and national level. Known donors in such projects include the World Bank, ADB, JICA, Dutch Aid (for Bangladesh) and the EU. The different international donors have different focus areas in which they finance projects. Different donors can thus be involved in different types of investments, e.g. infrastructure, early warning systems or community-based interventions.

Multinational Development Banks already incorporate biodiversity and nature considerations into their projects. The World Bank, for example, applies its Environmental and Social Framework (ESF) since October 2018 to all new World Bank investment project financing. The ESF, based on 10 environmental and social standards, has been introduced to better manage environmental and social risks of projects and to improve development outcomes. The application of Standard 6, “Biodiversity Conservation and Sustainable Management of Living Natural Resources” is especially relevant for infrastructure investments in coastal zones to move towards integrating nature-based solutions to maintain the benefits from ecosystem services (Thiele et al., 2020).

Capital for traditional bankable infrastructure projects is widely available in the market. However, available capital is often not channeled to innovative, nature-based solutions, due to unfamiliarity with the opportunities, lack of sizeable cash flows in the short term from goods and services, perceived risks due to governance and land ownership and longer-term uncertainties surrounding nature-based solutions under unpredictable climate change scenarios. Many of these challenges can be overcome by offering blended finance solutions, where grant and concessional funding from public or private climate finance sources will be mobilized to reduce identified risks. It is therefore encouraging to note that new platforms are now rapidly emerging, specifically targeting the preparation of sustainable infrastructure projects in developing countries, often using public donor funding. Examples are the recently announced collaboration of the Asian Development Bank with Infrastructure Asia to create the Innovative Finance Lab for Sustainable Infrastructure, which will complement the ASEAN Catalytic Green Finance Facility (ACGF). This Lab aims to accelerate collaboration with the private sector to improve policy making capacities and foster the adoption of innovative and green finance models in local and municipal infrastructure projects in ASEAN countries (Thiele et al., 2020).

ADB launched its Action Plan for Healthy Oceans and Sustainable Blue Economies in May 2019. It aims to scale up investments and technical assistance to USD 5 billion between 2019–2024. The action plan highlights four focus areas, including sustainable coastal infrastructure and ecosystem management and rehabilitation. ADB also launched an Oceans Financing Initiative, which aims to leverage ADB and donor funds and technical assistance, along with innovative financing instruments, to create “bankable” investment opportunities and attract financing from a range of sources, including the private sector. The initiative is first being piloted in Southeast Asia with support from the ASEAN Catalytic Green Finance Facility (ACGF) (under the ASEAN Infrastructure Fund), the Republic of Korea, and World Wide Fund for Nature (Thiele et al., 2020).

Similarly, there is the ProBlue program, a new Multi-Donor Trust Fund, housed at the World Bank, that supports the development of integrated, sustainable and healthy marine and coastal resources. It is part of the World Bank’s overall Blue Economy program, which as of March 2020 amounted to around USD 5.6 billion in active projects, such as Building government capacity to manage marine resources, including nature-based infrastructure such as mangroves (WB, 2020)

5.3.4 Climate finance

Climate finance is money earmarked for investment in projects that aim to reduce emissions (*climate mitigation)* or to adapt to the consequences of climate change (*climate adaptation)*. As future increased flood risk can partly be attributed to climate change (e.g. from sea level rise or increased storm intensity), these adaptation funds might be (partly) used for flood risk reduction, on the condition that the part that can be attributed to climate change should be quantified. There are several funds existing, each with its own specific scope and conditions (see Table 5-4).

Another mechanism are green bonds, which provide loans below market rate, but which have specific requirements that have to be met on climate mitigation or adaptation goals. Green bonds are normally used for projects that generate a cash revenue that can be used to service the loan. This could be used in a real estate development project that includes mitigation (e.g. energy neutral building) and adaptation (e.g. water retention and reduced runoff) targets.

As Bangladesh ranks sixth and India ranks fourteenth in the Global Climate Risk Index of most affected countries[11], there should be a good ability to gain access to climate finance funds available for the proposed measures. This would require a quantification of the climate change adaptation contribution of these measures. In Bangladesh, climate finance is expected to contribute 12% toward the total capital expenditures on the BDP2100 Investment Plan (GoB, 2018).

Table 5-4 Main climate change adaptation funds

Fund	Description
Adaptation Fund	The Adaptation Fund is a financial instrument under the UNFCCC and its Kyoto Protocol (KP) and has been established to finance concrete adaptation projects and programmes in developing country Parties to the KP, in an effort to reduce the adverse effects of climate change facing communities, countries and sectors.
Global Environment Facility (GEF)	The Global Environment Facility (GEF) was established on the eve of the 1992 Rio Earth Summit to help tackle our planet’s most pressing environmental problems.
Green Climate Fund (GCF)	The Green Climate Fund (GCF) was adopted as a financial mechanism of the UN Framework Convention on Climate Change (UNFCCC) at the end of 2011. It aims to make an ambitious contribution to attaining the mitigation and adaptation goals of the international community. Over time it is

[11] Bangladesh CRI score of 22.67. See: Germanwatch 2016. Global Climate Risk Index 2017: Who suffers most from extreme weather events? Weather-related loss events in 2015 and 1996 to 2015. Briefing paper written by: Sönke Kreft, David Eckstein and Inga Melchior

	expected to become the main multilateral financing mechanism to support climate action in developing countries.
Climate Investment Fund (CIF)	The $8 billion Climate Investment Funds (CIF) accelerates climate action by empowering transformations in clean technology, energy access, climate resilience, and sustainable forests in developing and middle income countries.
Special Climate Change Fund (SCCF)	The Special Climate Change Fund (SCCF) supports adaptation and technology transfer in all developing country parties to the United Nations Framework Convention on Climate Change (UNFCCC), supporting both long-term and short-term adaptation activities in water resources management, land management, agriculture, health, infrastructure development, fragile ecosystems, including mountainous ecosystems, and integrated coastal zone management
Least Developed Countries Fund	The Least Developed Countries Fund (LDCF), established under the United Nations Framework Convention on Climate Change (UNFCCC), addresses the special needs of the Least Developed Countries (LDCs) that are especially vulnerable to the adverse impacts of climate change.

