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Final Report

of
**Technical Study for Mapping of Potential Greenbelt Zone
in the Coastal Regions of Bangladesh**

under
Climate Resilient Participatory Afforestation and Reforestation Project
Bangladesh Forest Department

December 2016

Submitted to
Project Director
Climate Resilient Participatory Afforestation and Reforestation Project
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Abbreviation and Acronyms

AF	Arannayk Foundation
AHP	Analytical Hierarchical Process
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agriculture University
BBS	Bangladesh Bureau of Statistics
BCCRF	Bangladesh Climate Change Resilience Fund
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BCR	Benefit Cost Ratio
BFD	Bangladesh Forest Department
BFRI	Bangladesh Forest Research Institute
BIWTA	Bangladesh Inland Water Transport Authority
BMD	Bangladesh Meteorological Department
BPC	Bangladesh Parjatan Corporation
BTM	Bangladesh Transverse Mercator
BWDB	Bangladesh Water Development Board
CDMP	Comprehensive Disaster Management Programme
CEGIS	Center for Environmental and Geographic Information Services
CEIP	Coastal Embankment Improvement Project
CRPARP	Climate Resilient Participatory Afforestation and Reforestation Project
CVI	Coastal Vulnerability Index
DAE	Department of Agricultural Extension
DBH	Diameter at Breast Height
DDM	Department of Disaster Management
DECCMA	Deltas, Vulnerability and Climate Change: Migration and Adaptation
DEM	Digital Elevation Model
DFID	European Commission, Department for International Development
DLRS	Directorate of Land Record and Survey
DoE	Department of Environment
DSS	Decision Support System
EDP	Estuary Development Project
EGIS	Environment and GIS Support Project for Water Sector Planning
EIRR	Economic Internal Rate of Return
FIRR	Financial Internal Rate of Return
EPA	Environmental Protection Agency
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
FD	Forest Division
GBM	Ganges Brahmaputra Meghna
GCMs	General Circulation Models
GDP	Gross Domestic product
GED	General Economics Division
GIS	Geographic Information System

GoB	Government of Bangladesh
GUI	Graphical User Interface
HDI	Human Development Index
HIES	Household income and Expenditure Survey
IA	Important Assumptions
IMCC	Inter-Ministerial Co-ordination Committee
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
IUCN	The World Conservation Union
IWM	Institute of Water Modeling
IWTC	International Water Technology Conference
IWTC	International Workshop on Tropical Cyclones
LC	Land cover
LC	Land Cover
LGRDC	Ministry of Local Government, Rural Development and Cooperatives
M&E	Monitoring and Evaluation
MCA	Multi-criteria Analysis
MEA	Millennium Ecosystem Assessment
MES II	Meghna Estuary Studies
MOV	Means of Verification
MSS	Multispectral Scanner
MVC	Model View Controller
NDIDP	NijhumDwip Integrated Development Project
NFI	National Forest Inventory
NGO	Non-Government Organization
NPV	Net Present Value
NRS	National Reference System
NWRD	National Water Resources Database
OLI	Operational Land Imager
OVI	Objectively Verifiable Indicators
PCA	Principle Component Analysis
PPT	Parts Per Thousand
PSC	Project Steering Committee
PV	Present Values
PWD	Department of Public Works
RA	Resource Analysis
RDMS	Relational Database Management System
RHD	Roads and Highways Department
RIMS	Resource Information Management System
RS	Remote Sensing
SCF	Standard Conversion Factor
SDGs	Sustainable Development Goals
SPDSS	Spatial Decision Support System
SRDI	Soil Resource Development Institute
SRDI	Soil Resources Development Institute
SRTM	Shuttle Radar Topography Mission

SST	Sea Surface Temperature
SVI	Vulnerability Index
TEV	Total Economic Value
TM	Thematic Mapper
ToR	Terms of Reference
Triple F	Forest, Fish and Fruit
UN/ISDR	United Nations International Strategy for Disaster Reduction
UNDAF	UN Development Assistance Framework
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN-REDD	United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation
WARPO	Resources Planning Organization
WB	World Bank
WI	Wetland International
WWF	World Wildlife Fund

Executive Summary

Coastal greenbelts are proven 'soft' measure that can effectively reduce the height and energy of storm surge and strong winds associated with tropical storms. Greenbelts are also a 'green adaptation' that helps in sequestering carbon in significant quantity. They can enhance land accretion by trapping sediments. To mitigate the risk from such climate driven coastal hazards, which may become more intense with the changing climates, a greenbelt along the coastal region of Bangladesh can play a significant role in combination with the embankment system. Bangladesh Forest Department (BFD) already has patches of greenbelt established since 1960s which cover about 190000 hectares of coastal lands. However, they are not continuous in their physical extent and hence are not able to provide optimum protection.

A contiguous greenbelt has been proposed by this study that will extend from eastern boundary of the Sunderbans to the southwest tip of Teknaf in 37 upazilas of 9 coastal districts. The width of the greenbelt varies from a minimum of 200 m to a maximum of 1000 m. This minimum-maximum width range was established on the basis of recommendation from published scientific research, conferences on the subject, organization reports and practices of other countries. The exact width at specific locations was based on the height of storm surge inundation, coastal vulnerability index (CVI), presence or absence of embankment and critical infrastructure, and existing forest cover at those locations. The height of storm surge was considered as the most important criteria as suggested by scientific researches followed by CVI values. Five decision rules were developed with which the width of the greenbelt was determined. The final greenbelt was delineated using two approaches, (i) ArcGIS based vector mapping and (ii) SMCE (Spatial Multi Criteria Evaluation) based raster mapping. The ArcGIS based map was produced considering the current conditions of the criteria mentioned above. The SMCE analysis is a component of the DSS (Decision Support System) which will allow modification to the greenbelt under a future scenario where the parameters used to delineate the presently proposed greenbelt may change necessitating a change in the greenbelt geometry. The study delineated the proposed greenbelt with varying width covering a total of 126,748 hectares of land within the study area.

Tree species selection for planting in the greenbelt focused on two conditions: (i) trees should have physical properties (i.e., tall, wide, fast growing, deep roots) which are capable of serving the primary protective purpose of the greenbelt while producing sufficient economic benefits for the local community to encourage their active participation in establishing and maintaining the greenbelt; and (ii) trees that can grow well in the local environment such as soil, land and water conditions of the area. Both ArcGIS and SMCE based analysis were done to select a total of five mangroves and ten non-mangrove species which matched the aforementioned conditions. Based on these criteria maps of 'ideal trees for the greenbelt' were produced that placed them in 'environmentally suitable' locations. The design of the DSS will allow more trees to be analyzed and suitable locations for them can be mapped in the future as the conditions change.

An innovative planting design for non-mangroves was developed to maximize the utilization of greenbelt area for income generating activities besides the ones produced by the trees itself. This included allowing space for culture fishery, vegetable and spice cultivation. Beside providing economic support to the local resident this would also generate income to

offset some of the cost of developing the greenbelt. In this planting design a total of 83,180 trees (mangroves and non-mangroves) will be planted, 17,965 hectares of land will be allocated for aquaculture and 25,622 hectares will undergo vegetable and spice cultivation within the proposed greenbelt.

A broad category land tenure map was created by collecting field based information to categorize the land ownership of the area on which the proposed greenbelt will be established. The categories were, government owned (Khas), leased from the government, and privately owned. 66,752 hectares of the proposed greenbelt is on government owned (Khas) lands, 53,242 hectares on private lands and the remaining 6,859 hectares are government lands currently leased by private owners. This information was used in calculating the land acquisition and resettlement (19,597 hectares of settlement area) costs.

The economic analysis was done taking in to account all major cost components of establishing the greenbelt and the benefits expected from it. Two investment plans has been proposed; one based on Public-Private Partnership (PPP) model and the other with 100% ownership by the government involving acquisition and resettlement of the privately owned land.

The 'without land acquisition' model based investment plan was calculated where the greenbelt can be established without acquisition and resettlement of the private land. This plan is centered on the idea of encouraging the landowners to allow greenbelt on their land in exchange of the financial benefits that the greenbelt will produce. In this plan the financial cost of the greenbelt is 20.915 billion BDT, of which the plantation cost is 17.319 billion BDT about 82% of the total investment cost. This plan is only 8% of the cost of the 'with land acquisition' investment plan. Since the annual economic benefit remains the same this becomes a highly attractive investment plan as measured by all financial and economic indicators.

In the alternate 'with land acquisition' approach the total financial cost was calculated at 260.407 billion BDT for establishing greenbelt across 126,748 hectares of land. The two major costs are 63.697 billion BDT (25%) for land acquisition and 176.403 billion BDT (68%) for resettlement totaling to about 92% of the cost. The plantations cost of 17.319 billion BDT is approximately 6% of the total cost and the remaining will be spent on maintenance and logistics. Because of the high cost and complicated time consuming land acquisition and resettlement process this plan is financially unattractive and logistically cumbersome.

The benefits from the greenbelt are same for both plans. These include marketable products from the trees, fishes, vegetables and spices and other protective benefits of saving crops and infrastructures and sequestering carbon. These tangible economic benefits totaled to 122.072 billion BDT per year. About 77% of this is generated from Carbon sequestration by mangroves and non-mangroves, 8% from different uses of Nipa palms, 9% from aquaculture, 5% from tree products and remaining 1% from reduction in damages of embankment and agriculture from cyclones.

The economic indicators were calculated considering 30 year cycle and at a discount rate of 12% per year. In the 'without acquisition' plan, BCR was found to be 38.8 where >1 is acceptable; NPV was 462.105 billion BDT where >0 is acceptable and EIRR was 161% where $>12\%$ is acceptable. In the 'with acquisition' plan, BCR (benefits cost ratio) was found to be 2.8 where >1 is acceptable; NPV (net present value) was 307.652 billion BDT where >0 is acceptable and EIRR (Economic Internal Rate of Return) was 29% where $>12\%$ is acceptable. Though both plans are economically feasible, clearly the plan 'without land acquisition' is much more attractive in comparison.

The financial indicators were calculated in the same way. In the 'without acquisition' plan, BCR was found to be 8.6 where >1 is acceptable; NPV was 93.501 billion BDT where >0 is acceptable and FIRR was 63% where $>12\%$ is acceptable. In the 'with acquisition' plan, BCR was found to be 0.6 where >1 is acceptable; NPV was (-)70.095 billion BDT where >0 is acceptable and FIRR (Financial Internal Rate of Return) was 7% where $>12\%$ is acceptable. This plan is financially unattractive by all indicators. This plan without land acquisition is attractive according to both financial and economic indicators and is recommended as the preferred investment plan for establishing the greenbelt.

Few other intangible benefits such as cost of life saved, land accretion, tourism, recreation etc. were not used in these calculations. A three phase implementation plan of the greenbelt over 7 years has been proposed based on the multicriteria analysis of degree of vulnerability as measured by CVI and percent of khas land available in the different upazilas.

The institutional requirement in establishing the greenbelt was reviewed and some specific suggestions were made for accommodation in the current Forest act and social forestry rules. The most important suggestion is to amend the current land ownership framework where BFD now establishes greenbelt and hands them over to local administration (DCs) after 20 years of forestation and land stabilization. Instead the Government should consider putting these greenbelt lands under the permanent stewardship of BFD which will ensure the perpetual existence of the greenbelt and its protective and productive role for the coastal inhabitants of the country. Suggestions on the mechanism of involving the local community in greenbelt development, monitoring and maintenance and on risk management are also made at the end of this report.

The study has produced an integrated plan that can be put to immediate use in developing the greenbelt. It has also developed a DSS which can be used in planning for future scenarios if the greenbelt establishment begins at a later time or the current plan needs to be modified. Both ArcGIS based mapping and the DSS are versatile systems that can take in new parameters as they change in real time and generate multitude of options for greenbelt development under the changed conditions for the planners to choose from.

1. Introduction

1.1. Background

Bangladesh Forest Department (BFD) under the Ministry of Environment and Forest, has undertaken an initiative to enhance its afforestation program along the entire coastal zone of the country to reduce risks from climate change induced coastal hazards. This study is part of the larger project, Climate Resilient Participatory Afforestation and Reforestation Project (CRPARP), which is funded under the Bangladesh Climate Change Resilience Fund (BCCRF), with technical support from the World Bank. Bangladesh Forest Department (BFD) and Arannayk Foundation (AF) are jointly responsible for implementing the CRPARP Project. The objective of CRPARP is to reduce forest degradation through participatory planning/monitoring and to contribute in building the resilience of coastal and hilly communities to climate change.

The project is aligned with both Bangladesh Climate Change Strategy and Action Plan (BCCSAP), and Bangladesh Climate Change Resilience Fund (BCCRF) aiming to mitigate effects of climate change to ensure that citizenry are protected from climate induced adverse impacts. The CRPARP has been objectively designed with four components: (i) Afforestation and Reforestation Program, (ii) Alternative Livelihoods to Support Forest Communities, (iii) Capacity Development for Forest Resource Planning and Management and (iv) Project Management.

BFD wants to delineate potential plantation areas that can be developed as a Greenbelt to reduce the intensity of damage from extreme climate events like cyclones that also matches CRPARP objective (i). Therefore, there is a need to make an assessment of the coastal regions of Bangladesh to identify suitable land for large-scale afforestation program to develop the Greenbelt. The linear extent of this proposed belt will be along the entire coastal belt of the country from Teknaf to eastern boundary of the Sundarbans. This can be done efficiently by using digital mapping technologies using Geographic Information System (GIS), supported by Remote Sensing (RS) tools and secondary data from existing databases and field. In line with objective (iii) of CRPARP, BFD also deems necessary to develop a Decision Support System (DSS) that can combine environmental and socio-economic information of the study area to provide decision makers with a tool that can perform investment planning needed to create this Greenbelt and help to reduce redundancy in future investment planning from other agencies.

1.2. Rationale

Located along the northern shores of the Bay of Bengal the coastal zone of Bangladesh is very vulnerable to coastal hazards. The combined effects of sea-level rise, increased intensity of cyclone and associated storm surge, coastal erosion, and salinity intrusion pose a rising threat to the natural resource base and livelihood opportunities of coastal communities that is likely to be greater in the future. Major storms of 1970, and 1991 together caused deaths of nearly half a million people and economic loss exceeded \$200 billion (Quadir and Iqbal, 2008). Their analysis of cyclone data also showed the trend of increasing number of powerful storms while the total number of storms decreasing over the past 50 years. The dynamic coastline of Bangladesh undergoes rapid erosion-accretion processes. Morphological analysis shows the rates of erosion at parts of the coastline averages around 20 m/yr which is balanced by equal or greater rates of accretion at other areas (Sarwar and Woodroffe, 2013). Salinity intrusion is the other important process in coastal Bangladesh that increases vulnerability of the inhabitants of the region. During the dry winter months when freshwater discharge from the Ganges-Brahmaputra-Meghna is drastically reduced the saline waters trek inland limiting the use of water for agriculture, domestic and other purposes.

The ongoing climate change processes are increasing vulnerability of the coastal regions of the world by raising the sea surface temperature which is one of the main causes behind formation of cyclones. Researchers have attributed increase in frequency and intensity of tropical storm events over the past 30-35 years in part to the changing climate (Emanuel 2005; Webster et al. 2005; Bengtsson et al. 2006) causing greater risk to coastal settlements. More recent results from climate models indicate reduction in future frequency but increase in intensity of tropical cyclones while maintaining the incomplete nature of scientific understanding of this trend (Walsh et al. 2016). Combined with sea level rise these more intense storms are likely to generate larger storm surges that will also cause higher rate of erosion and drive the salinity front further inland along Bangladesh coast.

In this backdrop it is essential to take measures to enhance the degree of protection for the coastal communities, infrastructure, and ecosystem along Bangladesh coastline for current and projected future hazard scenarios. While 'hard' measures like embankments providing effective protection are in place and being upgraded, it is also necessary to explore the value of 'soft' measure of establishment of a greenbelt. This bio-shield of planted trees has been proven effective in attenuating the energy and height of storm surge waves, velocity of cyclonic winds and reduces erosion by speeding up accretion. In Bangladesh the area lying behind the Sunderbans has been protected from the devastating impact of many cyclones, most recently from Sidr in 2007 and Aila in 2009. Placed between 'hard measures' like embankments and the open sea greenbelts can help in reducing the impact of the storm surge on the embankment thereby increasing their lifespan and reducing the cost of maintenance and augmentation. Additionally if appropriate plant species are chosen for the greenbelt they integrate easily with the environment and help in sustaining the ecosystem. Greenbelt trees also help in Carbon sequestration and can be a source of timber, firewood and fruits for the local population when extracted in controlled quantity.

Elsewhere in the world there has been many reports and research indicating positive contribution of greenbelt in providing protection from coastal hazards like storm surge, tsunamis, and erosion. The degree of protection they can provide depends on various factors such as the geometry of the belt, nature of the coastline and the characteristics of the hazard. Afforestation along the coastal belt is economic and ecologically more beneficial than any other measure to protect the coastal areas and offshore islands from cyclone and storm surges (Siddiqi, 2008). Mangrove and other coastal forests can reduce wind and storm wave impact as well as current velocities (Fritz and Blount, 2007). Mangroves are blunt bodies that can absorb water wave energy as a result of wave induced reversing and unsteady flow around the vegetation (Wolanski, 2006). Thick and dense vegetation diminishes the height of tides and thus arresting the magnitude of devastation (Siddiqi, 2002).

Recent experiences of tsunami and major storms in Southeast Asia and other parts of the world have shown that mangroves can and have played important roles in absorbing and weakening wave energy as well as preventing damage caused by debris movement (Latief and Hadi, 2007). Yasuda et al. (2006) reported the reduction of tsunami wave height by 10m at a village in northeast coast of Sri Lanka protected by trees during the December 2004 tsunami. Badola and Hussein (2005) investigated the economic loss per household to 3 villages in Orissa, India during the super cyclone in 1999 and found that the village protected by the mangroves suffered the least damage. Mangroves have also been identified to enhance accretion by trapping sediments and slowing the water flow within their complex root system (Spalding et al., 2014). Fan et al. (2006) reported similar role of dense vegetation along the coast of Chanjiang delta in China. Based on field and numerical studies Mazda et al. (2002) concluded that degradation of mangroves intensified tidal currents and enhanced erosion process along Loang Hoa, Vietnam. Several other studies have described coastal vegetation's beneficial part in promoting accretion and reducing erosion.

1.3. Objectives

(i) The main objective of this study is to identify a zone along the entire coast of Bangladesh including the islands in Meghna estuary on which the proposed Greenbelt can be established to provide protection from cyclones, storm surges and other natural hazards. To make this determination, information on the hazards (cyclone, storm surge, and erosion), degree of vulnerability along the coastline, and extent of existing greenbelt needs to be ascertained.

(ii) The other significant objective of this study is to develop a Decision Support System (DSS) that will guide the investment planning associated with establishing this greenbelt by comparing various alternatives in site prioritization, plant selection and their ramification on cost and benefit calculation. The DSS will also work as a tool for future planning when the changing climate may make it necessary to add new areas to the greenbelt and the DSS will similarly help the decision maker by providing various options for them to choose from. A separate report has been prepared describing the concept, framework and programming of the DSS.

To achieve the two major objectives a series of secondary objectives will have to be completed first. These are:

- a. Use land cover (LC) map of recent years for project sites produced under the National Forest Inventory Project of BFD using high-resolution SPOT satellite data of 2015.
- b. Develop time-series LC maps of coastal zone to depict morphological changes over the last fifty years with 10 years intervals using available moderate resolution satellite images.
- c. Prepare a DEM of the entire study area and develop two and/or three dimensional map of the Greenbelt.
- d. Generate coastal vulnerability index map to help identify degree of vulnerability of different upazila and unions within them.
- e. Produce a list and map of plant species suitable for planting in the greenbelt by collecting field data on mangrove, non-mangrove species and ecological data and through consultation with BFD executives and literature survey.
- f. Prepare a broad category land tenure map by conducting field survey to determine ownership of land within the greenbelt zone.
- g. Develop a detailed investment plan of developing the Greenbelt zone which will quantify costs and benefits associated this activity. This plan will also address the various actions necessary to establish the greenbelt, encourage participation from the local inhabitants and ensure its sustainability.

1.4. Past initiatives of Greenbelt

Bangladesh Forest Department is very familiar with the concept of greenbelt and the benefit it can provide in mitigating vulnerability of coastal communities. BFD have been developing coastal greenbelt since 1960-61 and the effort was intensified in the wake of a major cyclone in 1964. Through various programs and projects they have established patches of greenbelt dominantly composed of mangrove species Kewra (*Sonneratia apetala*) and Bain (*Avicennia officinalis*) covering around 192,000 hectares (Hassan, 2014) of coastline till 2013. An additional 12,000 hectares of non-mangroves have also been planted by BFD within these initiatives through 'ditch and dike' and 'mound' plantation techniques. The various coastal

greenbelt afforestation programs of BFD are listed in Annex 1. However, the greenbelt development programs are guided by availability of land and hence this activity was primarily limited to newly accreted land in and around the Meghna estuary area. Consequently, they have been developed in discrete patches. Moreover, BFD is required by Bangladesh government to hand over the forested lands to local administration after 20 years by that time the land has been stabilized for settlement, agriculture and other form of economic use. Forest Department has already handed over about 40,000 hectares land to Ministry of Land (Mabud and Haque, 2014). The areas currently covered by greenbelt trees will eventually be handed over and cleared for human activities under the current '*modus operandi*'.

Through the 'Pilot Mangrove Afforestation Project' during the years 1965-66 to 1974-75 mangrove plantation initiative was accelerated by BFD. Though major mangrove plantations were undertaken by different externally funded projects, small scale mangrove plantations or other types of plantations in coastal areas or in Sundarbans were also carried out by revenue budget. Major externally funded projects includes 'Mangrove Afforestation Project' from 1980-1985 with financial support of World Bank that led to plantation of mangroves on 40,000 hectares over the lifetime of the project. This project also helped to establish Plantation Trial Unit of Bangladesh Forest Research Institute (BFRI). Coastal Greenbelt Project from 1995-2003 funded by Asian Development Bank planted 500 hectares of mangroves using 'mound' technique in the foreshore areas. United Nations Development Program (UNDP) also funded a coastal afforestation program that covered 6,300 hectares of land in 2012 that advocated the widely praised "Triple F" (Forest, Fish and Fruit) model.

