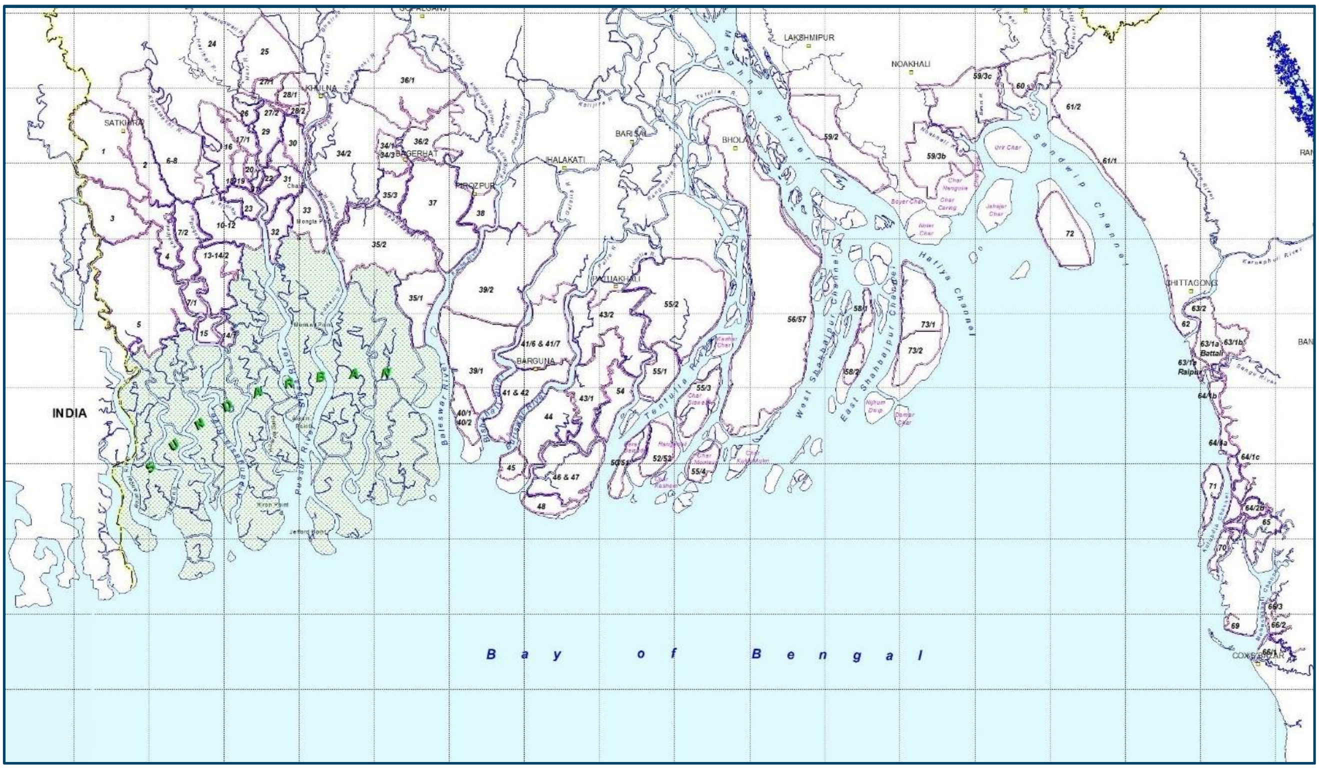
Ministry of Water Resources

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)

Component 5a: Reconstruction of the Polder at different coastal zones including their phasing and construction program





5A-2: Review/Improvements on-going work (CEIP-I)

December 2020 / June 2021

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

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ACRONYMS AND ABBREVIATIONS

BDP2100	Bangladesh Delta Plan 2100
BDT	Bangladesh Taka
BGP	Blue Gold Project
BWDB	Bangladesh Water Development Board
CBA	Coast Benefit Analysis
CBDRM	Community Based Disaster Risk Management
CC	Climate Change
CEGIS	Centre for Environmental and Geographic Information Services
CEIP	Coastal Embankment Improvement Project
CEP	Coastal Embankment Project
CERP	Coastal Embankment Rehabilitation Project
CGIAR	Consultative Group on International Agricultural Research
DEM	Digital Elevation Model
DWM	Department of Water Management
EIA	Environmental Impact Assessment
FCD	Flood Control and Drainage
FIAT	Flood Impact Assessment Tool
GIS	Geographical Information System
GoB	Government of Bangladesh
GPWM	Guidelines for Participatory Water Management
HYV	High Yielding Variety
IA	Implementing Agency
IPCC	Intergovernmental Panel for Climate Change
IPM	Integrated Pest Management
IPSWAM	Integrated Planning for Sustainable Water Management
ISR	Implementation Status and Result Report
IWM	Institute of Water Modelling
IWRM	Integrated Water Resource Management
LAP	Land Acquisition Proposal
LGED	Local Government Engineering Department
LGI	local Government Institute
LLP	Low Lift Pump
LV	Local Variety
MCA	Multi Criteria Analysis
MoU	Memory of Understanding
MoWR	Ministry of Water Resources
NGO	Non-Governmental Organization
O&M	Operation and Maintenance
PDO	Project Development Objective
RAP	Resettlement Action Plan
RCP	Representative Concentration Pathways
SLR	Sea Level Rise
SWRM	South West Regional Model
TRM	Tidal River Management
ToR	Terms of Reference
USD	United States Dollar
WARPO	Water Resources Planning Organization
WB	World Bank
WL	Water Level
WMA	Water Management Association
WMF	Water Management Federation
WMG	Water Management Group
WMO	Water Management Organization
WMU	Water Management Unit

1 Introduction

1.1 Scope of work

The main objective of the *Long-term monitoring, research and analysis of the Bangladesh coastal zone project* is to create a framework for polder design, based on understanding of the long-term and large-scale dynamics of the Bangladesh delta and experience with different sustainable polder implementation concepts. The diagram below shows the relations between the different project components. Component 5.A of the project specifically aims to refine concepts for polder design and management with the ultimate aim to prepare a Polder Development Plan (see the green boxes in Figure 1.1).

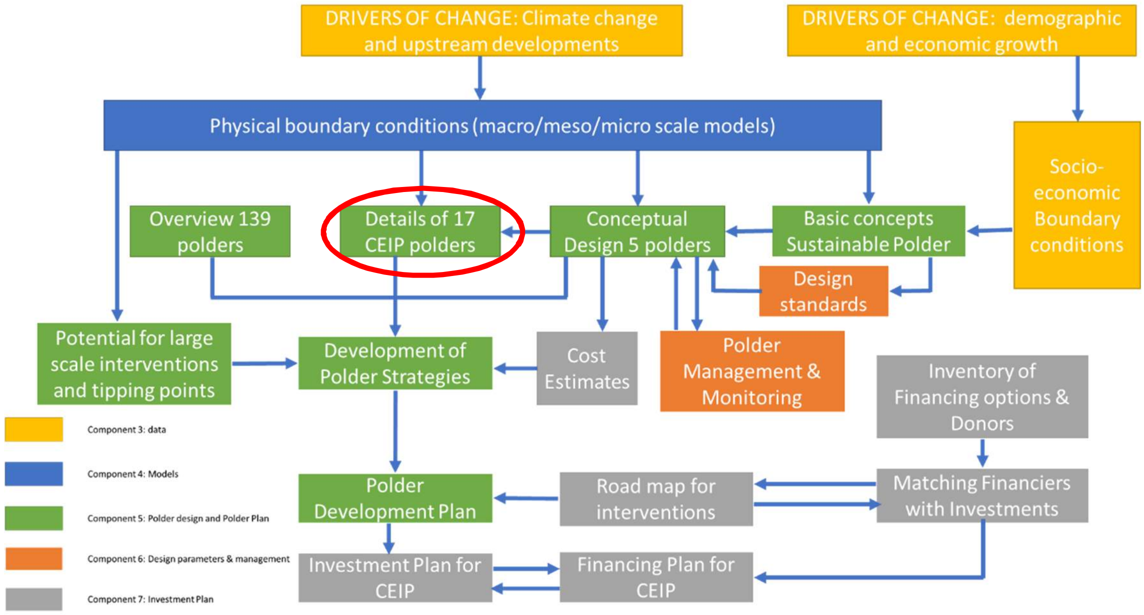

Figure 1.1 Diagram of the Long-Term Monitoring, Research and Analysis of the Bangladesh Coastal Zone Project (in red circle the position of this report is indicated)

As part of this work in Component 5.A, a review of the implementation of the CEIP-1 project has been made (see red circle in Figure 1-1), in order to learn from its experiences up until now that can be used for future (sustainable) polder development. Because the construction of improvements under CEIP-1 are still on-going it is difficult to evaluate their performance and impact. Based on a brief history of polder reconstruction and a literature review of water management issues in the polders of Bangladesh, the on-going and proposed CEIP-1 interventions are assessed on future impact. As there is a strong focus on embankment construction, this includes a risk assessment as part of the review to provide initial insights in the costs and benefits of the project. Although no final conclusions can be drawn (as the CEIP-1 project has not finished yet and more in-depth analysis is needed), the review does provide not only an overview of the challenges in polder development but also suggests directions for improvement. As such it helps improving the design of future polder projects and in drafting a polder development plan for the coastal zone of Bangladesh.

1.2 CEIP-1

The Coastal Embankment Improvement Project Phase 1 (CEIP-1) is a 400 million USD project, started in 2013 and is implemented by the Bangladesh Water Development Board (BWDB). The project aims to: (i) increase the area protected in selected polders from tidal floods and storms, which are expected to become more severe due to climate change; (ii) improve agricultural production by reducing saline water intrusion in selected polders; and (iii) improve the government's capacity to respond promptly and effectively to a crisis or emergency.

Originally, the CEIP-1 project was to support the rehabilitation and upgrading of 17 polders in 6 coastal districts to protect the areas from tidal flooding and frequent storm surges and reduce saline intrusion to enhance agricultural productivity. Due to cost overruns (caused by a variety of reasons, notably cost of land acquisition, price escalations and the need to carry out emergency protection works after cyclones Mora, Titli and Fani) and implementation delays, a restructuring was agreed in 2020. As per Restructuring Paper (WB, 2020), the scope of CEIP-1 has been reduced from 17 to 10 polders and the project period was extended from 31st of December 2020 to 30th of June 2022.

Currently the following polders are being reconstructed in two work packages:
- Package 1: 32, 33, 35/1 and 35/3
- Package 2: 39/2c, 40/2, 41/1, 43/2c, 47/2 and 48

A third package consists of the detailed design of the remaining 7 polders (Polders 14/1, 15, 16, 17/1, 17/2. 23 and 34/3), including the preparation of bidding documents, a Resettlement Action Plan (RAP), Land Acquisition Proposal (LAP) and Environmental Impact Assessment (EIA). Table 1.1 shows the Project Development Objectives (PDO) indicators, which give a good overview of the scope of the project as well as the current progress (up until October 2020).

Table 1.1 PDO indicators (updated after restructuring in 2020)

Indicator	Unit	Baseline	ISR* Oct. 2020	Target Value (at completion)
Gross Area Protected	ha	-	30,350 (46%)	66,012
Direct project beneficiaries from increased resilience to climate change	person, of which female (percentage)	0	333,024 (46%)	724,202 (50%)
Increase cropping intensity	%	140	140 (0%)	180
Length of upgraded embankment	km	0	197 (48%)	408
Drainage structures replaced	number	0	38 (43%)	88
Drainage structures repaired	number	0	2 (25%)	8
Flushing inlets replaced	number	0	29 (36%)	80
Flushing inlets repaired	number	0	14 (32%)	44
Length of drainage channels upgraded	km	0	158 (52%	305
Length of river bank protection	km	0	8 (85%)	9.37
Length of slope protection	km	0	15 (54%)	28
Area afforested	ha	0	332 (55%)	600
Water Management Association (WMA)	number	0	0 (0%)	10
Improved coastal monitoring		limited data	in progress	1.Modelling of the long-term physical processes and other relevant phenomena (subsidence, climate change, river morphology etc.) (scale: macro, meso and micro) 2.An investment plan describing a phased polder improvement roadmap for Bangladesh Coast
BWDB person days of training provided	number	0	461 (38%)	1200
Grievance Redress Committee (GRC)	number	0	36 (100%)	36
Detailed design of future 7 Polders (including EIA, RAP/LAP)	number	0	0 (0%)	7

*: ISR = Implementation Status and Result Report (see WB, 2020b)

1.3 Approach and setup of the report

The report will start with a brief description of the CEIP-1 polders, the situation prior to the start of the project and the key improvements under CEIP-1 already achieved, an overview of investment costs and the current status. Chapter 3 describes the socioeconomic situation of the polders, their land use and livelihood, while Chapter 4 presents the results of current flood risks and possible impact of climate change. Also, an evaluation of the investments in embankments is given, based on the risk assessment. Chapter 5 is fully devoted to the operation, maintenance and management of the polders. Based on the findings and challenges identified in the previous chapters, conclusions are drawn and presented in the last chapter.

2 Brief description of CEIP-1 polders

2.1 Basic facts of the 10 polders in the CEIP-1

The 10 polders that are currently under improvement encompass a gross protected area of around 66,000 ha with an estimated current population of around 440,000 (assuming a 1% annual growth since 2011). Details can be found in Table 2.1. Based on the classification on tidal fluctuation, salinity and exposure to storm surge and cyclones by Udding (2003), the polders 35/3 and 39/2C are considered interior, while the other polders are classified as exposed coastal polders (see Figure 2-1).

Table 2.1 Basic facts for the 10 CEIP-1 polders

				Cultivable Land			Main Project Feature					
No.	Polder No.	Location Name of Thana	Gross Protected Area (ha)	Total (ha)	Crop (ha)	Shrimp (ha)	Length embank-ment (km)	Regulators (no.)	Flushing Inlets (no.)	Drainage Channel (km)	Pop. (no.)	Afforesta tion (ha)
1	32	Dacope	8,097	6,500	6,497	5,328	49.5	13	32	45	38,397	58
2	33	Dacope	8,600	7,600	5,120	1,280	52.5	13	17	100	62,305	72
3	35/1	Sharankhola	13,058	10,700	10,400	300	62.5	18	20	70.5	99,182	22
4	35/3	Bagerhat	6,790	5,090	5,090	-*	40	4	11	75	31,075	26
5	39/2C	Bhandaria	10,748	8,500	3,800	-	61.5	13	12	57.2	43,077	
6	40/2	Pathargatha	4,453	3,300	3,300	-	35.6	12	14	50	41,317	30
7	41/1	Barguna Sadar	4,048	3,440	3,440	-	33.8	6	24	84	41,051	22
8	43/2C	Galachipa	2,753	2,000	2,000	-	25.7	6	18	26	14,851	10
9	47/2	Kalapara	2,065	1,850	1,850	-	17.6	4	6	30	5,411	22
10	48	Kalapara	5,400	3,715	3,715	-	37.9	8	4	45	26,260	16
			66,012	**52,695**	**45,212**	**6,908**	**416.6**	**97**	**158**	**582.7**	**402,926**	**278**

Source: Feasibility Study CEIP-1 (CEIP-1, 2012a) (Population estimated for 2011)
**: CEIP-1 report Vol. IV mentions 30% of area is under aquaculture*

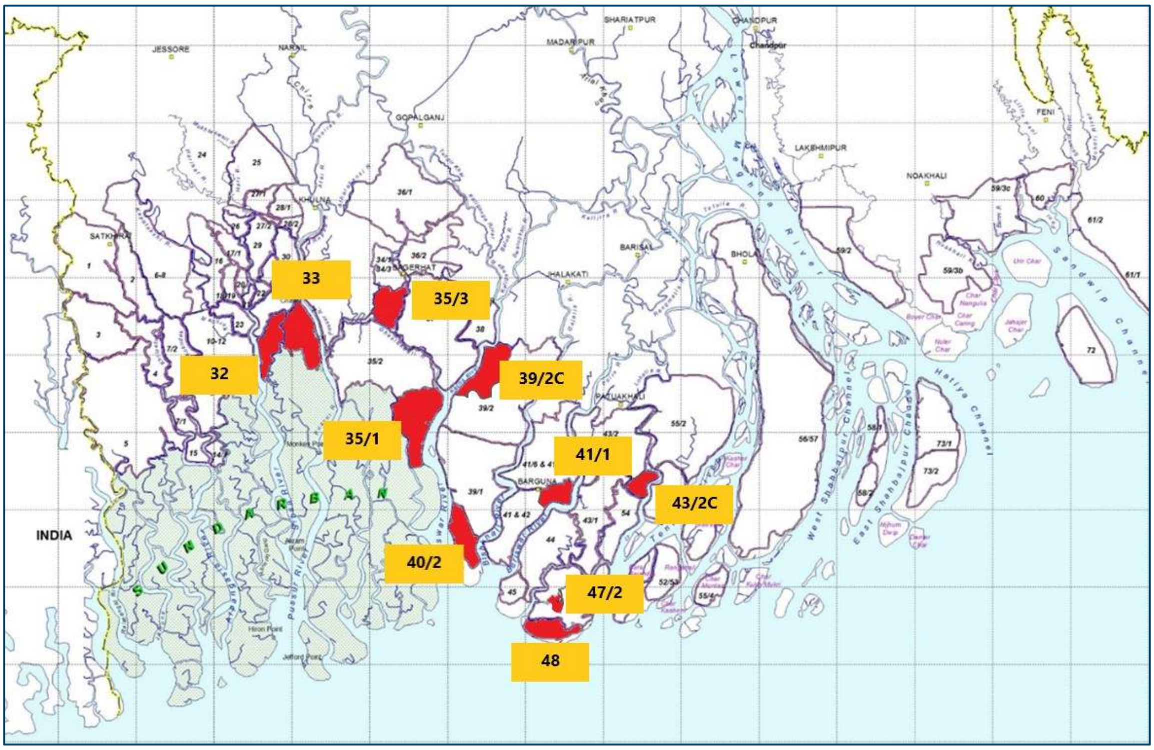

Figure 2-1 Map of the 10 polders under rehabilitation as part of the CEIP-1

2.2 Description of the polders and their challenges prior to the start of CEIP-1

Since its existence, the Bangladeshi government is committed to develop a safe and inhabitable coastal zone that allows for intensive rice cultivation by building embankments and polders. Under the Coastal Embankment Project (CEP), first the East Pakistan Water and Power Development Board (EPWAPDA) and after independence, the Bangladesh Water Development Board (BWDB) constructed 108 polders with a total surface of one million ha. 9 of the 10 CEIP-1 polders were constructed in the late 1960s (Polder 39/2 was constructed later due to fund constraints).

Under CEP high earthen embankments were constructed to protect the land from the daily tidal inundation of saline water as well as to protect it from the regular monsoon rains and storm floods (embankments were not designed to withstand more extreme events such as cyclones). The crest height of the embankments was determined as “the maximum normal high tide” (as recorded during 1960-1968) plus a freeboard of 5 feet.

Sluices were built to remove accumulated rainfall from the polders by gravity flow during the periods of low tide level. Drainage was easy during that time because the water level inside the polders was higher than the rivers and channels outside the polders. The polder system worked well for 10–15 years, as the land was developed intensively and allowed a significant increase in agricultural production until the mid-1980s (Nowreen et al., 2014; Ihstiaque et al., 2017, Gain et al., 2019).

Many local people were pleased with the polder embankments, as these enabled them to grow aman rice during Kharif-II (autumn) season and it protected their property and life. Also, embankments are important as transportation routes and refuges during extreme floods. The regular cutting of embankments during dry periods is not per se a sign that people are against the embankments but are rather a flexible, cost effective and appropriate operational method used by stakeholders to manage water. In most cases, the cuts are filled again by the inhabitants before the seasonal river floods, to be cut once again after the floods pass and before drainage congestion would become severe[1] (Wester & Bron, 1988).

After 10 – 15 years, problems arose in the polders, mainly due to the lack of maintenance of sluices, embankments and khals. This resulted in impeded drainage, water logging and increased salinity. That was the reason why the CERP was initiated in 1995 and three of the CEIP polders were rehabilitated under this project. It included rehabilitation of embankments (to withstand cyclonic storm surge), re-excavation of khals and repair or replacement of water regulators.

Another problem that started to develop was the sedimentation of the rivers and increase of tidal amplitude. In combination with soil subsidence and the lack of sedimentation within the polders, it becomes more difficult to use gravitational drainage to release excess water out. This was the main reason for the first examples of Tidal River Management (TRM) that were instigated by local people in the Khulna-Jessore Drainage Rehabilitation Project in Polder 24 (1993).

Before the start of the CEIP-1 project, all polders suffered from :

- Severely damaged embankments (due to cyclones Sidr and Aila and river erosion);
- Very bad condition of hydraulic structures (drainage sluices and flushing inlets);
- Internal drainage problems because channels have become silted up or blocked and the head for drainage between channels and river was reduced.

Appendix 1 provides a more detailed description of the polders and the associated problems. In general, the (proximate) reasons for these problems can be summarized as follows:

- Insufficient embankment maintenance and bank erosion;
- Severe cyclones Sidr and Aila caused storm surges that damaged the embankments;
- Afforestation of the foreshore was generally not successful;

[1] Nevertheless, this practice could lead to weak spots in the embankments that may be vulnerable to breaching during cyclones/monsoons.

- Lack of maintenance of regulators and khals so they become defunct;
- Multifunctional and sometimes conflicting use of the khals; and
- Changes in the tidal and sediment dynamics of the estuaries and peripheral rivers.

These points will be elaborated on in the following. However, the reasons behind these deteriorating developments are more complex and should be seen as a combination of political, governance and sociocultural dynamics. This will be discussed in further detail in in Chapter 5.

Embankment degradation (lack of maintenance and extreme events)
Many embankment sections face erosion due to tidal or river currents. As the delta is a relatively young and morphologically dynamic system, river erosion and sedimentation are natural phenomena. When polder construction started, this led to loss of tidal area and closure of a large number of small creeks which set in motion a large and complex channel network reorganization. Changes in tides and currents occurred and caused new patterns of erosion and sedimentation (Wilson & Goodbred, 2015). Especially, the tidal amplitude has increased significantly as a result of the loss of intertidal areas, but also due to deepening, smoothening of the bed, and flow reorganization. Hence, it may not come as a surprise that embankments, which are fixed elements in such a dynamic system may suffer from erosion. As previous embankment designs did not include effective bank protection at the toe of the embankment (now being implemented in CEIP-1), at many places the erosion caused instability of the embankments and subsequently damaged them.