References

A.S. Qureshi, S. Yasmin, N.C. Howlader, K. Hossain and T.J. Krupnik (2015). Potential for expansion of surface water irrigation through axial flow pumps to increase cropping intensification in southern Bangladesh. In: Humphreys, E., T.P. Tuong, M.C. Buisson, I. Pukinskis and M. Phillips. 2015. Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices Conference Proceedings. Colombo, Sri Lanka: CGIAR Challenge Program on Water and Food (CPWF). 600pp.

Azad, A. Kalam, C. Kwei Lin & Kathe R. Jensen (2008). Coastal aquaculture development in Bangladesh: un-sustainable and sustainable experiences. IIFET 2008 Vietnam Proceedings.

Blue Gold (2019): IMPROVING THE PRODUCTIVITY OF LAND IN COASTAL BANGLADESH Outcomes of Blue Gold Program interventions 2013 – 2019. PowerPoint slides.

CEGIS (2016a). Final report on Environmental Impact Assessment on Rehabilitation of Polder 29. Blue Gold Program, BWDB, Dhaka.

CEGIS (2016b). Final report on Environmental Impact Assessment on Rehabilitation of Polder 43/2B. Blue Gold Program, BWDB, Dhaka.

CEIP-I (2012). Technical Feasibility Studies and Detailed Design for Coastal Embankment Improvement Programme (CEIP). Contract Package No. BWDB/D2.2/S-3. Volume IV: Polder Reports.

CEIP-I (2021). Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone. Report on Selection of Polders for Conceptual Design as Pilot Program (Revised). IWM. Dhaka.

Deltares et al. (2020). Coastal Resilience: Developing New and Innovative Approaches in India and Bangladesh along the Bay of Bengal. Appendix B, Strategic Investment Agenda Bangladesh. Delft/Dhaka.

Dewan, C. & M. Das (2012). Situation Analysis Polder 43-2F, Amtoli Upazila, Barguna. G3: Water Governance and Community Based Management. Ganges Basin Development Challenge. CGIAR, IWMI & Shushilan, Dhaka.

Islam, Arpita (..) Mathematical Modelling for Analysis of Drainage Congestion Problem of Polder 29 In Khulna District.

IWM (2016). The study of river bank erosion, management in Polder 29, Khulna. Final Report. Blue Gold Program, Dhaka.

IWM, 2018, Technical Report on Storm Surge, Wave, Hydrodynamic Modelling and Design Parameters on Drainage System and Embankment Crest Level Volume-III: Package-3 (Appendix-B: Storm Surge and Monsoon Water Level)

IWM (2022). Component-5A: Drainage Modelling of Five Polders at Different Coastal Zones in Assessing Infrastructure need for Water Management. Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics). DHI and associates. Dhaka, April 2022.

Johnson, F.A., C.W. Hutton, D. Hornby, A.N. Lazar & A. Mukhopadhyay (2016). Is shrimp farming a successful adaptation to salinity intrusion? A geospatial associative analysis of poverty in the populous Ganges–Brahmaputra–Meghna Delta of Bangladesh. *Sustain Sci* (2016) 11:423–439.

Kabir, K.A., S.B. Saha, M. Karim, C.A. Meisner and M. Phillips (2015). Productivity, diversification and resilience of saline aquaculture systems in coastal southern Bangladesh. In: Humphreys, E., T.P. Tuong, M.C. Buisson, I. Pukinskis and M. Phillips. 2015. Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices Conference Proceedings. Colombo, Sri Lanka: CGIAR Challenge Program on Water and Food (CPWF). 600pp.

Mainuddin, M., Karim, F., Gaydon, D.S. et al. (2021). Impact of climate change and management strategies on water and salt balance of the polders and islands in the Ganges delta. Sci Rep 11, 7041 (2021). https://doi.org/10.1038/s41598-021-86206-1

Maniruzzaman, M. (2012). Situation Analysis. LGED subproject Latabunia, Dumuria Upazila, Khulna. G3: Water Governance and Community Based Management, Ganges Basin Development Challenge.

Mathiesen, J. (2018). Final Report Emergency Works - Polder 29. Blue Gold Program and Northwest Hydraulic Consultants. Dhaka.

Mita, K. S., M. Moshfika, N. U. Rahi and M. Hossain (2017). Impacts of Availability of Irrigation Water on Cropping Pattern, Farmers' Livelihood Change and Adaptation Choices at the Study Areas of Polder-29 in Khulna. 6th Int. Conf. on Water and Flood Management. Dhaka.

Mosselman, E. (2016). Review of IWM study of river bank erosion management in Polder 29, Khulna, Bangladesh. Deltares, Delft.

Mosselman, E. (2017). Review of BWDB designs for river bank erosion management in Polder 29, Khulna, Bangladesh. Deltares, Delft.

Rahman M. A., M. R. A. Sarker, N. Sharma, M. K. Mondal, M. R. Islam, G. B. Gregorio, E. Humphreys and T. P. Tuong (2015). Challenges and opportunities for aman rice cultivation in ghers used for brackish water shrimp production. In: Humphreys, E., T.P. Tuong, M.C. Buisson, I. Pukinskis and M. Phillips. 2015. Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices Conference Proceedings. Colombo, Sri Lanka: CGIAR Challenge Program on Water and Food (CPWF). 600pp.