The mangrove afforestation in Bangladesh is being carried out in a very dynamic natural environment and some problems associated with land stability have experienced by BFD. Four types of land stability problems have been recognized including: burial of mangrove seedlings when and where sediment accretion rates are particularly high, smothering of seedlings by sand in areas where wave action reworks large volumes of sand shorewards, the winnowing of fine sediment (clay and silt) from the plantation site during prolonged stormy periods, leaving a mobile sandy lag deposit; and the erosion of plantation margins through bank slumping by migrating tidal and river channels. Habitat destruction through human encroachment has been the primary cause of mangrove loss after they have been established (Mabud and Haque, 2014).

Recent inventory shows a significant reduction of these coastal forests. The main reason for deforestation are conversion of forest land to non-forest uses e.g., habitation and agriculture, fuel-wood collection and non-sustainable extractions of other forest products. The degradation of forests and the spatially discrete pattern of afforestation has somewhat compromised their ability to provide effective protection against coastal hazards as there are large gaps within the greenbelt. Within the umbrella of CRPARP, efforts are underway to address these concerns to increase forested areas that would play a significant role in reducing the risks created by coastal hazards.

1.5. Overall Approach

37 upazilas each with sea facing boundary within 9 coastal districts were identified as the study area. To achieve the main objective of this study, i.e., map a potential greenbelt zone in the coastal regions of Bangladesh, information input is required on several parameters. These include information on physical characteristics of the land and landcover type, vulnerability of the region in terms of environment, social and economic attributes nature of the coastal hazards, species suitability of mangrove and non-mangrove plant and cost and benefits associated with the greenbelt. Value of these parameters can vary spatially and temporally necessitating to build a dynamic decision making platform that can adjust for the variability and provide decision alternatives for future development of the greenbelt beyond

the recommendation of this study. This Decision Support System (DSS) will also be needing data on the above mentioned parameters to build the decision criteria framework.

The methodology of the study is organized into sequential steps to produce the information discussed above and to generate deliverable outputs as prescribed in the Terms of Reference (ToR) of the study. These steps are listed below and presented as a flow diagram in Figure 1.1.

- i. Preparation of present Landcover map
- ii. Assessment of Coastal Morphology and Trend Model
- iii. Preparation of 2D/3D maps using DEM
- iv. Preparation of Coastal Vulnerability Index Map
- v. Delineation of Greenbelt Zone
- vi. Develop broad category land tenure map
- vii. Identify site specific mangrove and non-mangrove species
- viii. Development of Investment Plan
- ix. Development of DSS and
- x. Field data collection to support all abovementioned activities

Time allocated for the study did not allow opportunity to generate all data required to complete the study. The study had to rely heavily on secondary data collected from various government departments. The sources include Bangladesh Forest Department (BFD), Bangladesh Forest Research Institute (BFRI), Bangladesh Bureau of Statistics (BBS), Bangladesh Water Development Board (BWDB), Soil Resource Development Institute (SRDI), Department of Agricultural Extension (DAE), Bangladesh Meteorological Department (BMD), Local Government Engineering Department (LGED), Department of Disaster Management (DDM), Institute of Water Modeling (IWM), and various academic and research institutions and different relevant NGOs who are working with Greenbelt related studies or projects. Most of the collected data were processed at CEGIS to the format required by the approach of the study without any modification of the data itself.

Physical characteristics of the area were obtained from landcover maps created from high resolution satellite images prepared under a separate project of BFD. Erosion-accretion pattern and trend at a decadal scale were interpreted from coastal morphology maps also derived from satellite imagery. Degree of vulnerability of the upazilas was determined by calculating the Coastal Vulnerability Index (CVI) on the basis of secondary data on social, economic and hazard information. Storm surge inundation height, CVI, embankment maps, and land cover information were the basis of delineating the potential greenbelt zone. The greenbelt map overlain on DEM and landcover map in a 3D setting can be used by planners/decision makers to visualize the potential greenbelt zone.

Literature survey, discussion with BFD and BFRI personnel, and information from the field helped in selecting suitable mangrove and non-mangrove species for planting at different locations within the greenbelt. A site specific suitability map of tree species was created from these data. Field surveys were carried out to collect land tenure information which is being used to produce a broad 3 class tenureship map. The field teams also collected information on land condition and cover, hazard characteristics, existing flora and costs associated with planting.

Land tenure information, costs of planting and secondary data on various benefits to be accrued through establishing a greenbelt helped in developing the investment plan. An implementation and maintenance plan for the greenbelt has been developed through consultations with BFD executives and survey of the Forest Act and guidelines. Input from

all components of the study discussed above and suggestions from BFD have been integrated into the decision criteria and eventual development of the DSS.

The following sections describe in details the methods followed in obtaining the results for each primary and secondary objectives and the deliverables of the study. A separate report is being prepared that discusses the development of the Decision Support System.

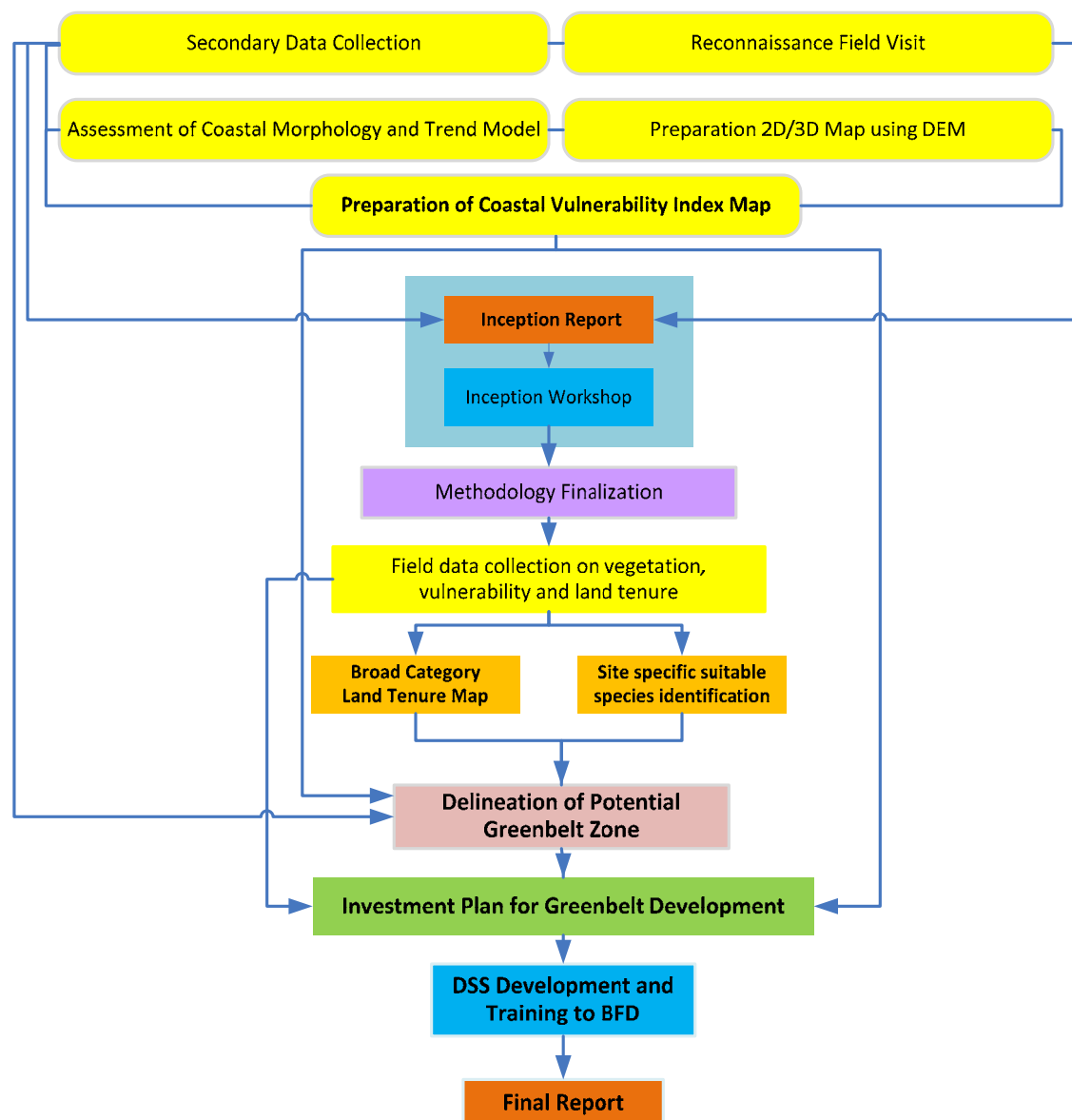


Figure 1.1: Flow chart of Methodology.

2. Coastal Zone of Bangladesh

2.1. Introduction

The coastal zone of Bangladesh is comprised of 19 districts (Bagerhat, Barguna, Barisal, Bhola, Chandpur, Chittagong, Cox's Bazar, Feni, Gopalganj, Jessore, Jhalkati, Lakshmipur, Narail, Noakhali, Patuakhali, Pirojpur, Satkhira and Shariatpur) and 147 upazilas declared by the government of Bangladesh. A total of 48 upazilas in 12 districts that are exposed to the sea are defined as 'exposed coast' and remaining 99 upazilas in 7 districts are termed 'interior coast' (Figure 2.1).

About 25% of the country's population lives in the coastal districts which is rich in many valuable resources including fertile agricultural lands, fishery, ecologic diversity, tourism, etc. Unfortunately this region is also periodically devastated by certain hazards that impact the rest of the country with the much lesser degree of severity. These coastal hazards include cyclone and associated storm surges and strong winds, salinity intrusion and bank erosion. The vulnerability of the region is further aggravated by the changing climate where sea level rise is expected to inundate a large part of land in future. This has necessitated some unique measures to provide protection to the large group of population living in this zone of which greenbelt is one.

The average elevation of the coastal zone ranges from 1-2 m in the southwest and 4-7 m in the southeast. The flat topography, active delta and dynamic morphology play a significant part in its vulnerability to sea level change. Based on the hydro-morphological characteristics, the coastal zone has been delineated into three regions: (i) the Ganges Tidal Plain or the Western Coastal Region, (ii) the Meghna Deltaic Plain or the Central Coastal Region and (iii) the Chittagong Coastal Plain or the Eastern Coastal Region.

Climate change in coastal zones poses potential additional stress on systems that are already under intense and growing pressure due to an increasing population and shortage of available land. Coastal environments particularly at risk include mangroves, tidal deltas and low-lying coastal plains, sandy beaches, coastal wetlands, estuaries and coral reefs. Devastating cyclones in 1991, Sidr in 2007, and Aila in 2009, killed thousands of people and destroyed inhabitation and infrastructures in the coastal areas of Bangladesh. Creation of green shelterbelt along the coastal region is highly desirable for reducing vulnerabilities and hazards of extreme climatic events like cyclone and storm surges of the future.

2.2. Major Resources

The coastal zone of Bangladesh is rich in diverse natural and socio-economic resources. The coastal resources can be categorized into three major groups are (i) Human resources, (ii) Natural resources and (iii) Economic Resources (Table 2.1).

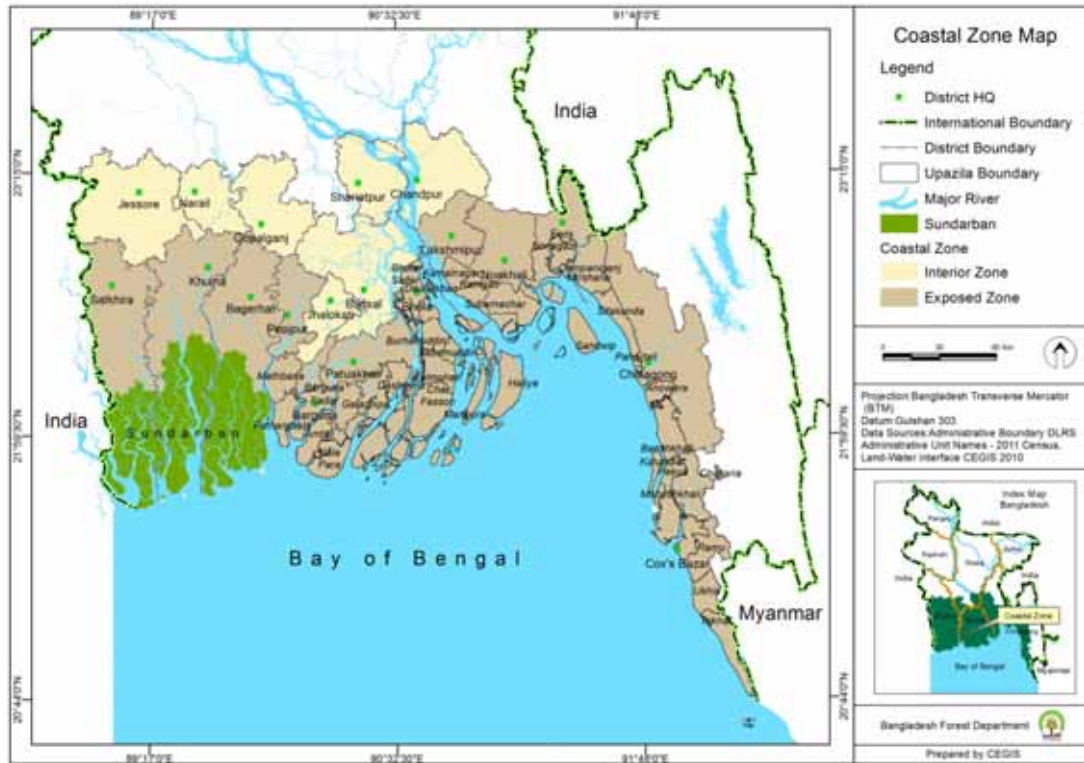


Figure 2.1: Map showing the coastal area of Bangladesh (Source: MoWR, 2006)

Table 2.1: Types of resources in the coastal area of Bangladesh

Type of Resources	Description
Human resources	Total population, Population by sex, Population by urban and rural areas etc.
Natural resources	Surface water salinity, Groundwater depth, Aquatic resources: <i>Inland fish production, Marine fish production, The Sundarbans fish production, Farm shrimp production</i> Land resources, Forest resources, Minerals resources, and Energy consumption
Economic resources	Agriculture, Industries, Services, Aquaculture, Contribution of resources to GDP, Net Cropped Area, Salt Farming, Tourism, Ports and harbours

Some of the important resources are: agricultural land, livestock, fisheries, forestry, navigational waterways, salt production, seaport facilities, sites of archeological importance and tourism. The coastal zone contains resourceful ecosystems, e.g. mangrove, marine, estuary, islands, coral and sandy beaches. The coastal ecosystems are playing important role in conservations. The Sundarbans, the world's largest single tract of mangrove forest; a World Heritage Site is located in the southwest coast of Bangladesh. The existing diverse coastal ecosystem is not only biodiversity hotspot but also they form the ecological foundation of the zone for natural and economic resource development of the country.

2.2.1. Human Resources

The total population in the coastal zone rose approximately from 15.7 million in 1961 to the present population of 38.52 million, which has been projected to rise to 64.25 million in 2051. The population is increasing at a declining rate. The decadal population data was collected from the Bangladesh Bureau of Statistics (BBS). The change of growth rate was based on

historical estimates. Growth means net growth rate, covering birth, death and migration. Before considering the projection type, several projections were made on an iterative basis and validation was conducted to get values close to the reality.

Population growth in the coastal region appears to be on the rise since 1961. The trend in population change of the area is presented in Table 2.2 which also includes a projection through 2051. Further, District wise population of the coastal zone is presented in Table 2.3.

Table 2.2: Summary of population trend and projection growth of the coastal region, 1961-2051

Year	1961	1974	1981	1991	2001	2011	2021	2031	2041	2051
Extent	Historical (million)						Projections			
Coastal Zone	15.7	21.5	26.1	30.65	35.35	38.52				
Projected							47.92	53.36	58.80	64.25

Table 2.3: Population of the coastal region by districts (Census 1991-2011)

District	1991	2001	2011	Population Density 2011	Population Change (2001 - 2011)
Bagerhat	1,431,332	1,549,031	1,476,090	1,027	(72,941)
Barguna	775,691	848,554	892,781	488	44,227
Barisal	2,207,426	2,355,967	2,324,310	835	(31,657)
Bhola	1,476,328	1,703,117	1,776,795	522	73,678
Chandpur	2,032,449	2,271,229	2,416,018	1,468	144,789
Chittagong	5,296,127	6,612,140	7,616,352	1,442	1,004,212
Cox's Bazar	1,419,253	1,773,709	2,289,990	919	516,281
Feni	1,096,745	1,240,384	1,437,371	1,451	196,987
Gopalganj	1,060,791	1,165,273	1,172,415	798	7,142
Jessore	2,106,996	2,471,554	2,764,547	1,060	292,993
Jhalokati	666,139	694,231	682,669	966	(11,562)
Khulna	2,010,643	2,378,971	2,318,527	1,046	(60,444)
Lakshmipur	1,312,337	1,489,901	1,729,188	1,200	239,287
Narail	655,720	698,447	721,668	746	23,221
Noakhali	2,217,134	2,577,244	3,108,083	843	530,839
Patuakhali	1,273,867	1,460,781	1,535,854	477	75,073
Pirojpur	1,063,481	1,111,068	1,113,257	871	2,189
Satkhira	1,597,178	1,864,704	1,985,959	1,044	121,255
Shariatpur	953,021	1,082,300	1,155,824	984	73,524
Total	30,652,658	35,348,605	38,517,698		

Table 2.4: Summary Population of 19 Coastal Districts

Year	1991	2001	2011
Population (19 Coastal Districts)	30,652,658	35,348,605	38,517,698
Population (Whole Country)	106,315,355	124,355,263	144,043,697
% of country's total population living in the coastal districts	28.83	28.43	26.74

According to the population census of 2011, the 19 coastal districts have about 38.52 millions of population living in 6.85 million households. This population in the coastal zones is unevenly distributed (Table 2.3). About one third of the total coastal population lives in the exposed coast. The population density in the exposed coast is significantly lower than that of the interior coast. It is to be mentioned that overall population is under increasing trend but in some districts the population have shown as declining trend, especially in Bagerhat, Barisal, Khulna and Jhalokati which could be due to internal push and pull factors. Further comparative analysis of population data for 19 coastal districts has been analyzed and presented in Table 2.4. The analysis show that though the total number of people is

increasing, when seen as percentage of country's total population, the population of the coastal districts has decreased from 28.83% to 26.74% within 1991-2011 period.

The individual upazila wise populations (Table 2.5) show a declining trend in the total population of Burhanuddin, Daulatkhan, Mathbaria, Chittagong Port, Sandwaip, Chakaria and Ramgati within 2001-2011 period.

Table 2.5: Population at study upazilas (1991-2011)

District	Upazila	2001	2011	Change (2001 - 2011)
Barguna	Amtali	259,757	270,802	11,045
	Barguna Sadar	237,613	261,343	23,730
	Patharghata	162,025	163,927	1,902
Bhola	Bhola Sadar	408,094	430,520	22,426
	Burhanuddin	244,137	233,860	(10,277)
	Char Fasson	413,593	456,437	42,844
	Daulatkhan	173,253	168,567	(4,686)
	Lalmohan	276,547	283,889	7,342
	Manpura	67,304	76,582	9,278
	Tazumuddin	120,189	126,940	6,751
Patuakhali	Dashmina	117,037	123,388	6,351
	Galachipa	325,235	361,518	36,283
	Kala Para	202,078	237,831	35,753
Pirojpur	Mathbaria	263,527	262,841	(686)
Chittagong	Anowara	228,530	259,022	30,492
	Banshkhali	391,320	431,162	39,842
	Chittagong Port	213,598	208,260	(5,338)
	Halishahar	125,255	151,515	26,260
	Mirsharai	368,950	398,716	29,766
	Pahartali	127,243	190,637	63,394
	Patenga	80,448	132,677	52,229
	Sandwip	292,773	278,605	(14,168)
	Sitakunda	335,178	387,832	52,654
	Chakaria	503,390	474,465	(28,925)
Cox's Bazar	Cox'S Bazar Sadar	348,075	459,082	111,007
	Kutubdia	107,221	125,279	18,058
	Maheshkhali	256,546	321,218	64,672
	Pekua	-	171,538	171,538
	Ramu	202,683	266,640	63,957
	Teknaf	200,607	264,389	63,782
	Ukhia	155,187	207,379	52,192
Feni	Sonagazi	235,229	262,547	27,318
Lakshmipur	Kamalnagar	-	222,915	222,915
	Ramgati	393,354	261,002	(132,352)
Noakhali	Companiganj	214,652	250,579	35,927
	Hatiya	341,176	452,463	111,287
	Subarnachar	-	289,514	289,514
Total		8,391,804	9,925,881	

Further, the study area of the greenbelt project consists of 37 coastal upazila where the present population is 9.9 million (BBS, 2011) which is almost one-fourth of the entire population of the coastal area. Total area of concern 37 upazilas is 15,259 Sq Km and the average population density almost 634 people per square kilometer of these upazilas. The highest population density is at Chittagong Pahartoly which is 20,253.47 people per square kilometer and lowest at Galachipa which is 417.09 (Table 2.5). The population is increasing

at a slower rate. The decadal population data was collected from the Bangladesh Bureau of Statistics (BBS). The change of growth rate was based on historical estimates.

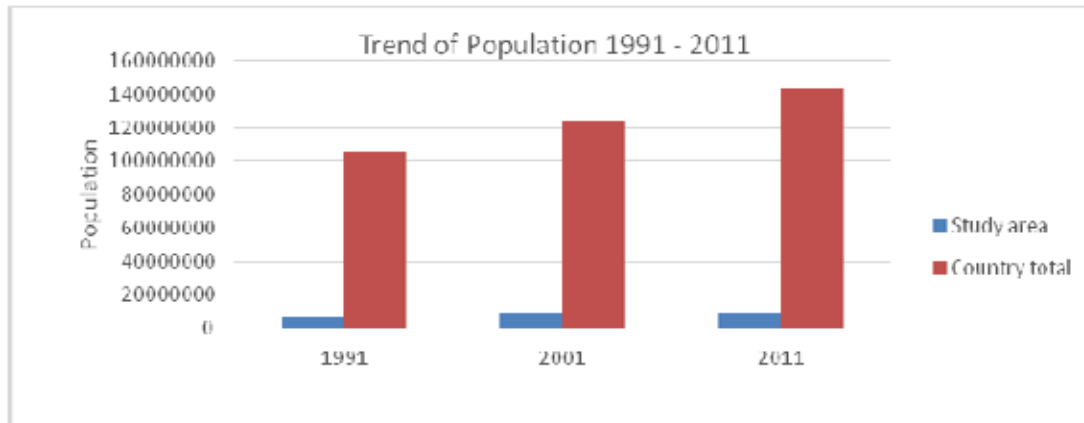


Figure 2.2: Comparison of total population of the study upazilas with country total

Figure 2.2 shows in graphical form how the population of the country and the coastal upazilas is increasing. Further population data for 37 upazilas of the greenbelt study area have been analyzed and presented in Table 2.6. Interestingly this table show an opposite trend compared to the rest of the coastal region. The population in these 37 upazilas is increasing in total number and also as a percentage of population of the whole country growing from 6.72% in 1991 to 6.89% in 2011.