Besides the gradual effect of river erosion, embankments are also vulnerable to extreme events, such as cyclones. Especially the cyclones Sidr and Aila caused huge damage to the embankments. On 15th of November 2007, Cyclone Sidr struck the south-west coast of Bangladesh with winds up to 240 kilometers per hour. It made landfall across the Barisal coast at 9:00 pm during ebb tide. The category 4 storm was accompanied by tidal waves up to five meters high and surges of up to 6 meters in some areas[2], breaching coastal and river embankments, flooding low-lying areas and causing extensive physical destruction. The cyclone affected around 2,290 km of embankment in 15 districts, of which 13 were in the coastal area. Of the affected embankments, 362 km were fully destroyed while the rest were partially damaged (GoB, 2008). On the 25th of May 2009, Category 1 Cyclone Aila affected coastal districts of Bangladesh, especially Khulna and Shatkira. Although it was less intense than Cyclone Sidr (Cat. 4), it occurred at high tide so that the storm surge caused destruction of large sections of the embankments in the region.

As has been mentioned earlier, the original polder embankments were not designed to withstand heavy cyclones. This meant that the absence of effective bank and slope protection and insufficient height made most embankments very vulnerable to these extreme events.

Afforestation: a mixed result
Afforestation plans with mangroves on the outer slope and foreshore of embankments became part of the embankment rehabilitation projects since the 1990s with varying success. For instance, under CERP a social forestry plan was introduced that aimed at involving local people in the management of the forest and embankment, while in return they could benefit from harvesting forestry products. Embankment settlers would be looking after the trees and doing minor maintenance as well as, most importantly, would deter cattle from entering and damaging the embankment areas - a major problem in the past. Planted areas also provide a sheltered habitat that encourages biodiversity, particularly grasses and other species that bind the soil (WB, 2005). However, in practice the foreshore afforestation component under CERP was only partly successful, because there are often too few incentives for stakeholders. Foreshore land belongs to the state and is administered by the local Deputy Commissioner who has the authority to lease it out, generally for fishing related activities - shrimp and fish ponds, and shrimp trawling - and for salt production, all more lucrative activities than mangrove afforestation (WB, 2005).

[2] Storm surge analysis by the Institute of Water Modeling (IWM) indicates surge levels of 5.5 to 6 meters at the outfall of Baleswar River; 5 meters at Sharankhola and Bagerhat; and 3.5 meters at Hiron Point (GoB, 2008)

Insufficient maintenance of regulators and khals
All primary, secondary and tertiary canals and drains need regular clearing of weeds and obstacles to function well. Also, gates need regular greasing, annual painting and minor repair, especially in a harsh environment along the coast where salty water easily causes corrosion. When regular maintenance is absent or ineffective, water management for the benefit of agriculture in the polder becomes very difficult. Fact is that in all polders of CEIP-1 the great majority of regulators needed repair or replacement and, in all polders, the khals suffered from a lack of maintenance. The reason why maintenance is not effective is further discussed in Chapter 4.

Another reason for the malfunctioning of some regulators is inappropriate use, e.g. sluices that were designed for drainage only, were used for reverse flow (inflow) of water during the dry season for irrigation of the Boro crop (winter season).

Multifunctional use of khals
The khals (natural drainage channels or creeks) in the polders serve three important water management functions: drainage, water storage (retention) and water inflow. Besides this, khals are used for fisheries, agriculture, navigation and domestic use. These different functions and uses of khals make their management complex, due to the involvement of different types of stakeholders with conflicting demands (Wester & Bron, 1988).

Changes in tidal and sediment dynamics of estuaries and peripheral rivers
The creation of polders leads to a loss of tidal flooding area for the incoming tide, resulting in amplification of the tidal wave and a complete cessation of sedimentation within the polder area, while at the same time there is increased settling of sediments in the rivers. Because there is a natural tendency of soil subsidence in deltas, due to compaction and other reasons, the polder area will gradually become lower as there is no incoming sediment to compensate this process. In combination with the increase in tidal amplitude this reduces the potential for gravity drainage. TRM applications have demonstrated its usefulness to increase sediment deposition and polder levels. However, the implementation of TRM in the polders is not without hurdles due to (temporary) resettlement and compensation issues.

2.3 Key improvements under CEIP-1

2.3.1 Structural measures

The structural measures under CEIP-1 can be grouped into the following 5 areas:

- Embankments:
  - re-sectioning
  - retirement
  - slope protection
  - bank protection
- Regulators (drainage / flushing / combined):
  - Repair of existing structure
  - Replacement of existing structure
  - Additional structures
- Re-excavation of drainage channels / khals
- Afforestation on the foreshore area
- Construction of cross dam, if required

Embankments
Embankments under CEIP-1 are designed to keep selected storm surges (with incident waves) and overtopping water out of the polder. They must also withstand toe scour and slope erosion due to incident waves during stormy weather. Slope and bank protection are expensive and form a significant part of the total project costs (up to 50%). Especially the construction of bank protection is complex because placing and dumping materials is under water via marine based equipment. This

resulted in a long learning curve for contractors to do so in a proper manner and has already led to delays. Also, the supervision of underwater works leaves room for improvement, such as using multi-beam surveys, which will also be utilized under CEIP-1.

The height of the embankment has been calculated by using the one in 25-year return period storm surge levels for cyclonic storms that would occur in 2050 under climate change, using 0.5 m sea level rise and 10% increase in wind speed. An additional 30 cm has been added to compensate for land subsidence, as well as a factor for freeboard to limit wave overtopping and an additional margin to allow for any uncertainty in the statistical curve fitting (CEIP-1, 2012d).

The design of embankments with bank and slope protection under CEIP-1 follows design guidelines introduced in the eighties that are still used by the BWDB. These guidelines will be critically reviewed in a separate report under Component 6.1 of the Long Term Monitoring, Research and Analysis Project.

Regulators

For the design discharge of a drainage-cum-flushing regulator, a 5-day duration storm of 1 in 10-years return period expected over the catchment area has been considered. By using the South West Regional Model (SWRM) of the Institute of Water Modeling (IWM), three-day inundation exceedance maps were used for judging the effectiveness of drainage before and after the project as well as with and without climate change scenarios. Where the drainage was considered insufficient (or in some cases as having excess capacity) the number of regulators, and/or their sizes were adjusted to obtain an optimal solution for the “with climate change” scenario. For the climate change scenario 2050, estimates were used for both the increase in monsoon precipitation and sea level rise. Furthermore, for the stability of the structure, hydraulic design conditions were also used, taking into account possible seepage, uplift pressure and scouring mechanisms (CEIP-1, 2012d).

Drainage channel improvement

In CEIP-1, a validated drainage model for the existing system is applied by IWM to assess the existing drainage performance of the present drainage networks and future drainage performance with the changed morphological condition of the peripheral rivers and sea level rise. A rainfall storm of 5-day duration and 1 in 10-year frequency is considered as design rainfall runoff for investigating the effectiveness of the drainage system and considered for the design of drainage canals/ Khals. As criteria it was taken that such design rainfall shall not cause submergence of more than 5% of the incremental area in addition to the area that cannot be drained by gravity to a greater depth than 0.3 m for a period of 3 days (CEIP-1, 2012d).

Afforestation

The main reason for the inclusion of afforestation in the project is that the establishment of a greenbelt along the polders can reduce the effect of toe and slope erosion due to wave action, river flow and promote land accretion. Moreover, it can provide revenue through harvesting of forest resources. The extent of land available for planting is however rather limited because the protected lands within the polders are heavily utilized and the strip of foreshore available is rather narrow. Officially the BWDB owns a strip of 80 ft (approx. 26 m) of land on the foreshore, which often got encroached upon by the adjoining private land owners (CEIP-1, 2013). In total approximately 278 ha of afforestation is planned under CEIP-1. This is being executed by the Forestry Department under separate contracts.

2.3.2 Non-structural measures

2.3.2.1 Operation

The CEIP-1 project prepared plans for the operation and for the management of the polders. The Operational Plan consists of the following operational activities:

- Operation of drainage regulators;
- Operation of flushing sluices/irrigation inlets; and
- Operation of privately-owned Low Lift Pumps (LLPs).

In the past BWDB employed the Gate Operators directly; but due to budget cuts this position has been discontinued. Currently the responsibilities of gate operation are given to beneficiaries in the polders (see Chapter 4 for more details). The planning of operation is divided into three parts: i) Seasonal Water Management Plan; ii) Weekly Operation Targets and iii) Day-to-day Operation.

Seasonal Water Management Plan
In the polders both the drainage and water conservation requirements are equally important; in the wet season drainage will get priority while in the dry season, conservation of fresh water inside the polder becomes the predominant factor. The seasonal water management plan must therefore cover the polder as a whole and on the basis of the requirements of all water users. The plan will have to be prepared jointly by the BWDB's O&M offices, the leaders of the Water Management Associations (WMAs) and the Department of Water Management (DWM) of BWDB. The plan needs to be prepared well ahead of the cropping season so that critical farm operations can be carried out in line with the plan. It is mentioned that in large polders, such a plan requires a computer model to compute several water management scenarios (CEIP-1, 2012e).

Weekly Operation Targets
By comparing the parameters in the seasonal Water Management Plan (basically water levels in the channels and discharges) with the actual field conditions, operation targets on a weekly basis should be set. The users can set, in close contact with O&M staff of BWDB, the weekly operation targets to maintain the desired field conditions (CEIP-1, 2012e).

Day-to day Operation
Daily structure operation requirements involve manipulation of gates or pumps to maintain water levels in the channels as laid down in the operation target. Actual structure operation is also implemented and adjusted on a daily basis by the O&M staff of BWDB. For each polder the operational practices developed in this way will have to be documented and kept in proper records for use by the WMGs / WMAs (CEIP-1, 2012e).

2.3.2.2 Maintenance

Under CEIP-1 three types of maintenance are distinguished: i) preventive or routine maintenance, ii) periodic maintenance and iii) emergency maintenance. Preventive or routine maintenance involves simple works, such as maintenance of vegetation on embankments, small earthworks, cleaning, greasing and painting of structures and cleaning of khals from aquatic vegetation and removing silt. These can be implemented through community-based functional groups (CEIP-1, 2012e).

Periodic Maintenance intends to bring the components of the hydraulic infrastructure back to its design standard. The works are more expensive than preventive maintenance and are implemented under contracts such as by the Landless Contracting Societies (LCSs) and Project Implementation Committees (PICs) (food for works). Periodic maintenance has the character of repair works and is identified during the field assessment at (more or less) regular intervals (CEIP-1, 2012e).

Emergency works cover unforeseen interventions that require immediate actions to protect the polder as a whole or a part thereof from the adverse effects of flooding or uncontrolled saline intrusion etc. associated with damage of lives and properties. This type of work requiring immediate attention includes the closure of an embankment breach, the repair and replacement of flap gates, or the construction of cross dams over canals if structure fails. As the title implies planning of these kinds of works is not possible (CEIP-1, 2012e). The emergency works under CEIP-1 were taken up to close the breaching of existing embankment at some vulnerable locations. The main target of these emergency works was to stop the intrusion of saline water into the Polders to save the crops. Up till September 2020 a total of approx. 155 million BDT was spent for these works (i.e. approx. 0.6% of the total CEIP-1 budget) (CEIP-1, 2020).

The report on O&M of CEIP-1 provides checklists for O&M, reporting schedules and time schedules for maintenance planning as well as duties and responsibilities of the different stakeholders. Also, a budget estimate is provided for all polders.

2.3.2.3 Management for O&M

At the start of CEIP-1, beneficiaries' organization did not exist in all of the 17 polders (CEIP-1, 2012e). Initially it was planned that Water Management Organizations would be trusted in 4 to 6 polders with the tasks of day-to-day operation and minor maintenance work. Their establishment would follow an eight-step process, as identified in the BWDB Guidelines for Integrated Planning for Sustainable Water Resource Management (2008). This would be executed under Component B1 "Implementation of Social Action Plans" and would be implemented through a well-established NGO (WB, 2013).

It was agreed that the BWDB will take the lead in forming these Water Management Associations, together with the afforestation activities and integrated pest management (IPM). On its turn the BWDB would contract NGO services to support them with these tasks. The objectives of these consulting services are to manage and oversee tasks for social mobilization, participatory scheme cycle management (PSM) and participatory afforestation in relation to the successful implementation of the CEIP-1. Specifically, consulting services were sought for (a) Social mobilization including setting up WMOs for introduction of IWRM practices through preparation and implementation of Social Action plan through engagement of local communities and community groups for PSM and participatory O&M of schemes, (b) Implementation of afforestation program specially in the fore-shore areas with ecologically appropriate species by adopting social afforestation approach, and (c) Implementation of the IPM practices.

It is noted that WMOs refer to all types of organizations within a polder or scheme for participatory water management. Water Management Group (WMG) is formed for each hydraulic boundary known as Water Management Unit (WMU) within a polder/scheme. There are a number of WMUs in a polder/scheme having WMG for each. An apex body of the WMGs is formed with representatives from each WMG called Water Management Association (WMA) for each polder/scheme.

In CEIP-1 Vol X (Sustainability Reports) (CEIP-1, 2012e) a scheme has been included showing the inter-relations between the WMOs, the BWDB and the local government institutions (see Figure 2-2). The report suggests three types of relations: i) participation of the WMOs in the Union Parishad and Upazilla Parishad Review Meetings; ii) creating opportunities for the Administration People to get involved in WMO's affairs, and iii) signing of MoUs by BWDB with other development agencies. Note that these relations are not formalized and depend on the initiative and good will of the respective stakeholders.

Specific attention is given during the development of the WMOs on gender (e.g. women will constitute a minimum of 30% of the members of executive committees in WMGs and WMAs) and effective participation of the beneficiaries.

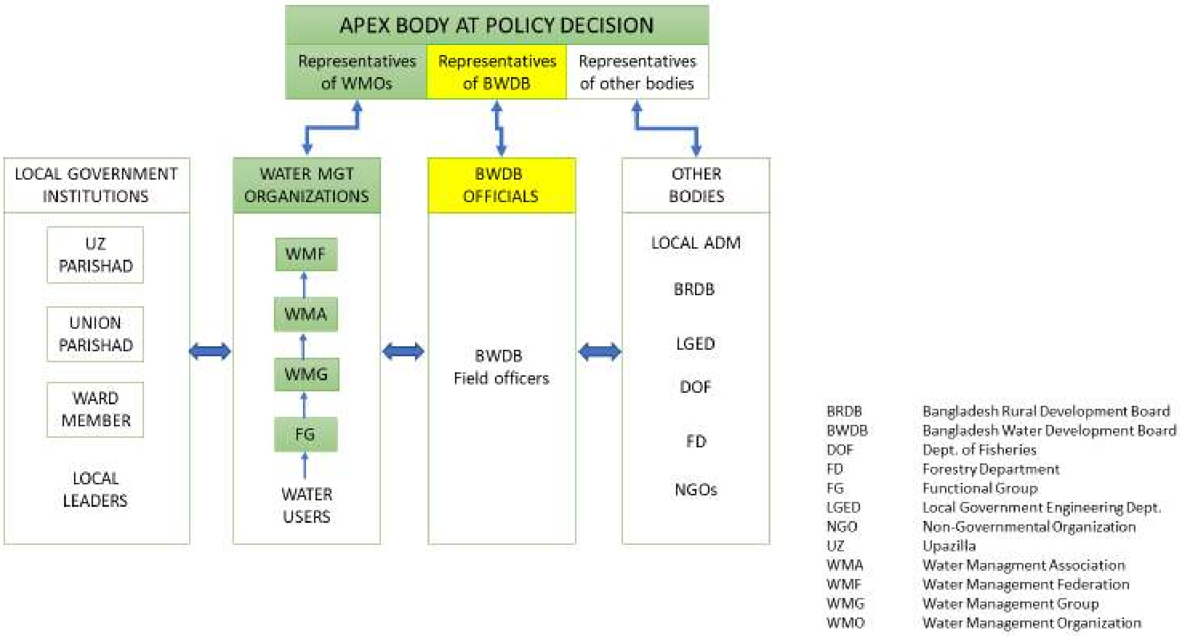

Figure 2-2 Relations between WMOs and LGIs (adapted from CEIP-1, 2012e)

As part of the restructuring of the project in 2020, it was decided that all polders under CEIP-1 would in the end have a new Water Management Association rather than only the 4-6 pilots mentioned earlier (WB, 2020). NGOs have been mobilized since March 2019 and execution of the work is on-going. As per September 2020 no WMOs were established yet (WB, 2020b). It was expected that at least 9-12 months will be spent undertaking the initial planning and social mobilization tasks in order that the WMOs are fully established prior to any rehabilitation and upgrading work. It is apparent that for the work packages 1 and 2 this has not fully been accomplished.

2.4 Analysis of investment costs under CEIP-1

In order to gain insight into the different cost components and their contribution to the costs of polder rehabilitation, an analysis is made of the different cost components in the investment program. Table 2.2 and Table 2.3 give details on the costs of the different components. In the chart in Figure 2-3 the distribution of cost over the different components is illustrated. Two polders within the CEIP-1 project are presented in detail (polder 35/1 and 40/2), showing significant differences in costs for the different components.

The following observations can be made from Figure 2-3:

- Over the two packages 1 and 2, 41% of total costs is required for embankment protection works, while 18% of the investment goes to the improvement of the actual embankments.
- The cost of land acquisition is a substantial part in the investments with a total of 15% of the investment costs. Average land prices seem high for the predominantly agricultural use in the polders, thus requiring a substantial part of investment costs.
- Actual drainage improvement by excavation of Khals is only a small part of the total investments (in the order of 2%) . Additional investments for drainage structures in the embankment can also be labelled as drainage improvements (8 % of total investments).

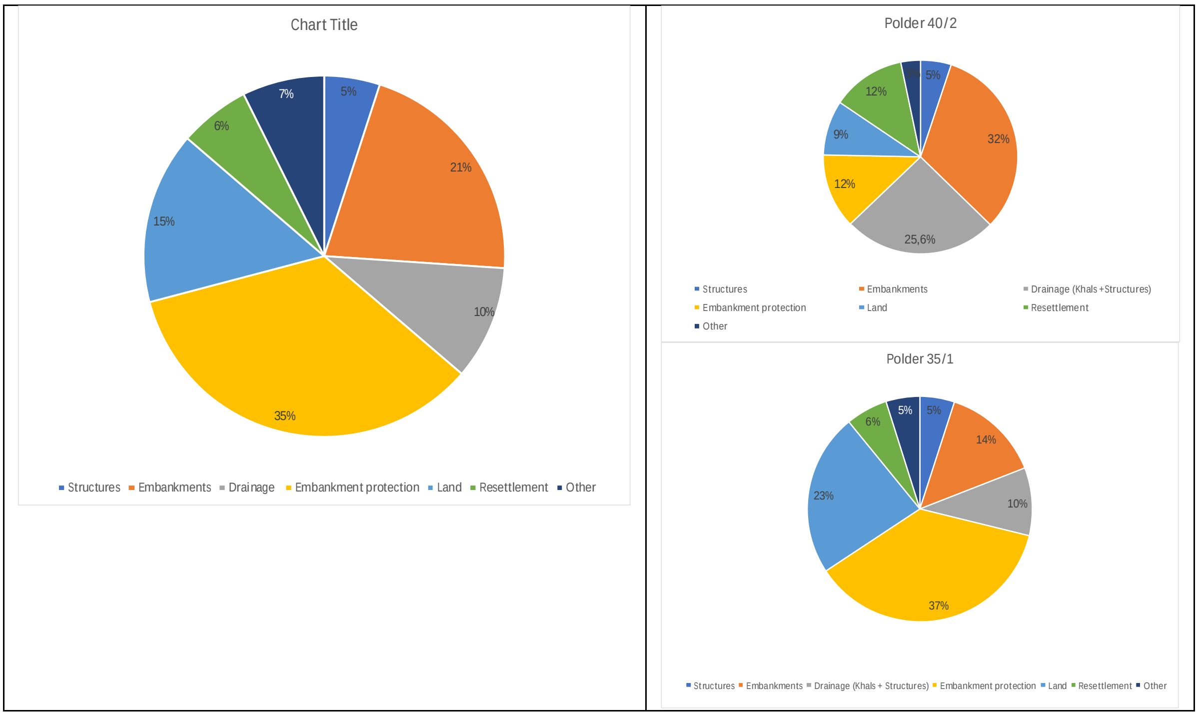

Figure 2-3 Costs distribution over different investments for polder improvement under CEIP-1 (left: work packages 1 and 2 combined; right: distribution for two polders)

Table 2.2 Budget for CEIP-1 polder improvement works package-1 (USD)

Sl No.	Interventions Under CEIP	Unit	Polder 32		Polder 33		P-35/1		P-35/3		Total (4 Polder)	
			Quantity	Estimated Cost	Quantity	Estimated Cost	Quantity	Estimated Cost	Quantity	Estimated Cost	Quantity	Cost
	Part -A											
1	Construction of Drainage Sluice	No	8.00	2,035,797	12.00	3,053,696	14.00	3,562,645	4.00	1,017,899	38.00	**9,670,037**
2	Repairing of Drainge Sluice	No	0.00	-	-	-	2.00	134,565	-	-	2.00	**134,565**
3	Construction / Resectioning of Embankment	km	49.50	5,569,346	51.48	5,792,120	62.50	7,032,003	40.00	4,500,482	203.48	**22,893,951**
4	Excavation / Reexcavation of Drainage Channel	km	17.50	297,198	63.21	1,073,479	70.50	1,197,284	-	-	151.21	**2,567,961**
5	Construction of Flushing Inlet	No	1.00	181,226	6.00	1,087,354	13.00	2,355,935	10.00	1,812,257	30.00	**5,436,772**
6	Repairing of Flushing Inlet	No	6.00	257,631	3.00	128,815	3.00	128,815	2.00	85,877	14.00	**601,138**
7	Embankment Slope Protection Work	km	3.30	3,383,297	4.02	4,121,471	11.75	12,046,587	0.90	922,717	19.97	**20,474,072**
8	River Bank Protection Work	km	2.00	9,100,956	1.40	5,425,098	0.90	6,406,928	0.15	520,228	4.45	**21,453,209**
	b. Additional Bank Protection (Appendix I)	km		-		-		-		-	-	**-**
9	Dismantling of brick soling/ bituminous carpeting road/ structure	km	9.30	404,096	25.50	518,147	13.00	614,608	4.70	380,943	-	**1,917,793**
		No	11	-	26.00	-	35.00	-	15.00	-	-	**-**
10	Construction of closure/cross dam	No	1.00	2,618,171	-	-	-	-	-	-	1.00	**2,618,171**
11	Construction of Road Pavement over Embankment and Road Crossing Embankment			-		-		-		-		**-**
12	Construction of RCC Flood Wall			-		-		-		-		**-**
11	Day Work	LS	LS	48,588	LS	60,941	LS	130,235	LS	39,205	LS	**278,969**
12	General Mobilization	Ls	0.00	1,579,718	-	1,347,600	-	1,457,212	-	1,456,247	-	**5,840,776**
13	EMP(works)	LS		211,830	LS	208,967	LS	226,142	LS	214,692	LS	**861,631**
Sub Total Part -A				**25,687,853**		**22,817,689**		**35,292,959**		**10,950,546**		**94,749,047**
Part - B												
1	Land acquisition	ha.	54.65	2,625,176	16.28	117,792	47.29	11,647,059	28.48	2,494,235	146.70	**18,684,118**
2	Resettlement	LS		2,036,118	LS	2,071,529	LS	3,012,000	LS	565,294	LS	**7,684,941**
Sub Total Part - B				**4,661,294**		**2,189,321**		**14,659,059**		**3,059,529**		**26,369,059**
Gross Total (A+B)				**30,349,147**		**25,007,010**		**49,952,018**		**14,010,076**		**121,118,106**