Riahi, Keywan, Detlef P. van Vuuren, Elmar Kriegler, Jae Edmonds, Brian C. O'Neill, Shinichiro Fujimori, Nico Bauer, Katherine Calvin, Rob Dellink, Oliver Fricko, Wolfgang Lutz, Alexander Popp, Jesus Crespo Cuaresma, Samir KC, Marian Leimbach, Leiwen Jiang, Tom Kram, Shilpa Rao, Johannes Emmerling, Kristie Ebi, Tomoko Hasegawa, Petr Havlík, Florian Humpenöder, Lara Aleluia Da Silva, Steve Smith, Elke Stehfest, Valentina Bosetti, Jiyong Eom, David Gernaat, Toshihiko Masui, Joeri Rogelj, Jessica Strefler, Laurent Drouet, Volker Krey, Gunnar Luderer, Mathijs Harmsen, Kiyoshi Takahashi, Lavinia Baumstark, Jonathan C. Doelman, Mikiko Kainuma, Zbigniew Klimont, Giacomo Marangoni, Hermann Lotze-Campen, Michael Obersteiner, Andrzej Tabeau, Massimo Tavoni (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change*, Volume 42, Pages 153-168, 2017, DOI:110.1016/j.gloenvcha.2016.05.009

Roman, O., Hoque, S. F., Ford, L., Salehin, M., Alam, M. M., Hope, R., & Hall, J. W. (2021). Optimizing rural drinking water supply infrastructure to account for spatial variations in groundwater quality and household welfare in coastal Bangladesh. *Water Resources Research*, 57, e2021WR029621. https://doi.org/10.1029/2021WR029621

Sultana & P. Thompson (2017). Community Based Integrated Water Management Final Report. Supported by the Blue Gold Program. → Polder 29

Taduker, Byomkesh, Md. Saifuzzaman and G.W. van Loon (2015). Sustainability of agricultural systems in the coastal zone of Bangladesh. *Renewable Agriculture and Food Systems*, 1-18.

USAID/Pro WASH/World Vision, Sustaining Reverse Osmosis Water Treatment Systems: An Example From Bangladesh, 2021, https://www.fsnnetwork.org/sites/default/files/2021-05/STC_PRO-WASH_ReverseOsmosisBrief_5-24-2021.pdf

Viscusi and Masterman (2017). Income Elasticities and Global Values of a Statistical Life. https://law.vanderbilt.edu/phd/faculty/w-kip-viscusi/355_Income_Elasticities_and_Global_VSL.pdf

World Bank (2014). Project Appraisal Document. Bangladesh Multipurpose Disaster Shelter Project (MDSP).

Annex A: Principle design sketches dike improvement Bangladesh

Introduction

Along the coast of Bangladesh and more inland along the river systems that form the Bangladesh delta several polders have been created in the past. To improve the safety against flooding of the polders an evaluation of the water retaining systems has been made and several measures to improve safety against flooding are elaborated. One of these measures is improving the dikes around the polders. This memo describes a series of principle sketches of improved dike cross sections. Based on these sketches a first impression of the consequences of dike improvement in this area can be elaborated.

The differences between the different the different elaborated cross sections follow from differences in loading conditions and bathymetry of the foreshore. It should be noted that subsoil conditions can have a strong influence on the required geometry of a dike. For example, low sub soil strength might result in low bearing capacity and therefore stability issues. Internal erosion processes, like piping, might weaken sub soil strength and as such induce failure during a high-water event. At the moment of writing this memo, little to no sub soil related information is available. However, a visual inspection of the protection system of one of the polders shows that besides the height of the dikes and levees, foreshore erosion due to wave action or river scour represents the main failure mechanism. Stability issues and / or internal erosion, either through the dike body or in the subsoil was not observed. It should be noted that these mechanisms could become relevant when upgrading the existing structures such that it can withstand higher water levels.

A proper dike reinforcement design should deal with all relevant failure mechanisms. Due to the absence of subsoil information, the resistance against the different failure mechanisms is not elaborated here. The principle sketches, discussed in this memo, cannot be seen as a design of the required dike reinforcement. Instead the principle sketches are meant to provide an educated impression what the dimensions of the dike reinforcement could be. Since raising a dike also requires widening the base, in order to secure stability issues, conflicts with land ownership and the presence of buildings on or the present dike might emerge. The principle sketches are meant to acquire a first approach in the footprint of the improved dike system and will be the input for a budget estimate required to realize the improved safety against flooding.

Construction material

At this early stage of designing the dike reinforcement, the construction material is assumed to be produced by locally dredged material. At this moment no specifications of the locally dredged material are available and the applicability of this material for dike construction is unknown. When using dredged material for dike construction, the following issues are relevant:

Liquidity;

When the material is too wet, the material volume will considerable shrink upon drying. This volume reduction will lead to considerable cracking when the initial water content is above the liquid limit of the material. It is obvious that considerable cracks in the dike body should be avoided. The liquidity index, I_l, and consistency index, I_c, is a measure for the liquidity of the material:

$$I_l = \frac{w - PL}{I_p}, \quad I_c = \frac{LL - w}{I_p}$$

In which:

I_l = liquidity index

I_c = consistency index

w = water content

PL = plastic limit

I_p = plasticity index, $I_p = LL - PL$

LL = liquid limit

It should be noted that the liquidity index is the inverse of the consistency index, I_c. Typically, after dredging, the water content will be beyond the liquid limit and $I_l > 1$. In that case the material should allow to dry until the water content is sufficiently dropped and $I_l < 0.25$, $I_c > 0.75$, before it is used as a construction material. For the core of the dike $I_c > 0.6$ can be used. Drying clay means that the dredged material should be placed in ridges of 0.5 – 1.0 m high and is allowed to dry for several weeks or months before used as construction material.

Ability to densify

To improve material properties like stiffness and strength, resistance against erosion and reduce development of cracks, the material should be densified when building the dike. For optimum densification, the material should not be too wet, see text above. For clayey material, the densification should be done by using a static load.

Typically, silts and sands in Bangladesh contain mica. Mica is recognised as the shiny thin plates that are present between the sand grains. The presence of the flaky mica particles between the spherical sand particles will cause bridging and other complex behaviour at microscopic level. As such micaceous sands are known for their problematic densification abilities. Before the material is used for construction material the properties of the material and the ability for densification should be tested.