Table 2.6 Summary Population at 37 Upazilas under the greenbelt project

Year	1991	2001	2011
37 Upazilas under the Greenbelt Project	7,144,484	8,391,804	9,925,881
Population (Whole Country)	106,315,355	124,355,263	144,043,697
% of Population at study area considering the country Total	6.72	6.75	6.89

The literacy rate (Table 2.7) of the study upazila on average is 47% where highest literacy rate is 75 in Chittagong Port and lowest rate is 26 at Teknaf. The poverty level is considered at 25% where highest poverty level is at Bhola which is 49 and lowest poverty level is at Patenga Chittagong.

Table 2.7: Population density, literacy rate and poverty level

Name of Upazila	Population density	Literacy rate	Poverty Level
Amtali	525.55	52.80	22.80
Anowara	1769.38	51.90	15.50
Banshkhali	1230.90	37.40	27.90
Barguna Sadar	804.82	58.60	19.20
Bhola Sadar	1339.68	45.20	49.20
Burhanuddin	1031.35	47.90	28.30
Chakaria	991.88	47.60	28.50
Char Fasson	672.02	43.50	28.20
Chittagong Port	16849.21	75.70	12.40
Companiganj	868.47	51.30	7.60
Cox'S Bazar Sadar	2187.56	49.20	26.20
Dashmina	555.87	48.70	21.80
Daulatkhan	1521.39	41.60	30.30

Name of Upazila	Population density	Literacy rate	Poverty Level
Galachipa	417.09	45.40	26.00
Halishahar	12595.67	70.80	5.60
Hatiya	688.41	34.20	16.00
Kala Para	535.67	52.00	20.30
Kamalnagar	1010.00	30.70	18.70
Kutubdia	1748.95	34.00	31.10
Lalmohan	1053.29	40.00	27.80
Maheshkhali	1028.29	30.80	40.20
Manpura	429.89	32.10	32.80
Mirsharai	866.27	55.10	13.40
Pahartali	20253.47	65.80	30.00
Patenga	4700.99	69.90	3.90
Patharghata	686.55	60.50	12.90
Pekua	1252.30	35.30	30.90
Ramgati	1444.58	39.30	30.40
Ramu	687.50	36.60	34.30
Sandwip	832.72	51.50	19.10
Sitakunda	1466.21	59.20	11.50
Sonagazi	1254.68	51.60	44.50
Subarnachar	569.07	32.70	18.70
Tazumuddin	786.18	42.90	22.30
Teknaf	832.08	26.70	38.20
Ukhia	798.46	36.30	37.80
Mathbaria	764.00	61.70	25.60

2.2.2. Natural resources

The coastal areas, which include the Sundarbans, are criss-crossed by a number of tidal rivers and creeks. The main coastal rivers are Gorai, Madhumati, Arial Khan, Swarupkati, Buriswar, Bishkhali, Tentulia, Kopotakhho, Noboganga, Poshur, Boleshwar, Rupsha, and Shibsha. In addition, the southern part has a large number of beels and low lying areas. The south-eastern coastline is vulnerable to cyclones during the monsoon season when storm surges can cause dramatic increases in water level. The region behind the Sunderbans along the south-west coastline is protected to some extent due to the dampening effects of the Sundarbans although surges do move inland through the estuary of the major rivers of the region.

The important natural resources of the coastal zone are mangrove ecosystems which include Sundarbans, Chokoria mangrove forest and other patches of planted mangrove forest. These forest resources acts as barriers to natural disasters of the coastal zone providing protection against cyclones, storm surges, strong winds and erosion. This unique ecosystem has the highest rate of carbon sequestration among all types of vegetations. They are host to some unique flora and fauna that thrives in mangrove ecosystem. The Royal Bengal Tiger is one of many such species found only in the Sunderbans mangrove forest. The coastal zone have several habitat, these are: (i) Shore, (ii) Low mangrove forest, (iii) High mangrove forest, (iv) Open land/grass land and (v) Estuarine/ riverine habitat. The brackish water of the mangrove ecosystem is the ideal breeding ground for shrimps and few other types of fish. Among all ecosystems mangrove produces the maximum amount of biomass (Iftekhar and Islam, 2004). Sundarbans Mangrove forest and Different islands (e.g. St. Martine, Sonadia, Nijhum Dwip Island etc.) are the two highly important natural resources which have been briefly described below:

The dynamic geomorphologic processes active in Meghna estuary causes high rate of accretion adding new lands to Bangladesh's coastline. On an average about 20 sq. km. of land is accreted annually (CEGIS, this study). These lands provides areas for new mangrove plantation and under the current administrative practice these are felled after 20

years (MoEF, 1990) and the land is opened for settlement, agriculture, fisheries and other economic activities. They also help in raising land level which possibly helps in keeping sea level rise in some check.

Sunderbans Mangrove Forest

Mangrove forests are a natural scenic attraction (Figure 2.3) and an ecologically importance resource of the country, which protects coastal belt and provides recreational ecosystem services to the society. The Sundarbans is the largest single mangrove forest in the world with tidal halophytic characteristics and it has been declared an UNESCO World Heritage Site. The Sundarbans are divided into three protected zones are; (i) Sundarbans East, (ii) Sundarbans South, and (iii) Sundarbans West.



Figure 2.3: A part of upper view of Mangrove forest of the study area

Sundarban's beauty lies in its unique natural surroundings. Thousands of meandering streams, creeks, rivers and estuaries enhance its charm. This region supports several mangroves plants, like the Mangrove apple (*Sonneratia apetala*), Milky mangrove (*Excoecaria agallocha*), Nipa Palm (*Nypa fruticans*) and dense stands of Spurred mangrove (*Ceriops decandra*), with discontinuous patches of Mangrove date palm (*Phoenix paludosa*) on drier ground, riverbanks and levees. The fauna of the sanctuary is very diverse with some 49 species of mammals, 260 species of birds and 59 species of reptiles (UNESCO, 2016). The greatest of these being the Bengal tiger of which an estimated 106 remain in the Bangladesh Sundarbans (Dey et. al., 2015). Other large mammals are the Wild boar, Spotted deer, Smooth-coated otter, and the Macaque monkey. There are ducks and Snipes, Herons, Lesser adjutant, Coots, Yellow-lags, Sandpipers and many more attractive birds .

Saint Martin's Island

The Saint Martin or Narikel Jinjira coral island is situated in the southernmost tip of Bangladesh. This island is encircled by a cluster of smaller islets and the zone is mostly bounded either by boulders of corals or rocks similar to the sandstones of the tertiary hills of Chittagong. The only source of fresh water for plants, animals and human beings of the island is the rainwater retained in the depressions, so fresh water is always in short supply. The islanders are mainly dependent on the Screw pine and Nishinda of the dune vegetation and mangrove formation for their daily supply of fire woods, poles for thatched houses and fencing the cultivated crop fields. This practice has literally destroyed the natural vegetation of the island. This island represents a high wave, energy rich, and oceanic bio-ecological zone. Different mollusks, echinoderms, five different species of marine turtles, other reptiles like Ring Lizard and sea snakes are known to nest in the area (Rashid,1986).

Sonadia Island

Sonadia Island is a barrier island north of the Teknaf Peninsula. This supports the last remaining remnant of mangrove forest in southeast Bangladesh. The mangrove species grown in this island can tolerate more saline condition than that of the Sundarbans. This island supports a large number of water birds, mollusks, echinoderms and different marine turtles.

Nijhum Dwip Island

Nijhum Dwip Island is located in the Ganges-Brahmaputra estuary and generally consists of raised foreshore and embankments. This island is covered by Kewra (*Sonneratia apetala*) and some other mangrove tree species and has an abundance of Chetal, a good number of bird species, some amphibians and reptiles.

2.2.3. Economic resources

The economic resources can be further divided into two types (Table 2.8) which are productive and service type.

Table 2.8: Types of Economic Resources

Sl. No.	Type of Economic Resources	Major Arenas
1	Productive	Agricultural activities Salt production Fishing (marine) Fish processing Shrimp fry collection Shrimp farming Crab/shell collection Industries Extraction of forest products (wood, honey, golpata and wax collection from the Sundarbans.), Mineral resources
2	Services	Tourism Shipbreaking Industry Boat building (boat carpentry). Marine Port Airport Deep Sea Port Natural beauty of different islands and mangrove forest Road Embankment and Polders

A brief description of these is given in following sections.

Productive Services

The Productive economic resources of the coastal zone includes Agricultural activities, Salt production, Fishing (marine and coastal), Fish processing, Shrimp fry collection, Shrimp farming, Crab/shell collection, Industries, Extraction of forest products (wood, honey, golpata and wax collection from the Sundarbans.), and Mineral resources. Some these resources are described below:

Agricultural: In the coastal zone, mainly agricultural activities dominate the productive economy contributing about 16.3% to the GDP (BBS, 2014). The agricultural land resource is limiting due to continuously increasing pressure of rapidly growing population. Considering the agricultural dependency population, the availability of arable land per capita is less than 0.1 hectares which make difficulties on proper land use allocations based on land capability.

According to the Agricultural Census Report (BBS, 2008), net cultivated area of the coastal region of Bangladesh is 497,968 ha. (1,230,507 acre). These areas suffer from salinity intrusion during the dry season and crops can be grown primarily during monsoon when the rain water flushes and reduces the salinity to a level favorable for agriculture. Overall the coastal zone contributes around 22% from the agricultural sectors.

The dominant crop grown in the saline areas is local transplanted Aman rice crop with low yields. The cropping patterns followed in the coastal areas are mainly Fallow-Fallow-Transplanted Aman rice. The crop yield is negatively impacted mainly by salinity, water logging and drainage congestion. The factors which contribute significantly to the development of saline soil are, tidal flooding during wet season (June-October), direct inundation by saline water, and upward or lateral movement of saline ground water during dry season (November-May). Total crop production in 2008 in the coastal agricultural lands was 50,958 tons.

Fisheries: This is intensive and quick-yielding sector, which enhances growth and alleviates poverty country especially in the coastal region of Bangladesh. The country has immense natural potential for developing the fisheries sub-sector. As a whole, the sector contributes 4.53% of the total GDP and 24.66% (BBS, 2011) of the agricultural sector. The fish resource has earned 213, 31,210 taka in 2008-2009. The other two are Wood that has earned 88, 00,179 taka in 2008-2009 and Nipa palms (*Nypa frutican*) which earned 45, 95,912 taka in the same year. The other resources are Gewa (*Excoecaria agallocha*) and Goran (*Ceriops decandra*) wood, Plant saplings, and Fuel wood. Shon, Nolkhagra, Hogla, Hetal, Bola, and Dhansi are collected for thatching the roofs of houses. Honey, Wax, Prawn, and Mollusk shells are also a source of income for the local people as these are widely exported throughout the country and abroad as well. Also, Crab has earned us 37, 43,766 taka in the year 2008-2009. Salt production is also on the rise from 350,000 metric tons in 2003 to 1,410,000 metric tons in 2013.

Industries: Although Bangladesh is predominantly an agricultural country, a great number of large-scale industries based on both indigenous and imported raw materials have been set up. Substantial percentage of the industries in the coastal areas is cottage industries. But other notable industries are engineering and ship building, shrimp fry industries, shrimp processing industries, boat building, textile, paper and newsprint, sugar, iron and steel including re-rolling mills, oil refineries, paints, colors, and varnishes; electric cables and wires etc. Overall the coastal zone contributes around 22% of the industrial sector.

Salt farming: The salt producing areas are in the coastal belt of Chittagong, Noakhali, Barisal and Khulna districts and these are offshore lands. Apart from that, substantial amount of new land in Satkhira area has also been taken under for the purpose of salt farming and all necessary preparation are almost taken by BSCIC. The substantial amount of salt production has been started during 2008 (MI, 2008). More than 50,000 farmers are involved in salt farming in Bangladesh. The areas of major salt farming of Bangladesh are presented in Figure 2.4. During 2007-2008 about 1.67 million tones has been produced. However, the production fluctuated from year to year due to natural calamities, variations in rainfall and changes in terms of land lease.

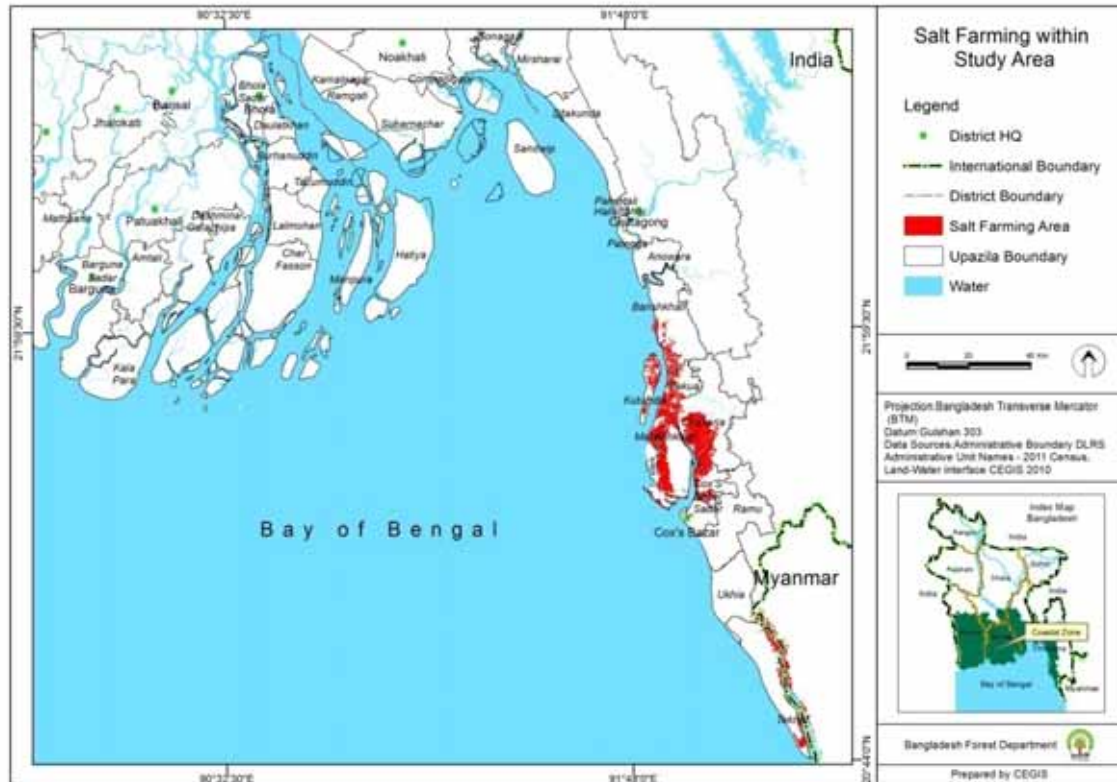


Figure 2.4: Salt Farming within the Study Area

In 2003-04 salt was cultivated in around 25 thousand hectare of land and 0.9 million metric ton salt was produced. Between 1990-91 and 2003-2004, the production of salt increased by 43%. However, the production fluctuated from year to year due to natural calamities, variations in rainfall and changes in terms of land lease.

Mineral Resources: Different types of mineral resources available in Bangladesh such as oil, gas, peat, hard rock, construction sand, beach sand, glass sand, gravel and black gold. It is known that deposits of peat occur at shallow depths in different low-lying areas of Bangladesh. According to Geological Survey of Bangladesh, the reserve of dry peat is about 170 million tons. The major deposits are in greater in the districts of Faridpur (150 million tons), Khulna (8 million tons). Peat requires drying before making briquettes for use as fuel. Petrobangla implemented a pilot project for extraction of peat and making briquettes but the result were discouraging and economically not viable at present. This scenario however may change in future. The coastal area is also resourceful with heavy minerals. Heavy mineral availability in the coastal zone has been presented in Table. 2.9.

Table 2.9: Heavy minerals found in the Coastal area

Heavy Minerals-Valuable Components									
Deposits	Total	Valuable Components							
	Heavy Mineral (%)	Zircon	Rutile	Ilmenite	Lecoxene	Kyanite	Monazite	Magnetite	Garnet
Main Coast									
Badarmokam	23.3	1.2	0.8	23	4.38		1.2	2.5	
Sabrang	19.7	6.1	2	28.6	5.06	1.06	0.3	1.46	4.4
Teknaf	22.8	6.4	3	37	4.55	3.33	0.7	1.63	5.1
Silkhali	17.8	6.8	2.2	35.4	2.24	0.9	0.8	0.63	8.1
Inani	24.1	6.2	2.3	30.3	0.25	0.8	0.55	3.16	7.3
Cox's Bazar	18	2.5	0.8	17.5	1.14		0.22	3.61	5.5
Kuakata	28.95	1.2	0.4	9.14	1.16	2.2	0.01	0.52	6.3
Moheshkhali									
Fore-Shore Beach	42.2	6	3.2	46	2.42	Trace	0.11	0.69	
Kutubjum	20.8	4.3	2	34.3	1.09	2.48	0.19	1.1	
Fakkirghona	23.5	2.2	2.1	23	1.39	7.4	0.08	0.42	6.8
Fakirahata	21.8	5.7	4	22.9	3.8	9.9	0.2	0.1	6.2
Baraghoriapara	19.2	3.3	3.7	28.7	3.53	7.6	0.51	0.68	6.5
Panichara	12.8	6	3.2	29.4	2.7	8.04	0.26	1.89	6.6
Hcanak (Naibila)	7.3	1.4	2.2	19.7	0.97	1.55	0.05	1.78	
Matarban	22.4	5.2	1.9	32.6	2.46	Trace	0.13	3.78	
Nijhum Dwip	25	2.1	0.4	13.5	0.06	2.69	0.02	4.55	
Kutubdia	29	3.3	1.6	19.8	2.03	2.16	0.08	2.82	5.3
Mean Value	23	4.2	2	26	2.3	3.92	0.31	1.87	6.5

Source: Begum, Ferdous A. 2014

Service type Economic Resources

The services economic resources of the coastal zone includes (i) Tourism, (ii) Shipbreaking Industry, (iii) Boat building (boat carpentry), (iv) Marine Port, (v) Airport, (vi) Deep Sea Port, (vii) Natural beauty of different islands and mangrove forest, (viii) Road and (ix) Embankment and Polders etc. Some these resources are described below:

Tourism: Another valuable economic resource of the coastal areas is tourism which is a thriving industry in Bangladesh. Every year thousands of people visit these coastal areas to enjoy the scenic beauty of the world's longest sea beach in Cox's Bazaar, which is now being developed as an international and national tourist resort. The St. Martin's Island and Kuakata sea beach are also developing as other major coastal tourist attraction. According to World Travel and Tourism Councils report (2016) direct contribution of travel and tourism to national GDP in 2015 was 407.6 billion (2.4 % of total GDP) which they forecast will rise by 5.2% in 2016. Bangladesh Parjatan Corporation which runs the nationally owned hotels and motels in the country reported that in 2012-13, 33% of the total guests in their facilities were visiting the coastal areas (Majid, 2016).

Infrastructure (Road and Embankment): A total of 123 flood control polders involving 5,107 km of embankment have been constructed covering approximating 1.5 million ha of the

coastal area under the Coastal Embankment Project (PDO-ICZMP, 2004). The objective of the polders is to prevent inundation of floodplain agricultural land by saline water during high tide. The polders have brought major changes in the tidal regime by reducing storage area for flood tide. The study area upazilas have 2094 km of embankment and 16970 m of roads that includes 3855 km of paved road and 13116 km of unpaved road (NWRD, 2011).

Ports and harbors: Bangladesh has two international sea-ports, Chittagong and Mongla. The ports play an important role in export and import in national and international sectors. The Chittagong port handles 15 million tons of cargo/year and the Mongla port handles 5 million tons of cargo/year.

2.3. Natural Hazards

2.3.1. Cyclones and Storm surges

About 10% world tropical cyclone form in the Bay of Bengal and more than 40% of world-wide death caused by cyclones took place in Bangladesh (Hossain *et al.*, 2010). Majority of the tropical storms in the world called cyclones, hurricanes or typhoons occur within the zone lying between 15°N to 15°S latitude. The shallow coastal bathymetry of the Bay of Bengal intensifies storm surges resulting in large damaging events.

Singh *et al.* (2000) analyzed cyclone frequency data of north Indian Ocean from 1877-1998 and found Bay of Bengal had 4 times more cyclones than Arabian Sea. Cyclones occur mostly in May, October and November as shown in Table 2.10 within the 122 years of analyzed record the occurrence of cyclones in November is twice the number of events that occur in May, the month of second highest occurrence. In addition to cyclones, flooding is another hazard that affects the coastal areas of Bangladesh. Frequency of these hazards is on the rise due a general increase in temperature related to climate change.

Table 2.10: Cyclones frequency of north Indian Ocean during May - November from 1877-1998

	Month				
	May	June	September	October	November
Bay of Bengal					
Cyclonic Storms	59	35	40	89	114
Severe Cyclonic Storms	42	5	16	38	63
Arabian Sea					
Cyclonic Storms	24	25	4	24	20
Severe Cyclonic Storms	29	17	2	11	15

Because of the funnel shaped coast, Bangladesh very often becomes the landing ground of cyclones formed in the Bay of Bengal and farther. Most of the damage occurs in the coastal regions of Khulna, Patuakhali, Barisal, Noakhali and Chittagong and the offshore islands of Bhola, Hatiya, Sandwip, Manpura, Kutubdia, Maheshkhali, Nijhum Dwip, Urir Char and other newly formed islands.

Over the decades, a large number of cyclones have formed in the Bay of Bengal. Of them, the damage done by the cyclones of 1948, 1960, 1970, 1971, 1986, 1991, 2007 and 2009 are most severe. The 1970 Bhola Cyclone intensified into a severe cyclonic storm and made landfall at the coast of Bangladesh with wind speeds of 224 km/hr (Table 2.11, DDM website). It is estimated that between 300,000 to 500,000 people perished in that cyclone where storm surge hit the Meghna estuary region with greater than 6 m height. The 1991 Cyclone was significantly stronger when it made a landfall along the southeastern coast around Chittagong as a Category 5 cyclone with 225 km/h (Table 2.11, DDM, 2016). At least 138,000 people were killed by this storm..