Table 2.3 Budget for CEIP-1 polder improvement works package-2 (USD)

Sl No.	Interventions Under CEIP	Unit	Polder-48		Polder-47/2		Polder-43/2C		Polder-40/2		Polder-41/1		P-39/2C		Total (6 Polder)	
			Quantity	Estimated Cost	Quantity	Estimated Cost	Quantity	Estimated Cost	Quantity	Estimated Cost	Quantity	Estimated Cost	Quantity	Estimated Cost	Quantity	Estimated Cost
	Part -A															
1	Construction of Drainage Sluice	No	6.00	2,598,003	4.00	1,732,002	8.00	3,464,004	9.00	3,897,004	10.00	4,330,005	13.00	5,629,006	50.00	**21,650,023**
2	Repairing of Draiange Sluice	No	3.00	130,919	0.00	-	0.00	-	3.00	136,083	0.00	-	0.00	-	6.00	**267,002**
3	Construction / Resectioning of Embankment	km	38.00	8,121,273	17.55	525,934	25.70	3,214,165	34.40	5,159,826	33.81	2,389,589	59.25	7,425,861	208.71	**26,836,647**
4	Excavation / Reexcavation of Drainage Channel	km	32.72	523,086	9.17	146,598	28.16	450,186	4.23	67,624	23.13	369,773	57.23	914,920	154.64	**2,472,187**
5	Construction of Flushing Inlet	No	3.00	513,453	3.00	513,453	7.00	1,198,058	3.00	513,453	16.00	2,738,418	21.00	3,594,174	53.00	**9,071,011**
6	Repairing of Flushing Inlet	No	0.00	-	2.00	57,253	7.00	200,386	11.00	314,893	10.00	286,266		-	30.00	**858,798**
7	Embankment Slope Protection Work	km	4.080	7,158,359	0.00	-	0.261	457,924	1.137	1,994,866	0.00	-	4.00	7,017,999	9.48	**16,629,149**
8	.River Bank Protection Work	km	0.00	-	0.52	3,591,622	0.50	3,173,404	0.00	-	0.88	6,975,564	3.50	49,396,489	5.40	**63,137,079**
	b. Additional Bank Protection	km		-		-		-		-		-		-	0.00	**-**
9	Dismantling of brick soling/bituminous carpeting road/structure	km	17.50	66,331	6.00	32,822	4.00	113,373	13.28	121,836	29.11	323,409	8.00	140,267	77.89	**798,039**
		No	9.00	-	6.00	-	24.00	-	19.00	-	28.00	-		-	86.00	**-**
10	Construction of closure / cross dam			-		-		-		-		-	8.00	1,189,693	8.00	**1,189,693**
11	Construction of Road Pavement over Embankment and Road Crossing	Km		-		-		-		-		-		-	0.00	**-**
12	Construction of RCC Flood Wall	Km	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	**-**
11	Day Work	Ls	0.00	167,270	0.00	68,019	0.00	94,393	0.00	81,900	0.00	119,380	0.00	180,333	0.00	**711,295**
12	General Mobilization	Ls	0.00	223,818	0.00	223,818	0.00	223,818	0.00	223,818	0.00	223,818	0.00	576,759	0.00	**1,695,848**
13	EMP(works)	Ls	0.00	100,000	0.00	80,000	0.00	94,118	0.00	94,118	0.00	96,047	0.00	292,941	0.00	**757,224**
Total Amount of Part-A				**19,602,512**		**6,971,521**		**12,683,830**		**12,605,420**		**17,852,269**		**76,358,442**		**146,073,994**
	Part -B															
1	Land acquisition	ha.	3.07	2,164,706	4.08	1,744,000	19.66	4,141,176	14.05	1,474,118	13.35	1,065,294	119.09	14,256,000	173.30	**24,845,294**
2	Resettlement	Ls		2,000,000		448,000		941,176		1,967,647		1,057,059		842,353		**7,256,235**
	Total Amount of Part-B			**4,164,706**		**2,192,000**		**5,082,353**		**3,441,765**		**2,122,353**		**15,098,353**		**32,101,529**
	Total Amount (Part A+B)			**23,767,218**		**9,163,521**		**17,766,183**		**16,047,185**		**19,974,622**		**91,456,795**		**178,175,523**

2.5 Current status of CEIP-1 improvements

2.5.1 Progress

CEIP-1 is being executed under three work packages:

- Construction package 1 for Polder 32, 33, 35/1 and 35/3
- Construction package 2 for Polder 39/2c, 40/2, 41/1, 43/2c, 47/2 and 48
- Package 3 for survey and design, bid documents, Resettlement Action Plan (RAP), Land Acquisition Proposal (LAP) and Environmental Assessment Report for the remaining 7 polders (polders 14/1, 15, 16, 17/1, 17/2. 23 and 34/3).

The work is being supervised by the Detailed Design, Construction Supervision and Project Management Support Consultant (DDCS & PMS) on behalf of the Employer (BWDB). Physical progress of Package 1 is 90% as per September 2020 and for Package 2 this is almost 53% (CEIP-1, 2020). Also, auxiliary activities, such as resettlement payments, land acquisition, and resolving grievances, are on-going. EIA reports are being reviewed and new versions drafted for 7 polders. The design of Embankment of 7 Polders and design of 45 Drainage Regulators have been approved by the BWDB Design Circle-5. The design of the remaining infrastructures is under process of approval by the concerned Design office.

As per October 2020, a total area of 332 ha has been afforested. As per the current results framework, the end target for area afforested is 600 ha (WB, 2020b).

Completed DS of Polder-32

Completed Slope Protection Works in Polder-32

Ongoing DS-3 In Polder-43/2C

Embankment work from Km 9+800 to Km 11+000 in Polder-43/2C

Figure 2-4 Illustrative pictures of on-going physical works (2020) in CEIP-1

2.5.2 Challenges encountered

Project progress has been substantial (see Table 1.1) with around 50% of embankments upgraded leading to a same percentage of Gross Area Protected. Also construction works for drainage structures and flushing inlets show progress (varying between 36 to 43% of target numbers).

Technical issues

River bank and slope protection are going well with 85 and 54%, respectively, after having to deal with initial challenges. The peripheral rivers around the polders are of all sizes, varying from large rivers like the Baleswar, Sibsa and Pussur to the smallest tidal creek. The strong river currents and wave action can rapidly change the shape and position of the riverbank through riverbank erosion. This can threaten the embankment, and should either be solved by bank protection or by its retirement (set-back).

The bank protection works for combatting erosion, which are included in the 2 ongoing CEIP-1 implementation Contracts, have been identified in studies conducted in the years 2010 to 2012. The first bank protection work was completed in the year 2016 and thereafter in the years up to now. This is quite a long period between identifying and implementing in view of the morpho-dynamics of the system and is reason why during the implementation of the bank protection works variation orders had to be prepared for reducing and/or increasing the lengths of the bank protection works in order to cope with the (changed) actual situation. Paying more attention to morpho-dynamics of the system during the construction of bank protection works could avoid making ad-hoc decisions which now sometimes happens.

Under CEIP-1 initially hard rock was considered for the bank protection works, however, due to the limited availability of rock in Bangladesh, CC blocks are now being used under the implementation of CEIP-1.The bank protection works are specifically complex because placing and dumping materials is under water via marine based equipment. It requires a long learning curve for contractors to do so in a proper manner whereby it is safeguarded that materials are actually placed at the right locations with thickness of layers as per specifications. This learning curve of contractors under CEIP-1 has been too long and this should be a more stringent criteria during procurement of works.

The constructability of the slope protection is also challenging, and special attention must be paid to the construction of the toe protection, since this constitutes the major reason for failures of slope protections. It is noted that due to the relatively steep and deep river profile at the riverbank (up to 1:1 to -10 m PWD) it is challenging to fix the present river bank with hard structures.

Non-technical issues

Besides these technical challenges, CEIP-1 contractors also encounter several other issues, such as delays and extra costs due to land acquisition and resettlement, bad weather and (recently) the outbreak of COVID. Contractors' work flow slowed down from the month of March 2020 due to the COVID-19 pandemic situation. The situation continued from the months of April, May, June, July & August including the reporting month of September 2020 resulting in very poor progress of works. The supply chain of materials (cement, stone / brick chips, geotextile etc.) was largely interrupted due to restrictions applied on transportation by the Government due to spread of Corona Virus (CEIP-1, 2020). Weather conditions and a pandemic are contingencies which are difficult to cope with and apply to any kind of development project in a harsh coastal environment such as the polders in Bangladesh.

Land acquisition and resettlement are different, as they are specifically relevant to the kind of project such as CEIP, where embankment improvements to new safety levels (making them stronger, higher and wider or realigning them) could need extra space, which is difficult because of the high population density in the project locations. The major physical works that may require private land acquisition are the improvement of embankment, construction of retired/new embankments and new hydraulic structures. Many authorities are also involved in land acquisition and resettlement, from central government to Deputy Commissioner (DC) and local communities, which make it a complex and time-consuming process.

CEIP-is working according to the regulations and stipulations from both the national government and the World Bank (Environmental and Social Safeguards Frameworks) and prepared likewise a Resettlement Action Plan (RAP). Starting point of this plan is that land acquisition will be avoided or minimized to the extent feasible and displacement of people will be kept to a minimum the least. The project will not acquire any land owned by the indigenous peoples or affect their livelihood and cultural resources. Where adverse impacts are found unavoidable, BWDB will compensate the affected persons at full replacement cost irrespective of title and tenure status. Displaced households including squatters and encroachers will be assisted for their relocation and livelihood restoration. Affected common property structures will be compensated and assisted for reconstruction at alternative sites. Owners of land and physical assets on the land to be acquired are eligible for Compensation under Law (CUL). The non-titled users of public and private lands and persons losing their livelihoods due to the project interventions will be entitled to assistance under this RAP.

It is the BWDB that undertakes and completes land acquisition process before the start of civil works construction. Hence, as per safeguards requirements, contractors cannot commence their construction activities prior to the completion of the land acquisition and resettlement procedures, which often leads to delays and additional cost and associated claims.

Delays such as these are continuing to challenge the progress, but, as stated in the progress report of September 2020, all stakeholders, including the Client, Client's Local Offices, DC's, Contractor and Consultants are applying their utmost efforts to organize this in a practical and pragmatic manner. It further suggests that: "*When there would be a land availability issue, joint efforts of Contractors, Engineer and Employer should be enhanced to solve the issues at stake. It is highly appreciated that the Employer plays a vital role here and increased efforts should continue; rooms for improvement are less reporting and more resolving on the spot*"(CEIP-1, 2020)

3 Socio-economic situation of the polders

3.1 Introduction

The ultimate project objective of CEIP-1 is to increase the resilience of the project beneficiaries to climate change, mainly through interventions in the physical environment. Besides increased protection against cyclone hazards, the project also aims at increasing the cropping intensity in agriculture, afforestation and capacity building. However, these measures can only be seen in the context of the socio-economic situation of the polder as different economic activities will benefit differently from changes to the water management. In this chapter the attention will be given to the different types of land use in the polder and on how these activities could benefit from the project interventions of the CEIP-1.

3.2 Agriculture

3.2.1 Land use and cropping patterns

The land use in the polders is dominated by crop lands and settlements. In some polders (notably Polders 32, 33, 35/1 and 35/3) a considerable part of the land is permanently used for fish or shrimp ponds. For instance, in polder 35/3 some 30% of the Net Cultivable Area (NCA) is being used for brackish water shrimp culture (EIA Report polder 35/3, 2013).

Cropping patterns are similar in all polders and are mainly determined by the land type (high land – F0, medium high land – F1, medium lowland – F3). They are all subjected to the following three growing seasons:

- Kharif-I March-June: hot humid summer;
- Kharif-II July-Oct: monsoon (autumn);
- Rabi Nov-Feb: cool, dry winter.

The traditional crop is rice (Boro, Aus, Aman), but cash-crop production is increasing and includes crops such as wheat, chilli, potato, mustard, tomato and pulses. Boro is grown in the Rabi season, Aus during Kharif-I and Aman during Kharif-II. Increasingly High Yielding Varieties (HYVs) are used over the years. Rice yields vary between 1.5 t/ha (local variety of Aus) and 2 to 3.5 t/ha (HYVs of Aman and Boro, respectively) (EIA Reports Polder 32, 35/1 and 35/3, 2013). An example of rice crop yields is provided in Table 3.1 for Polder 35/3. The table also shows that some 5% or about 679 metric ton of paddy was (potentially[3]) lost from this polder in 2012 due to drainage congestion, heavy rain fall, pest and disease infestations, drought and salinity, natural calamities etc.

Table 3.1 Rice crop yields and production in Polder 35/3 (2012)

		damage free area			damage area						
	total cropped area	area	yield	prod.	area	yield	prod.	Total prod	potential prod	prod. lost	% lost
	A	B	C	D	E	F	G	H	I	J	K
Rice-T.Aus(LV)	50	25	1.5	38	25	0.8	20	58	75	18	23.3%
Rice-T.Aus(HYV)	2,840	1,988	1.6	3,181	852	1.2	1,022	4,203	4,544	341	7.5%
Rice-T,Aman(LV/LIV)	1,605	1,284	2.5	3,210	321	1.5	482	3,692	4,013	321	8.0%
Rice-T.Aman(HYV)	247	247	2.25	556	-	-		556	556	-	0.0%
Rice-Boro(LV/LIV)	900	900	3.5	3,150	-	-		3,150	3,150	-	0.0%
Total rice	5,642	4,444	*2.28*	10,134	1,198	*1.27*	1,524	11,658	12,337	679	5.5%

Source: EIA Report Polder 35/3

[3] Potentially, because it is the difference between potential yield and actual production

In theory, it should be possible to grow three rice crops per year in parts of the coastal zone where fresh water is available year-round and with optimal water management for lands of different elevation (Saha et al., 2015). Average cropping intensity in the CEIP polders before the start of the project was recorded to be around 140% (CEIP, 2013). Most of the cultivable land remains fallow for 3-7 months each year, although some of these lands are grazed by goats and cattle. The main reasons for the low cropping intensity and low productivity in the polders are waterlogging (prolonged periods with water depth of 30-50 cm) during the rainy season, the late rice harvest (December/January) and the lack of ready access to fresh water during the dry season (Bhattacharya et al., 2019).

3.2.2 Challenges in crop production

Crop yields in the polders are relatively low compared to elsewhere in the country, where during the ‘Green Revolution’ high-yielding rice varieties were introduced and traditional tall Aman varieties were replaced (Tuong et al., 2014). The causes and issues that explain the underperformance of the polders are manifold and complex; this report focuses on the water-related challenges since this is directly related to the interventions of CEIP-1.

Water shortage and salinity
Due to salinity intrusion during the dry season, water resources in the coastal zone have been described as a constraint to agricultural production. However, there are big differences between regions and polders. In low salinity areas such as much of the Barisal Division, there is adequate fresh water in the rivers for irrigation throughout the dry season, whereas in moderately saline areas, such as parts of the Khulna Division, fresh river water is available from mid-June to mid-February (Tuong et al., 2014). Irrigation is provided to Boro (HYV) crop and is also provided to other crops like chilies, potatoes, vegetables and spices in dry season. Surface water is the major source of irrigation, although also groundwater is being used. Salinity especially affects the Boro rice and the initial stage of the Aus rice (Lazar et al., 2015), but in low-salinity areas such as much of Barisal Division it should be possible to intensify production to two or three high yielding crops per year (Saha et al., 2015).

Although there is in many polders abundant fresh water in the rivers surrounding the polders, it is often currently not available to most farmers during the dry season because of management problems with the sluice gates to fill the canals as well as siltation of (some of) these canals (Bhattacharya et al., 2019).

Drainage problems and waterlogging
The water management within the polder has become a key issue for further agricultural production increase. Although the embankments succeeded in reducing tidal flooding, drainage congestion, due to siltation of peripheral rivers, sedimentation in drainage khals and often poor condition of drainage structures, has become a serious impediment for the traditional cropping pattern with rice. The resulting waterlogging has become a yearly recurrent problem in many polders. In the Feasibility Report of 2013 for CEIP-1 it was observed that in all polders silting of internal drainage channels was a problem due to the lack of maintenance. It is often mentioned that waterlogging (instead of salinity levels) is the primary constraint for agricultural productivity (Mondal et al., 2015; Bhattacharya et al., 2019; Nowreen et al, 2014). An example of the waterlogging extent is given for Polder 35/3 in Figure 3-1 (for year 2012).

The waterlogging is a result of high rainfall, lack of separation of lands of different elevation and poor drainage management. Waterlogging prevents the use of high yielding and earlier maturing modern Aman rice varieties (HYV Aman) due to their shorter stature than the traditional / local varieties. The late harvest of the local Aman varieties and the saturated soil at harvest prevent the cultivation of high yielding dry season (Rabi) crops such as maize and sunflower. The soil usually remains too wet for tillage until mid to late February, and this delays establishment of traditional Rabi crops such as mungbean and sesame, which are then often damaged or destroyed by pre-monsoon rains and cyclones (Bhattacharya et al., 2019).

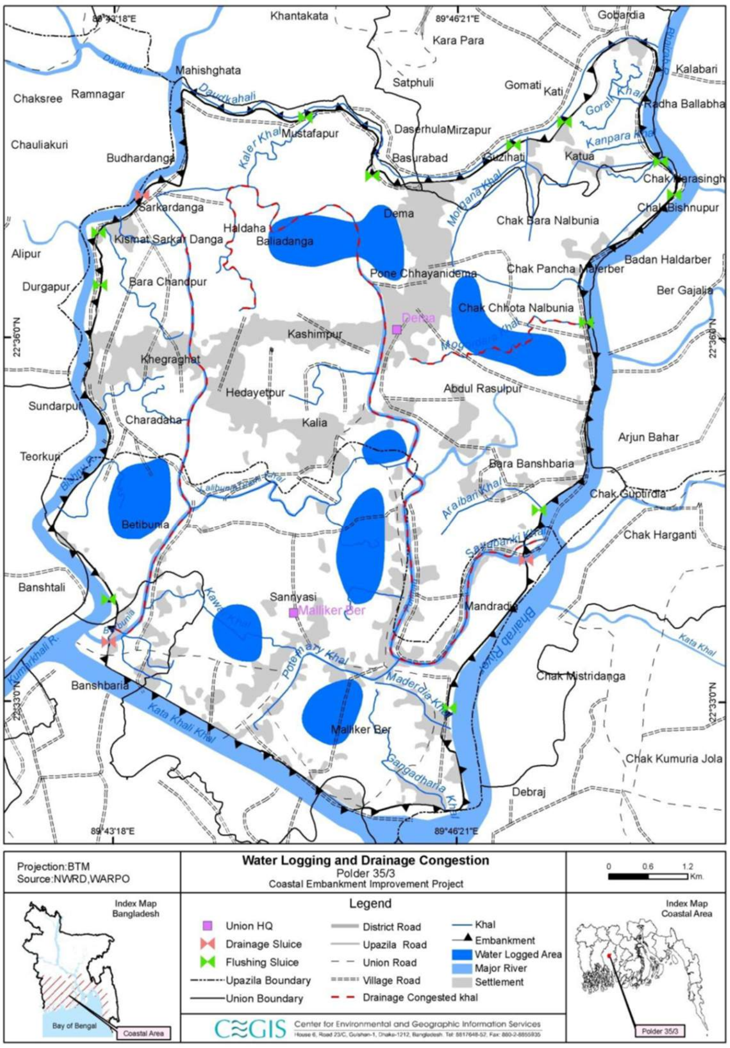

Figure 3-1 Water logging and drainage congestion Polder 35/3 (2012).

3.2.3 Livestock

Livestock and poultry play an important role in the economy of the polder. Livestock provides draft power for cultivation, threshing and crushing of oil seeds; cow dung is used as a source of manure and fuel. Livestock is also used as a ready source of funds and obviously provide meat, milk and eggs for household consumption. Most of the households in the polders raise poultry and livestock, a practice that reduces poverty through generating income and employment. Livestock and poultry rearing are constrained by fodder and grazing availability during part of the year (esp. when during the Kharif seasons the fields are occupied with rice). Also, recurrent diseases cause the death of a considerably number of animals each year (EIA Reports polder 32, 35/1 and 35/3, 2013). It was reported that 5-10% of the animals die each year due to diseases, malnutrition and poor management. It is expected that livestock would profit from the interventions under CEIP-1 through reduction of salinity and subsequent improvements of grazing land and fodder availability (CEIP-1, 2013).