Erodibility

Sand and silty material will easily erode when in contact with water. When the construction material contains a high silt or sand fraction erosion problems are to be expected. Regarding shore protection, a revetment or other protective constructions will be built. However, the material should contain at least enough resistance against erosion due to rainfall. Consequently, the construction material should contain a sufficiently high clay fraction.

The consequences of these issues above are that the dredged material might not be used directly in the same cross section. Instead mining locations should be found where the right material can be found and / or processing of the material is required before it is applied for construction. Construction alternatives in which the dike body is constructed of an erodible material, sand, protected by a clay cover will not be considered. Since the main failure mechanism, observed in the field, is erosion due to waves and river scour, high resistance against erosion is favoured for the entire construction.

Principle sketches

In total 5 principle sketches are derived for the different loading conditions that can be found in the Bangladesh delta. The loading conditions will be discussed in the description of the principle sketches below. The principles sketches are developed on the following rules:

- The daily mean water table is taken at PWD 0 m.
- The ground level fluctuates between PWD + 1.0 m and PWD + 2.0 m. The dimensions in the principal sketches are elaborated for both values.
- The loading contains a combination of storm surge and wave action. The raised water level due to the storm surge are referred in the principle sketches as Design Water Level. The design wave action is represented by a significant wave height at deeper water, H_s.
- The relevant storm surge levels and significant wave heights are taken from the CEIP technical report on *Storm Surge, Wave, Hydrodynamic Modelling and Design Parameters on Drainage System and*

Embankment Crest Level, Volume-III: Package-3, Appendix-B: Storm Surge and Monsoon Water Level, March 2018.

- The crest width is taken as 3 m in all sketches. In case of severe wave action, a wider crest might be beneficial in improving the probability of failure due to erosion by wave action.
- The inner slope in all sketches are taken at 1(V):3(H). This is an engineering estimate to create a slope which is sufficiently stable for typical construction materials. For low quality construction material and large construction height for example the sea defence Figure and Figure, the slope might be built shallower.
- The slope angle of the outer slope is selected in combination with dike height and expected wave action during design conditions. Wave overtopping should be kept to a minimum unless the inner slope is protected to withstand the expected amount of wave overtopping. The expected amount of wave overtopping during design conditions is estimated following the Overtopping Manual[12] and the computer program PCOverslag.
- According to the overtopping manual an unprotected inner slope should not be loaded with overtopping discharge more than 0.1 l/s/m. A high-quality grass cover can withstand an overtopping discharge of 5 l/s/m. The freeboard presented for the sketches below is based on an overtopping discharge of 1 l/s/m. Consequently, it is assumed that the inner slope is protected by at least a low-quality grass cover.
- In cases where no severe wave action is expected during design conditions, the outer slope angle is selected as 1(V):3(H).
- An additional freeboard of 0.5 m is added. This freeboard accounts for settlement due to added weight, setting of the dike body, general land subsidence and inaccuracies in construction. Due to lack of sub soil information a settlement prediction cannot be made, and 0.5 m is a rough estimate. When organic soils are present in the sub soil settlement, larger than 0.5 m, is to be expected. Regarding settlement it should be noted that:
  - Dikes are already present, so the sub soil is already pre-loaded and not full cross section, as presented below in the principle sketches can be considered as a new loading.
  - Soft soil is expected more inland, where due to reduced wave conditions dike heights are also reduced. The larger dikes are required at the coast where the sub soil contains more stiff sands and silts.
- Due to the additional freeboard the overtopping discharge during design conditions at the start of the life cycle of dike will be smaller than 1 l/s/m/, for which the overtopping freeboard is determined. During its lifetime, the dike will settle and the expected overtopping discharge will increase to 1 l/s/m.

The different sketches are discussed below:

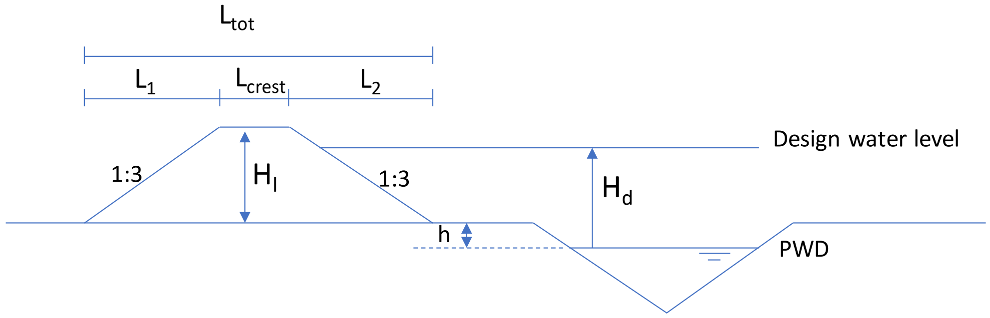
<u>Sketch 1, Narrow channel with foreland</u>

Specifications:

- Some polders are separated by relatively narrow channels.
- During extreme events the water level might rise considerably.
- Wave action and currents are absent or insignificant.
- Daily water levels are within the channel; Under daily conditions the dikes remain dry
- An example of this situation is the channel between polder P45 and P44, with design conditions given for points 39 and 50 in the Annex A of the technical report *Storm Surge, Wave, Hydrodynamic Modelling and Design Parameters on Drainage System and Embankment Crest Level*

---

[12] EurOtop, Manual on wave overtopping of sea defences and related structures, second edition 2018, www.overtopping-manual.com