Cyclone Sidr in 2007 was another major cyclone to land on the coast of Bangladesh that was responsible for at least 3,447 deaths. The force of Sidr was felt way inland as the capital Dhaka faced power cut for days as the cyclone went through the country causing significant loss to the infrastructure of the country. Bangladesh faced yet another devastating cyclone Aila on May 26, 2009. 11 of the 64 districts were affected by Aila and approximately 600,000 thatched homes, 8800 km of roads, 1000 km of embankments and 123,000 hectares of land were either damaged or destroyed. Approximately 9.3 million people were affected by this cyclone, of which 1 million were rendered homeless. The Sundarbans was inundated with 6.1m (10ft) of water. Dozens of tigers are feared to have drowned in Aila's storm surge along with deers and crocodiles. Table 2.11 lists some of the major cyclones that has hit Bangladesh coastline within the past 50 years and the associated wind speed, surge height and number of people killed by them (DDM, 2016).

Table 2.11: Major Cyclones affecting Bangladesh in past 50 years.

Date	Max Wind Speed (km/hr)	Surge Height (m)	Death Toll
11 May, 1965	161	3.7 – 7.6	19,279
15 Dec, 1965	217	2.4 – 3.6	873
1 Oct, 1966	139	6.0 – 6.7	850
12 Nov, 1970	224	6.0 – 10.0	300
25 May, 1985	154	3.0 – 4.6	11,069
29 April, 1991	225	6.0 – 7.6	138,882
19 May, 1997	232	3.1 – 4.6	155
15 Nov, 2007	223	---	3363
25 May, 2009	92	---	190

Source: Department of Disaster Management, Website <http://old.ddm.gov.bd/cyclone.php>

2.3.2. Coastal Erosion

Coastal erosion is a hazard that puts in risk inhabitants and economic activities of those areas. The deltaic coastline of Bangladesh consists of two basic physiographic units: the inactive or abandoned Ganges tidal plain and the active Meghna deltaic plain. The erosion-accretion processes are dominant within this active Meghna deltaic plain. Broad map comparisons indicate that the delta of the Ganges-Brahmaputra River has not grown significantly toward the sea over last two centuries. Changes can be noticed in Sandwip and adjacent islands, in Hatiya Island, in Bhola Island, and in the coastline of the Noakhali mainland. Sandwip Island has reduced in size over the past 200 years. Sandwip channel was nearly isolated from the main distributaries network of the rivers in 1764-1793. The Hatiya island elongated and migrated considerably southward during this period. The island Bhola has also elongated in a north-south direction over time. All these is an indication of how actively the coastal erosion along the Meghna estuary is being modified by geomorphological processes the erosion component of which makes some areas very vulnerable. A more detailed description of erosion-accretion process in Bangladesh coast is discussed in Section 2.3.

2.3.3. Salinity Intrusion

Salinity intrusion is a major hazard of the coastal areas which severely impact agricultural activity and productivity, causes shortage of freshwater that leads to various health hazards. In monsoon season saline water ingress to 10% of country's area but in the dry season saline water covers about to 40%. A study by World Bank (2015) reported that now and in the coming decades, salinization of water and soil are on the rise and will increase significantly in many areas of Barisal, Chittagong and Khulna district. This will lead to shortage to drinking water and irrigation water and cause change to aquatic ecosystem. Changes in the river salinity and the availability of freshwater will affect the productivity of many capture fisheries. It will adversely affect the habitats of freshwater fish and giant

prawns. People near the coastal area are forced to abandon rice cultivation in favor of shrimp farming due to salinity. The study of World Bank (2015) indicates that, rice yield will decline by 15.6 percent in the 9 coastal upazilas where measured soil salinity will exceed 2560 ppm (4 Deci-siemens per meter) by 2050. It is also feared that, the ecological system of the Sundarbans will be influenced by salinity intrusion. High salinity in both monsoon and dry season in the coastal belt is associated with the decreasing upstream freshwater flow as well as the silting of major channels (Figure 2.5).

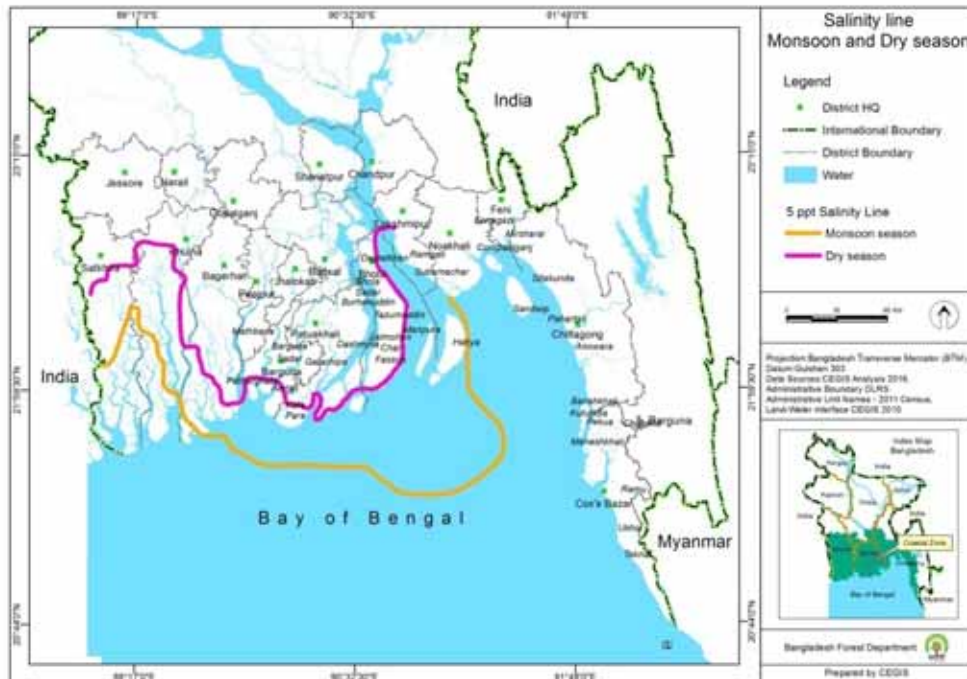


Figure 2.5: Monsoon and dry season salinity line (regenerated from CEGIS and IWM, 2007)

Bangladesh has faced a number of catastrophic disasters over the years. These disasters have shown that the coastal area of Bangladesh is extremely vulnerable. The hazard of natural disaster cannot be prevented. But it is possible to reduce the risk and vulnerability of these disasters by increasing mitigation capacity. Conventional outlook to disasters like disaster preparedness, capacity building to face disaster, relief and rehabilitation activities etc. are not adequate enough to face climate change vulnerabilities and development challenges. Creation of a greenbelt along the coastal belt will be an additional measure in reducing vulnerabilities from coastal hazards discussed above.

2.4. Hydro-Morphological Dynamics

The Bengal basin is the largest delta in the world, the size of which is ever increasing. Based on the hydro-morphological characteristics, the coastal zone has been delineated into three regions: (i) the Ganges Tidal Plain or the Western Coastal Region, (ii) the Meghna Deltaic Plain or the Central Coastal Region and (iii) the Chittagong Coastal Plain or the Eastern Coastal Region (Pramanik, 1983).

The Ganges Tidal Plain or the Western Coastal Region

The Western Coastal Zone or the Ganges Tidal Plain extends from the Bangladesh-India border in the west to the Tetulia River in the east. It is mainly covered by the Sundarbans mangrove forest, greater Khulna and part of Patuakhali district. The topography is low with an elevation between 0.9 to 2.1 m above mean sea level (Iftekhar and Islam, 2004). This

zone is a semi active delta mostly receiving flow from the Rupsha-Passur and the Baleswar River system. The supply of sediment is relatively low in this region hence morphology in this region is relatively stable. Tidal ranges of this area varies from 1 - 2.5 m. Salinity of this zone is higher due to the low availability of fresh water during dry season (15-20 ppt).

The Meghna Deltaic Plain or the Central Coastal Region

The Meghna estuary is morphologically very dynamic. Lateral erosion and accretion rates are very high, being in the scale of several thousand hectares per year. Every year the Ganges, Brahmaputra, and Meghna rivers pour about 10^{12} m³ of water into the sea. The flow carried by the Lower Meghna River is distributed by a number of channels to the estuary. Currently, the Tetulia Channel carries about 15% of the monsoon flow, and the Hatiya Channel about 10%, and the rest is carried by the Shahbajpur Channel (MES II, 2001). This huge amount of water transports hundreds of million tons of sediment every year to the estuary out of which, >75% is silt and clay and the rest is composed of fine sand (Sarker et al., 2011). The beds of the channels in the estuary consist of fine sand and silt (25–50%), the representative grain size of which varies from 0.016 to 0.25 mm (MES II, 2001).

Tides are semidiurnal in the Bay of Bengal. According to Hayes (1979), estuaries can be divided into three categories on the basis of tidal range i.e. micro-tidal (0–2 m), meso-tidal (2–4 m) and macro-tidal (>4 m). All three of these characteristics are present in the Meghna estuary. The micro-tidal range is present in Tetulia Channel and the Lower Meghna River close to Chandpur and the meso-tidal range is observed at the south of Bhola Island and north of Hatiya Island. In the east of the Hatiya and Sandwip channels, the tidal range falls in the macro-tidal category. The maximum tidal range (>) 8.6 m was observed in the northeast corner of the estuary (Sarker et al., 2011).

Salinity in the estuary varies over a very wide range from the monsoon to the dry season. Salinity up to one p.p.t. (parts per thousand) may intrude up to the northern end of Shahbajpur Channel. In the eastern part of the estuary the salinity may reach up to 10–20 p.p.t.

The Chittagong Coastal Plain or the Eastern Coastal Region

The Eastern Coastal Zone or Chittagong Coastal Plain extends from Teknaf upazila (the southern tip of mainland) to Mirsarai upazila along the estuary of the Feni River. It is the most stable part of the Bangladesh coast and storm surge is less effective here. The sediment is mostly composed of submerged sands and mudflats (Islam, 2001). This submerged sand forms the 145 km long sandy beach from Cox's Bazar towards Teknaf.

2.4.1. Historical Development

The survey of Rennell (1779) in the 1760–1770s showed that the Padma and the Meghna entered the estuary at two different locations on the northwest and northeast sides of the then Bhola Island, respectively. At that time the Brahmaputra flowed on the eastern side of the Madhupur Tracts and joined the Meghna somewhere close to Bhairab, about 80 km north of Chandpur. By the early nineteenth century, the flow of the Brahmaputra joined with the Ganges at Aricha and flowed in a southeast direction as the Padma up to Chandpur where it met with the Meghna River. In 1943, the combined flow of the three great rivers divided into three channels at the northeastern tip of Bhola Island—the Meghna, Shahbajpur and Tetulia channels. The changes from 1943 to 1973 are very striking. The course of the Meghna River, at the east of Bhola Island, was abandoned, resulting in the shifting of flow to the Shahbajpur Channel. The Hatiya Channel was separated from this channel at the north of Hatiya Island. A very large land mass accreted to the south of Noakhali and Bhola (Sarker et al., 2011). During the following decades the development of the Meghna Estuary followed a similar trend, but the rate of change slowed down significantly.

2.4.2. Sedimentation Process

The sediment distribution process in the estuary is mainly governed by the sediment characteristics, the tidal range and its characteristics, waves and the estuary planform (Palinkas et al., 2006; Bird, 2008). Most of the river-borne sediment enters the estuary during the months of the monsoon. A major part of the sediment, especially the finer fraction, takes temporary residence in the zone of the turbidity maximum, which is close to the lower limit of the Shahbajpur Channel (Sokolewicz & Louters, 2007). Sediment concentrations at those locations are very high at about 2000 ppm (MES II, 2001). During the dry season the sediment supply from the catchment becomes insignificant, but sediment concentrations in the northeastern tide dominated part remain close to that of the monsoon (IWM, 2009; IWM, 2010). The temporary storage of sediment during the monsoon in the zone of the maximum turbidity is the main source of sediment redistribution during the dry season.

The relative strength of flood and ebb tide determines the locations for sedimentation build up (Bird, 2008). Generally, higher flow velocity during flood tide in the shallow estuary brings sediment to the landward inter-tidal areas to settle. This is known as so-called tidal pumping process. A tidal circulation process disperses fresh water and river-borne sediment into the northeastern part of the estuary. Tidal residual flow in the Meghna Estuary, as obtained from a mathematical model and field observations, showed that a part of fresh water that enters through the Shahbajpur and Hatiya channels makes nearly a u-turn and forms loop-type circulations around Sandwip, Uri Char and Jahajer Char. Based on MES II (2001) and Sokolewicz & Louters (2007), the relative importance of river and tidal flow with respect to sediment discharge has been drawn on satellite images of 2010 (Figure. 2.6). It shows the tidal meeting points and subsequent sedimentation in the northeastern part of the estuary. The monsoon sediment was moved temporarily by the river flow and was forced to remain close to the southern boundary of the estuary (downstream of the Shahbajpur Channel), having been brought to the north-eastern side by tidal circulation and tidal pumping process. The fine fractions of the sediment dominate the sediment redistribution process (Sokolewicz & Louters, 2007).

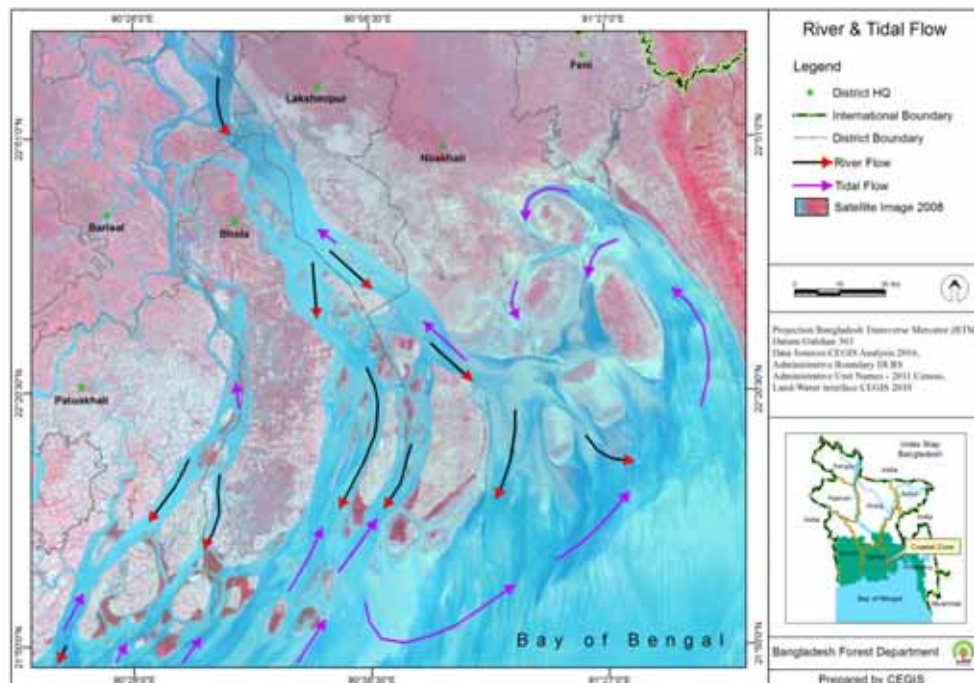


Figure 2.6.: The direction and relative importance of river and tidal flows in influencing sediment discharge (based on Sokolewicz, & Louters, 2007).

2.4.3. Coastal Dynamics

Erosion and accretion in the Meghna Estuary have been studied by Eysink (1983), EGIS (1997), Allison (1998), MES II (2001), EDP (2009), Sarwar and Woodroffe (2013) and Brammer (2004). The results of all these studies show that accretion is the dominant process during the last 200 years in the coastal areas of Bangladesh. Based on the analysis of satellite images, MES II estimated erosion and accretion for the period 1973–2000. During this period, the net accretion rate was 18.9 km²/y.

Similar work using satellite images at decadal scale has been carried out as part of this study. The following discussion focuses on the methods used and output produced from this effort. Freely available Landsat images from Multispectral Scanner (MSS), Thematic Mapper (TM) and Operational Land Imager (OLI) sensors have been collected for year 1973, 1984, 1996, 2006 and 2015 (Table 2.12).

Table 2.12: Image dataset used for assessing coastal morphology and trend model development

Sl. No.	Satellite	Sensor	Resolution (Meter)	Acquisition Time
1	LANDSAT	MSS	80	1973
2	LANDSAT	MSS	80	1984
3	LANDSAT	5 TM	30	1996
4	LANDSAT	5 TM	30	2006
5	LANDSAT	8	30	2015

First the images were prepared through few preprocessing steps for analysis. Then shorelines were drawn on each of the images. Due to the semi-diurnal tidal variation within a range of several meters, the existence of very wide (several hundred meters to a few kilometers) intertidal mudflat makes the demarcation of shoreline very difficult in the Meghna estuary area. The following guidelines were used for delineating shorelines:

- Areas covered by Uri grass or any type of vegetation considered as land.
- If the width of the tidal creeks is less than 100 m, it is considered as part of the shoreline.
- The area of an island greater than 1 ha is considered as a minimum unit of land.

Erosion-Accretion

Shorelines delineated from satellite images have been used for the planform analysis and assessment of erosion/accretion. Change in shorelines between a particular time period has been considered as erosion or accretion for that time. ArcGIS tool has been utilized for the identification and quantification of erosion and accretion. Erosion-accretions have been assessed for the periods of 1973-1984, 1984-1996, 1996-2006 and 2006-2015. The original plan of conducting this analysis over a 50 year timespan beginning from late 1960s were modified to 40 years as the CORONA images acquired in late 1960s did not fully cover the study area.

Analysis of satellite images of 1973 and 2015 show that the net rate of accretion of land is highest in Noakhali district, followed by Chittagong and Patuakhali as shown in Figure 2.7 and Table 2.13. Residual tidal flow also indicates that the Noakhali district is the most deposition prone area in the Meghna Estuary. During this period the extent of erosion was 1275 km² while that of accretion was 2076 km² with a corresponding net accretion of 801 km². The annual rate of net accretion was 19.1 km². Although the criteria for delineating banklines were different for MESII and CEGIS, the updated rate of net accretion was very close to that calculated by MESII in 2001 for the period 1973-2000.

Erosion occurs in the estuary area mainly due to the shifting and widening of channels. Subsequently, accretion occurs due to the extension of mainland towards the sea and also

formation and enlargement of islands. The magnitude of erosion and accretion within the Meghna Estuary area varies spatially. The estuary area within Barisal, Bhola, Chittagong, Noakhali and Patuakhali is morphologically very active.

Erosion and accretion in Barisal district are very similar to each other, although erosion dominates the process. Erosion was the highest in Bhola District from 1973- 2015 at 366 km². Erosion was the dominating process along the eastern and northern boundaries of Bhola Island. On the other hand accretion in Bhola district during the same period was 412 km² due to the formation and extension of islands on the east and south of Bhola island. The rate of net accretion was 1.1 km²/y.

Accretion in Chittagong district was about 293 km² and erosion was only 112 km². Both accretion and erosion occurred along the shoreline. Accretion was the dominating process and the net accretion rate during 1973-2015 was 4.3 km²/y.

Most significantly, accretion was the dominating process in Noakhali district. Accretion was 622 km², 3.65 times higher than the erosion that occurred during 1973-2015. Accretion had occurred due to the extension of the mainland into the sea and the formation of islands. Erosion was mainly due to the erosion of the northern and western boundaries of Hatiya Island. The rate of net accretion was 10.8 km²/y.

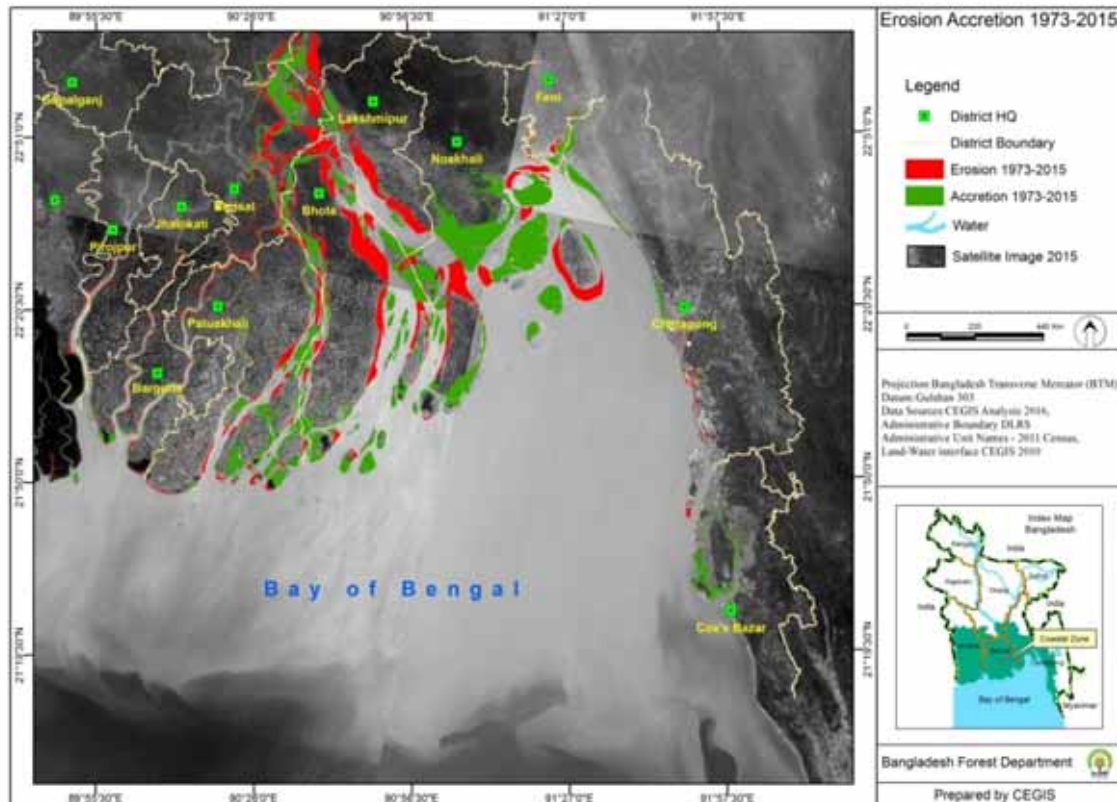


Figure 2.7: Erosion accretion in the Coastal Region during 1973-2015

Table 2.13 District wise erosion and accretion during 1973-2015

District	Accretion (km ²)	Erosion (km ²)	Net Accretion (km ²)	Accretion rate (km ² /yr)
Bagerhat	10	9	1	0.0
Barguna	40	27	13	0.3
Barisal	165	175	-10	-0.2
Bhola	412	366	46	1.1
Chandpur	46	76	-30	-0.7
Chittagong	293	112	181	4.3
Cox's Bazar	82	11	71	1.7
Feni	32	11	20	0.5
Jhalokati	4	9	-4	-0.1
Lakshmipur	54	134	-79	-1.9
Noakhali	622	170	452	10.8
Patuakhali	282	149	133	3.2
Pirojpur	8	9	-1	0.0
Shariatpur	28	19	9	0.2
	2076	1275	801	19.1

District wise erosion and accretion for the coastal regions are given in Annex 2. It is found that the net accretion rate for the entire region is 19.1 km²/year. During 1973 to 2015, the net rate of accretion of land is very high in the Noakhali district, followed by Chittagong and Patuakhali (Table A-1). From decadal analysis (Table A-2 to A-5), it is found that net accretion rate was 13.3 km²/year during 1973-1984. After that it increased to 26.4 km²/year during 1984-1996, which might have been initiated after of the Assam earthquake 1950. The net accretion rate lowered to 14.4 km²/year for period 2006-2015.