3.3 Aquaculture and fisheries

Fisheries have always been an important activity in the coastal areas, as elsewhere in Bangladesh. The fisheries sector plays a particularly crucial role among poor as a main or additional source of employment, livelihood and income. However, fish stocks in the rivers and floodplains are declining gradually for a variety of reasons. One reason linked to the polders is that the embankments and sluices as well as the silting of khals interfere with the successful completion of fish migration, on which many species are dependent. Most of the indigenous fish are migratory and rely on seasonal flooding for spawning and larval rearing habitat on the floodplain (Hossain, 2014). In the polders open water fishery exist from rivers and khals, but in general, open water fish production is declining gradually due to the decrease of open water fish habitat, loss of khal-river connectivity, water regulatory structures on the khals and improper operations (EIA Polder 32, 35/1 and 35/3).

In turn, aquaculture is becoming more important, also in several of the polders under the CEIP-1. Often a combination of agriculture and fish cultivation can be found: growing Boro rice or other crops during Rabi and fishing during the Kharif seasons. Large scale aquaculture in Bangladesh can be found in Khulna, Satkhira and Bagerhat districts. Indeed, several of the CEIP-1 polders (notably 32, 33 and 35/1) contain large areas of aquaculture farms, called gher. The main cultivated species are marine tiger shrimp (*Penaeus monodon*), locally called *bagda chingri* and the giant fresh water shrimp (*Macrobrachium rosenbergii*), locally referred to as *golda chingri*. Also, commercial poly culture with marine and brackish water species including mullet (*Liza* spp.) and mud crab (*Scylla serrata*) is carried out on a small scale. Most of the farms have been constructed in the beel (natural depressed lands) area and are owned by urban people or leased to them in case of government-owned land (Azad et al., 2008).

The growth in saline shrimp farming over the past 20 years can be viewed as an effective adaptation to increasing salinity in the region. However, the environmental impacts of this intense aquaculture practice (e.g. increasing soil toxicity) raises concerns over its sustainability whereas it also leads to socioeconomic changes such as livelihood displacements, food insecurity and health, rural unemployment, social unrest and conflicts. It also seems that despite the asserted monetary benefits of shrimp, its impact on poverty amongst the local populations is trivial and may even increase livelihood vulnerability among local communities (Johnson et al., 2016; Nath et a., 2019, Nowreen et al., 2014).

3.4 Housing and livelihood

The average population density in the 10 polders is approximately 610 persons/km^2, of which the great majority is rural. There are no big cities and people live mostly in villages and hamlets, in a ribbon development kind of way on slightly elevated ground (see Figure 3-2). A small portion of people (mostly landless) resides on the embankments. It was estimated that more than 14,000 households are living on the embankment of the 17 polders (CEIP-1, 2012c).

The majority of livelihood is based on agriculture, aquaculture and / or fisheries (depending on the polders there can be large differences, as in polder 32 and 33 aquaculture is much more widespread than in the other polders of CEIP-1). This can be up to 75% of the household occupation. The remainder earn their livelihood from services, business, remittances, etc. (CEIP-1, 2012c).

Housing conditions are dominated by semi-pucca houses (around 80%), the remainder of which consists of pucca (permanent) and kutcha houses (GoB, 2008). Semi-pucca houses have corrugated iron roofs and walls of brick, wood or mud. Kutcha houses are entirely made of organic materials and earth and are highly vulnerable to natural hazards such as wind and floods. The exact percentages differ between the polders, but overall the housing conditions are not very good.

Figure 3-2 Typical settlement pattern (Polder 35/1)

3.5 Road Infrastructure

The road system in most polders consists of unpaved roads following the settlement pattern. Embankments are usually constructed with a road on top, which are important transportation links.

4 Flood and cyclone risks

The protection benefits from embankments are based on the amount of flood risk reduction and have been calculated with the Delft-FIAT Accelerator model as part of this review. This tool allows a preliminary risk assessment using global and local data and is based on loss of assets (housing), loss of agricultural crop revenues and interruption of economic production. For the hazard calculation (floods with a number of return periods) the flood inundation model SFINCS was used. SFINCS (Super-Fast Inundation of CoastS) is a rapid state-of-the-art coastal inundation model (Leijnse et al., 2020) and includes the effects of tides, storm surge, wave set-up and wave run-up. A separate report is being prepared to describe the details for the SFINCS and FIAT calculations. FIAT calculations were made for CEIP-1 Polders 35/1 and 40/2.

4.1 Economic risk

The results of the FIAT calculations (summarized in Table 4.1) show a significant economic risk reduction thanks to embankments (in the order of 41 to 57%). It also shows that relative sea level rise (a combination of absolute SLR and subsidence, in 30 years will have a drastic increase in risk. Also, mortality risk will significantly increase in 2050 and can only partly be offset by embankments. This underlines the importance of additional disaster risk reduction measures (early warning, Community Based Disaster Risk Management and cyclone shelters) even with the improved embankments.

In Figure 4-1 it can be seen that a major share of the potential damage is related to agriculture (43 to 76%) and housing (15 to 35%). Semi-pucca housing is relatively worst off, because it still is the most prominent house type in the delta, and it has a higher damage vulnerability than pucca housing.

Table 4.1 Summary of risk assessment for Polders 35/1 and 40/2 based on embankments re-construction under CEIP-1

ECONOMIC RISK (USD / YEAR)									
	current		2050		Climate induced risk increase	risk reduction			
Polder	No (new) embankment	New embankment	No (new) embankment	New embankment		current		2050	
35/1	1,900,885	1,122,254	4,518,212	2,702,795	138%	778,631	-41%	1,815,416	-40%
40/2	737,069	319,458	2,152,574	1,156,867	192%	417,611	-57%	995,707	-46%

PEOPLE AT RISK (NUMBER OF PEOPLE AFFECTED / YEAR)									
	current		2050		Climate induced risk increase	risk reduction			
Polder	No (new) embankment	New embankment	No (new) embankment	New embankment		current		2050	
35/1	784	488	2,195	1,348	180%	297	-38%	847	-39%
40/2	147	108	911	639	521%	39	-27%	272	-30%

MORTALITY (CASUALTIES / YEAR)									
	current		2050		Climate induced risk increase	risk reduction			
Polder	No (new) embankment	New embankment	No (new) embankment	New embankment		current		2050	
35/1	5.09	3.90	25.78	19.10	406%	1.19	-23%	6.7	-26%
40/2	0.45	0.41	17.16	16.28	3712%	0.05	-10%	0.9	-5%

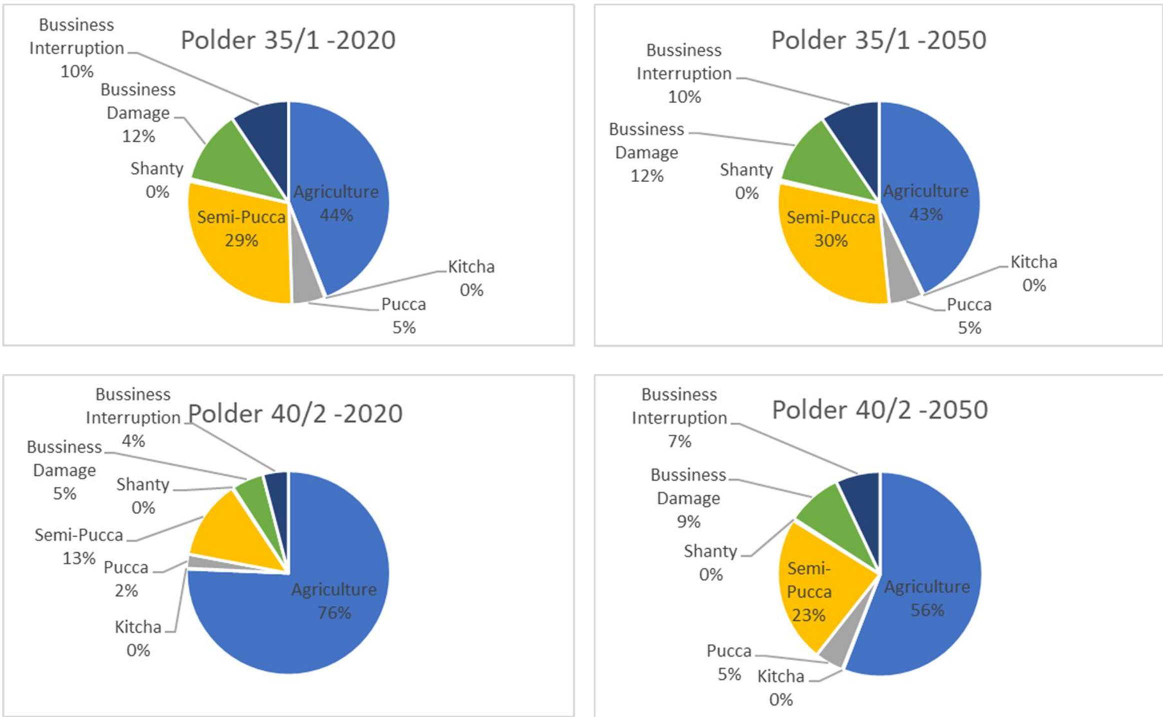

Figure 4-1 Risk characteristics of Polders 35/1 and 40/2 under current and future situation (2050)

When the calculated risks and the subdivision of the damages for the different sectors is compared with actual events like the damage assessment of cyclone Sidr, the damages over the sectors are in the same order of magnitude, as can be assessed from the Sidr PDNA (GoB, 2008). The subdivision of the economic sectors in the Sidr PDNA is somewhat different as used in our report (in which water, electricity and other services are included in "business"). When rearranging the sectors in a similar way, the PDNA gives the following ratio of damages per sector: housing 50 %, businesses 23% and agriculture 26%. This is a similar ratio as the analysis by D-FIAT: housing 44%, business 24% and agriculture 31%.

There is a significant difference between the polders with damage in Polder 40/2 predominantly from the agricultural sector reaching 63%, which is in line with the current economic activities in the polder. As for a comparison of the damages in terms of absolute value, this is difficult as no specifics on the different polders is provided in the PDNA. When comparing damages per area, e.g. per hectare, damages in the PDNA vary between BDT 65,000 – 140,000 (in 2018 prices and depending on dividing the damages over total area, or most affected area in the PDNA), these damages are comparable with damages in the polders of a 1/25 event as determined by the D-FIAT risk calculations[4]. More details of the comparison between calculations and recorded damages of cyclone Sidr and cyclone Aila can be found in Appendix 2 section 4.

4.2 Evaluation of investments

A Cost Benefit Analysis (CBA) has been made for the two polders (35/1 and 40/2) for which data is available for both the investments for risk reduction measures (Section 2.4) and risk calculations from both the current and the 2050 situation in respect to climate change (i.e. sea level rise) and subsidence (Section 4.1). Furthermore, for the situation in 2050, use has been made of the Shared Socioeconomic Pathways (SSP) scenarios (Riahi et al., 2017) to assess economic and demographic developments in Bangladesh that affect the results of the risk calculations. To predict

[4] For Polder 40/2 this is 95,732 BDT/ha; for Polder 35/1 49,377 BDT/ha

future damages and risk reduction the SSP2 scenario has been used. The summary of population and economic performance in Bangladesh is presented in Table 4.2; details of the SSP narratives and data for Bangladesh can be found in Appendix 2. In the CBA the Internal Rate of Return (IRR) is calculated of the investment under the CEIP-1 project as well as the Benefit Cost Ratio.

For the CBA calculations the following basic assumption apply:

- Costs are based on the costs estimates as provided by the CEIP-1 project as presented in Table 2.2 and Table 2.3. For the CBA costs are determined including all costs for construction (high costs) and excluding costs for drainage related infrastructure (low costs).
- Benefits are based on the risk reduction from flooding as calculated with the FIAT model and adjusted for future Climate Change and increase in assets and population according to the SSP2 scenario (see Table 4.2 and Appendix 2). Furthermore, a bandwidth has been applied for the benefits with a range of 75 % (Low) and 125 % (High) of the benefits as determined with the FIAT model to account for uncertainties in the different modelled calculations.
- Potential benefits from CEIP-1 to agricultural production are not used, as many other factors are important for increase in agricultural production that are outside the scope of the current CEIP-1 project.
- The factors derived from the SSP scenarios are assumed to be the same for all polders.
- Lifespan of the embankments is assumed to be 30 years. Although in general lifespan of this type of infrastructure can be significantly longer, under the current conditions 30 years have been used in the calculations.
- In the CBA the IRR of the investment and the benefits are presented.
- Investments are assumed to be all in the first year. Although this is not realistic, current uncertainties on exact year of investments and duration of implementation make this a manner in which all investments for each polder are treated in a similar way.
- Costs for O&M are assumed to be 2% of the investment costs per year.
- Value of a Statistical Life (VoSL) for mortality in Bangladesh from floods is US$ 217,000 based on Viscusi and Masterman (2017).
- The combined effect on the socio-economic developments and climate change are assumed linear between 2020 and 2050.
- To obtain a bandwidth for the Benefit/Cost ratio high costs are combined with low benefits and vice versa (low costs with high benefits).
- For the Benefit/Cost ratio calculation a discounting percentage of 8% is used, which is a net rate of 3.5 %, as average economic growth in the period 2020 – 2050 under a SSP2 scenario is 4.5%.

Based on the FIAT data provided in Table 4.1 and adjusted for future socio-economic conditions using the SSP2 scenario (see Table 4.2) the risk reduction for both polders in 2050 are given in Table 4.3. Note that the risk reduction in 2050 is significantly higher than in Table 4.1 as the results from FIAT do not include the socioeconomic growth nor the VoSL. By using these risk reductions, the net benefits have been calculated for the CBA, the results of which are presented in Table 4.4.

Table 4.2 Population and GDP (PPP) in Bangladesh under different SSP scenarios

Population (million)	2020	2050
SSP1	164	178
SSP2	166	196
SSP3	169	222
SSP4	164	177
SSP5	163	171
GDP (USD billion, PPP)		
SSP1	422	2,637
SSP2	425	1,754
SSP3	429	1,236
SSP4	416	914
SSP5	423	3,367

Table 4.3 Risk reduction from investments under CEIP-1 for 5 selected polders under current (2020) and future (2050) conditions

	Economic Risk		Mortality	
	M USD/Year		# Casualties/year	
Polder	2020	2050	2020	2050
35/1	0,8	8,8	1	7
40/2	0,4	4,8	0,0	1

Table 4.4 Cost Benefit Analysis for polders 35/1 and 40/2

Polder 35/1	**Polder 40/2**
Investments = US$ 50 million	Investments = US$ 16 million
Costs for O&M = 2% of investment	Costs for O&M = 2% of investment
Nett Benefits_{2020} = US$ 0.04 million	Nett Benefits_{2020} = US$ 0.1 million
Nett $\text{Benefits}_{2050(L)}$ = US$ 7.0 million	Nett $\text{Benefits}_{2050(L)}$ = US$ 3.3 million
Nett $\text{Benefits}_{2050(H)}$ = US$ 15.5 million	Nett $\text{Benefits}_{2050(H)}$ = US$ 7.0 million
IRR: 3.4 % - 9.5 %	IRR: 6.0 % - 14.4 %
B/C: 0.5 – 1.3	B/C: 0.7 – 2.2

As can be seen from Table 4.4 the B/C ratio for especially polder 35/1 is relatively low. From the details of the budget (Table 2.2) it is apparent that a significant portion of the costs goes towards embankment protection (slope and bank protection). These high investment costs pose the question whether alternative options exist that are more cost effective to reduce the flood risk. For instance, at locations highly vulnerable to bank erosion, the embankments can be realigned further inland (although creating other challenges regarding land acquisition and resettlement). Finding more cost-effective solutions for bank protection could be another way to reduce these costs. Now very expensive concrete block type bank protections are made, but a more cost-effective solution could be to make more use of combinations of geobag/concrete block protections (which are now implemented for one of the polders and has been a design optimization during CEIP-1).

It should be noted that this risk analysis has its limitations and uncertainties, because of which the results should be used as an indication of a trend rather than hard facts. Besides the assumptions mentioned above, the analysis is dependent on several input values, of which the most important ones are:

- Data on current and future hydrodynamics (e.g. sea level rise);
- Digital Elevation Model (for determining the flooding depths and extent);
- Data on exposed people and assets (houses, agriculture etc.); and
- Depth-damage relationships for houses and other assets (such as crops).

Details on these datasets and their level of accuracy will be given in a separate report that describes the FIAT calculations for 5 polders, including the 2 CEIP-1 polders presented here.

5 Review of Operation, Maintenance and Management of the polders

5.1 Operation for water management

Because the polder is a highly artificial environment, there is hardly any natural water flow any more. The water infrastructure that has been created can be manipulated through weirs, drains and regulators, which – in principle – can result in an optimal water regime. But there are at least two problems: 1) there are conflicting water demands between users (such as high land and low land farmers, aquaculture farmers and fishermen) and 2) who should operate the system?

Opening and closing of the gates remains one of the most controversial and debated issues in the polders. The conflicts occurring between shrimp culture and agriculture, small and large farmers, and low and high land farmers are due to issues coordinating water quantity, quality (salinity) or timing (Kenia & Buisson, 2015). For instance, low land farmers would demand early drainage of their land at the end of the monsoon, whereas highland farmers would prefer retention of water in the low-lying areas, so that there is freshwater during the (beginning of the) dry season. Note that the difference between “high” and “low” land can be quite small, but even half a meter can give quite a significant difference in the problem of waterlogging, especially if drainage is hampered by blocked khals. There also may be a conflict of interest between gher owners and rice farmers, as the former may want to keep water inside longer than the latter. For instance, gher owners do not want to drain out water from the gher as a consequence of which neighboring paddy farmers cannot plant aman paddy in proper time (Maniruzzaman, 2012).

The second issue – who should operate the system – is of course related to the first one. Ideally, the management of water resources should be such that potential conflicts are minimized, and a fair distribution of water is assured. For this the concept of Participatory Water Management should provide guidance. We therefore have to look at the official GoB policy in this respect, which has been laid down in the Guidelines for Participatory Water Management of 2001. Basically, these Guidelines institutionalize the establishment of WMO’s through which a governance structure is created to manage the operation and (some) maintenance tasks within a polder. As has been stated in Section 2.3.2.3, within CEIP-1 in all polders such WMO’s are planned to be established. It is too early to evaluate the success of these WMO’s. Based on past experiences we can nevertheless identify a number of challenges that these (new) WMO’s will certainly have to cope with (see Section 4.3).

5.2 Maintenance

Clearly, khals need to be properly maintained so that their original (design) discharge capacity remains intact. However, the proper functioning of the khals (for drainage of water during the monsoon and keep and convey fresh water for irrigation purposes in the dry season), is in most polders hampered. The hydrological connectivity of the khals is disrupted by a range of causes. For instance, cross dams, which are constructed for a variety of reasons, can cause drainage congestion in the upstream areas in the post-monsoon and water shortage in the downstream areas in the dry season, something which was already noticed many years ago by Wester & Bron (1988). However, this situation remains very common in recent times. For example, in Polder 43/2C (next to a CEIP-1 polder), 16 dams were inspected with only 2 of them having a culvert (Douben et al., 2019). Other reasons for the reduced functioning of khals is the silting up and growth of water hyacinth, debris and fishing nets etc., reducing the drainage capacity.

Embankments need regular maintenance too. For instance, repairing loose bricks and blocks of the slope and bank protection, keeping the embankment road in good condition, avoiding disruption of the dike vegetation, filling rodent holes and rain cuts etc. These small, day-to-day (preventive) maintenance tasks are to be distinguished from major repairs after a storm or serious river bank erosion. But in most cases these regular tasks are not executed. One reason is given by Wester & Bron who already in 1988 noted that the poor condition of many embankments is partly because of the multiple use of them: because they are a public good that provides benefits to a wide range of people, nobody feels directly responsible for them.

BWDB owns the water-related infrastructure in the polders. In each district BWDB has a special wing called Operation and Maintenance for the polders and an O&M office headed by an executive engineer. However, findings from Naz & Buisson (2015) indicate that BWDB executes repair work only occasionally, when funds are available. These funds are typically only given after some disaster takes place or when minor maintenance becomes major and attracts the attention of higher authorities or donors.

Apart from the major repairs, which is the job of BWDB, all the other maintenance should be done by the Water Management Groups (WMGs). According to the Guidelines for Participatory Water Management, these WMGs are tasked with: (i) preventive maintenance of the medium and minor hydraulic structures, bridges, culverts, etc.; (ii) preventive maintenance of the main embankment and secondary embankment; (iii) routine/annual maintenance (desalting) of field channels, drains etc.; (iv) clearing weeds, obstacles from secondary and tertiary channels, canals drains etc.; (v) regular greasing of gates; and (vi) annual painting and minor repair of minor gates and replacement of fall board. However, even if these repairs are referred to as minor, they are most of the time beyond the capacity of the WMGs (Naz & Buisson, 2014).

5.3 Challenges in O&M

Based on the past experiences in polder management and participatory water management, the following challenges in O&M can be defined:

- Unclear mandates and coordination;
- Financial constraints;
- Knowledge and skill deficiencies; and
- Conflict handling / power inequality.

Unclear mandates and coordination

The Guidelines for Participatory Water Management (GPWM) give a central role of the WMOs that would make them “responsible for planning, implementing, operating and maintaining local water resources schemes”. Local Government Institutes (LGIs) “will provide supporting, facilitating and coordinating assistance to the concerned WMO” and “provide such assistance through their representation as advisors to the concerned WMOs and also through their representative Standing Committees”. Mandates and responsibilities are further detailed according to the type of project and selected agreement. The GPWM makes a distinction between several constructions, based on their size. Schemes above 5,000 ha will need a joint management agreement (between IA, LGI and WMO). This is the most common type of agreement for polders, in which the ownership remains at the IA, but the O&M responsibilities are divided over the IA, LGI and WMO. Projects smaller than these would divide the O&M between the LGI and WMO (GoB, 2001).

Although tasks and responsibilities for the WMOs are explicitly mentioned in agreements, the role of LGIs is much less clear. Depending on how active or inactive WMOs are, Union Parishads have sometimes taken over the roles of a WMO (for instance as active members of a gate committee, see Dewan et al., 2015), but sometimes are sidelined in water management. Facing a lack of legal mechanisms and resources to take on these roles, many Union Parishads are only informally involved in water management. Their limited role is not only contrary to the intent of the policy but also to the wishes of most community members (Naz & Buisson, 2015). In their report “Sixty years of Water Resources Development in Bangladesh: Lessons learnt” the BDP2100 reported: “One of the main causes of dysfunctional water management groups was the undefined responsibilities of the concerned officials. Improper institutional interaction between implementing agencies and local government institutions at Upazila and Union levels is another reason of malfunctioned Participatory Water Management" (GoB (2018)).