Figure, Sketch case 1, narrow channel with foreland

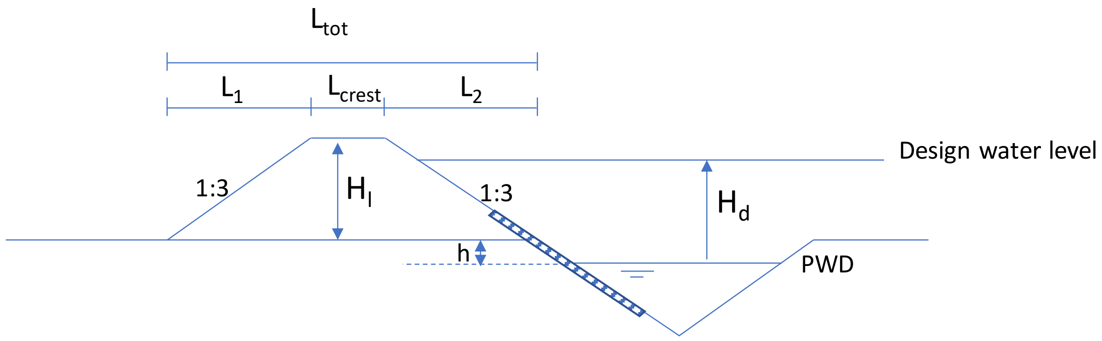
Parameter	Symbol	Unit	Set 1	Set 2
ground level relative to mean sea level	h	[m]	1.0	2.0
design water level relative to mean sea level	H_d	[m]	5.5	5.5
crest level relative to ground level	H_l	[m]	5.0	4.0
length polder side slope	L_1	[m]	15	12
length river side slope	L_2	[m]	15	12
crest width	L_c	[m]	3.0	3.0
total length dike body	L_{tot}	[m]	33.0	27.0

Due to the absence of wave action and strong currents erosion will be limited. A good grass cover or similar protection will suffice to withstand erosion due to rainfall and occurrence of design water level.

Sketch 2, Narrow channel without foreland

Specifications:

- Basically equal to sketch 1,
- During extreme events the water level might rise considerably.
- Wave action and currents are absent or insignificant.
- No foreland presence; dike directly retains water also during daily conditions.



Figure, Sketch 2, Narrow channel without foreland

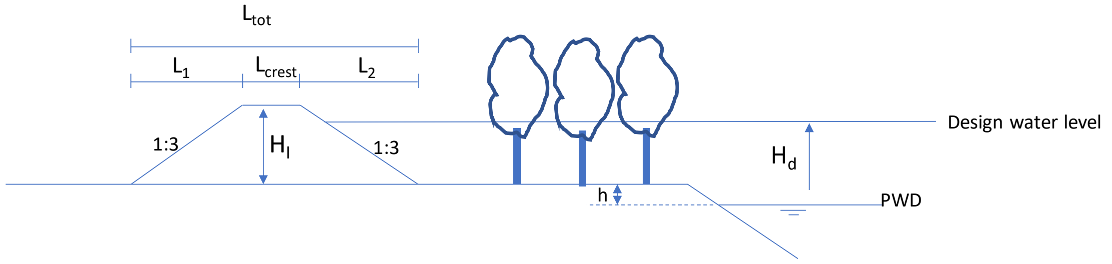
Parameter	Symbol	Unit	Set 1	Set 2
ground level relative to mean sea level	h	[m]	1.0	2.0
design water level relative to mean sea level	H_d	[m]	5.5	5.5
crest level relative to ground level	H_l	[m]	5.0	4.0
length polder side slope	L_1	[m]	15	12
length river side slope	L_2	[m]	15	12
crest width	L_c	[m]	3.0	3.0
total length dike body	L_{tot}	[m]	33.0	27.0

Due to the absence of wave action and strong currents erosion will be limited. Above the water table, a good grass cover or similar protection will suffice to withstand erosion due to rainfall and occurrence of design water level. Around the water level is stone revetment is required.

Sketch 3, along the riverbank

Specifications:

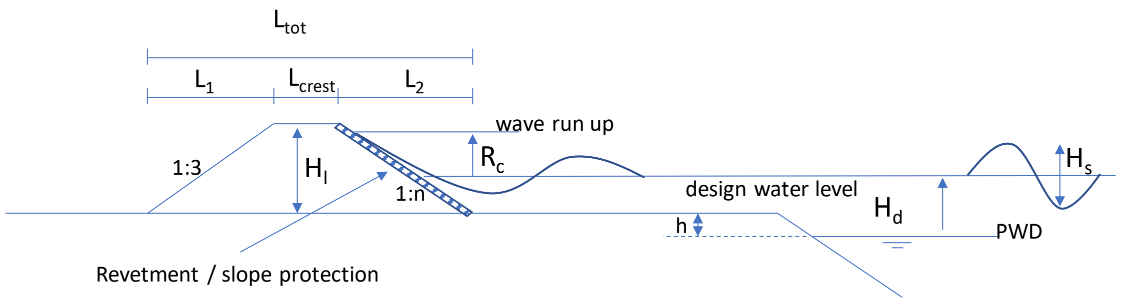
- Along the riverbank
- Foreland typically above daily water levels
- No scour erosion. (sketch 4 includes the conditions with scour)
- if dense mangrove forest is present wave action at the dike will be negligible. Therefore, two options: with and without wave action



Figure, Sketch case 3a, river bank with foreland, no wave action

Parameter	Symbol	Unit	Set 1	Set 2
ground level relative to mean sea level	h	[m]	1.0	2.0
design water level relative to mean sea level	H_d	[m]	2.75	2.75
cfrest level relative to ground level	H_l	[m]	2.25	1.25
length polder side slope	L_1	[m]	6.75	3.75
length river side slope	L_2	[m]	6.75	3.75
crest width	L_c	[m]	3.0	3.0
total length dike body	L_{tot}	[m]	16.5	10.5

When the mangrove is absent, waves will reach the dike and additional height might be required to minimise the amount of overtopping. Large waves will break when reaching the foreland, reducing wave impact on the dike. The level of impact reduction depends on the length and elevation of the foreland. The table below provides the dimensions for two different slopes in combination with different elevations of the foreland and a foreland length of 50 m.