Trend analysis for erosion

The amount of erosion and accretions has been quantified for different time frame and different locations. Linear regression method has been used for the development of any trend between erosion or accretion with time. Different key locations have been used for the trend development. Prediction of future erosion and accretion has been done through extrapolation of trends.

A total of 25 key erosion prone locations have been identified in the coastal region as shown in Figure 2.8. Three factors affect the erosion of the entire region: fluvial flow, wave action and tidal circulation (Figure 2.9). Wave action mainly affects the sea facing shoreline especially the western part of the coast such as Bagherhat, Barguna, Patuakhali and downstream part of the Bhola district. Maximum of 10 to 40 m per year erosion was observed at those areas. River flow governs the erosion at the middle part of the Meghna estuary where very high rate of erosion was observed for the last few decades (100-300 m per year). Tidal circulation causes erosion on Chittagong coast and south-eastern part of Noakhali district. It caused shifting of the channel between Urir char and Noakhali towards the mainland with a rate of around 100 m per year. Again in the eastern coast (Cox's Bazar and lower part of Chittagong), wave action is the main driving force. Rate of erosion at those locations are as low as 1-5 m per year and difficult to identify through satellite image analysis.

Maximum rate of erosion for the selected locations have been estimated for different periods. Linear regression method has been used for the development of trends between the erosion rates with time (Figure 2.10). Some locations show very good correlation between the observed and estimated trends and some locations show relatively poor correlation. Developed relations between erosion rates with time have been extrapolated for the future prediction of erosion rate as well as eroding distance for 2015 to 2025 (Figure 2.8). Out of those 25 locations, 10 location show decreasing trend (Table 2.14). In addition to the amount of erosion, eroding period has also been considered during trend analysis. If

no erosion occurred in any location for last decade, it is considered that no erosion will be occurred for the next decades. Predicted erosion rates are higher for the two sides of the Lower Meghna River, where maximum of 4450 m will be eroded for the next ten years at the offtake of the Tentulia channel (E-9). Predicted rate is relatively lower for the western part of coastal region where wave action is the main driver for erosion as mentioned earlier. Erosion occurs through wave action maintains a gentle slope. Implementation of green belts in those areas might reduce the rate of erosion. Erosion is very low at the eastern coastal region. Erosion occurs along the eastern coast due to wave action and tidal circulation, which is balanced due to the long-shore sediment circulation; result of which is very low to negligible erosion.

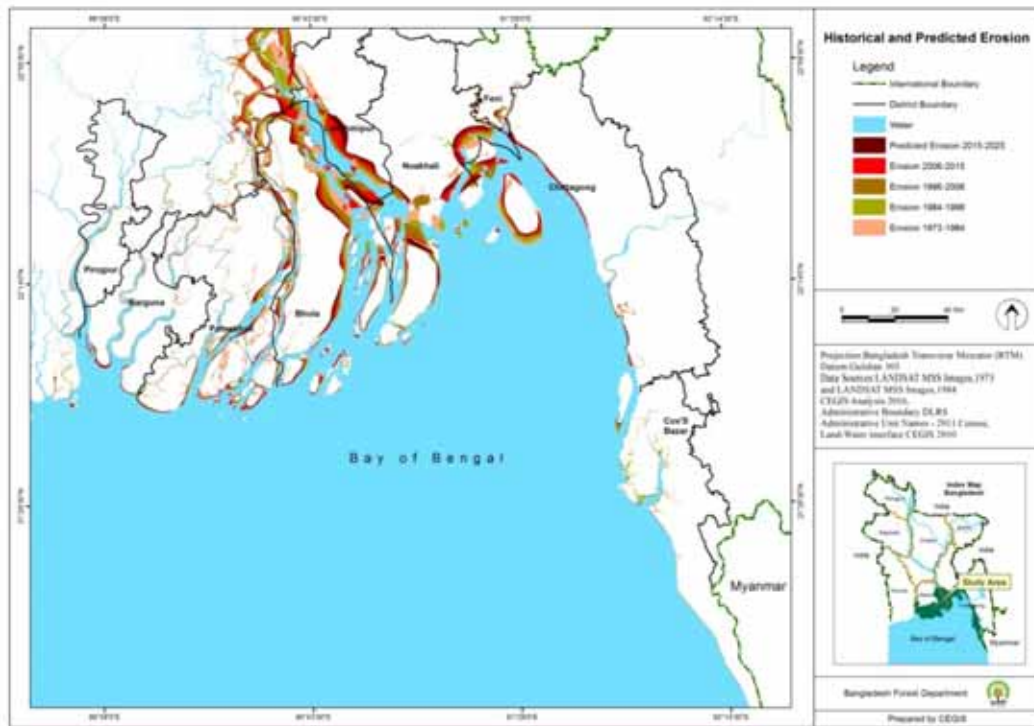


Figure 2.8: Historical and predicted erosion for the coastal region of Bangladesh

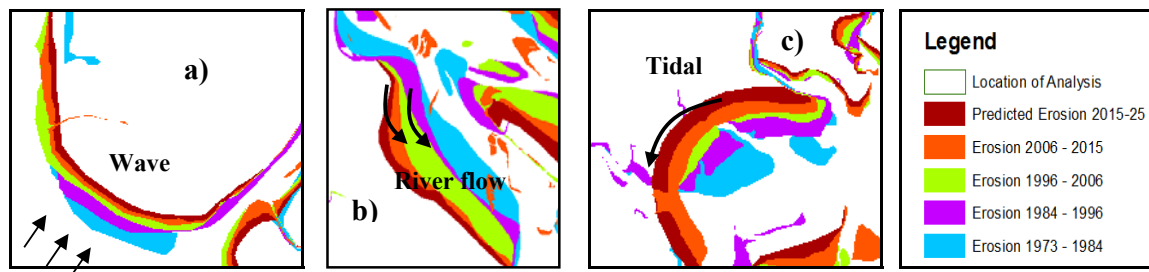


Figure 2.9: Erosion pattern due to a) wave action (E-2), b) river flow (E-11) and c) tidal circulation (E-19)

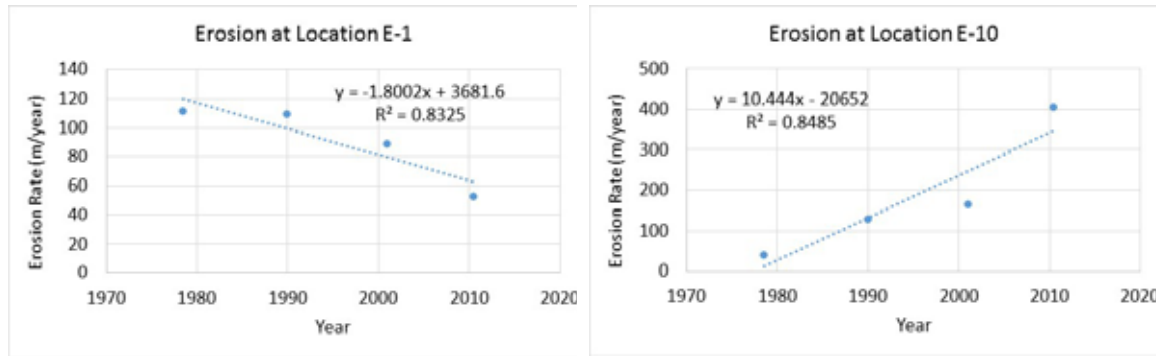


Figure 2.10: Trend line of location E-1 and E-10

Table 2.14: Historical erosion rate and predicted erosion for different location in the coastal area

Main Driver	Location	Erosion rate (m/yr)				Eroding period (yr)	Trend	Predicted Erosion rate (m/yr)
		1973-1984	1984-1996	1996-2006	2006-2015			2015-2025
Wave Action	E-1	110.9	109.2	89.0	52.2	> 42	Decreasing	45.2
	E-2	46.4	37.5	25.0	21.7	> 42	Decreasing	12.3
	E-3	0.0	10.0	25.0	22.8	31	Increasing	34.2
River Flow	E-4	15.5	25.0	23.0	22.2	> 42	Increasing	25.8
	E-5	89.1	95.8	55.5	60.0	> 42	Decreasing	45.1
	E-6	9.1	40.8	28.0	25.0	> 42	Increasing	34.6
	E-7	81.4	109.6	41.0	11.1	> 42	Decreasing	0
	E-8	75.5	103.3	61.0	63.3	> 42	Decreasing	57.7
	E-9	39.1	127.1	164.0	405.6	> 42	Increasing	444.9
	E-10	102.7	82.9	125.0	171.1	> 42	Increasing	176.7
	E-11	186.4	60.0	222.0	162.2	> 42	Increasing	178.1
	E-12	57.3	85.8	99.0	180.0	> 42	Increasing	193.1
	E-13	0.0	37.5	249.0	227.8	31	Increasing	339.3
	E-14	300.0	175.0	384.0	126.7	> 42	Decreasing	178.5
	E-15	27.3	102.9	104.0	182.2	> 42	Increasing	212.4
	E-16	80.0	108.3	94.0	44.4	> 42	Decreasing	55.2
	E-17	0.0	11.7	28.0	27.8	31	Increasing	40.4
	E-18	34.1	22.5	22.5	19.4	> 42	Decreasing	14.2
Tidal Circulation	E-19	243.2	125.0	103.0	150.0	> 42	Decreasing	81.4
River Flow	E-21	32.7	15.4	49.0	33.3	> 42	Increasing	41.0
	E-22	27.3	5.0	9.0	0.0	> 33	Decreasing	0
	E-23	72.7	27.5	84.0	307.8	> 42	Increasing	294.3
	E-24	47.3	39.6	76.5	92.8	> 42	Increasing	104.2
	E-25	25.0	64.6	42.0	41.1	> 42	Increasing	49.9
Wave Action	E-20	0.0	20.8	25.0	13.3	> 42	Increasing	25.8

Trend analysis for Accretion

Sediment supply, waves and tides exert important controls on the formation of the delta planform. The Meghna estuary is a tide dominated delta and sediment is constantly reworked and redeposited due to tidal process (Hori & Saito, 2007). The land development process is relatively rapid wherever both riverine and marine processes are simultaneously active and overlap with one another. Sediment availability might also be another contributing factor (Sarker et al., 2011). Accretion map for different time periods are generated from satellite images. Time series analyses of these maps provide a general idea about the accretion aided land development pattern of the area. It is observed that, accretion mainly occurred along the southern part of Noakhali and Bhola district, although any defining trend is very difficult to find. Both erosion and accretion are gradual processes. Whereas it is obvious that the physical effect of erosion process can be visible from the very beginning,

the same cannot be said for accretion. Accretion is the gradual deposition of sediment at bed level and therefore its effect or influence cannot be visually interpreted prior to vertical land formation above sea level and as such, any observe in changing trend is rather hard to identify. Substantial land accretion in Patuakhali occurred during 1984-1996 which might be an aftermath result of the Assam earthquake in 1950 (Sarker et al., 2011). Very active tidal circulation and sediment pumping processes ensure the gradual land formation in the south of the Noakhali and Urir Char area. Southern parts of Bhola and Hatiya Island are accreted due to the sediment supply from fluvial flow. If sediment supplies from upstream remains similar, the accretion process might continue in future.

On the other hand, accretion in the western coast is negligible due to very low supply of sediment. In the eastern coast, the sedimentation is balanced out by subsequent erosion. The historical trend of accretion in the coastal region is shown in Figure 2.11.

Despite the hydro-morphological complexity of the Meghna estuary, an effort was made to identify the erosion and accretion pattern of the coastal region of Bangladesh. Based on the historical trends, erosion prone area was predicted for the next decades (Figure 2.12). This type of study can provide better outputs when done with more time than that was available.

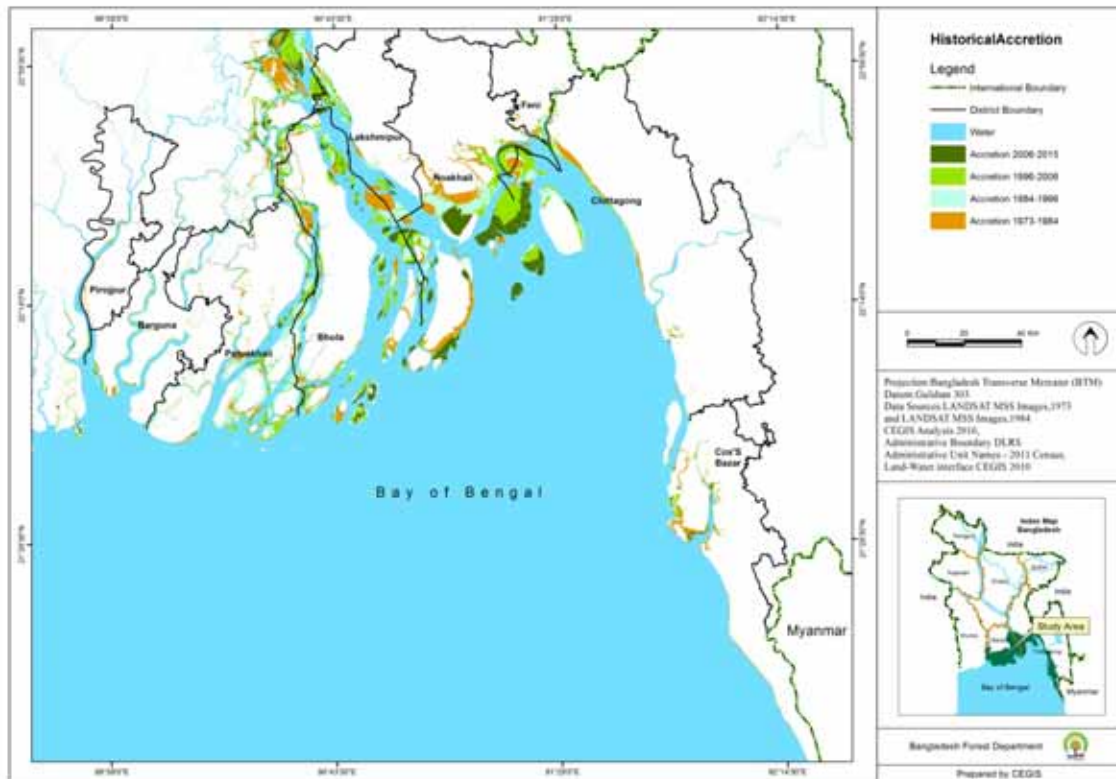


Figure 2.11: Historical accretion for the coastal region of Bangladesh

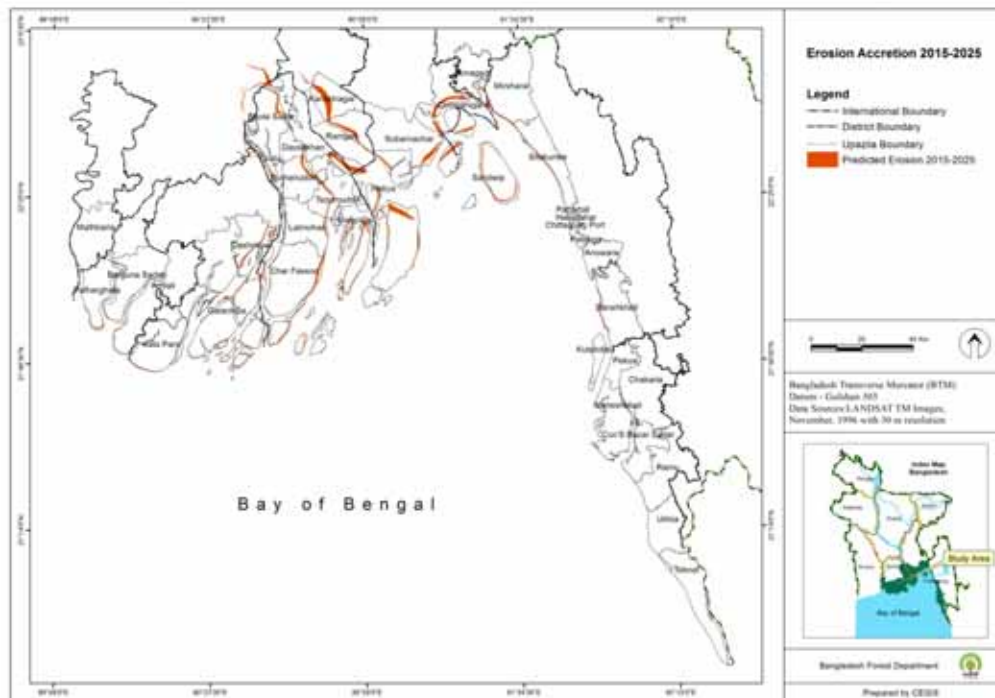


Figure 2.12: Predicted erosion map for period 2015-2025 in the Meghna estuary region

2.5. Impact of Climate Change

The geographical location, flat topography, high population density, etc. have made Bangladesh one of the most vulnerable countries of the world to be affected by the impact of climate change. About 10% of Bangladesh is 1m above the mean sea level and one-third is under tidal influence. The coastal region of the country is characterized by vast river networks, enormous discharge of sediment laden water, large number of islands in between the channels, rivers and shallow area all along the coast. This combination of factors makes Bangladesh very susceptible to future sea level rise expected to occur due to impact of climate change.

2.5.1. Climate Change

The tropical weather in Bangladesh features a hot and humid summer, humid monsoon and mild winter season. The weather pattern in the coastal region varies slightly due to topographic features. From historical data (1948 to 2013) analysis it was found that the temperature of the coastal region varies from 10 to 37 °C with a mean annual temperature of around 26 °C. The temperature during 1948-2010 shows increasing trend in different parts of the coastal region (CDMP II, 2013). There was an increasing rate of 0.01, 0.23, 0.15 and 0.27 °C/decade for Khulna, Bhola, Chittagong and Cox's Bazar region respectively with a 95% level of confidence. Increasing trend of annual rainfall has also been observed for the coastal region and the rate is higher for the western part of coastal region.

The rainfall and temperature pattern is likely to change in future due to global climate change. Statistical downscaling using delta method has been utilized for climate projection. Ensemble mean of five GCMs (CCSM4, GFDL-ESM2M, HadGEM2-ES, MIROC5, and MPI-ESM-MR) have been used. It can be estimated that, temperature might rise in the country around 1.6 °C for RCP 4.5 and around 2 °C for RCP8.5 by 2050. Further rise in temperature is expected in the latter half of the century. The rainfall pattern is going to be more variable and erratic in the future. There is an indication that, pre monsoon rainfall will decrease and monsoon rainfall will increase due to climate change.

2.5.2. Sea Level Rise

At present, the coastal region of Bangladesh is in the threat of submergence for the consequences of global warming. The Intergovernmental Panel on Climate Change (IPCC) in 2014 has predicted a rise in the sea of 0.2 to 1.0m by the year 2050. A recent study (CEGIS, 2015) found that the tidal water trend in the Ganges floodplain is 7-8 mm/year. On the other hand, the trend is 6-9 mm/year in the Meghna Estuarine floodplain and 11-20 mm/year in the Chittagong coastal plain areas. It is approximated that, Bangladesh could lose upto 15% of its land under the sea and about 30 million people living in the coastal area may become climate refugees because of this. Migration of people inland will raise population density there and causing socio-economic problems and other harmful impacts on their living. Sea level rise will bring more coastal area under inundation. Approximately, 2500, 8000 and 14000 sq. km. land will be lost due to sea level rise of 0.1 m, 0.3 m and 1.0 m respectively. Coastal waters will become more saline and soil salinity will also increase.

Scientific research indicates sea levels worldwide have been rising at a rate of 0.14 inches (3.5 millimeters) per year since the early 1990s. Most predictions say the warming of the planet will continue and likely will accelerate. Oceans will likely continue to rise as well, but predicting the amount is an inexact science. Table 2.15 shows the possible impact of sea level rise along Bangladesh coastline and hinterland.

Table 2.15: Sea Level Rise (SLR) in Bangladesh and its possible impact

Year	2050	2100
Sea Level Rise	25cm	1.0m (high end estimate)
Land Below SLR	4% of land (6,300 km ²)	17.5% of land (25000 km ²) Patuakhali, Khulna and Barisal regions will be most affected
Storm Surge	cyclones with a 10 % increase in intensity, wind speed increases from 225 to 248 km/h; storm surge goes from 7.1 to 8.6 m with 0.3 m SLR.	Storm surge goes from 7.4 to 9.1 m with 1 m SLR.
Flooding	Increased flooding in Meghna and Ganges floodplain. Monsoonal floods increase yield loss.	Both inundation area and flood intensity will increase tremendously.
Agriculture	0.3 m SLR inundate 0.5 Mmt. of production; 2% of current total.	Devastating flood may cause crop failure for any year.
Ecosystem	Inundates 40% of the Sundarbans.	The Sundarbans would be lost. Loss of the Sundarbans and other coastal wetlands would reduce breeding ground for many estuarine fish, which would reduce their population.
Salinity	Increase	Increase

Source: World Bank (2010)

2.5.3. Salinity Intrusion

A direct consequence of sea level rise would be increased intrusion of salinity with tide through the rivers and estuaries which would be more acute in the dry season. In dry season, when the flows of upstream water reduce drastically, the saline water goes up to 240 kilometers inside the country and reaches to Magura district (Rahman et al., 2014). The present interface between freshwater and saline water lies around 120 to 160 km inland in the southwest. This could well be pushed northward as far as central Jessore region in the event of a sea level rise. The isosaline lines of 1, 5 and 15 ppt have been drawn for base (2005) and 2050 conditions to show changes in salinity in the coastal area of Bangladesh (IWM & CEGIS, 2007) (Figure 2.13). It indicates that in base (2005) condition about 10% area is under 1 ppt salinity and 16% under 5 ppt salinity and this area will increase up to 17.5% (1 ppt) and 24% (5 ppt) by 2050 in extreme scenarios. So, there will be around 7% increases in area under 5 ppt salinity levels.