Financial constraints

Past experiences show that O&M budgets are always inadequate. As local BWDB offices do not have a fund of their own for management of the polders (Rahman et al., 2020) they have to make requests to the central level. It has become a general complaint that field offices responsible for O&M are provided with only one-fifth or even less of the total requirement in a fiscal year. As a result, much of their planned activities remain unattended causing poor operation and maintenance of the water resources systems (CEIP-1, 2012e).

As part of the CEIP-1 Feasibility Study, estimates were given for the annual O&M budget needed for the polders. The average over the 10 selected polders is as follows:

Table 5.1 Annual estimated O&M costs for one CEIP polder (average over 10 polders)

Annual O&M costs	**Lac BDT**	**equivalent US$ (using 2013 conversion)**
Preventive maintenance	79	99,395
Periodic maintenance	370	467,975
Establishment and operation	19	23,972
Subtotal O&M	*468*	*592,405*
Emergency fund	198	250,000
Rehabilitation	540	682,911
TOTAL	**1,204**	**1,524,253**

Source: CEIP-1, 2013e

These are significant numbers. Assuming an average number of 11,000 families in one polder, preventive maintenance alone is in the order of 700 BDT/year per family (8.80 US$). For O&M in total this would be 4,250 BDT/year per family (53.47 US$).

WMOs are responsible for collecting the beneficiary contribution, the amount of which is stated in the Implementation Agreement with the Implementing Agency. However, the regular collection of contribution fees is not always guaranteed, and many WMOs are in shortage of funds (Naz & Buisson, 2015; BGP, 2013, Tuong et al., 2014). Even when WMOs are actively collecting the fees, this is often not sufficient for the execution of all required O&M (Dewan et al., 2015).

Knowledge and skill deficiencies

Managing water in a polder is not simple. It requires a lot of local knowledge when to close and open the gates, considering seasonal and day-to-day hydrological conditions. Ideally, a monitoring network and computer model is used to compute different water management scenarios, the effects of measures (such as early drainage or flushing, and to develop weekly operation targets (CEIP-1, 2012e; Douben et al., 2019). In reality, such knowledge tools are non-existent up to now and gate keepers use their experience instead.

Indeed, there is huge potential for greatly increasing productivity through cropping system intensification and diversification combined with better water management in the polders. New species, new varieties, timely crop establishment and improved crop, nutrient and water management have enabled high productivity in areas/seasons where this was not previously possible, as has been shown in the CGIAR Ganges Basin Development Challenge (Tuong et al., 2014). But to unlock this potential, a coordinated effort is needed to introduce better water management together with new crop varieties and agricultural extension (Saha et al., 2015; Bhattacharya et al., 2019). This requires improved knowledge and skills for the agriculture-water nexus.

Besides, there is a lack of skills at several levels on participatory water management. WMOs often lack the necessary training to perform cooperative functions on top of their water management responsibilities and the staff of BWDB is lacking proper training for institutional arrangements (BGP, 2013).

Conflict handling / power inequality

As mentioned earlier, different stakeholders (viz. farmers and aquaculture owners, upstream and downstream farmers etc.) often have different water management needs (on water quantity, salinity and timing) that can cause conflicts on what is the best operation. Also, the multifunctionality of water infrastructure (embankments, khals) can result in differences in opinion about the best way to maintain these features. Although the Water Management Group (the lowest level of participatory water management organization) has the task to resolve conflicts and the "concerned local government bodies will act in an advisory capacity to the WMA and WMF, particularly in the areas of land acquisition and resolving conflicts among the various local stakeholders" (GoB, 2001), in practice their role is often limited. For instance, Kenia and Buisson (2015) write that "the timing of gate opening and closing is supposed to be decided jointly by all the members of the WMO but more often than not the decision is made by influential people to suit their own needs". The Functionality Assessment at the start of the Blue Gold Project concluded that in the Blue Gold Polders the "interference of influential and rich people as well as other interest groups in the operation and maintenance of FCD/I structures worsened water management conditions in the polders" (BGP, 2013). The Bangladesh Delta Plan 2100 concluded in their sixty years of lessons learnt that "Local elites and politically powerful people might have negative influences on the PWM in terms of management and leasing of the khals" (GoB, 2018).

This all should not come as a surprise. After all, such power inequalities can be found in all parts of society. But the question here is if the decentralized and depoliticized water management set-up is *in principle* capable of coping with these conflicts and able to make fair and impartial decisions. Some authors see advantage in increasing the role of elected local government bodies (e.g. Nowreen et al., 2014; Naz & Buisson, 2015; Dewan et al., 2015), although these institutions are "just as prone to elite capture as WMOs" (Dewan et al., 2015).

For the CEIP-1 polders it is too early to evaluate how effective and successful the WMOs are, as their work has yet to start. It should be noted, however, that due to the significant delay in their installation, the project missed the opportunity to give them influence and participation in the planning and design of the rehabilitation works.

6 Conclusions

Rehabilitation of the polders under CEIP-1 is currently on-going, which makes it difficult to evaluate its success. It is simply too early to see the results of the investments in terms of risk reduction, higher agricultural output or improved water management. However, based on what has been done so far as well as on literature from these and similar polders, a lot of information is available to learn from and what can be used for future planning and polder development. Based on this information, the following conclusions can be drawn:

1. The polders under CEIP-1 will have strong embankments, based on sound design criteria, that will significantly improve the safety against tidal incursions and storm surges for over half a million people. The embankments will also improve the road connectivity in the rural areas.

2. Notwithstanding the greatly improved slope and bank protection measures, the risk of undercutting at local river erosion hotspots remains. Furthermore, it is a highly costly measure that consumes approximately half of the total project investment costs. Actually, a very high percentage of the investments is embankment related (75%), while only 2 – 10 % (dependent on whether investments have drainage improvement as primary objective) goes to drainage improvement. There are no other investments that have a primary objective to improve agricultural production. This seems like an imbalance, considering that one of the main PDOs is to increase agricultural production, that currently suffers from inadequate water management and often still has the characteristics of subsistence farming.

3. The risk assessment shows a significant reduction of risk thanks to the rehabilitation of the embankments. However, the combination of sea level rise and subsidence will steadily increase the risk again. Especially the mortality rates will rise sharply towards 2050 and show that even after completion of the CEIP-1 embankments there will remain a need for additional disaster risk reduction (such as early warning, CBDRM and cyclone shelters).

4. Initial risk and cost/benefit analysis for two CEIP-1 Polders (35/1 and 40/2) show relatively low benefit-cost ratios of the embankments. This raises the question whether cost reductions could be found to protect the land and people from flooding. Also, other measures that would decrease people's vulnerability (such as stronger houses, cyclone shelters, early warning, disaster relief etc.) continue to be of the highest importance. It is recommended to enrich the initial flood risk analysis presented in this report with more detailed data to improve the knowledge basis on which future investment decisions can be based.

5. The anticipated increase in agricultural yields has not yet been confirmed, due to a lack of agricultural data. As most of the water infrastructure has only recently been upgraded, it is not possible at this moment to tell what the results of the combined efforts are.

6. The formation of WMA's is ongoing, so it is too early to measure their role in the O&M of the polders. However, it is apparent that the installation of the WMA's is lagging behind the actual civil engineering designs and implementation, which is not according to the GPWM. Thus, the project missed the opportunity to give them influence and participation in the planning and design of the rehabilitation works.

7. CEIP-1 has a strong focus on agriculture. There is no PDO for other land use activities, such as fisheries and livestock rearing. This is similar to other polder projects and in general one could say that until now, polders have not been designed for multifunctional land use nor is the current diversity of the land used in the design of the risk reduction measures.

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A.1 APPENDIX 1: CEIP-1 Polder descriptions

Polder nr	Origin	Embankment condition	Water management condition	Other special conditions
32	Completed in 1971-72 under CEP	Many segments of the embankment are damaged, mainly by overtopping action due to Sidr and Aila. The river side slope and berm in many places are subject to severe river erosion and wave action.	The internal drainage channels have become silted up and needs to be re excavated on the basis of CEIP design. Some local land owners are going on with shrimp culture within the polder. To facilitate this, some Inlets structures were constructed under Third &Fourth Fisheries Project. But these are not being properly operated by the Gher owners, due to which acute internal water management problems are created within the polder.	58 ha of afforestation is planned.
33	Completed in 1971-72 under CEP	Many segments of the embankment were damaged mainly by overtopping during Sidr and Aila. The river side slope and berm in many places are subject to river erosion and damaged by wave action.	Many of the hydraulic structures are partially damaged and few are non-functioning due to missing gates and silted up diversion channels.	72 ha of afforestation is planned.
35/1	Completed in 1968 under CEP but additional structures were carried out afterwards. Rehabilitated in 1997-98 under CERP-11.	Many segments of the embankment in different places were damaged during Sidr and to a lesser extent by Aila mostly by overtopping of embankment, severe wave action and river erosion.	Most of the existing drainage sluices are in a very bad condition and have become almost non-functional. The internal drainage channels have become silted up.	Rayenda Bazar and other private establishments were open to the river and regularly suffered from tidal inundation during high spring tides. 22 ha of afforestation is planned.
35/3	Completed in 1986	The polder is vulnerable to river erosion. Many segments of the embankment have been damaged and eroded in river side slope in different places mainly due to river erosion, wave action and overtopping during Sidr	All drainage sluices are in a very bad condition. All the Flushing-Inlets are not in good condition, loose aprons are damaged in almost all the cases, vertical lift gates and flap gates are not working properly (missing or damaged). Local farmers are taking fresh water in the paddy field inside the polder by cutting the existing embankment in many places. The internal drainage channels have silted up due to lack of maintenance for a long time.	There are some shrimp culture Ghers inside the polder occupying about 30% of the total area of lands as reported by the local people. Conflicts in between Gher owners and farmers are there in the Polder area. For consolidation of agricultural activities, conflicts in between the Gher owner and the farmers have to be resolved.

Polder nr	Origin	Embankment condition	Water management condition	Other special conditions
				26 ha of afforestation is planned.
39/2C	The construction of this polder could not be undertaken under CEP due to fund constraints. On the basis of the demand of the local people, BWDB took initiative to start construction of embankment along the left bank of Kocha River on piece-meal basis. About 28 km of embankment has been constructed out of 61.50 km.	The portions of the embankment damaged by Sidr - so far re-constructed by BWDB have been damaged by Aila. Some segments of the embankment have fallen under the thrust of wave action and some segments have been engulfed by river erosion.	No sluices were constructed and all the internal khals were kept open to the river. As the peripheral boundary is not covered by embankments, the people of the area are suffering from tidal inundation twice a day. It becomes disastrous during high spring tides and monsoon due to drainage congestion in the low pockets area. Most of the paddy fields are submerged during the monsoon and sometimes even in the dry season during high tide. Tidal water along with rainfall runoff remains stagnant at a depth of 1m to 1.5m over the land during monsoon and delays the cultivation of T-Aman. Sometimes seedling and T-Aman is damaged due to stagnancy of sandy water which enters with tidal water over the land. Besides, it is hardly possible to cultivate Rabi Crop in the dry season due to intrusion of saline water through khals and Rivers. Salinity starts at the end of December and continues until April.	Every year at the end of November, local people construct earthen cross-dams over the mouth of the internal Khals to protect the agricultural land from saline and sandy water intrusion. 22.5 ha of afforestation is planned.
40/2	Completed in 1966-67 as part of CEP. Rehabilitated under CERP in 1996-98	Many segments of the embankment have been damaged mainly by overtopping due to Sidr and Aila. The river side slope of the embankment in many places is subject to severe wave action.	The internal drainage channels are silted up. Most regulators are required to be replaced. People demanding fresh water storage during post-monsoon season.	Afforestation (30 ha) has to be provided for the segment of embankment from km13.10 to km 13.750 and other locations for the safeguard of the embankments.
41/1	Completed in 1966-67 as part of CEP.	Many segments of the embankment have been damaged mainly by overtopping action due to Sidr and Aila. The river side slopes in many places are subject to wave action and severe river erosion	The internal drainage channels are silted up. Most regulators are required to be replaced. People demanding fresh water storage during post-monsoon season.	Afforestation (22 ha) has to be applied for the segment of embankment from mk 22.00 to km 33.00 along the River Paira (Buriswar) for the safeguard of the embankment.
43/2C	Polder 43/2 was a very large polder (25,998 ha) under CEP. For efficient	Many segments of the embankment have been damaged mainly by overtopping action due to Sidr and Aila. The river-side	The internal drainage channels are silted up. Almost all the regulators are required to be replaced.	This polder benefits from the lower salinity levels found in the vicinity of the Lower Meghna Estuary.

Polder nr	Origin	Embankment condition	Water management condition	Other special conditions
	water management as well as to keep the channels open for navigation the polder had been sub divided into 6 Sub- polders by constructing dykes along tidal creeks. Polder 43/2C is one of the 6 Sub Polders	slope of the embankment has been damaged in many places by severe wave action.	Most of the land of the polder area is under triple cropping. Water intake into the polder through sluices is needed for supplementary irrigation during dry period.	
47/2	Completed in 1965-66 as part of CEP-1.	Many segments of the embankment have been damaged by Sidr. Breaches were formed at some weak sections of embankment and the polder area were inundated by about 1m of water. The river side slopes at some segments of embankment has been severely damaged by river erosion and wave action.	Internal drainage channels have been silted up. Regulators need replacement/repair. River water becomes saline in the dry season. People demanding fresh water storage during post-monsoon season.	There is scope of afforestation along the bank of the river Charpara (km 8.70 to 12.50).
48	Completed in 1967-68 as part of CEP-1. Rehabilitated under CERP in 2003	Many segments of the embankment have been damaged by Sidr and Alia. The sea dike from km 29.5 to 34.6 is subject to severe wave action from the sea during storms.	Internal drainage channels have been silted up. Regulators need replacement. River water becomes saline in the dry season. People demanding fresh water storage during post-monsoon season.	Kuakata sea beach is a tourist spot. There is wide scope for afforestation. Parts of the foreshore adjacent to the embankment (between km 26.5 to 19.0) has naturally accreted towards the sea.

Source: CEIP-1, 2012b

A.2 APPENDIX 2: Population and GDP data for Bangladesh under different SSP scenarios

Model	Scenario	Region	Variable	Unit	2010	2015	2020	2025	2030	2035	2040	2045	2050
OECD Env-(	SSP1	BGD	GDP|PPP	Annual Average Growth	6.243	7.114	7.160	7.098	6.866	6.294	5.561	4.811	4.159
OECD Env-(	SSP2	BGD	GDP|PPP	Annual Average Growth	6.385	7.102	6.288	5.424	4.743	4.494	4.196	3.908	3.677
OECD Env-(	SSP3	BGD	GDP|PPP	Annual Average Growth	6.509	7.181	5.813	4.452	3.342	2.978	2.642	2.360	2.192
OECD Env-(	SSP4	BGD	GDP|PPP	Annual Average Growth	6.256	6.779	5.350	3.882	2.476	1.914	1.404	0.995	0.723
OECD Env-(	SSP5	BGD	GDP|PPP	Annual Average Growth	6.191	7.181	7.847	8.279	8.125	7.207	6.226	5.319	4.580

Model	Scenario	Region	Variable	Unit	2010	2015	2020	2025	2030	2035	2040	2045	2050
OECD Env-(	SSP1	BGD	Population	million	148.692	156.300	163.543	169.475	173.814	176.853	178.519	178.797	177.675
OECD Env-(	SSP2	BGD	Population	million	148.692	157.346	166.226	174.289	181.146	186.736	191.092	194.105	195.777
OECD Env-(	SSP3	BGD	Population	million	148.692	158.266	168.989	179.919	190.251	199.416	207.600	215.035	221.609
OECD Env-(	SSP4	BGD	Population	million	148.692	156.393	163.885	169.986	174.360	177.329	178.799	178.691	177.054
OECD Env-(	SSP5	BGD	Population	million	148.692	155.919	162.575	167.583	170.957	173.030	173.744	173.096	171.098
Model	:nario (Histc	Region	Variable	Unit	1960	1965	1970	1975	1980	1985	1990	1995	2000
History	World Banl	BGD	Population	million	50.102	57.792	66.881	70.582	80.624	92.284	105.256	117.487	129.592

Model	Scenario	Region	Variable	Unit	2010	2015	2020	2025	2030	2035	2040	2045	2050
OECD Env-(	SSP1	BGD	GDP|PPP	billion US$2005/yr	221.30	299.56	422.38	596.86	840.97	1,172.14	1,590.47	2,084.68	2,636.73
OECD Env-(	SSP2	BGD	GDP|PPP	billion US$2005/yr	221.30	301.56	424.97	576.48	750.71	946.45	1,179.10	1,448.14	1,754.13
OECD Env-(	SSP3	BGD	GDP|PPP	billion US$2005/yr	221.30	303.33	429.04	569.09	707.55	833.95	965.74	1,100.23	1,236.33
OECD Env-(	SSP4	BGD	GDP|PPP	billion US$2005/yr	221.30	299.74	416.08	539.95	653.22	738.18	811.59	870.17	914.33
OECD Env-(	SSP5	BGD	GDP|PPP	billion US$2005/yr	221.30	298.83	422.67	616.65	917.81	1,356.40	1,920.86	2,598.08	3,366.51
Model	:nario (Histc	Region	Variable	Unit	1960	1965	1970	1975	1980	1985	1990	1995	2000
History	World Banl	BGD	GDP|PPP	billion US$2005/yr					54.567	65.486	78.646	97.496	125.677

A.3 APPENDIX 3: Risk calculations

5A-2: Review/Improvements on-going work (CEIP-I)

APPENDIX 3: RISK CALCULATIONS

June 2021

Contents

FIGURES

TABLES

1 Introduction

This Appendix describes the modelling methods for analyzing the current and future risk to flooding from a storm surge for the two CEIP Polders 35/1 and 40/2. A flood inundation model called SFINCS was used to do the hazard modelling. For the risk analysis the FIAT-Accelerator software was used.

2 Hazard modeling

2.1 SFINCS model

SFINCS is a rapid state-of-the-art coastal inundation model (Leijnse et al., 2020). SFINCS (Super-Fast Inundation of CoastS) includes the effects of tides, storm surge, wave set-up and wave run-up. It applies the simplified approximation of the momentum balance equations described in Bates et al. (2010) with added capability of modelling waves by including advection and a generating-absorbing boundary condition. SFINCS is on average two orders of magnitude faster than traditional coastal flood models (Leijnse et al., 2020). It can therefore be run at higher horizontal resolutions and/or larger areas, which allows for a more accurate representation of coastal topography in the model. The shorter computational time will make it possible to run many scenarios, needed to carry out a probabilistic risk assessment for current and future time horizons.

2.2 Data

In this section, an introduction is given to the data necessary for setting up a SFINCS model. In order to estimate the probability of the selected polders to flooding, both terrain elevation and hydrodynamic conditions (such as water levels) during extreme events are needed for each polder.

2.2.1 Topography

In the absence of a proper local DEM, the topography is estimated using the MERIT DEM, which is a high accuracy global DEM based on both the SRTM3 v2.1 and AW3D-30m v1 DEMs. After removing multiple error components from these existing DEMS, the MERIT DEM reaches ~ 90m horizontal resolution at the equator (Institute of Industrial Sciences, 2018). The resulting topography for each of the polders is provided in Figure 2-1 and Figure 2-2. Ideally the currently existing embankments would be included in the model explicitly to ensure a best representation of the actual state but required data regarding the actual heights and extends of the embankments is not available in sufficient detail. Nevertheless, while using the MERIT DEM to estimate the topography of the polders, elevations of the embankments are (partly) captured as well in this topography data. It should be noted however that due to the ~ 90m horizontal resolution, this approximation of the embankment heights may not be fully accurate and could result in an underestimation of the actual embankment height, and therefore an overestimation of the flooding.

2.2.2 Boundary conditions

In an earlier stage of the Coastal Embankment Improvement Phase (CEIP-1), hydrodynamic modelling is used to quantify hydrodynamic conditions in the Bangladesh' coastal zone, which is elaborately described by IWM (2018a, 2018d). Storm surge was determined by performing an extreme value analysis (EVA) on the water levels obtained from hindcasting a total number of 19 historic cyclones with a process-based storm surge model (Bay of Bengal model), forced by the astronomic tide, river discharge, and meteorological conditions during the cyclones. The EVA provided 10, 25, 50, and 100-year return periods for the maximum attained storm surge during cyclonic storms in meters above PWD (Public Works Datum). The cyclone modelling was performed with a phase shift in the tidal components as well, to consider an unfavorable tidal phasing with respect to the moment of the cyclonic surge (i.e. the worst-case scenario of high tide during the cyclone is covered). An additional water level set-up due to wind-driven waves during the cyclonic events was assessed using a wave model. Using an approach similar to the EVA on the water levels, the 10, 25, 50, and 100-year return periods of the significant wave height (H_s) was obtained.

Additionally, extreme water levels due to monsoonal flooding (i.e. high river discharge) were determined as well, by applying a freeboard computation on the monsoon-driven water levels which were modelled with a validated one-dimensional river model capable of translating upstream river discharge to water level over the whole GBM delta (South West Regional Model). The various models provided the necessary data on strategically chosen points covering the coastal zone of Bangladesh.

Within the CEIP-1 project, maximum storm surge and wave heights are not only calculated for the different return periods, but also considering scenarios with and without the effects of climate change. Within the project, the effects of climate change for the area of interest were approximated with a 50 cm sea level rise in 2050 and an increase of the windspeeds with 8%. In this flood risk analysis, we applied the same projections as used by CEIP-1 for modelling climate change.