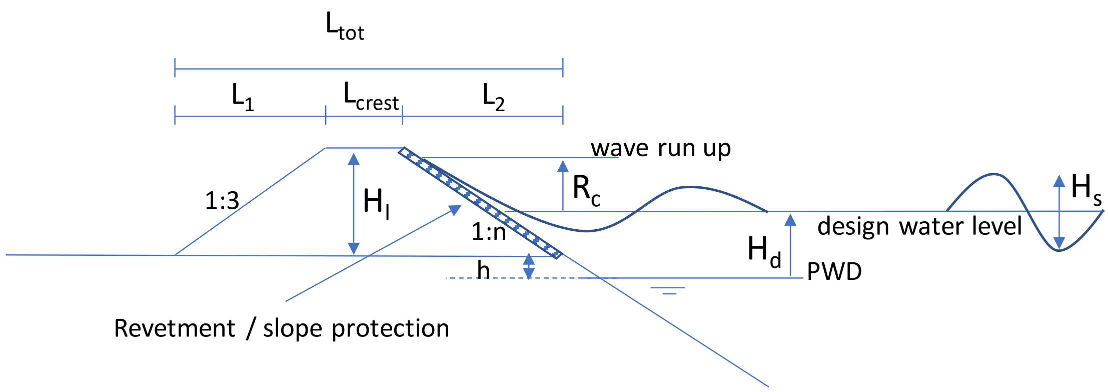
Figure, Sketch case 3b, river bank with foreland and wave action

Parameter	Symbol	Unit	Set 1	Set 2	Set 3	Set 4
ground level relative to mean sea level	h	[m]	1.0	2.0	1.0	2.0
steepness outer slope	n	[-]	3	3	4	4
design water level relative to mean sea level	H_d	[m]	2.75	2.75	2.75	2.75
significant wave height	H_s	[m]	1.5	1.5	1.5	1.5
Freeboard, to reduce overtopping to q_c =1 l/s/m	R_c	[m]	2.25	0.81	1.65	0.81
crest level relative to ground level	H_l	[m]	4.5	2.0	3.9	2.0
overtopping discharge at design conditions	q_c	[l/s/m]	0.25	0.07	0.16	0.07
length polder side slope	L_1	[m]	13.5	6.0	11.7	6.0
length river side slope	L_2	[m]	13.5	6.0	15.6	8.0
crest width	L_c	[m]	3.0	3.0	3.0	3.0
total length dike body	L_{tot}	[m]	30	15	30.3	17

<u>Sketch 4, Riverbank with scour</u>

Specifications:

- Along the riverbank
- Foreland is under attack from river scour
- In the sketch the presence of the foreland is neglected



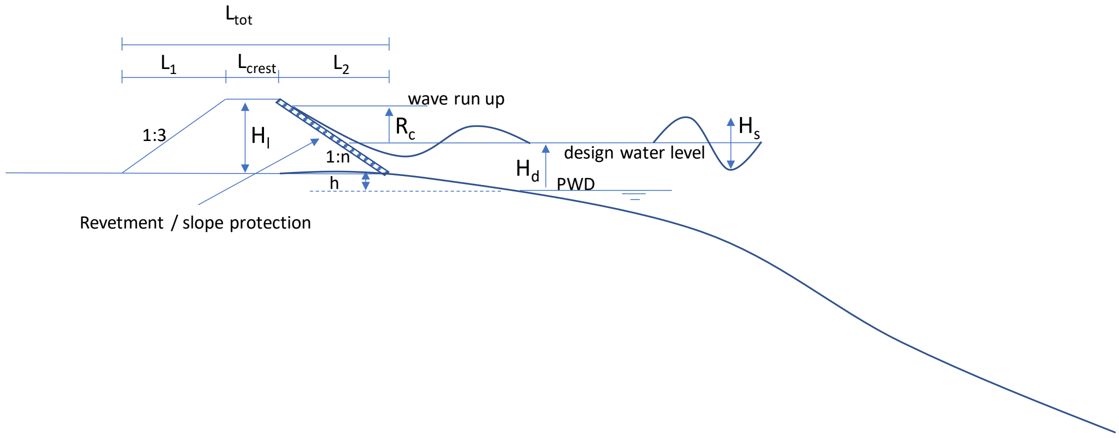
Figure, Sketch case 4, River bank, no foreland with wave action

Parameter	Symbol	Unit	Set 1	Set 2	Set 3	Set 4
ground level relative to mean sea level	h	[m]	1.0	2.0	1.0	2.0
steepness outer slope	n	[-]	3	3	4	4
design water level relative to mean sea level	H_d	[m]	2.75	2.75	2.75	2.75
significant wave height	H_s	[m]	1.5	1.5	1.5	1.5
Freeboard, to reduce overtopping to q_c =1 l/s/m	R_c	[m]	3.25	3.25	2.35	2.35
crest level relative to ground level	H_l	[m]	5.5	4.5	4.6	3.6
overtopping discharge at design conditions	q_c	[l/s/m]	0.32	0.32	0.25	0.25
length polder side slope	L_1	[m]	16.5	13.5	13.8	10.8
length river side slope	L_2	[m]	16.5	13.5	18.4	14.4
crest width	L_c	[m]	3.0	3.0	3.0	3.0
total length dike body	L_{tot}	[m]	36.0	30.0	35.2	28.2

<u>Sketch 5, Sea defence</u>

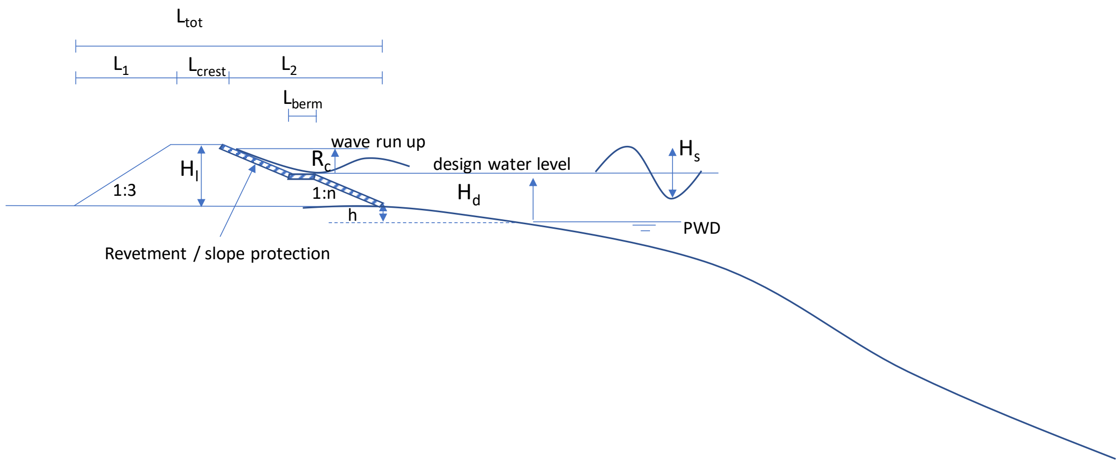
Specifications:

- Direct wave attack from the sea
- Sandy coast
- Due to large wave loads and storm surge, two solutions have been elaborated;
  - Protected slope
  - Protected slope with spilling berm



Figure, Sketch case 5, Sea defence, no berm

Parameter	Symbol	Unit	Set 1	Set 2	Set 3	Set 4
ground level relative to mean sea level	h	[m]	1.0	2.0	1.0	2.0
steepness outer slope	n	[-]	5	5	7	7
design water level relative to mean sea level	H_d	[m]	4.0	4.0	4.0	4.0
significant wave height	H_s	[m]	4.0	4.0	4.0	4.0
Freeboard, to reduce overtopping to q_c =1 l/s/m	R_c	[m]	6.10	6.1	4.25	4.25
crest level relative to ground level	H_l	[m]	9.5	8.5	7.75	6.75
overtopping discharge at design conditions	q_c	[l/s/m]	0.6	0.6	0.4	0.4
length polder side slope	L_1	[m]	28.5	25.5	23.25	20.25
length sea side slope	L_2	[m]	47.5	42.5	54.25	47.25
crest width	L_c	[m]	3.0	3.0	3.0	3.0
total length dike body	L_{tot}	[m]	79	71	80.5	70.5



Figure, Sketch case 5, Sea defence, with berm

Parameter	Symbol	Unit	Set 1	Set 2
ground level relative to mean sea level	h	[m]	1.0	2.0
steepness outer slope (below and above berm)	n	[-]	5	5
design water level relative to mean sea level	H_d	[m]	4.0	4.0
significant wave height	H_s	[m]	4.0	4.0
Freeboard, to reduce overtopping to q_c =1 l/s/m	R_c	[m]	4.7	4.7
crest level relative to ground level	H_l	[m]	8.2	7.2
overtopping discharge at design conditions	q_c	[l/s/m]	0.45	0.45
berm length (outer slope berm)	L_{berm}	[m]	10	10
length polder side slope	L_1	[m]	24.6	21.6
length sea side slope	L_2	[m]	51.0	46
crest width	L_c	[m]	3.0	3.0
total length dike body	L_{tot}	[m]	78.6	70.6

Case 5 is also elaborated for more severe loading conditions, storm surge of 7 m and significant wave height, at deep water, of 5 m. The dimensions are elaborated according to the sketches given by the figures above.

Parameter	Symbol	Unit	Set 1	Set 2
ground level relative to mean sea level	h	[m]	1.0	2.0
steepness outer slope	n	[-]	7	7
design water level relative to mean sea level	H_d	[m]	7.0	7.0
significant wave height	H_s	[m]	5.0	5.0
Freeboard, to reduce overtopping to q_c =1 l/s/m	R_c	[m]	5.5	5.5
crest level relative to ground level	H_l	[m]	12	11
overtopping discharge at design conditions	q_c	[l/s/m]	0.5	0.5
length polder side slope	L_1	[m]	36.0	33.0
length sea side slope	L_2	[m]	84.0	77.0
crest width	L_c	[m]	3.0	3.0
total length dike body	L_{tot}	[m]	123	113

Parameter	Symbol	Unit	Set 1	Set 2
ground level relative to mean sea level	h	[m]	1.0	2.0
steepness outer slope (below and above berm)	n	[-]	7	7
design water level relative to mean sea level	H_d	[m]	7.0	7.0
significant wave height	H_s	[m]	5.0	5.0
Freeboard, to reduce overtopping to q_c =1 l/s/m	R_c	[m]	4.7	4.7
crest level relative to ground level	H_l	[m]	11.2	10.2
overtopping discharge at design conditions	q_c	[l/s/m]	0.48	0.48
berm length (outer slope berm)	L_{berm}	[m]	10	10
length polder side slope	L_1	[m]	33.6	30.6
length sea side slope	L_2	[m]	88.4	81.4
crest width	L_c	[m]	3.0	3.0
total length dike body	L_{tot}	[m]	125	115

Annex B: Risk Calculations; assumptions and damage functions

Values used in the Fiat Configuration Files

Assumptions

Household size (for all polders): 4 --> (value used to compute how many building per cell are)

Type of House/land use	**% of total residential houses**	**Maximum unit damage (BRT)**	**Maximum damage (BRT/m2)**
Pucca	8%	880,000	-
Semmi Pucca	84%	261,500	-
Kitcha	1%	115,200	-
Shanty	7%	30,000	-
Agricultural Land (rice and similar)	-	-	22.14
Agricultural Land (Shrimp - Polder 15 only)			66.42

-->fresh water 66.42 **-->Salty water average value**

In case of flood with salt water cultivation will be hampered for a longer period. When we assume 1 - 3 years to full production losses could be BDT 442,800 – 885,600 (assuming a gradual return to full

We use a final value of 44.28 for rice and similar

2018 values

Replacement costs for houses (from RAP report - CEIP, 2018):