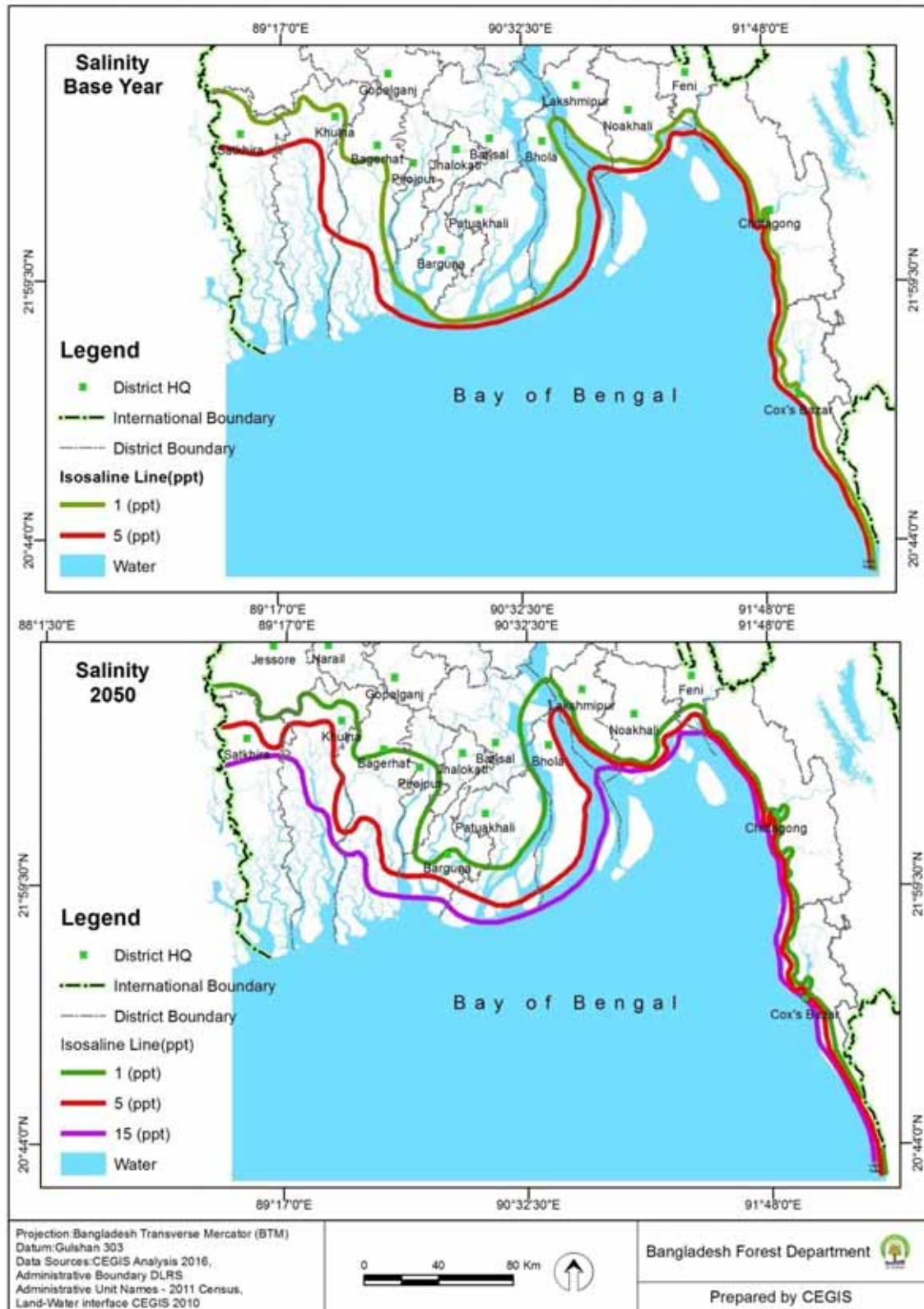


Figure 2.13: Surface water salinity in the coastal region of Bangladesh (regenerated from IWM & CEGIS, 2007)

A recent study shows that 5 ppt saline front will penetrate about 40 km inland for SLR of 88 cm which is going to affect the only fresh-water pocket of the Tetulia River in Meghna Estuary. Not only that, even the ground water aquifers will bear the brunt of salinity intrusion. Agriculture, forestry and fisheries sectors will be severely affected by increased water and soil salinity. Due to changing climate, salinity situation will further deteriorate by increased sea level, decreasing fresh water flow from the upstream, upward sub-surface pressure of the saline and fresh water interface, increased frequency and intensity of tidal surges etc.

2.5.4. Flooding and coastal inundation

Hydrological settings of Bangladesh are such that it receives and drain-out huge volume of upstream flow of the mighty Ganges, Brahmaputra, and Meghna (GBM). The combined effect of both upstream flows and monsoon rainfall generates run-offs that often results in flooding, causing water logging and prolonged inundation throughout the year. With warming trend of climate change the Himalayan glaciers are melting faster increasing the net flow into the GBM system. This will likely increase the frequency of flood events, causing greater devastation. The low elevation of Bangladesh's coastal plain will possibly result in large scale inundation by only 1 meter rise in sea level (Shamsuddoha & Chowdhury, 2007). The major reason behind these assumptions is the fact that there is no clearly defined defense mechanism for the protection of coastal region. The sediment rich and fresh water flow dominated areas of the central zone are naturally well protected. Nonetheless some areas are remaining under risk of flooding due to back water effect. Many places, where sustainable drainage network system hasn't been developed, will likely face increased waterlogging problems. Unplanned polderization and embankment construction and most importantly their lack of maintenance, on one hand, is causing flooding and water logging problems, and on the other hand contributing to sea level rise through hampering natural siltation processes. Likewise densely populated coastal areas, Sundarban, the world's largest stretch of mangrove forest, is also vulnerable to the consequences of global warming and sea level rise. As the tidal flow and wave action is high in the mangrove forest area so only 45 centimeters sea level rises would inundate about 75 percent of forest area and 67 centimeters rise in sea level would submerge the entire Sundarbans.

Figure 2.14 show coastal flooding situation for business as usual (BAU) scenarios. Analysis indicate that, flooding extent will increase up to 6% from base (2005) in central part of Coastal region by 2050. The west portion of coastal region will face 5% more coastal flooding. No significant changes have been found in eastern portion of coastal area (World Bank, 2010).

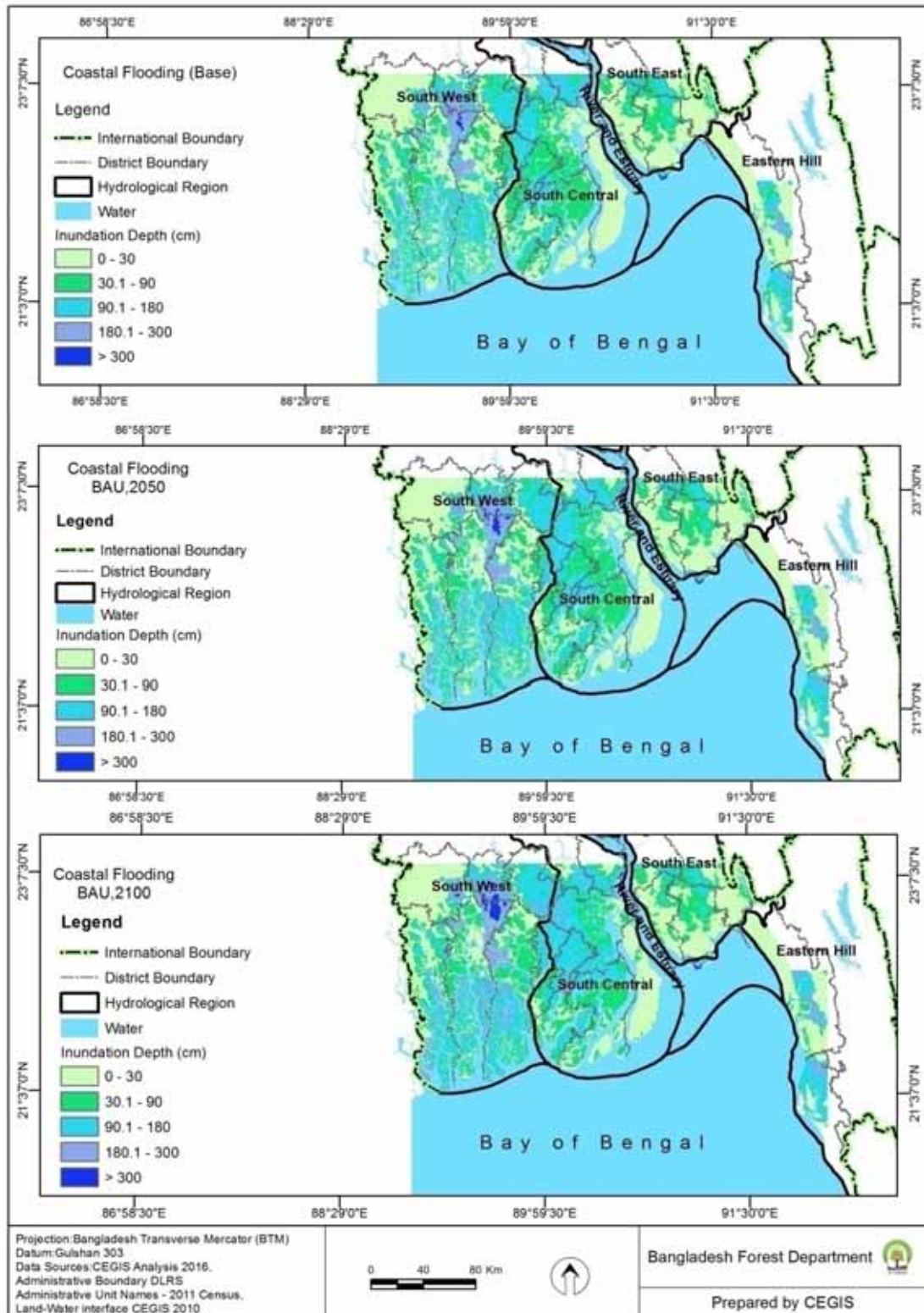


Figure 2.14: Coastal flooding under climate change scenario (adopted from World Bank, 2010)

2.5.5. Cyclones and storm surges

Low lying areas of coastal region is highly vulnerable to cyclones, which pose serious threat to lives and properties of the region. Nearly every year, cyclones hit the country's coastal region and a severe cyclone strikes the country every three years, on average. Intensity of cyclonic storm surges as well as depth and extent of storm surge induced coastal inundation are likely to increase in changing climate through rising sea surface temperature (SST) and sea level (IWTC 2006; Hansen and Sato 2011). The IPCC further indicates that future cyclonic storm surges and related coastal floods in Bangladesh will likely become more severe as future tropical cyclones increase in intensity.

Recurvature of tropical cyclones in the Bay of Bengal; the wide, shallow continental shelf, especially in the eastern part of the country; the high tidal range are the major reasons for this disproportionately large impact of cyclones. Low lying topography like nearly sea-level geography of the coastal land, high-density population and poor coastal protection system are aggravating the situation. Furthermore, triangular shape at the head of the Bay of Bengal, which helps to funnel sea water pushed by the wind towards the coast, causing further surge amplification; Meghna-estuarine region is facing the most surge amplifications.

Previous records indicate that the greatest damage during cyclones has resulted from the inundation caused by cyclone-induced storm surges. Though time-series records of storm-surge height are scarce, existing literature indicates a 1.5 m to 9 m height range during various severe cyclones (Dasgupta et al., 2010).

According to Dasgupta et al. (2013), in extreme scenario (Figure 2.15), the areas vulnerable to inundation depths more than 1 m and 3 m, respectively would be 14 and 69 percent higher than the baseline scenario. A 10-year-return period cyclone in extreme scenario will be more intense by 2050 and cover 43 percent of the vulnerable area, 17 percent more than the current coverage.

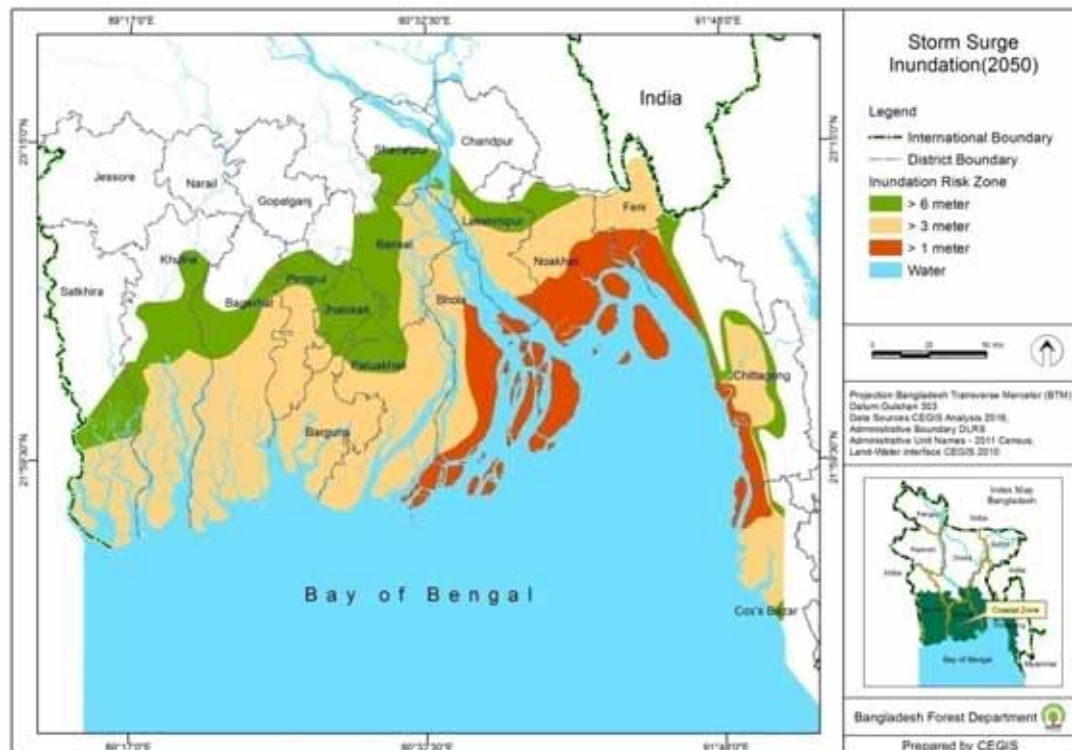


Figure 2.15: High-risk area for cyclone induced storm surge inundation by 2050 in extreme climate change scenario (Adopted from Dasgupta et al., 2013)

Impacts of aquatic temperature on coastal ecosystem

Coastal waters have warmed during the last century, and are very likely to continue to warm throughout the 21st century potentially by as much as 4 to 8°F (EPA, 2016). This warming may lead to big changes in coastal ecosystems, affecting species that inhabit these areas. Warming coastal waters cause suitable habitats of temperature-sensitive species to shift poleward. Some areas have recently seen range shifts in both warm- and cold-water fish and other marine species. Pollock, halibut, rock sole, and snow crab in Alaska and mangrove trees in Florida are a few of the species whose habitats have already begun to shift. Suitable habitats of other species may also shift, because they cannot compete for limited resources with the southern species that are moving northward.

Higher sea surface temperatures increase the risks of coral bleaching, which can lead to coral death and the loss of critical habitat for other species (The Royal Society, 2005). The rising concentration of carbon dioxide (CO₂) in the atmosphere has increased the absorption of CO₂ in the ocean, which subsequently makes the oceans more acidic (Pramanik, 2014). This trend is very likely to continue in the coming decades. A more acidic ocean adversely affects the health of many marine species, including plankton, mollusks, and other shellfish. In particular, corals can be very sensitive to rising acidity, as it is difficult for them to create and maintain the skeletal structures needed for their support and protection.

3. Assessment of Climate induced Coastal Vulnerability Index

3.1. Introduction

Coastal zone of Bangladesh is highly vulnerable to natural disasters like cyclone, storm surge, tidal flood, river erosion, salinity intrusion etc. The impact of climate change is further exacerbating the vulnerability situation of the zone. Especially the sea facing upazilas are exposed to these recurrent phenomena more severely. This study aims to delineate potential boundary of green belt zone in the sea facing 37 upazilas, which are the most vulnerable in terms of natural disasters, climate change and socio-economic aspects. Vulnerability induced by climate change in these coastal upazilas has been assessed to facilitate the delineation of potential green belt boundary.

3.2. Assessment Process

Desktop based climate induced coastal vulnerability mapping has been conducted through following steps (Figure 3.1):

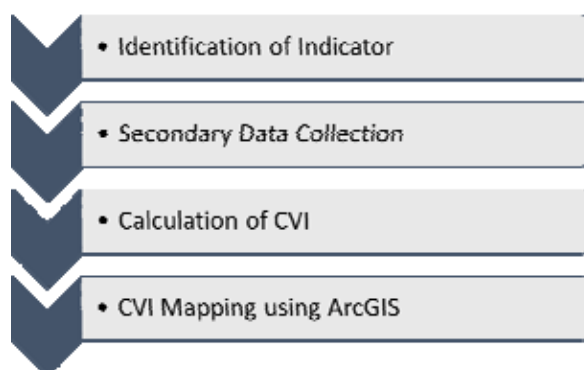


Figure 3.1: Process for assessment of Climate induced Coastal Vulnerability Index

3.2.1. Identification of indicators

Vulnerability of a system is the inability to cope with the effects of hostile environment. For this study purpose system responses for mostly climate change related hazards have been considered. According to the IPCC Fifth Assessment Report (2014), climate vulnerability is defined as “The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity”. As per definition vulnerability has three components: exposure, sensitivity and adaptive capacity. **Exposure** is a determination of whether the system will experience a specific changing climate condition or impact. **Sensitivity** is the degree to which the system would be impaired by the impact if it were exposed. **Adaptive capacity** is the ability of the system to change in order to maintain its primary functions even as it is exposed to an impact. When a system is exposed, with high sensitivity and low adaptive capacity, it is likely to be vulnerable (McCarthy et al., 2001).

Thus, different indicators like flood extent and depth, literacy rate, crop production etc. are important to determine the vulnerability of an area. Indicators with respect to biophysical, social and economic vulnerabilities have been selected through literature reviews, expert judgment and data availability. For this study identified indicators of exposure, sensitivity and adaptive capacity considering bio-physical and socio-economic factors are listed in Table 3.1. Most of the exposure indicators are directly caused by or induced by climate.

Table 3.1: Vulnerability indicators of exposure, sensitivity and adaptive capacity considering bio-physical and socio-economic factors

Components of Vulnerability	Indicators
Exposure	Land elevation
	Inundation depth due to monsoon flood or SLR
	Inundated area due to storm surge (for different surge height)
	Soil salinity affected area
	Shoreline erosion
	Surface water salinity affected area
Sensitivity	Population density
	Percentage of disable person
	Percentage of dependent people
	Percentage of small scale farmer
	Percentage of landless farmer
	Number of livestock
	Percentage of kutcha house (non brick)
	Poverty level
Adaptive Capacity	Literacy rate
	Embankment length
	Length of road (paved)
	Length of road (unpaved)
	No. of cyclone shelter
	Crop production

3.2.2. Secondary data collection:

Most of the data representing the indicators have been collected from various secondary sources the dates of which vary because of availability. The synchronization of different years of data is difficult, however based on the available knowledge and judgment data has been prepared for presentation of a base period ranging from 2005 to 2014. The future scenario of vulnerability due to the impact of climate change has been considered for the period of 2050. For future Coastal Vulnerability Index (CVI) of 2050, data are available only for three exposure indicators i.e. inundation depth due to sea level rise, inundated area for storm surge and surface water salinity which have been collected for the analysis.

Spatial analysis has been performed using GIS to extract upazila level data for exposure indicators. Data for sensitivity and adaptive capacity was collected mostly from population census and agricultural census. However, secondary data available in National Water Resources Database (NWRD) which are collected from different organizations (e.g. BBS, CDMP, DDM, LGED, RHD, IWM) also used to calculate CVI. Some data such as- population density, literacy rate, percentage of disable people, percentage of kutcha (non-brick) house, number of cyclone shelter, length of embankment and road etc. have been used directly in the formula. Data such as, % of dependent people, % of small and landless farmer, livestock population and crop production, which were not available for direct input, were calculated using different assumption. Data type, unit and sources of identified indicators are given in Annex 3.

3.2.3. Assessment of Climate Induced Coastal Vulnerability Index (CVI)

Quantitative assessment of vulnerability is usually performed by constructing a 'vulnerability index'. This index is based on several set of identified indicators that result in vulnerability of a region. It produces a single number, which can be used to compare different regions. Concept of vulnerability (Figure 3.2) implies that the first two components together represent the potential impact and adaptive capacity is the extent to which these impacts can be averted.

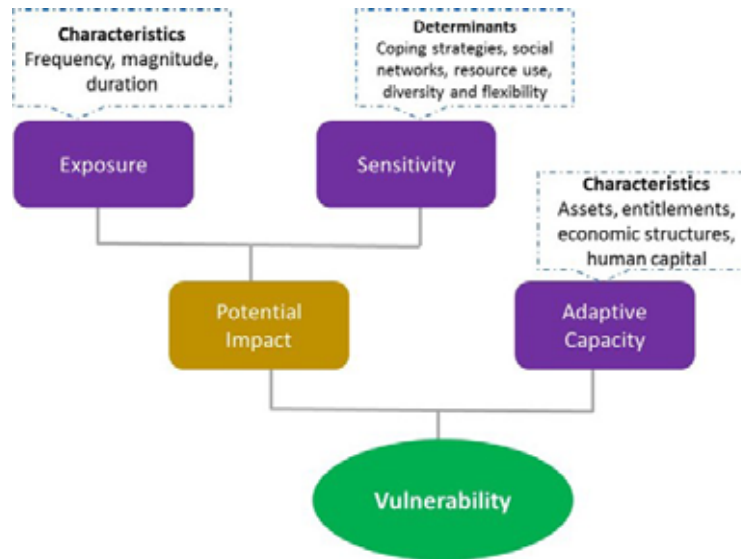


Figure 3.2: Concept of vulnerability (adopted from Gbetibouo and Ringler, 2009)

Thus vulnerability is potential impact (I) minus adaptive capacity (AC). This leads to the following mathematical equation for vulnerability:

$$V = f(I - AC)$$

In this study, CVI will be calculated adopting the concept of *DANIDA (2014)* and *Palmer et al., (2011)* using the following formula:

$$CVI = (\sum S + \sum E) - \sum A$$

$$\text{or, } CVI = (wS_1 + \dots + wS_n + wE_1 + \dots + wE_n) - (wA_1 + \dots + wA_n) \dots \dots \dots (1)$$

Here, w is the weight obtained from the principal component scores or expert judgments, $A_1, A_2, \dots, A_n$ are the adaptive indicators, $S_1, S_2, \dots, S_n$ are sensitivity indicators and $E_1, E_2, \dots, E_n$ are exposure indicators. Calculation of CVI value has been done in the following steps for both base and future period as shown in Figure 3.3:



Figure 3.3: Methodology of CVI calculation (prepared by author based on DANIDA, 2014; Palmer et al., 2011; Gbetibouo and Ringler, 2009; Thornton et al., 2006; and Cutter et al., 2003)

Firstly, indicators matrix has been prepared arranging value of each indicators for respective upazilas. **Secondly**, all individual values of respective upazila have been normalized within 0 to 1 value as units and scales of indicator values are different. Normalization of indicator value has been done using the standard methodology. Functional relationship with vulnerability has been considered in normalization procedure as shown in Table 3.2.