Both polders are surrounded by several strategically chosen points (see Figure 2-3), from now on referred to as extraction points (IWM, 2018c). Maximum storm surge and wave heights for each of these extraction points are presented in Table 2-1 and Table 2-2**.** However, only the values shown in black could be derived directly from the published reports **(**Table B3.1 to B3.5 & B5.1 to B5.4 in Appendix B of IWM (2018a, 2018b))**.** The values for the significant wave height in the case of no climate change were not available and were estimated using the quadratic relationship between wave height and wind speed**:** $H_s \sim u_{wind}^{2}$ **.** Since wind speeds are assumed to increase with 8%, wave heights without climate change are expected to be a factor $1/1.08^2 = 0.86$ lower. Peak periods associated with the return periods are not provided in literature but were estimated using (Van Rijn, 2011): $T_p = 6H_s^{0.33}$

Table 2-1 Maximum storm surge in meters above PWD at the observation points. Source: Table B3.1-B3.5 of IWM (2018b)

		WITHOUT CLIMATE CHANGE STORM SURGE (M) FOR DIFFERENT RETURN PERIODS (YEARS)				WITH CLIMATE CHANGE STORM SURGE (M) FOR DIFFERENT RETURN PERIODS (YEARS)			
POLDER	**Point ID**	**10**	**25**	**50**	**100**	**10**	**25**	**50**	**100**
35/1	**31**	2.59	3.34	3.90	4.47	2.97	3.50	4.04	4.49
35/1	**32**	2.52	3.29	3.86	4.43	2.95	3.62	4.05	4.51
35/1	**33**	2.51	3.31	3.90	4.49	3.03	4.19	4.34	4.90
40/1&2	**34**	2.76	3.74	4.46	5.18	3.51	4.86	5.85	6.84
40/1&2	**35**	2.99	4.09	4.9	5.71	3.83	5.41	6.59	7.75
40/1&2	**37**	2.99	4.11	4.94	5.76	3.96	5.67	6.93	8.19
40/1&2	**105**	2.79	3.79	4.53	5.27	3.49	4.7	5.6	5.49
40/1&2	**106**	3.02	4.15	4.98	5.81	3.8	5.2	6.23	7.26
40/1&2	**107**	2.79	3.79	4.53	5.26	3.57	4.83	5.76	6.69
40/1&2	**108**	2.74	3.7	4.41	5.12	3.46	4.63	5.5	6.36

Table 2-2 Maximum wave heights in meters at the observation points. Values without climate change in red are derived within this study. Source: Table B5.1-B5.4 of IWM (2018b)

		WITHOUT CLIMATE CHANGE WAVE HEIGHT (M) FOR DIFFERENT RETURN PERIODS (YEARS)				WITH CLIMATE CHANGE WAVE HEIGHT (M) FOR DIFFERENT RETURN PERIODS (YEARS)			
POLDER	**Point ID**	**10**	**25**	**50**	**100**	**10**	**25**	**50**	**100**
35/1	**31**	0.36	0.57	0.78	1.04	0.62	0.99	1.36	1.80
35/1	**32**	0.52	0.79	1.00	1.21	1.00	1.52	1.92	2.33
35/1	**33**	0.69	1.01	1.25	1.48	1.43	2.10	2.59	3.07
40/1&2	**34**	1.49	1.99	2.31	2.61	1.74	2.32	2.69	3.04
40/1&2	**35**	1.51	2.04	2.39	2.71	1.76	2.38	2.79	3.16
40/1&2	**37**	1.78	2.55	3.09	3.58	2.08	2.98	3.6	4.17
40/1&2	**105**	1.56	2.07	2.38	2.67	1.82	2.41	2.78	3.11
40/1&2	**106**	1.45	2.04	2.43	2.80	1.69	2.38	2.84	3.27
40/1&2	**107**	1.23	1.83	2.26	2.68	1.44	2.14	2.64	3.13
40/1&2	**108**	0.92	1.47	1.92	2.39	1.07	1.72	2.24	2.79

2.2.3 Subsidence

To account for possible subsidence, the value of 1 cm / y as in the CEIP-1 embankment designs (BWDB, 2012) is used. Since the future climate conditions are derived for 2050 this gives a total subsidence to be included of 0.3m.

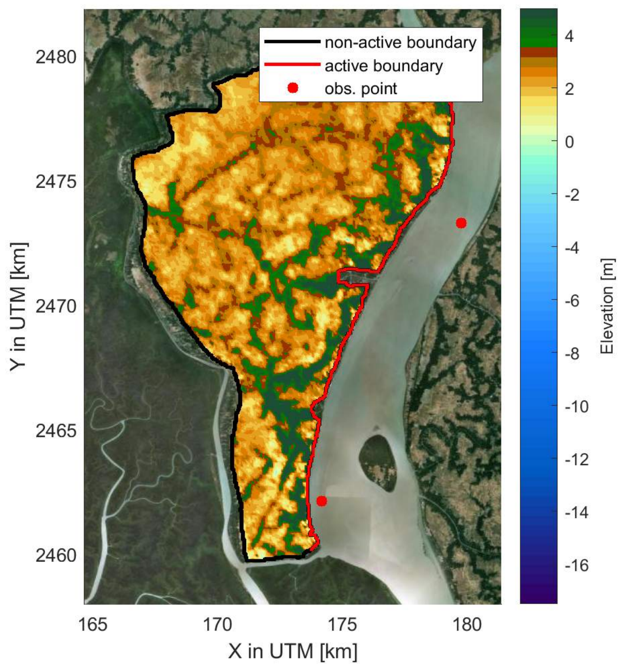


Figure 2-1 Elevation with respect to PWD for polder 35/1

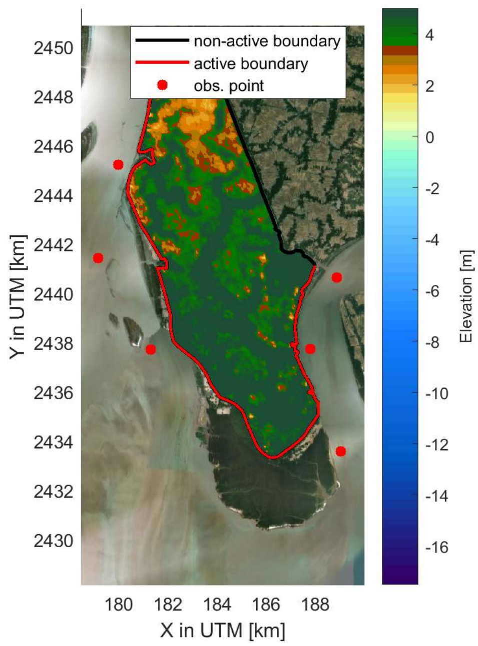


Figure 2-2 Elevation with respect to PWD for polder 40/1&2

2.3 Modelling approach

A flood inundation model was set-up for each polder to estimate the extent of flooding under extreme surge levels and wave heights determined in CEIP-1 (see Table 2-1Error! Reference source not found. and Table 2-2). The SFINCS model is used for this purpose. The SFINCS model does not account for morphological changes and therefore only overtopping is considered, i.e. no breaching or other bank failure is modelled. A model is set-up covering the area of the specific polder, with a numerical grid of 20 m grid cells. The extent of the numerical grid is limited to the extent of the topo-bathymetric data available. The vertical reference level of the models is PWD. Since the MERIT DEM is defined with respect to the geoid, a correction was applied to express the topography in PWD as well. Mean sea level (MSL) around Bangladesh is defined at 1.1m above the geoid EGM1996 according to the global Mean Dynamic Topography model MDT-CNES-CLS18 (Aviso, 2018), whereas PWD is MSL-0.46m. Combining the latter gives that PWD is 0.64m above the geoid, which was used to correct the MERIT DEM to PWD.

The models are set-up with open (active) boundaries along the main river banks and along the Bay of Bengal where the storm surge and waves are forced. The (relatively) small canals that surround the polders are assumed not to play a role considering inundation and since no boundary conditions are derived for these small canals these are therefore modelled as closed (inactive) boundaries. The models get input from the closest model extraction points (Figure 2-3). Using linear interpolation these values are forced along the active boundary of the SFINCS models.

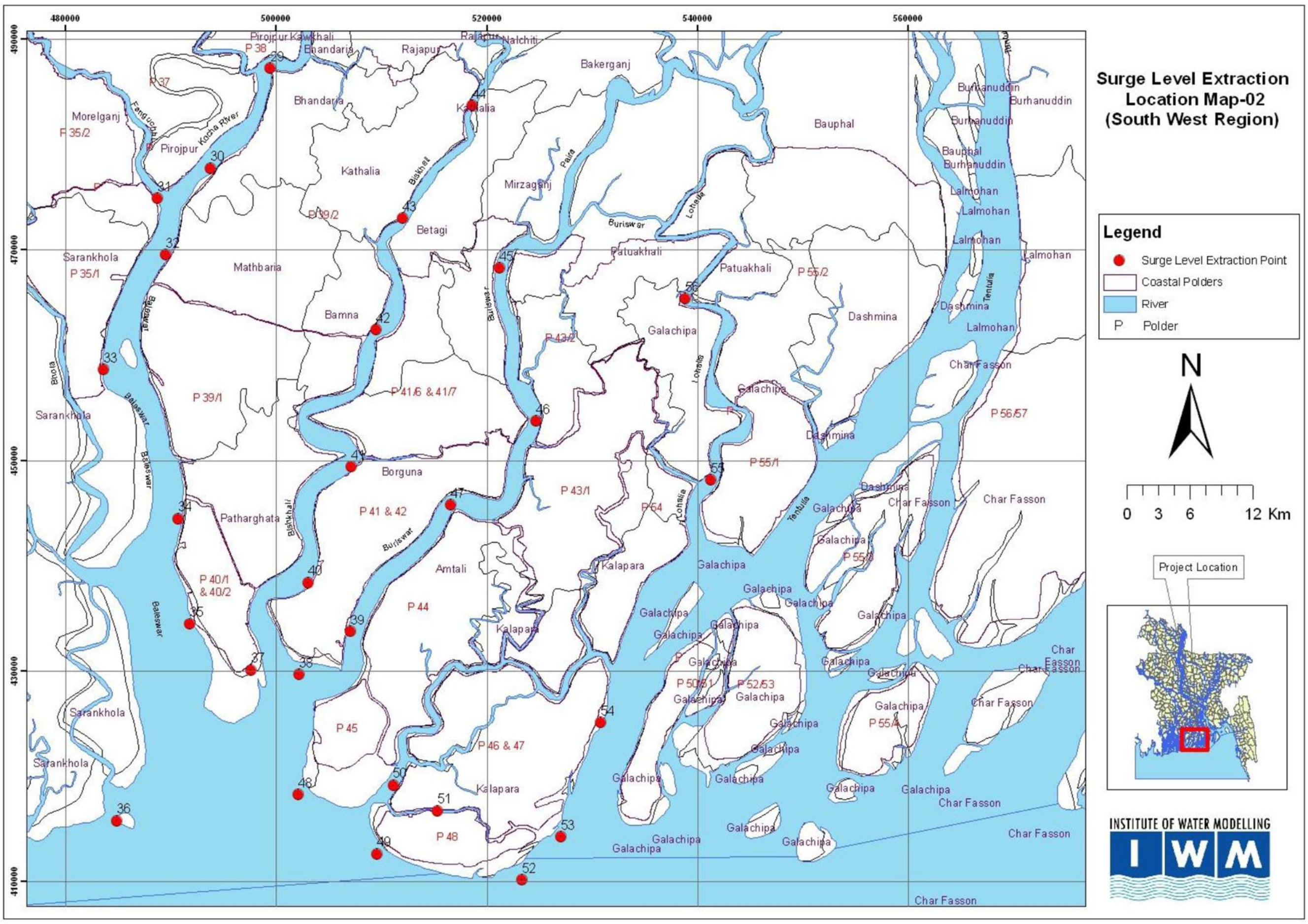


Figure 2-3 Locations of storm surge level extraction points for different return periods

The forcing of the water levels is described as a 48 hour sinusoidal signal which reaches the maximum surge level indicated in Table 2-1 after 1 day (see Figure 2-6 for polder 35). An additional wave signal is described as a signal of random fluctuations, that is made using a JONSWAP spectrum[1] using the wave height and peak periods from the previous section (see Table 2-2). The same methodology is followed as in Schrijvershof (2020). The models were consequently run for a set of simulations (10, 25, 50, and 100-year return periods) with and without the influence of climate change and land subsidence (i.e. relative sea level rise). This gives a total set of 8 simulations per polder.

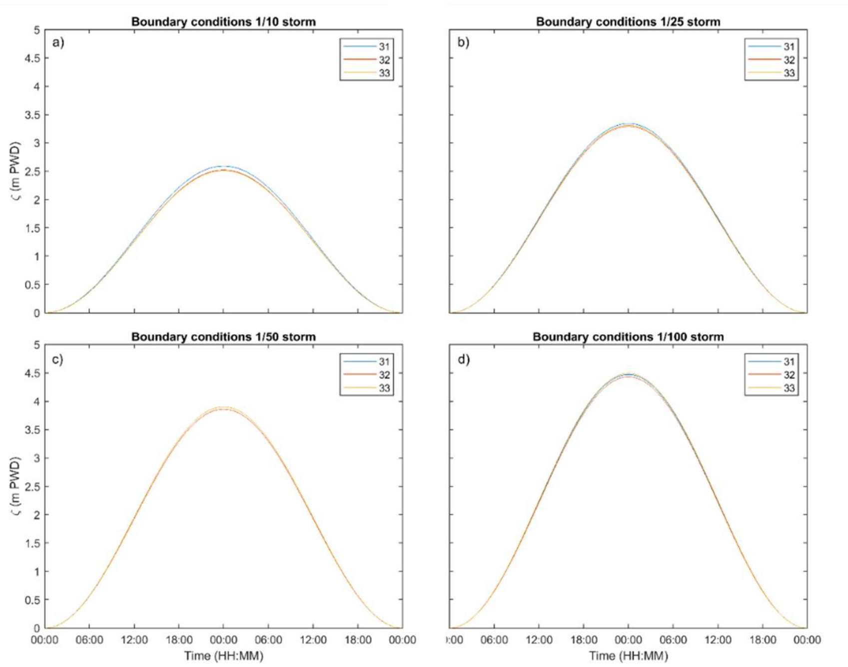


Figure 2-4 Boundary condition for different return periods and at several locations (colours) along the Baleshwar bank of polder 35/1 (see Figure 2-3 for locations)

2.4 Results

For each polder, 8 different inundation scenarios have been modelled using the SFINCS model. In this chapter, general trends between the different scenarios will be discussed taking polder 40/1&2 as an example. Furthermore, differences between the polders will be highlighted by comparing the 25-year return period including climate change for both polders.

2.4.1 Polder 40/1&2

The results of the most distinctive scenarios for polder 40/1&2 are provided in Figure 2-5 to Figure 2-8. For each scenario a map is presented which indicates the maximum water depth reached at each location during the storm. Although the magnitude between the different polders may vary, the general trends between the different scenarios show similar results for all polders. At first, it should be noted that the influence of relative sea level rise is already visible for relatively small storms with a 10-year return period (Figure 2-7). The inundation is minimal for a 10-year return period storm without relative sea level rise (Figure 2-5). The maximum inundation is found while considering a 100-year return period storm and accounting for relative sea level rise. Scenarios in between the two extremes often result in partial inundation (clearly visible in Figure 2-6), i.e. higher land remains dry whereas low lying land

[1] The JONSWAP spectrum is an idealized wave spectrum that describes the energy distribution over different wave frequencies. The JONSWAP spectrum is widely used as design spectrum to model waves during storm conditions (Hasselmann et al., 1973).

is inundated. The maximum water depths in the presented flood maps are very much dependent on the local topography.

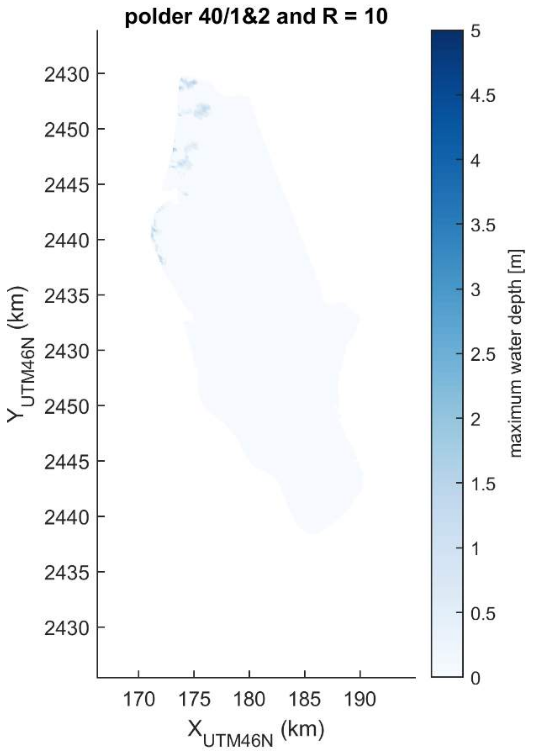


Figure 2-5 No relative SLR and R=10 years

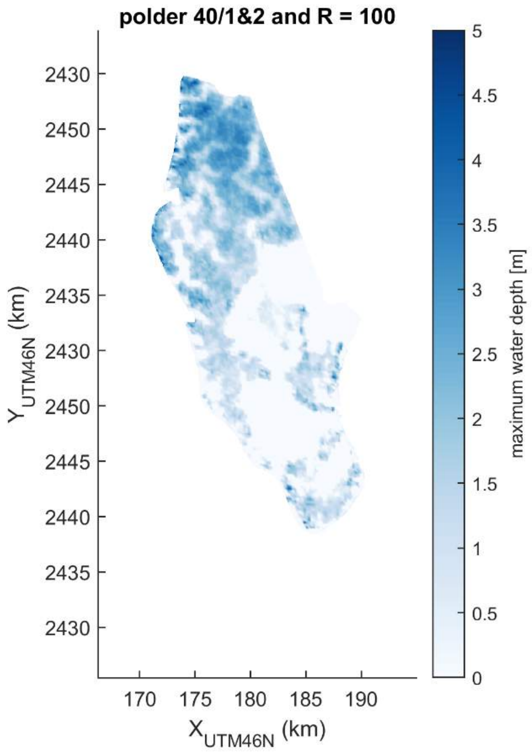


Figure 2-6 No relative SLR and R=100 years

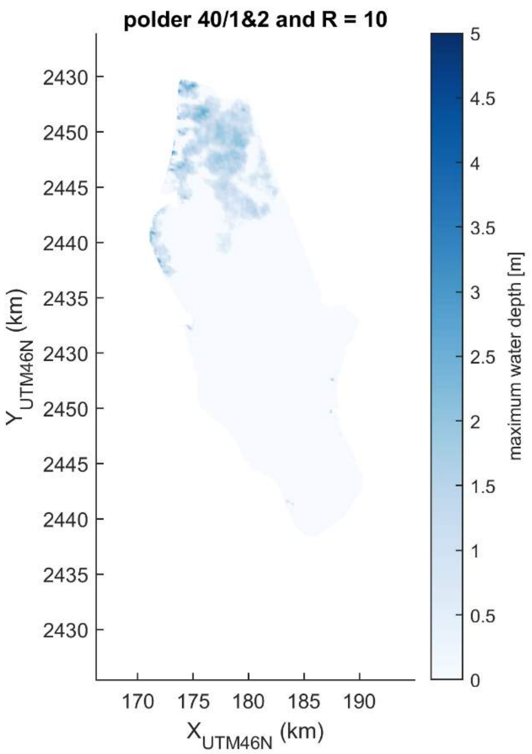


Figure 2-7 With relative SLR and R=10 years

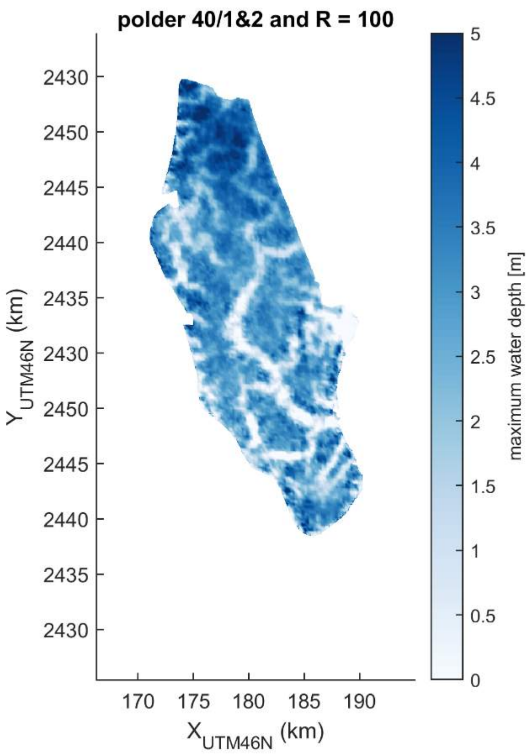


Figure 2-8 With relative SLR and R=100 years

2.4.2 Both polders

Since the embankments proposed during the CEIP-1 project were designed to withstand conditions with a 25-year return period in 2050, the expected flooding (without embankments) for the 25-year return period including the effects of relative sea level rise are also presented below. In Figure 2-9 and Figure 2-10 it can be seen that both polders are susceptible to inundation. In the polders 35/1 and 40/1&2, depths may be reached up to 5 m, especially near the embankments. Nevertheless, both polders have a large area which remains dry during storms with a return period of 25 year. Although these results provide some first insights of what areas are prone to flooding, it should be noted that by not specifically taking into account the current embankments this might result in an overestimation of the flooding, especially when embankments are partially not captured in the MERIT DEM. These findings are quantitatively visualized in Table 2-3 which shows the relative area of the polder for which the maximum water depth exceeds 0.5 m.