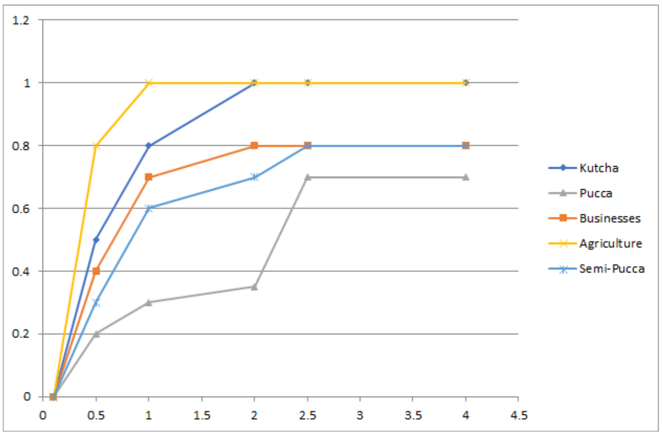
house type	cost per sft	average cost	average size* (sft)	cost per house	USD eq.
pucca	1100	1100	800	880,000	8,916
semi-pucca	475 – 570	523	500	261,500	3,028
Katcha	242-525	384	300	115,200	1,778
kuregor (hut?)	100-200	150	200	30,000	347

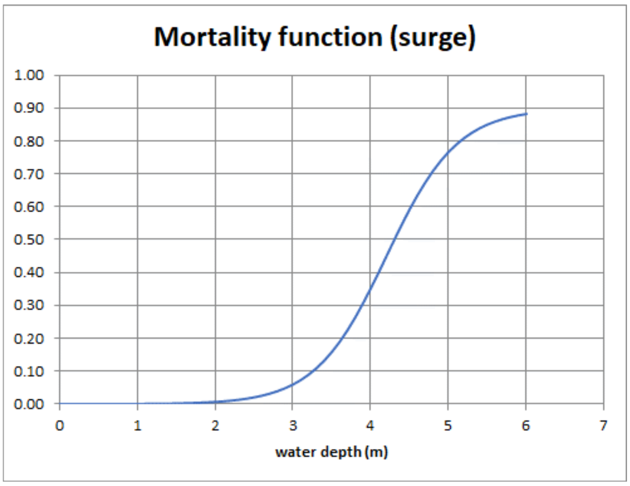
*: own estimation

Other Type of Damages	**Factor over all residential damages (sum of 4 categories)**
Business damages	0.25
Business interruption (indirect damages)	0.2

Total Damage = Residential damage (4 types of housing) + Agricultural damage + 0.25*Residential damage (4 types of housing)+ 0.2* Residential damage(4 types of housing)

Damage Functions	**Depth**	**0.1**	**0.2**	**0.5**	**1**	**2**	**2.5**	**4**
Kutcha	Depth Damage Fractions (0 to max. 1)	0	0.13	0.50	0.80	1.00	1.00	1.00
Semi-Pucca		0	0.08	0.30	0.60	0.70	0.80	0.80
Pucca		0	0.05	0.20	0.30	0.35	0.70	0.70
Shanty		0	0.13	0.50	0.80	1.00	1.00	1.00
Businesses		0	0.10	0.40	0.70	0.80	0.80	0.80
Agricultural Land (rice and similar)		0	0.20	0.80	1.00	1.00	1.00	1.00
Agricultural Land (Shrimp - Polder 15 only)		0	1.00	1.00	1.00	1.00	1.00	1.00





Annex C: Factsheet per polder

<table>
<tr><td>Polder</td><td>«Polder»</td><td></td><td></td></tr>
<tr><td colspan="2">Basic information</td><td></td><td></td></tr>
<tr><td></td><td>2020</td><td>2050</td><td></td></tr>
<tr><td>Population (#)</td><td>Polder population in 2020</td><td>Polder population in 2050</td><td></td></tr>
<tr><td>Area (ha)</td><td>Gross area of the polder</td><td></td><td></td></tr>
<tr><td>Loading Category</td><td></td><td></td><td></td></tr>
<tr><td>Ongoing projects</td><td>Possible ongoing projects in the polder</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Technical data</td><td>Investment (USD)</td><td>Benefits (USD)</td></tr>
<tr><td>Embankment length (km)</td><td>Embankment length</td><td rowspan="2">Combined investment for the embankments of the polder</td><td>Risk</td></tr>
<tr><td>Embankment type</td><td>Location of the embankment</td><td rowspan="4">Benefits by reduction in flood risk in the polder</td></tr>
<tr><td>Erosion (km)</td><td>Length of erosion of the embankment</td><td rowspan="3">Combined investment for bank protection works of the polder</td></tr>
<tr><td>Breach (km)</td><td>Length of breached/weak stretch of embankment</td></tr>
<tr><td>Bank protection (km)</td><td>Length of bank protection required for the embankment</td></tr>
<tr><td>Khals (km)</td><td>Length of excavation of khals</td><td>Combined investment for excavation of the khals in the polder</td><td>Agriculture</td></tr>
<tr><td>Regulators reconst. (#)</td><td>Number of structures to be reconstructed</td><td>Combined investment for reconstruction of structures in the polder</td><td rowspan="2">Benefits from increased agricultural production from improved drainage in the polder</td></tr>
<tr><td>Regulators repair (#)</td><td>Number of structures to be repaired</td><td>Combined investment for repair of structures in the polder</td></tr>
<tr><td rowspan="2">New Cyclone Shelters</td><td rowspan="2">Number of new cyclone shelter required within the polder</td><td rowspan="2">Combined investment for new cyclone shelters in the polder</td><td>Mortality</td></tr>
<tr><td>Benefits from reduced mortality in the polder</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Economic Evaluation</td><td></td><td></td></tr>
<tr><td>Total Investment (USD)</td><td>Total amount of the investments</td><td></td><td></td></tr>
<tr><td>Total Benefits (USD)</td><td>Total amount of the benefits</td><td></td><td></td></tr>
<tr><td>B/C-ratio</td><td>Benefit/Cost ratio</td><td></td><td></td></tr>
</table>

SD	Sea Defence	GOB	Polder with a project by the GOB
ID	Intermediate embankment	BG	Polder with a project by the Blue Gold project
MD	Marginal embankment	DPP	Polder with a Development Project Proforma/Proposal
C1	CEIP I project	NPP	Newly planned polder
FS	Feasibility study CEIP II		