Table 3.2: Functional relationship of indicator value with vulnerability

Indicators	Functional Relationship
Land elevation	↓
Inundation depth by monsoon flood or SLR	↑
Erosion affected area	↑
Soil salinity affected area	↑
Area under surge (1m-3m) inundation	↑
Area under surge (3m-6m) inundation	↑
Area under surge (>6m) inundation	↑
Surface water salinity (1 PPT) affected area	↑
Surface water salinity (5PPT) affected area	↑
Population density	↑
Percentage of dependent people	↑
Percentage of disable people	↑
Percentage of small scale farmer	↑
Percentage of landless farmer	↑
Livestock population	↑
Percentage of kutcha house (non brick)	↑
Length of road (Unpaved)	↑
Poverty level	↑
Literacy Rate	↓
No. cyclone shelter	↓
Embankment length	↓
Length of road (Paved)	↓
Crop production	↓
Percentage of forest coverage (added after validation workshop)	↓
<i>Note: (↑) means vulnerability will increase with higher value of indicator, (↓) means vulnerability will decrease with higher value of indicator</i>	

Thirdly, weightage of each indicator has been estimated using both Principal Component Analysis (PCA) and expert judgments. It was expected that, Principal Component Analysis (PCA) would give better estimation of weight as data for calculating the vulnerability indices were multivariate in nature, however the expert judgment provided better weightage (Asaduzzaman, et al. (2015), . Possibly due to the complex nature of coastal zone of Bangladesh the statistical technique of PCA was not suitable for vulnerability assessment. Therefore, estimation of weight has been considered by expert judgments emphasizing the physical characteristics and local experiences. Same weight has been used for calculation of CVI value for both the base and future period (Table 3.3).

Table 3.3: Estimated weightage for CVI calculation by expert judgment

Elements of vulnerability	Indicators	Weight
Exposure	Land elevation	0.10
	Inundation depth by monsoon flood or SLR	0.12
	Erosion affected area	0.15
	Soil salinity affected area	0.05
	Area under surge (1m-3m) inundation	0.02
	Area under surge (3m-6m) inundation	0.17
	Area under surge (> 6m) inundation	0.25
	Surface water salinity (1 PPT) affected area	0.07
	Surface water salinity (5PPT) affected area	0.07
Sensitivity	Population density	0.22
	Percentage of dependent people	0.05
	Percentage of disable people	0.05

Elements of vulnerability	Indicators	Weight
	Percentage of small scale farmer	0.12
	Percentage of landless farmer	0.12
	Livestock population	0.07
	Percentage of kutcha house	0.17
	Poverty Level	0.20
Adaptive Capacity	Literacy rate	0.08
	No. of Cyclone shelter	0.22
	Embankment length	0.25
	Length of road (Unpaved)	0.17
	Length of road (Paved)	0.18
	Crop production	0.10

Fourthly, CVI has been calculated using the formula (equation 1) for each upazila under both base period and future with climate change situation. For calculating CVI for 2050, future value of three aforementioned exposure indicators has been used along with base period value for the remaining indicators.

Lastly, ranking of each upazila has been made using the calculated score of CVI. Table 3.4 and Table 3.5 show the calculated CVI value and rank for the base and 2050 conditions respectively.

Table 3.4: Coastal Vulnerability Index (CVI) value and rank for selected sea-facing upazilas (base condition)

Upazila Name	CVI	Rank
Sandwip	1.124	1
Hatiya	1.111	2
Ramgati	1.070	3
Tazumuddin	0.979	4
Subarnachar	0.976	5
Char Fasson	0.891	6
Lalmohan	0.813	7
Burhanuddin	0.808	8
Daulatkhan	0.799	9
Dashmina	0.757	10
Companiganj	0.749	11
Bhola Sadar	0.743	12
Ukhia	0.734	13
Pekua	0.710	14
Galachipa	0.670	15
Sonagazi	0.609	16
Kala Para	0.596	17
Cox'S Bazar Sadar	0.578	18
Kutubdia	0.544	19
Ramu	0.520	20
Patharghata	0.517	21
Mathbaria	0.517	22
Manpura	0.517	23
Maheshkhali	0.500	24
Teknaf	0.474	25
Kamalnagar	0.470	26
Amtali	0.392	27
Pahartali	0.388	28
Anowara	0.219	29
Chakaria	0.188	30

Upazila Name	CVI	Rank
Mirsharai	0.051	31
Halishahar	0.045	32
Barguna Sadar	0.041	33
Banshkhali	-0.125	34
Chittagong Port	-0.215	35
Patenga	-0.284	36
Sitakunda	-0.436	37

Table 3.5: Coastal Vulnerability Index (CVI) value and rank for selected sea-facing upazilas (future condition, 2050)

Upazila Name	CVI	Rank
Sandwip	1.222	1
Hatiya	1.111	2
Char Fasson	1.101	3
Tazumuddin	1.034	4
Ramgati	1.012	5
Lalmohan	0.945	6
Subarnachar	0.936	7
Burhanuddin	0.923	8
Daulatkhan	0.860	9
Bhola Sadar	0.836	10
Pekua	0.833	11
Galachipa	0.817	12
Companiganj	0.805	13
Dashmina	0.804	14
Kala Para	0.786	15
Ukhia	0.765	16
Cox'S Bazar Sadar	0.680	17
Sonagazi	0.675	18
Patharghata	0.664	19
Amtali	0.628	20
Mathbaria	0.618	21
Maheshkhali	0.618	22
Manpura	0.578	23
Ramu	0.570	24
Kutubdia	0.564	25
Kamalnagar	0.507	26
Teknaf	0.474	27
Pahartali	0.451	28
Anowara	0.308	29
Chakaria	0.215	30
Barguna Sadar	0.207	31
Mirsharai	0.107	32
Halishahar	0.107	33
Banshkhali	-0.016	34
Chittagong Port	-0.162	35
Patenga	-0.228	36
Sitakunda	-0.355	37

3.3. Assessment of Vulnerability

Climate induced coastal vulnerability map has been prepared for both base period (2007-2014) and future period (2050) based on CVI value. Six different classes of vulnerability i.e. very low, low, medium, medium high, high, and very high have been used to represent different degrees of vulnerability in the maps. This classification has been made by using

expert judgments on calculated CVI value (Table 3.6). Figure 3.4 and 3.5 show the number of upazilas under these vulnerability classes for base and future condition.

Table 3.6: Coastal Vulnerability Index (CVI) value and range for selected sea-facing upazilas (base and future condition, 2050)

Degree of vulnerability	Range of CVI value
Very High	≥ 0.900
High	0.801 – 0.900
Medium High	0.501 – 0.800
Medium	0.201 – 0.500
Low	0.000 – 0.200
Very Low	≤ 0.000

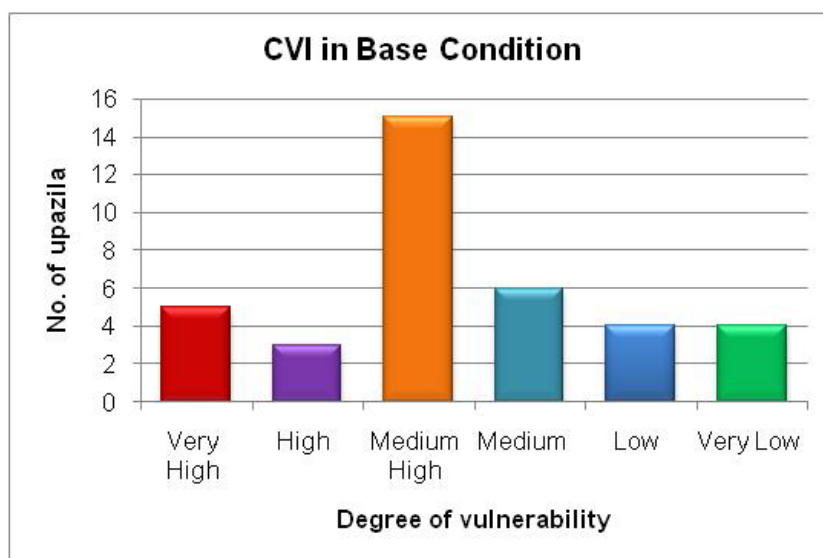


Figure 3.4: Number of upazilas under different vulnerability classes in base condition

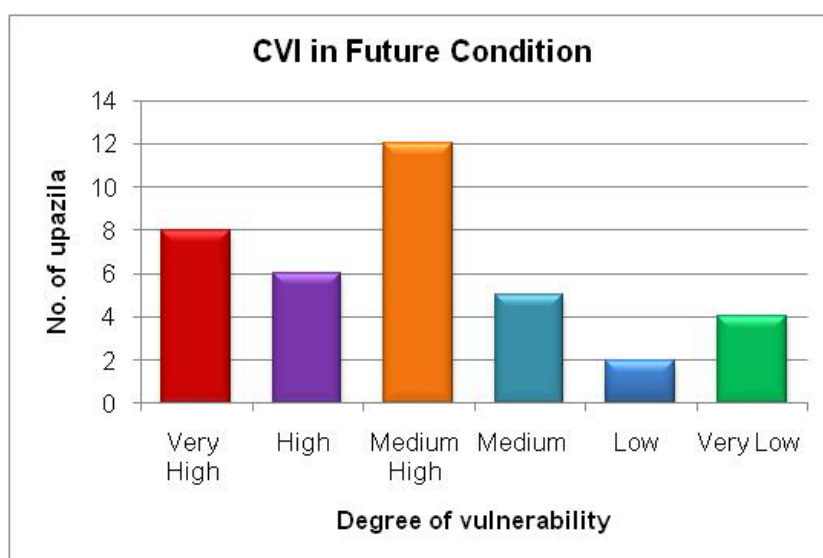


Figure 3.5: Number of upazilas under different vulnerability classes in future condition

Figure 3.6 and Figure 3.7 show the delineated Coastal Vulnerability Index Map for base (2007-2014) and future (2050) respectively. For the future CVI only sea level rise value was available from which value of storm surge, water salinity and SLR inundation were extrapolated and used. The base level value was used for the other indicators. This has produced a future CVI map that shows changes of CVI values in some upazilas only. Using the same value of the base period for all sensitivity, adaptive capacity indicators and most of the exposure indicators as base period may be the reason behind this. Uncertainties among future data of three exposure indicators i.e. storm surge inundation, surface water salinity and inundation due to SLR may also influence this output.

Attempt was then taken to prepare CVI map at union level with a view to get better spatial distribution of vulnerabilities at higher resolution. This exercise was expected to produce a CVI map of higher precision that would lead to better defined greenbelt boundary. Unfortunately union level data was not available for most of the selected vulnerability indicators and linear extrapolation method was used to generate these data from upazila data. This resulted in a union level CVI map that did not match with the upazila level map and the pattern also appeared to be haphazard (Annex 3.1). The deviation between adjacent unions was pronounced and the discrepancy from known field condition was also noteworthy. Based on the obtained result this approach to produce and use union level CVI map was abandoned in favor of the upazila level CVI map.

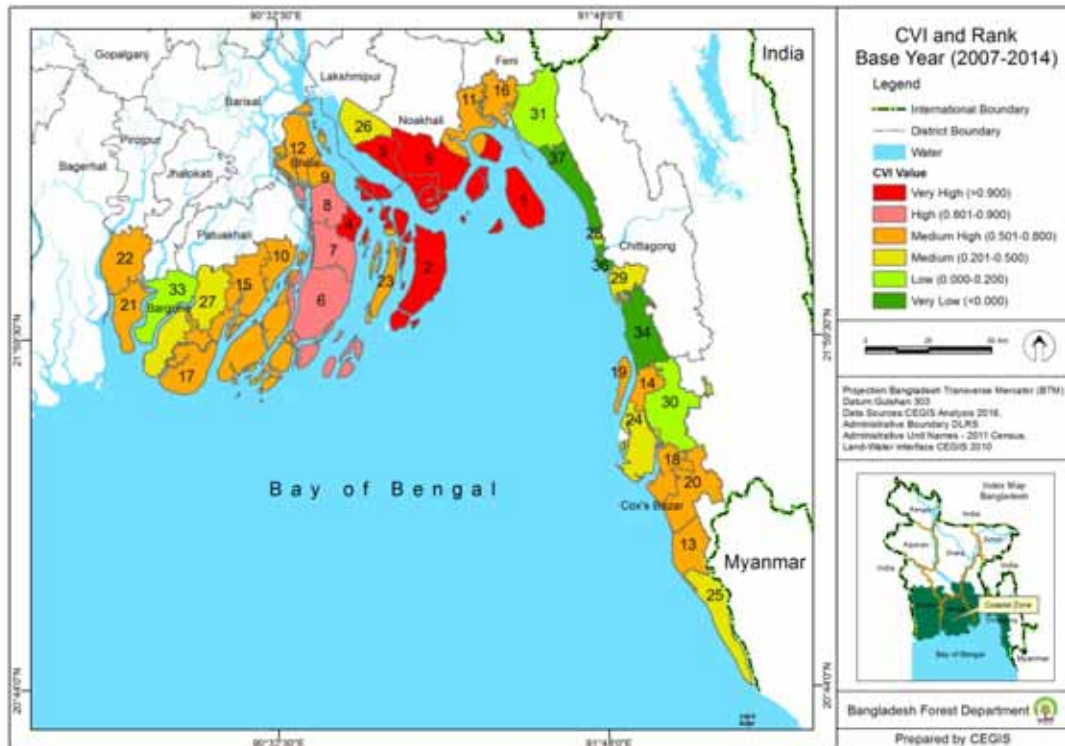


Figure 3.6: Coastal Vulnerability Index Map for base condition (2007-2014)

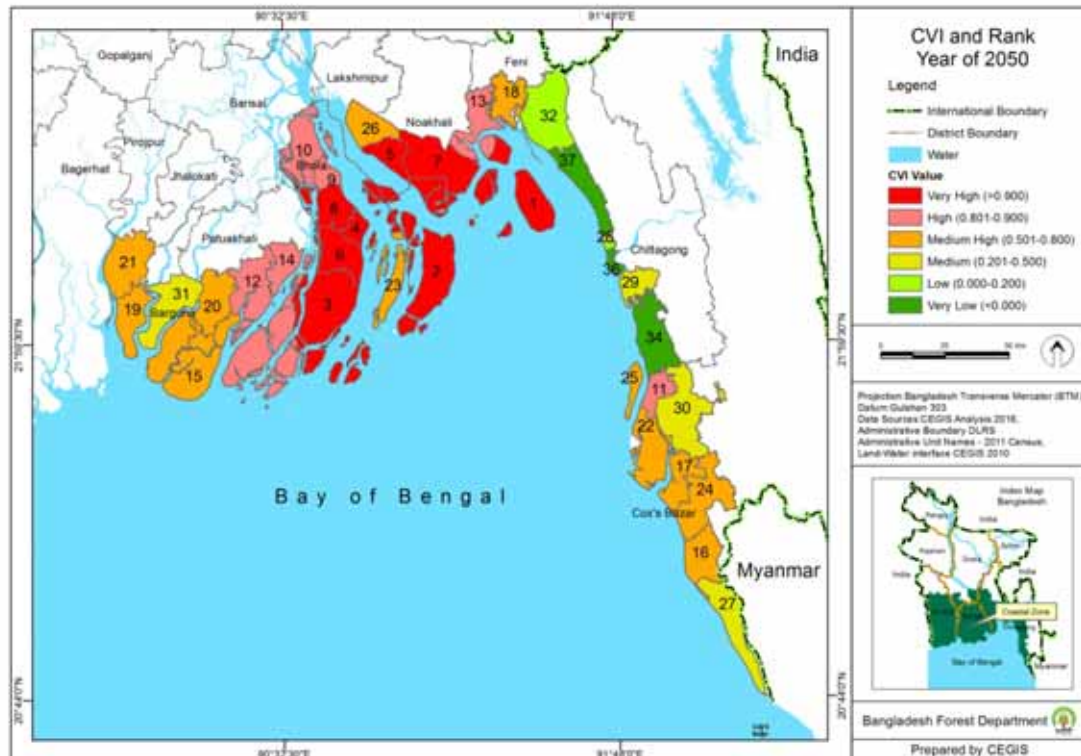


Figure 3.7: Coastal Vulnerability Index Map for future condition (2050)

3.4. Validation of Assessment

A workshop was organized to evaluate the Climate induced Coastal Vulnerability map produced. Executives from Bangladesh Forests Department (BFD) and Bangladesh Meteorological Department (BMD) as well as professionals from different projects under BFD were present and spontaneously gave their feedback on the prepared CVI map based on their expertise and experiences. They proposed 12 new vulnerability indicators shown in Table 3.7 to improve upon the developed CVI map. They also prioritized all vulnerability indicators (including proposed indicators) and suggested weightage to each indicator. Data requirement issue was discussed and noted that the suggested indicators could only be used conditional upon data availability.

Based on these recommendations, attempt was made to collect data from secondary sources for the additional 12 indicators. However, data were not found for some indicators and for few others the data was not available in a format usable in CVI assessment. Details of data availability, sources, status of use and explanation behind not using in some cases are summarized in Table 3.7.

Table 3.7: Proposed additional indicators for validation and their status of use

Vulnerability Component	Proposed Indicators	Status of data availability and use in CVI mapping	Explanation to not use in CVI calculation
Exposure	Erosion affected area (CEGIS)	Used	
	Monsoon depression (BMD)	Found but not in interpretable format to use	For CVI analysis Upazila wise data of Monsoon depressions and wind speeds are required. But available data from BMD was summed data instead of spatially distributed data. Therefore, these data were not included in CVI calculation
	Wind velocity (BMD)	Found but not in interpretable format to use	
Sensitivity	No. of deaths and damages (NWRD, 2011)	Not found in desired format to use	Spatially distributed for upazila level was not available, rather data was available as total number of deaths and damages for all affected upazilas. So this data was not included in CVI calculation.
Adaptive Capacity	No. of Medical Health Center (NWRD, 2011)	Used	
	Embankment Length per perimeter (NWRD, 2011)	Used	
	Sources of safe drinking water per capita (Hassan, 2016)	Used	
	No. of safe heaven (NWRD, 2011)	Used	
	River length per capita (CEGIS analysis)	Used	
	Length of road (Unpaved) per capita (NWRD, 2011)	Used	
	Length of road (Paved) per capita (NWRD, 2011)	Used	
	Percentage of forest coverage (NFIP, unpublished)	Used	
	Percentage of pukka (brick) house (NWRD, 2011)	Used	
	Income per capita	Data not found	This data was not found at upazila level. So it was excluded from vulnerability indicators list

Using these data of different additional indicators along with previous indicators and giving weightage according to the recommendation of the workshop, CVI was calculated and CVI map was prepared using ArcGIS. This map though providing a reasonable illustration of vulnerability also showed pattern that in some cases did not match with known field conditions, especially for upazilas along the Chittagong coast. Pekua was classed as very high, Sandwip as medium high, Sitakunda and Mirsarai both as very low; all straying away from the known situation. One possible explanation could be that the weightage given were equal for many of the indicators. The weightage used and the resulting CVI map are shown in Table 3.8 and Figure 3.8.

Based on results of these two approaches of assessment, further effort was made to finalize the CVI map combining indicators suggested in the workshop with the ones selected earlier.