Table 2-3 Percentage of polder area for which maximum water depth exceeds 0.5 m, where the background color indicates the vulnerability to flooding from safe (green) to susceptible (orange)

		With relative sea level rise				Without relative sea level rise			
Polder	**Area (ha.)**	**10**	**25**	**50**	**100**	**10**	**25**	**50**	**100**
35/1	13680	3,7%	24,9%	58,3%	86,0%	1,1%	4,0%	17,1%	59,8%
40/1&2	6855	14,1%	52,0%	80,2%	92,5%	0,9%	12,6%	32,6%	54,0%

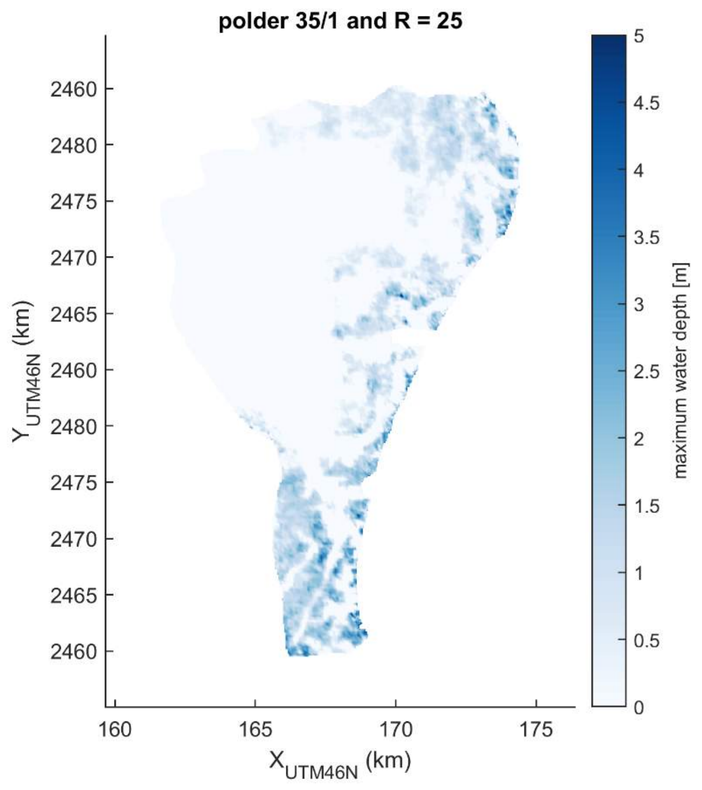


Figure 2-9 25-year return period for polder 35/1, including relative sea level rise

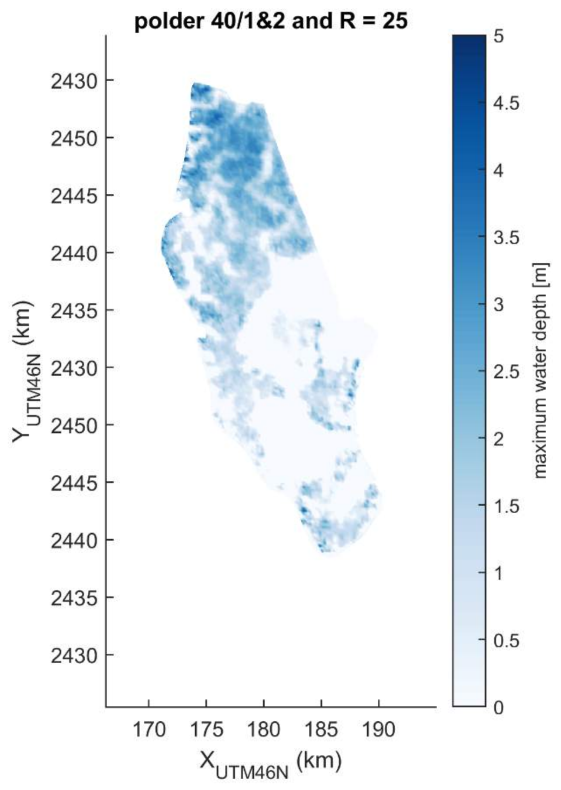


Figure 2-10 25-year return period for polder 40/1&2, including relative sea level rise

3 Risk modelling

3.1 Introduction

The goal of the risk analysis is to assess the risk reduction (i.e. reduction in annual direct impacts to exposed assets and people in the polders) resulting from the improvement of embankments up to a safety level of 1:25 year in 2050. For this purpose, the Delft- Flood Impact Assessment Tool (D-FIAT, Slager et al., 2016) is used. D-FIAT is an open source toolset for building and running impact models, based on the unit-loss method. The tool requires input for a flood impact assessment; inundation maps, exposure maps, damage functions and maximum damage (Figure 3-1). The risk analysis is quantitative and expresses direct and indirect damages of houses, infrastructure and production in monetary values as well as mortality.

D-FIAT has been applied at several flood risk studies around the world due to its flexible modelling scheme and its computational speed. The tool estimates economic damages and impacted assets by linking hazard information (water depth maps) to exposure maps (object maps) via vulnerability functions (damage functions) for different types of assets using the flow diagram presented in Figure 3-1. The results of the tool are available as (monetary) damage (impact) per flood return period (associated to the probabilities of exceedance). Finally, the tool integrates the damage-probability curve and the Expected Annual Average Losses (EAAL) to obtain total risk.

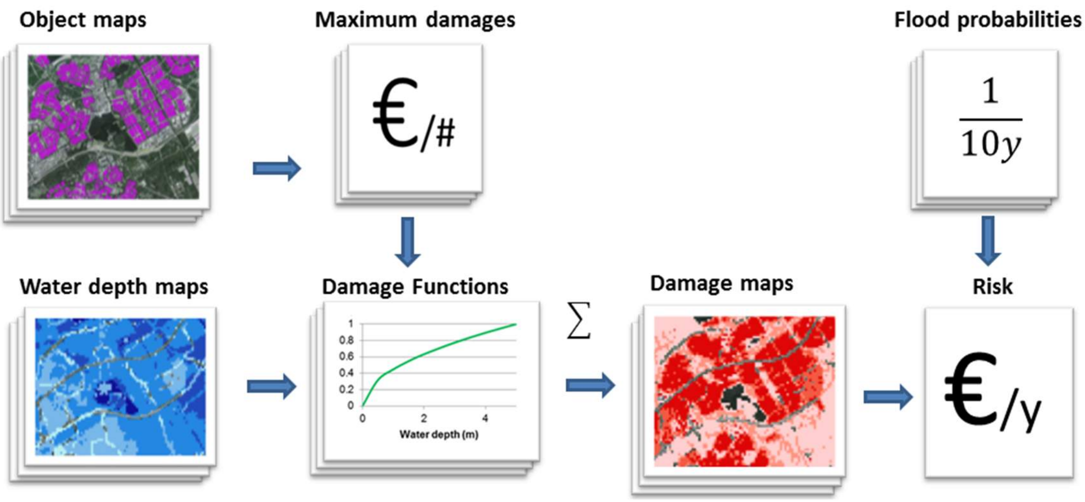


Figure 3-1 Overview of damage and risk calculations in Delft-FIAT.

For each polder one impact model was set-up, using the inundation results corresponding to the different scenarios (4 return periods with and 4 return periods without relative SLR), as well as the exposure maps and damage functions (see next section). For the risk reduction due to (new) embankments it was assumed that all damages and mortality are zero for return periods lower than the design safety level of these embankments.

3.2 Damage categories and vulnerability

Three types of exposed assets were analyzed:

- Residential buildings (consisting of the following types: Pucca house, Semi-Pucca house, Kutcha and Shanty types)
- Businesses and services infrastructure
- Agriculture

Furthermore, the flood impact includes affected people and mortality due to flooding. Seven different vulnerability functions were used which are combined (multiplied)with the maximum damage values in

Table 3-1:

- 4 functions for structural damage of different types of residential building categories (Figure 3-2)
- 1 function for damage to crops (agricultural damage; Figure 3-2), and
- 2 functions for the estimation of affected people by flooding (threshold of 10 cm; Figure 3-3) and flood mortality (Figure 3-4)

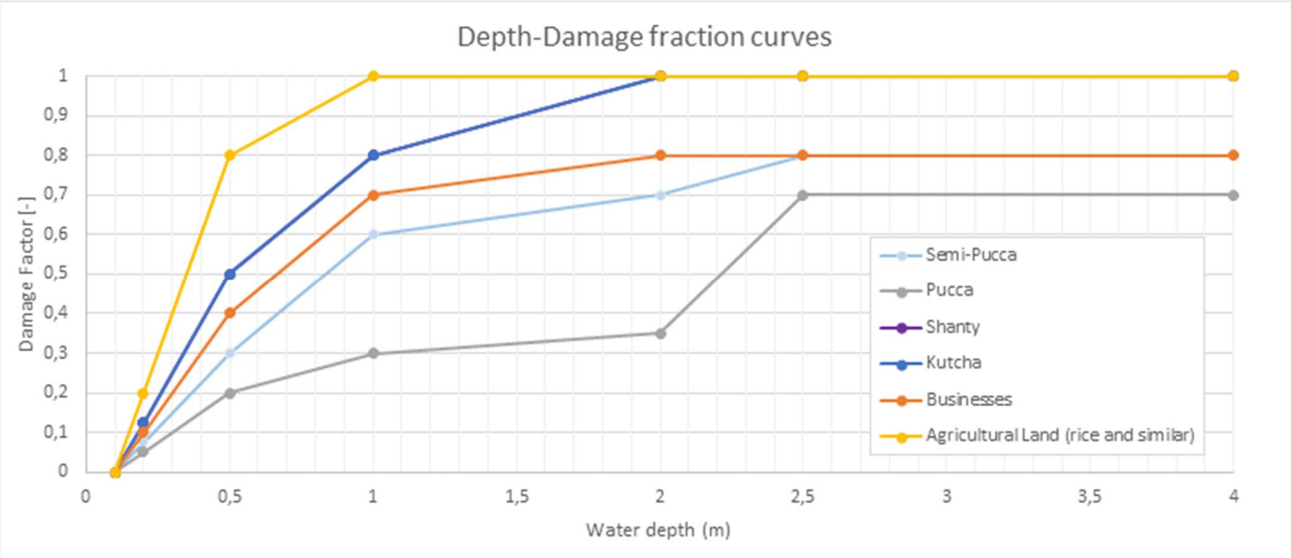


Figure 3-2 Damage functions for houses and agriculture

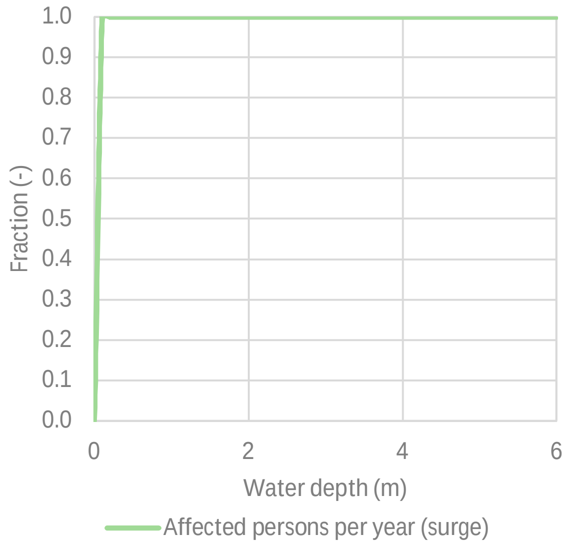


Figure 3-3 Vulnerability function for affected people (threshold 0.1m)

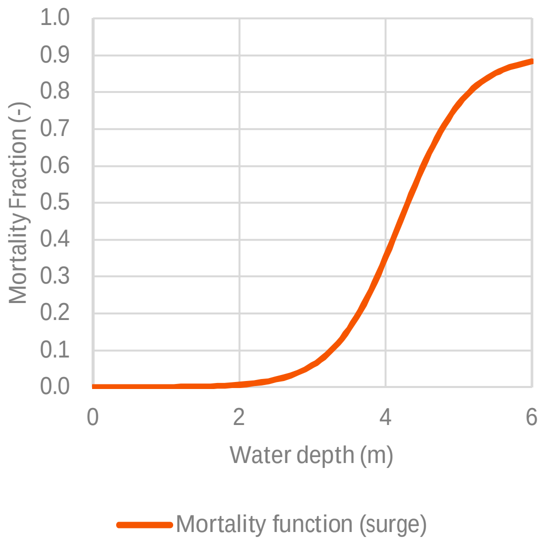


Figure 3-4 Function for flood mortality. Source: Adapted from Jonkman, 2007.

Table 3-1 Maximum damage per asset analyzed. Values are multiplied by damage fraction to obtain depth-damage curves.

Asset	**Maximum Damage**	**Building type distribution****
*Pucca House**	880,000 BDT/house	8%
*Semi-Pucca House**	261,500 BDT/house	84%
*Kutcha House**	115,000 BDT/house	1%
*Shanty House**	30,000 BDT/house	7%
Business and services	25% of total residential assets	
Agriculture	442,800 BDT/ha	--
Affected people	1 person	--
Mortality	1 person	--

Sources: *see table 3-2; ** GOB (2008)

The maximum damage of residential buildings has been estimated using the replacement costs for houses that were assessed under the Resettlement Action Plan of CEIP-1 (RAP Report - CEIP, 2018). Because the RAP assessment only provides costs per square feet of the different house types, an average cost per house type has been approximated by using an average size of each house type (see Table 3-2).

Table 3-2 Replacement costs for houses

House type	**cost per sq ft***	**average cost per sq ft**	**average size** (sq ft)**	**average cost per house**
Pucca	1100	1100	800	880,000
Semi-pucca	475 – 570	523	500	261,500
Katcha	242-525	384	300	115,200
Kuregor (hut)	100-200	150	200	30,000

* Source: RAP Report - CEIP(2018); ** estimation.

Damage for agriculture is based on added value from agriculture as provided by BBS (2019), which is BDT 221,400 per ha/crop. Damages to businesses and services is based on value of residential houses in the polder and set at 25 % of total residential value. Next to direct damages, there is also indirect damages for agriculture and businesses. For agriculture indirect damages are assumed to be 100 % of direct damages, assuming a gradual return to normal production in 1 – 3 years after the flood event. For businesses and services, the indirect damages are assumed to be 80 % of direct damages, which is based on international experiences and calculations from The Netherlands as described in De Bruin et al (2014). More information on Delft-FIAT can be found at https://publicwiki.deltares.nl/display/DFIAT/Delft-FIAT+Home .

Table 3-3 Other type of damages (Businesses)

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

3.3 Exposure data

3.3.1 Population and houses

The number of residential units in the polders was calculated from the World Settlement Footprint (WSF) dataset[2] and a reported average household size of 4 people (CEIC data, 2016). The WSF dataset has estimations of population (2015) per grid cell of 20m x 20m. The total number of people per grid cell was divided by the household size to obtain the number of residential units.

3.3.2 Land use

For agriculture a land use map was used (see Figure 3-5) by rasterizing to the same resolution of the flood maps (20x20m) and georeferenced the map to UTM 46N.

Detailed maps of each polder are provided in figures 3-6 and 3-7.

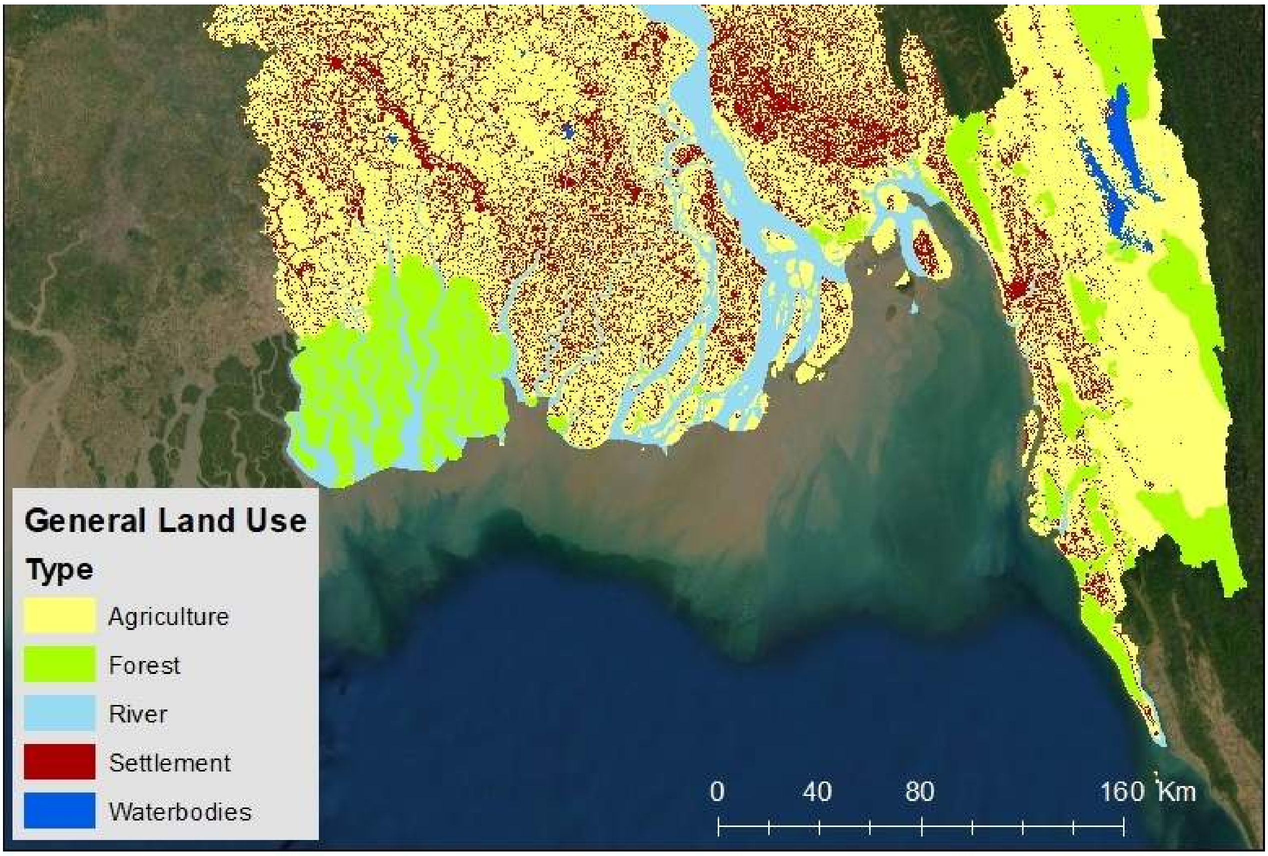


Figure 3-5 Coastal part of the land use map (original projection GCS_Everest_1830)

[2] World Settlement Footprint 2015- available at: https://urban-tep.eu/puma/tool/?id=574795484&lang=en

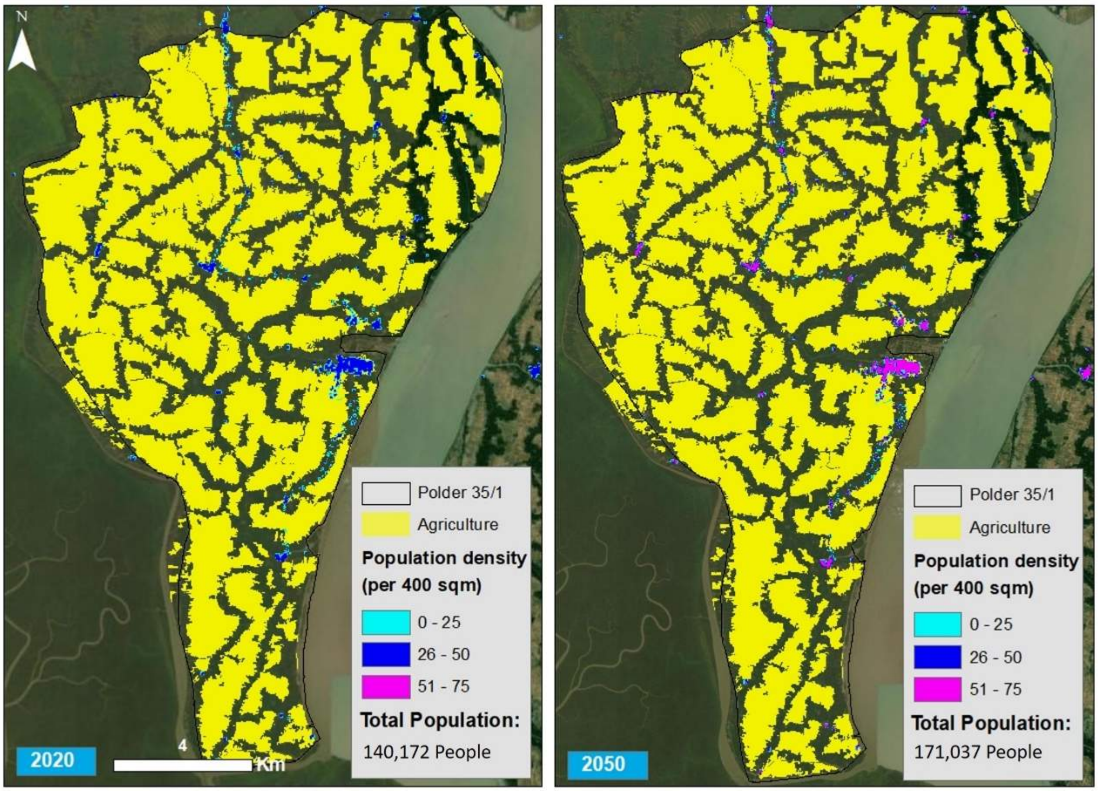


Figure 3-6 Land use and Population density Polder 35/1 (current and projected)

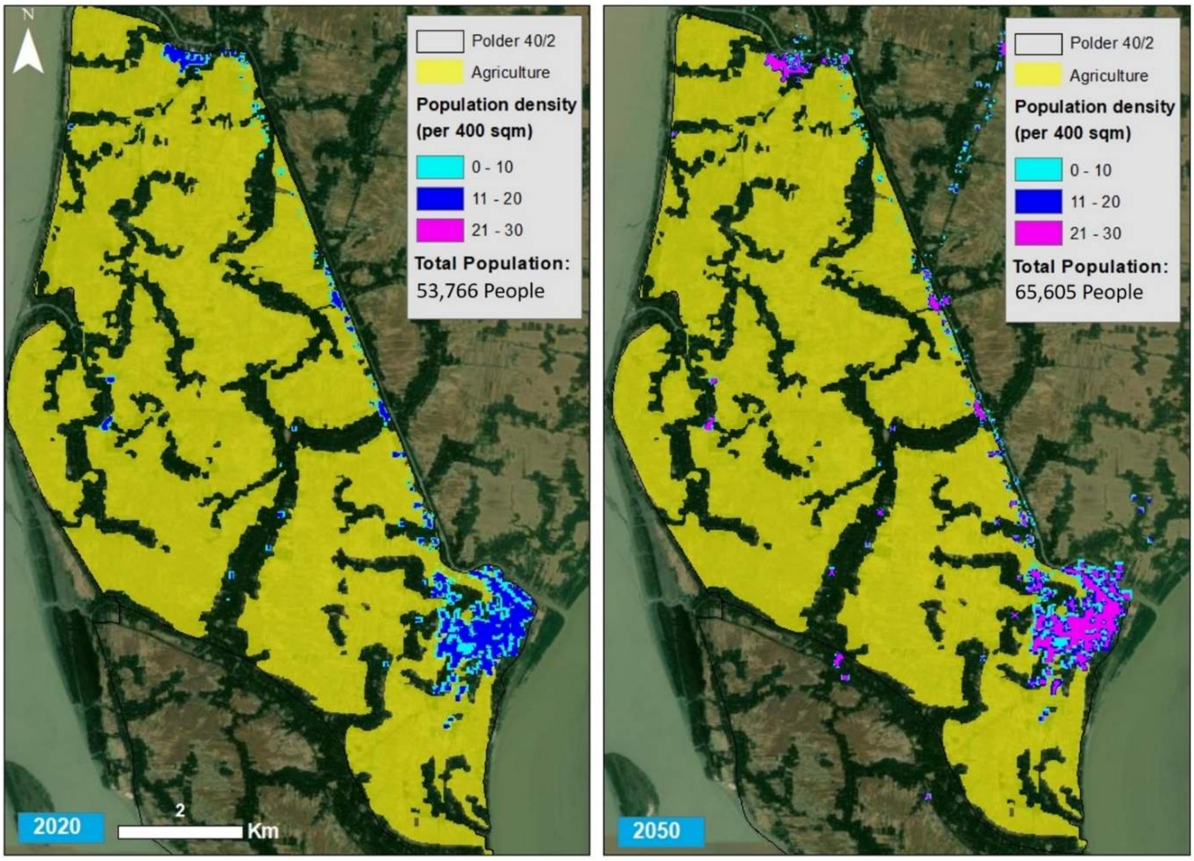


Figure 3-7 Land use and Population density Polder 40/2 (current and projected)

For Polders 40/2 and 40/1, the flood modelling exercise using SFINCS was done for the area covering both polders. This meant that an extra post-processing step was needed to have the individual risk results for each polder.

In order to have separate results, the exposure layers (land use and population) were clipped (using ArcMap 10.6) to the extents of each polder (40/1 and 40/2) in order to have 2 different exposure data sets. The clipping process maintains the data within the boundaries of the Polder and assigns anything outside it as 'NoData' values. When doing the clipping process attention was given to avoid losing valuable information about land use and population. When separating the layers, an extra check was done to see if the population of each individual polder corresponded to the estimates given by the CEIP-1 feasibility study.

By following the previously described approach, the initial flood map of the entire area (overlaying it with the 2 exposure data sets in different runs) could be used since D-FIAT only computes damages where there is a geographical intersection of both the exposure layer and the hazard maps.

3.4 Assumptions and limitations

The following assumptions were made in computing the risks for the polders:

- A threshold of 10 cm of water depth was used as an indicator of affected people by flooding.
- The risk estimation was based on 2018 prices.
- Risk for residential houses only considered structural damages. Damage to content was not considered due to lack of detailed data[3].
- The method to calculate direct annual damages does not reflect differences in risk resulting from inequalities between population. Differences in income lead to differences in social vulnerability, as the loss of the same monetary value of an asset (such as a house) has a different social welfare value.
- The method assumes a risk neutral approach in which equal values are assigned to low probability/high consequence and high probability/low consequence events. This means that risk aversion is not included in the analysis.

[3] Global assumptions (e.g. Huizinga et al, 2017) often consider that damage to content represent 50% of the structural damage

4 RESULTS OF FIAT CALCULATIONS

4.1 Detailed results

On the following pages the detailed results of the calculations with FIAT for polders 35/1 and 40/2 are provided.

Table 4-1: Risk results for initial situation

Polder Name	Return Periods	Probability	Time Horizon	Agriculture	Kitcha	Pucca	Semi-Pucca	Shanty	Int step calc	Bussiness Damage	Bussiness Interruption	Total Economic Impact	Total Economic Impact	People	Mortality
				BDT	BDT	BDT	BDT	BDT	BDT	BDT	BDT	BDT	USD	# People	# Casualties
35/1	10	0.1	2050	211,345,889৳	1,087,134৳	26,586,711৳	138,551,668৳	1,981,756৳	233,715,968৳	58,428,992৳	46,743,194৳	484,725,344৳	USD 5,816,704	1,990	8
	25	0.04		1,368,769,615৳	7,966,542৳	192,551,944৳	1,064,271,992৳	14,522,343৳	1,712,202,752৳	428,050,688৳	342,440,550৳	3,418,573,674৳	USD 41,022,884	19,672	161
	50	0.02		2,912,092,903৳	12,373,327৳	297,800,332৳	1,656,793,751৳	22,555,544৳	2,650,135,808৳	662,533,952৳	530,027,162৳	6,094,176,971৳	USD 73,130,124	31,532	316
	100	0.01		3,750,527,548৳	19,846,336৳	496,314,481৳	2,716,072,491৳	36,178,217৳	4,227,582,208৳	1,056,895,552৳	845,516,442৳	8,921,351,067৳	USD 107,056,213	58,354	957
	10	0.1	Current	64,407,704৳	39,794৳	953,487৳	4,878,957৳	72,541৳	8,444,391৳	2,111,098৳	1,688,878৳	74,152,459৳	USD 889,830	49	0
	25	0.04		227,979,441৳	1,665,544৳	40,741,956৳	210,780,148৳	3,036,148৳	356,826,272৳	89,206,568৳	71,365,254৳	644,775,059৳	USD 7,737,301	2,804	11
	50	0.02		985,317,709৳	5,781,121৳	138,356,985৳	756,976,830৳	10,538,502৳	1,246,783,872৳	311,695,968৳	249,356,774৳	2,458,023,889৳	USD 29,496,287	12,212	50
	100	0.01		2,923,881,727৳	12,879,769৳	309,760,842৳	1,722,981,528৳	23,478,747৳	2,759,468,032৳	689,867,008৳	551,893,606৳	6,234,743,227৳	USD 74,816,919	32,504	260
40/2	10	0.1	2050	434,343,936৳	190,294৳	4,569,368৳	23,255,238৳	346,891৳	40,820,212৳	10,205,053৳	8,164,042৳	481,074,822৳	USD 5,772,898	222	0
	25	0.04		1,103,035,275৳	2,385,002৳	55,238,997৳	320,149,616৳	4,347,660৳	507,616,672৳	126,904,168৳	101,523,334৳	1,713,584,052৳	USD 20,563,009	6,644	22
	50	0.02		1,426,830,543৳	5,191,196৳	140,043,035৳	717,467,912৳	9,463,119৳	1,089,842,816৳	272,460,704৳	217,968,563৳	2,789,425,072৳	USD 33,473,101	15,964	181
	100	0.01		1,444,928,877৳	8,115,558৳	251,498,705৳	1,157,332,975৳	14,793,986৳	1,690,985,728৳	422,746,432৳	338,197,146৳	3,637,613,679৳	USD 43,651,364	26,630	904
	10	0.1	Current	39,205,724৳	0৳	0৳	0৳	0৳	0৳	0৳	0৳	39,205,724৳	USD 470,469	0	0
	25	0.04		392,847,342৳	137,823৳	3,330,170৳	16,485,152৳	251,241৳	29,427,482৳	7,356,871৳	5,885,496৳	426,294,095৳	USD 5,115,529	136	0
	50	0.02		845,934,401৳	1,015,247৳	23,656,264৳	133,907,576৳	1,850,711৳	218,895,760৳	54,723,940৳	43,779,152৳	1,104,867,291৳	USD 13,258,407	2,259	3
	100	0.01		1,126,127,259৳	2,531,496৳	59,067,466৳	340,510,797৳	4,614,707৳	537,585,664৳	134,396,416৳	107,517,133৳	1,774,765,274৳	USD 21,297,183	7,169	27

Table 4-2 Summary table of risks for after embankment construction

Summary Table				Risk(after construction of embankments)				Initial Risk (No embankment)				Residual Risk (after construction of embankments)			
Polder Name	Return Periods	Probability	Time Horizon	Economic Risk	Economic Risk	People	Mortality	Economic Risk	Economic Risk	People	Mortality	Economic Risk	Economic Risk	People	Mortality
				BDT/Year	USD/Year	# People/year	# Casualties/year	BDT/Year	USD/Year	# People/year	# Casualties/year	BDT/Year	USD/Year	# People/year	# Casualties/yea
35/1	10	0.1	2050	225,232,921	2,702,795	1,348	19	376,517,628	4,518,212	2,195	26	151,284,707	1,815,416	847	7
	25	0.04													
	50	0.02													
	100	0.01													
	10	0.1	Current	93,521,148	1,122,254	488	4	158,407,083	1,900,885	784	5	64,885,934	778,631	297	1
	25	0.04													
	50	0.02													
	100	0.01													
40/2	10	0.1	2050	96,405,581	1,156,867	639	16	179,381,188	2,152,574	911	17	82,975,607	995,707	272	1
	25	0.04													
	50	0.02													
	100	0.01													
	10	0.1	Current	26,621,479	319,458	108	0	61,422,424	737,069	147	0	34,800,945	417,611	39	0
	25	0.04													
	50	0.02													
	100	0.01													

Table 4-3 Damages per ha for polder 35/1 (current situation)

Polder 35/1	Polder area: 13058 ha	
Return period	damage (USD)	damage/ha
0.1	889,830	68.14
0.04	7,737,301	592.53
0.02	29,496,287	2,258.87
0.01	74,816,919	5,729.58

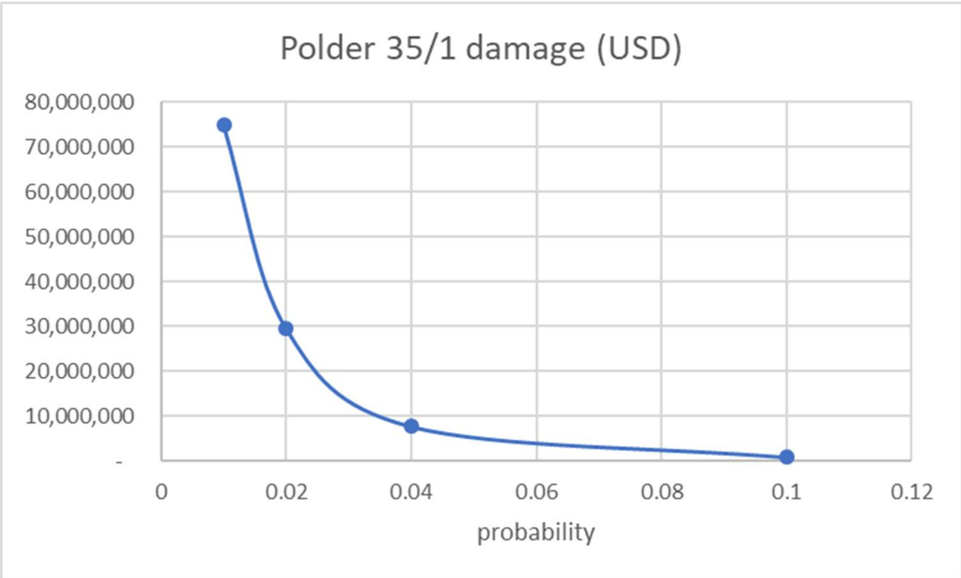


Figure 4-1 Damage curve for initial situation Polder 35/1

Table 4-4 Damages per ha for polder 40/2 (current situation)

Polder 40/2	Polder area: 3644 ha	
RP	damage (USD)	damage/ha
0.1	470,469	129.11
0.04	5,115,529	1,403.82
0.02	13,258,407	3,638.42
0.01	21,297,183	5,844.45

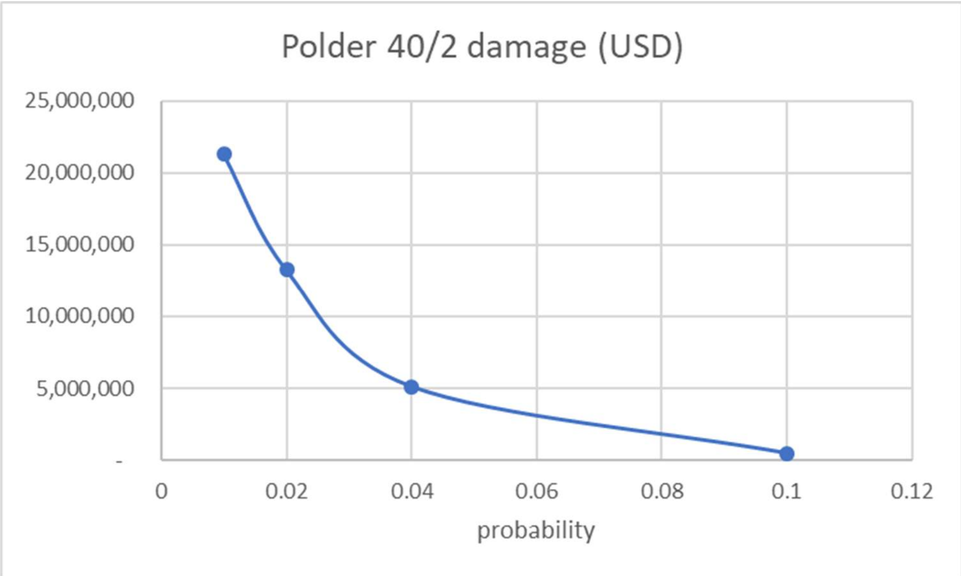


Figure 4-2 Damage curve for initial situation Polder 40/2

4.2 Comparison with Cyclone Sidr

According to the distribution of damages and losses during cyclone Sidr (as illustrated in the map below, Figure 4-3), the minimum and maximum damages per districts are inferred. For the two provinces where Polder 35/1 and 40/2 are located (Bagerhat and Barguna, respectively), the damages per ha can be calculated (see Table 4-5). When compared with the calculated damages from FIAT (see Table 4-3 and Table 4-4), there is a good similarity with a return period of 0.04 (once in 25 years) for both polders. Note that reported damages from Sidr are from a combination of inundation (storm surge, heavy rainfall) and wind. FIAT only calculates storm surge damage, which implies that the calculations are probably at the high end.

Table 4-5 Estimated damages per hectare of cyclone Sidr for two districts

Districts	surface	Billion BDT		USD million		USD/ha		BDT/ha	
	(km2)	Min	Max	Min	Max	Min	Max	Min	Max
Bagerhat	2542	15	19	180	228	708	897	59,009	74,744
Barguna	1271	15	19	180	228	1,416	1,794	118,017	149,489

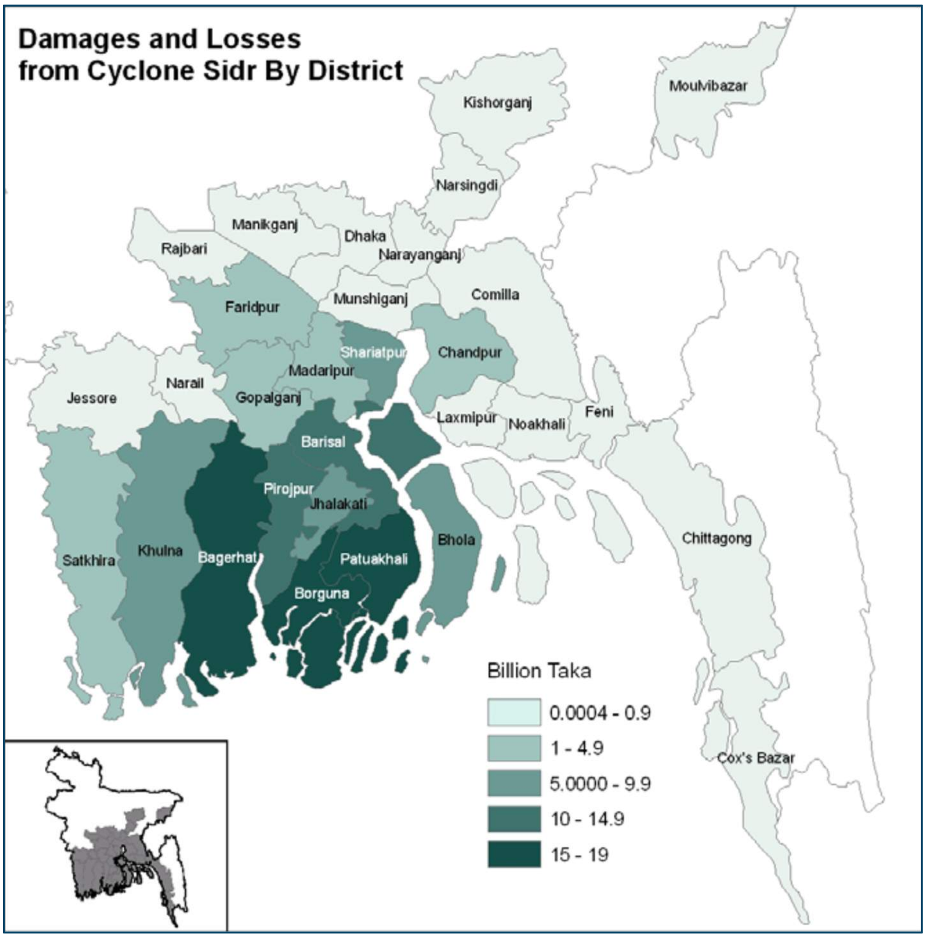
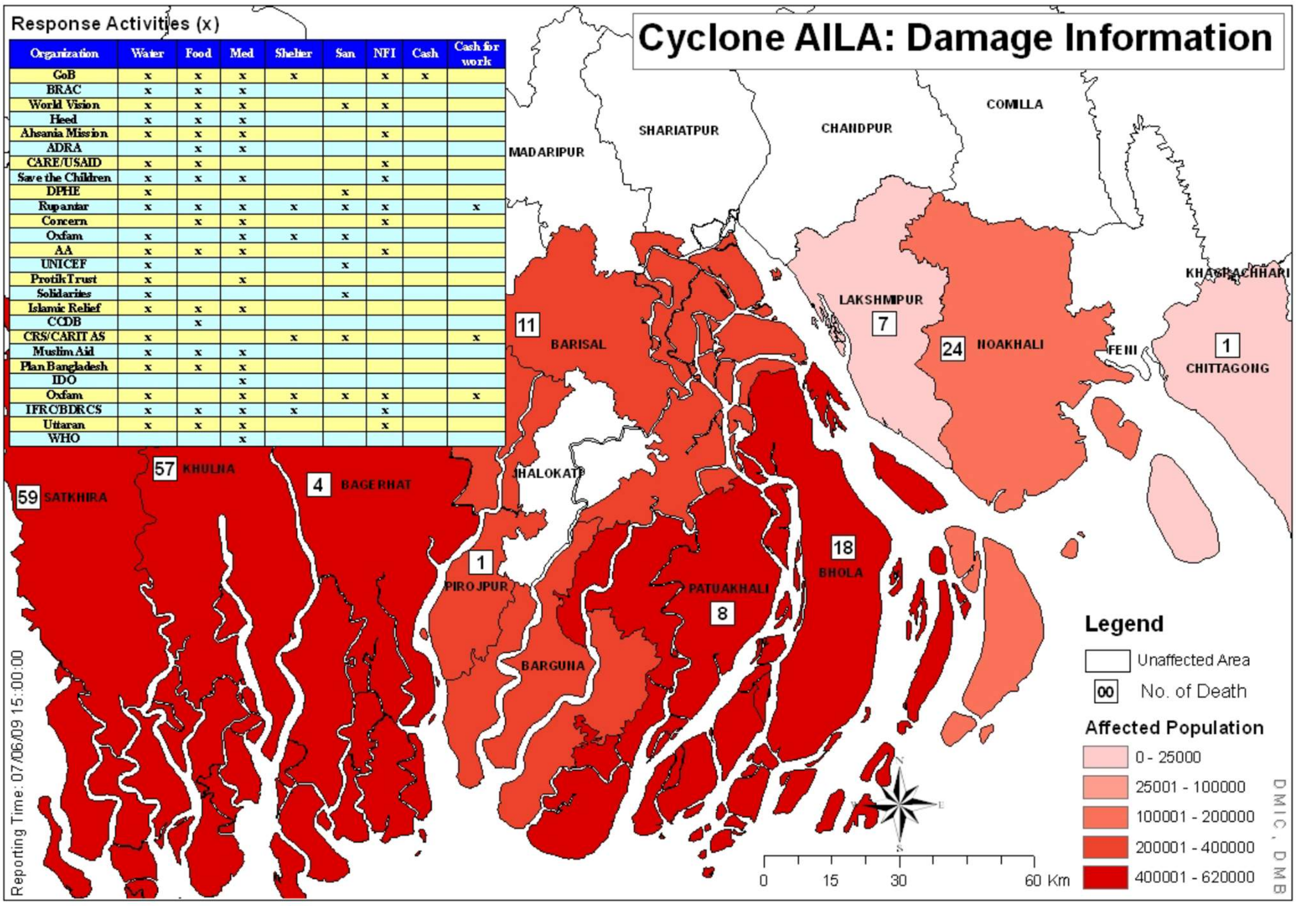


Figure 4-3 Damages and losses from Cyclone Sidr by district (Source: PDNA, GoB 2008)

4.3 Comparison with Cyclone Aila

For Cyclone Aila no district wise damages were available. But from the map (see Figure 4-4) it can be deducted that the most affected are 8 districts, with a total surface area of 18,919 km2 (Table 4-6). Total damage estimates range from 269 million USD (Reliefweb.int) to around 1 billion USD (Wikipedia). This would result in an average damage per hectare of between 142 and 528 USD. This would compare with FIAT results for a return period between 0.1 and 0.04 (once in 10 to once in 25 years).



Organization	Water	Food	Med	Shelter	San	NFI	Cash	Cash for work
GoB	x	x	x	x		x	x	
BRAC	x	x	x					
World Vision	x	x	x		x	x		
Heed	x	x	x					
Ahsania Mission	x	x	x			x		
ADRA		x	x					
CARE/USAID	x	x				x		
Save the Children	x	x	x			x		
DPHE	x				x			
Rupantar	x	x	x	x	x	x		x
Concern		x	x			x		
Oxfam	x		x	x	x			
AA	x	x	x			x		
UNICEF	x				x			
Protik Trust	x		x					
Solidarites	x				x			
Islamic Relief	x	x	x					
CCDB		x						
CRS/CARITAS	x			x	x			x
Muslim Aid	x	x	x					
Plan Bangladesh	x	x	x					
IDO			x					
Oxfam	x		x	x	x	x		x
IFRC/BDRCS	x	x	x	x		x		
Uttaran	x	x	x			x		
WHO			x					

Figure 4-4 Affected areas of Cyclone Aila

Table 4-6 Most affected districts of Cyclone Aila

Most affected districts according to the map:	sq. Km
Bagerhat	2542
Barguna	1271
Barisal	2752
Bhola	3245
Khulna	3236
Patuakhali	2090
Pirojpur	1929
Satkhira	1854
	18919

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