Table 3.8: Weight and priority for CVI assessment as recommended by experts at validation workshop

Elements of vulnerability	Indicators	Weight
Exposure	Land elevation	0.12
	Inundation depth by monsoon flood or SLR	0.12
	Erosion affected area	0.17
	Soil salinity affected area	0.05
	Area under surge (1m-3m) inundation	0.05
	Area under surge (3m-6m) inundation	0.17
	Area under surge (> 6m) inundation	0.22
	Surface water salinity (1 PPT) affected area	0.05
	Surface water salinity (5PPT) affected area	0.05
Sensitivity	Population density	0.20
	Percentage of dependent people	0.06
	Percentage of disable people	0.06
	Percentage of small scale farmer	0.15
	Percentage of landless farmer	0.15
	Livestock population	0.06
	Percentage of kutcha house	0.12
	Poverty Level	0.20
Adaptive Capacity	Literacy rate	0.07
	Embankment length	0.14
	Length of road (Unpaved)	0.08
	Length of road (Paved)	0.08
	Crop production	0.08
	No. of Medical Health Center	0.07
	Sources of drinking water per capita	0.07
	No. of safe haven per capita	0.12
	River length per capita	0.07
	Pucka house percentage	0.12
	Percentage of forest coverage	0.12

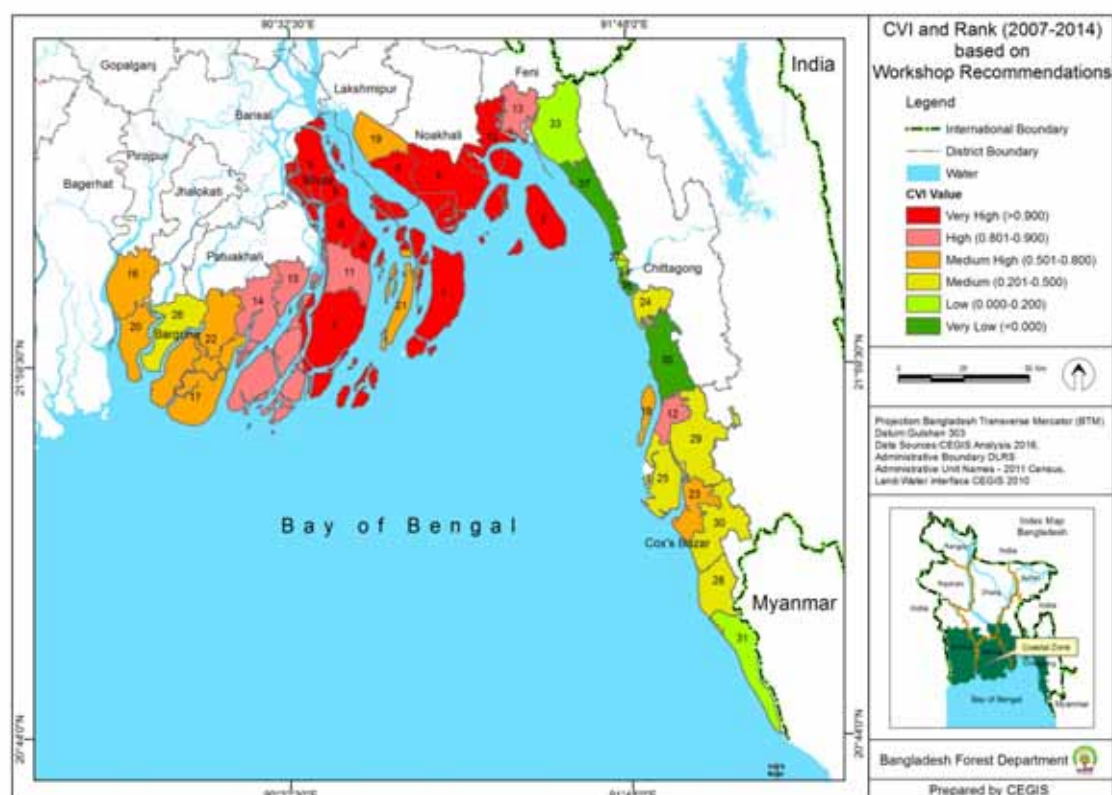


Figure 3.8: CVI map prepared based on expert recommendation at workshop

3.5. Finalization of Vulnerability Index

From the list of the indicator proposed in the workshop only forest cover indicator were included during the finalization of the CVI assessment. The remaining indicators for which data was available but not used in the assessment process was because (i) percentage of pukka house has already been considered indirectly when percentage of kutcha house has been used; (ii) the river as a mode of transport to safety was not used because the cyclone warning system strongly advises everyone not to use waterways during an incoming cyclone; (iii) sources of safe drinking water have negligible influence in the context of vulnerabilities assessment particularly when cyclone is the hazard in question. Percentage of forest coverage has significant implications as an adaptive capacity indicator as it can reduce the impact of strong winds and storm surges during a cyclone and therefore has an appreciable impact and was used in the final vulnerability assessment. Table 3.9 shows indicators used and their weightage in producing the final CVI map.

Table 3.9: Indicators and weightage used for finalization of CVI map

Elements of vulnerability	Indicators	Weight
Exposure	Land elevation	0.10
	Inundation depth by monsoon flood or SLR	0.12
	Erosion affected area	0.15
	Soil salinity affected area	0.05
	Area under surge (1m-3m) inundation	0.02
	Area under surge (3m-6m) inundation	0.17
	Area under surge (> 6m) inundation	0.25
	Surface water salinity (1 PPT) affected area	0.07
	Surface water salinity (5PPT) affected area	0.07
Sensitivity	Population density	0.22

Elements of vulnerability	Indicators	Weight
	Percentage of dependent people	0.05
	Percentage of disable people	0.05
	Percentage of small scale farmer	0.12
	Percentage of landless farmer	0.12
	Livestock population	0.07
	Percentage of kutcha house	0.17
	Poverty Level	0.20
Adaptive Capacity	Literacy rate	0.05
	No. of Cyclone shelter	0.21
	Embankment length	0.22
	Length of road (Unpaved)	0.10
	Length of road (Paved)	0.12
	Crop production	0.10
	Percentage of forest coverage	0.20

Figure 3.9 and Figure 3.10 show the final Climate induced Coastal Vulnerability Index map for base and future (2050) year. Maps show that, south central part of the coastal belt can be generally categorized as very highly vulnerable zone which has suffered much through most historic cyclone events. The north-eastern portion (particularly Mirsharai, Sitakunda, Anowara, Bashkhali) of coastal belt, generally shows lower vulnerability values even though this part was severely affected during the 1991 cyclone. It is assumed that the adaptive capacity of this region has been improved significantly since then via strengthening and rehabilitation of embankment, addition of forest coverage, building of cyclone shelters or other safe haven facilities which has lowered its vulnerability. In addition this part also has significantly higher elevation than the rest of the coastal region of Bangladesh due to the presence of hill ranges few miles from the coastline which would also lower the vulnerability.

Future map shows, substantial portion of coastal belt will be more vulnerable in future due to climate change induced hazards. Table 3.10 and Table 3.11 show CVI value and ranking for final CVI map. Figure 3.11 and 3.12 shows the number of upazilas under these vulnerability classes for finalized base and future condition.

Table 3.10 : Final Coastal Vulnerability Index (CVI) value and rank for selected sea-facing upazilas (base condition)

Upazila	CVI	Rank
Hatiya	1.289	1
Ramgati	1.180	2
Sandwip	1.104	3
Subarnachar	1.083	4
Bhola Sadar	1.061	5
Tazumuddin	1.038	6
Char Fasson	0.970	7
Burhanuddin	0.955	8
Daulatkhan	0.940	9
Companiganj	0.909	10
Lalmohan	0.895	11
Pekua	0.850	12
Sonagazi	0.835	13
Galachipa	0.813	14
Dashmina	0.813	15
Mathbaria	0.760	16
Kala Para	0.754	17
Kutubdia	0.710	18
Kamalnagar	0.658	19
Patharghata	0.633	20
Manpura	0.570	21
Amtali	0.565	22

Upazila	CVI	Rank
Cox'S Bazar Sadar	0.529	23
Anowara	0.428	24
Maheshkhali	0.425	25
Barguna Sadar	0.420	26
Pahartali	0.410	27
Ukhia	0.410	28
Chakaria	0.327	29
Ramu	0.224	30
Teknaf	0.184	31
Halishahar	0.177	32
Mirsharai	0.073	33
Chittagong Port	0.055	34
Banshkhali	-0.032	35
Patenga	-0.066	36
Sitakunda	-0.436	37

Table 3.11: Final Coastal Vulnerability Index (CVI) value and rank for selected sea-facing upazilas (future, 2050)

Upazila	CVI	Rank
Amtali	0.800	18
Anowara	0.517	26
Banshkhali	0.076	35
Barguna Sadar	0.585	24
Bhola Sadar	1.155	4
Burhanuddin	1.070	7
Chakaria	0.354	29
Char Fasson	1.179	3
Chittagong Port	0.108	34
Companiganj	0.964	12
Cox'S Bazar Sadar	0.631	23
Dashmina	0.859	17
Daulatkhan	1.001	10
Galachipa	0.960	13
Halishahar	0.239	31
Hatiya	1.289	1
Kala Para	0.944	14
Kamalnagar	0.696	21
Kutubdia	0.730	20
Lalmohan	1.027	9
Maheshkhali	0.543	25
Manpura	0.632	22
Mathbaria	0.860	16
Mirsharai	0.129	33
Pahartali	0.472	27
Patenga	-0.009	36
Patharghata	0.779	19
Pekua	0.973	11
Ramgati	1.122	5
Ramu	0.273	30
Sandwip	1.202	2
Sitakunda	-0.355	37
Sonagazi	0.901	15
Subarnachar	1.043	8
Tazumuddin	1.094	6
Teknaf	0.184	32
Ukhia	0.441	28

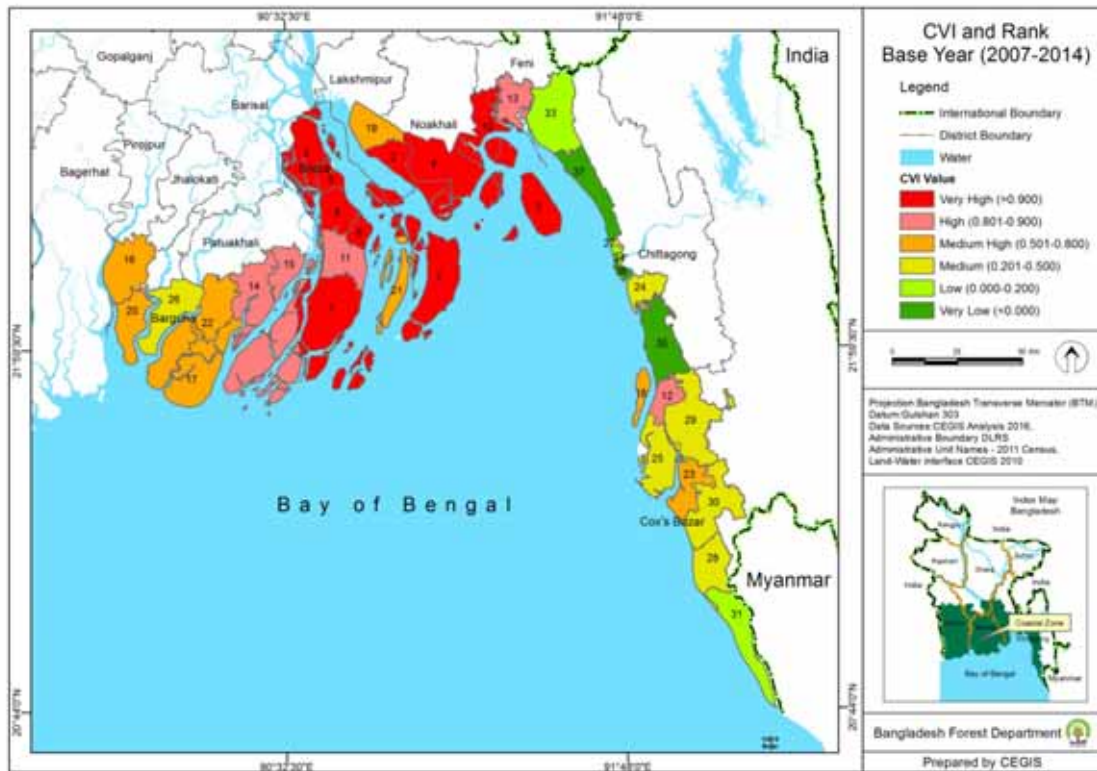


Figure 3.9: Final Coastal Vulnerability Index Map for base year (2007-2014)

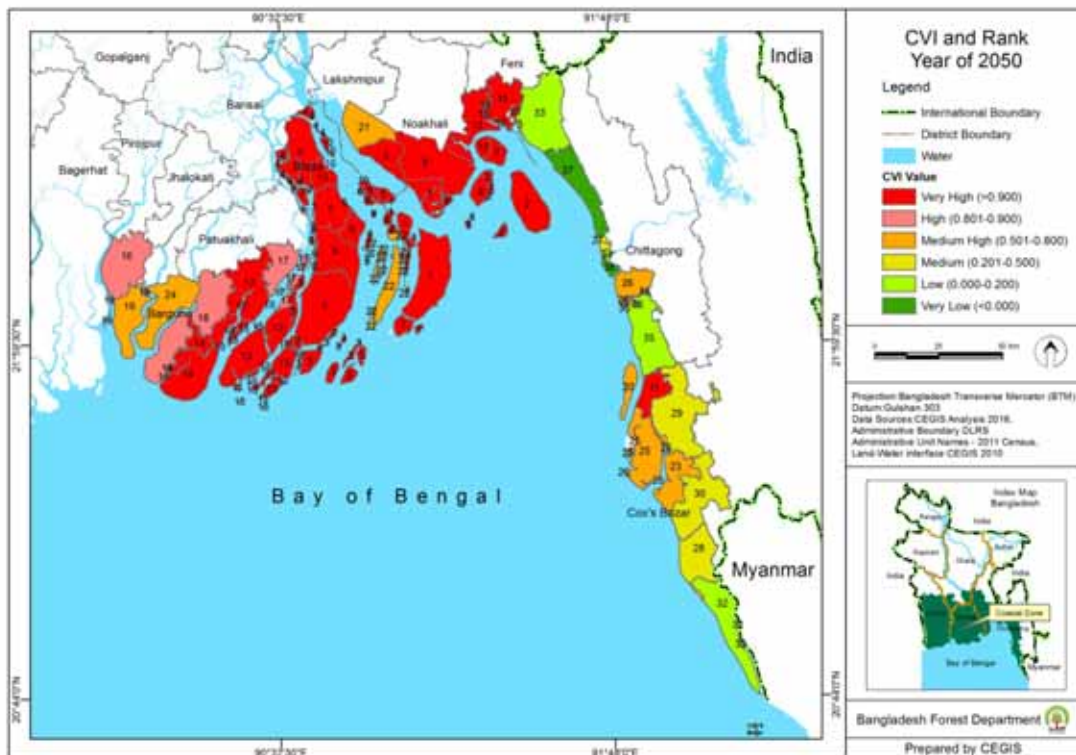


Figure: 3.10: Final Coastal Vulnerability Index Map for future (2050)

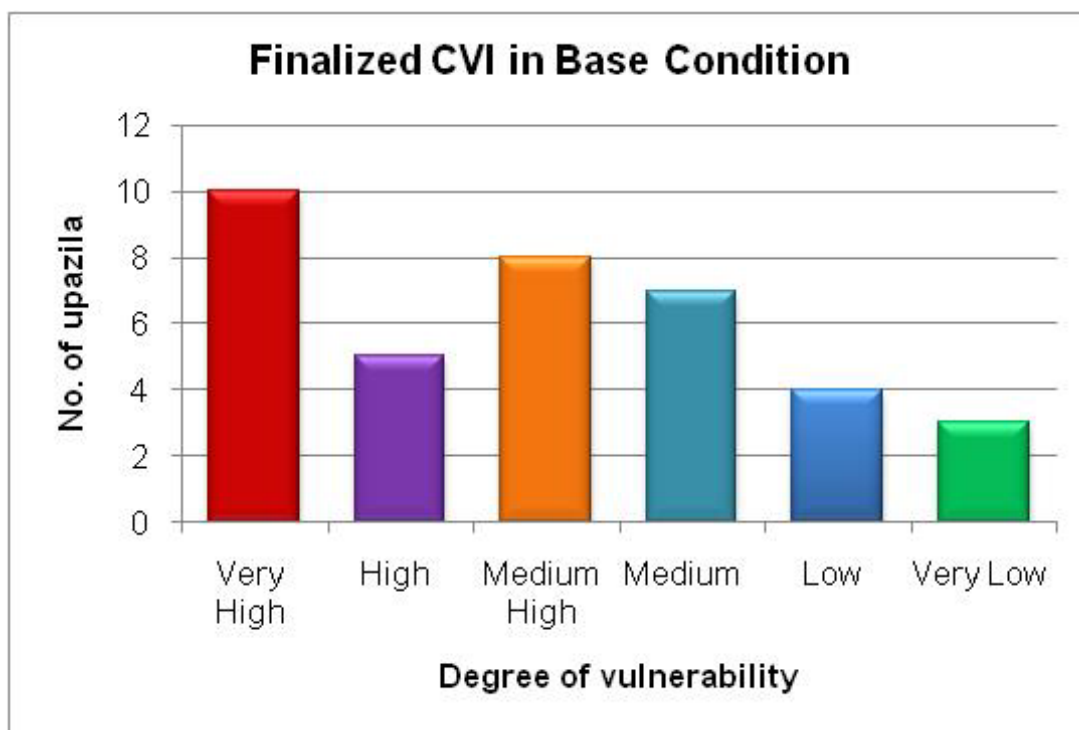


Figure 3.11: Number of upazilas under different vulnerability classes for finalized base condition

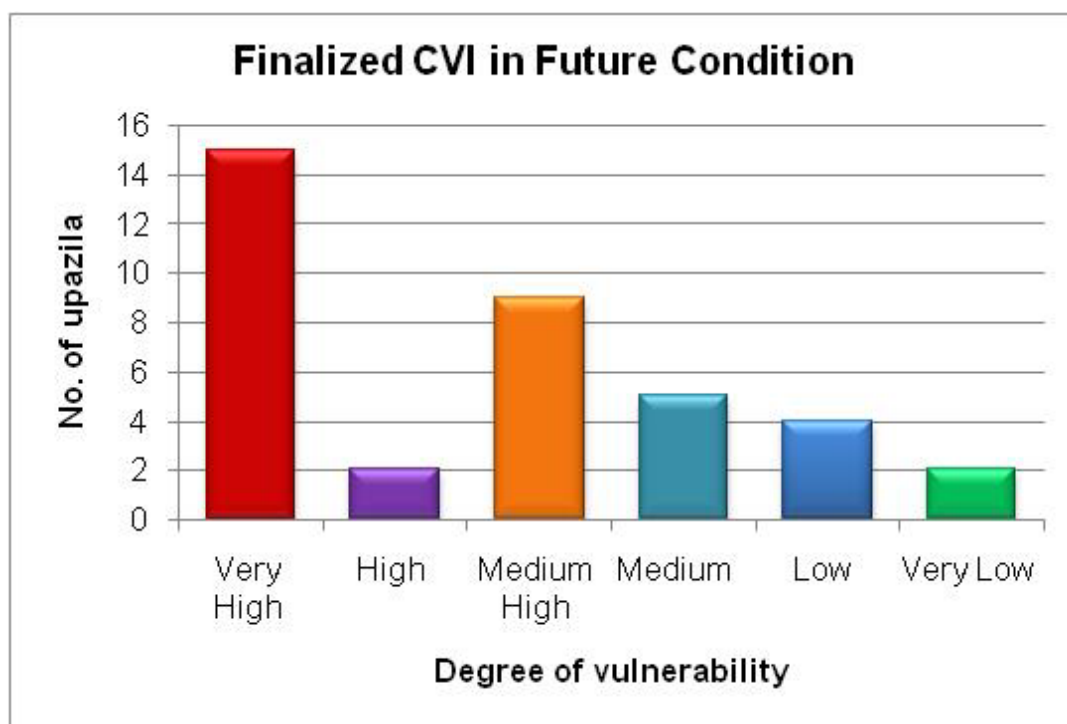


Figure 3.12: Number of upazilas under different vulnerability classes for finalized future condition

4. Delineation of Greenbelt

4.1. Functions of Green belt

Greenbelts also known as shelterbelts and bioshields have been recognized as an effective 'soft' measure of protection from hazards like storm surge, erosion and Tsunamis. Their efficacy depends on various factors such as the geometry of the belt, nature of the coastline and the characteristics of the hazard. Afforestation along the coastal belt is also the cheaper and ecologically more beneficial than any other measure to protect the coastal areas and offshore islands from cyclone and storm surges (Siddiqi, 2008). Mangrove forests are the most productive ecosystem on the earth and they perform a variety of useful ecological, bio-physical and socio-economic functions, which bring multiple benefits to coastal populations (Siddiqi 2001). Mangrove and other coastal forests can reduce wind and storm wave impact as well as current velocities (Fritz and Blount, 2007). The dense forests along the coastline can protect human habitation, lives, properties, and agricultural crops from extreme weather events resulting from climate change (Islam et al. 2015). Silori (2010) stated that coastal protection is important function of mangrove forests, serving as a natural barrier against storms, typhoons, and tsunami, and thus protecting coastal inhabitants.

Recent experiences of tsunami and major storms in Southeast Asia and other parts of the world have shown that mangroves can and have played important roles in absorbing and weakening wave energy as well as preventing damage caused by debris movement (Latief and Hadi, 2007). In fact after the December 2004 Indonesian Tsunami, it has been found that wherever there were wide, thick belts of mangroves and/or seashore forest, it had reduced the impact of tsunami on coastal settlements and property (Fritz and Blount, 2007). Other benefits of coastal vegetation includes the conservation of biodiversity, providing livelihood support for coastal communities through agricultural and forestry crops, affording shade for various human activities, and in contributing to recreation and scenic beauty (IUCN, 2007).

Yasuda et al. (2006) reported the reduction of tsunami wave height by 10m at a village in northeast coast of Sri Lanka protected by trees during the December 2004 tsunami (Figure 4.1 left). Badola and Hussein (2005) investigated the economic loss per household to 3 villages in Orissa, India during the super cyclone in 1999. Of the 3 villages, Bankual protected by mangroves incurred the lowest loss (US\$ 33.31) followed by Singdi with no mangrove and no embankment (US\$ 44.02) and highest in Bandhamal (US\$ 153.74) without mangrove but protected by an embankment that breached during the storm (Figure 4.1 right).

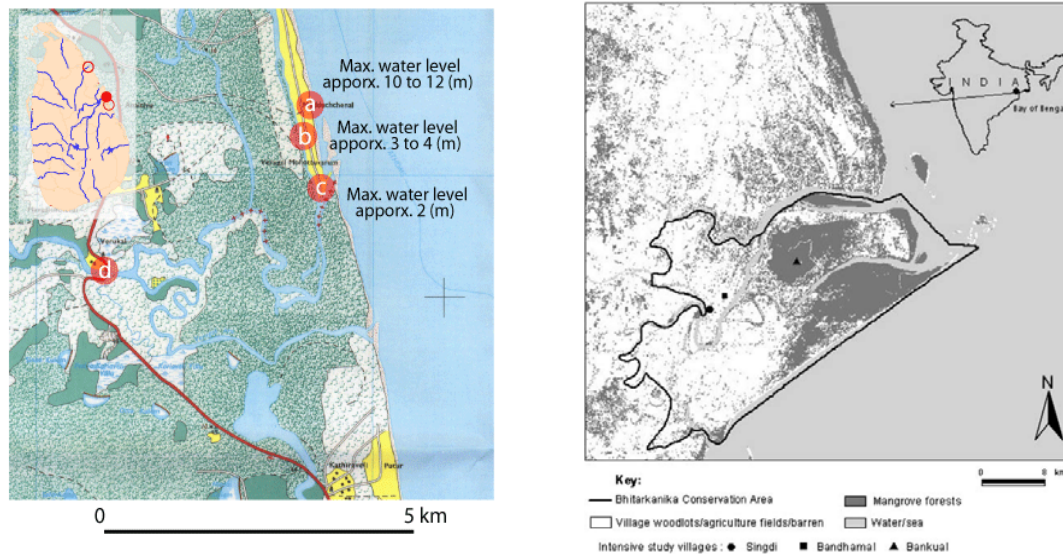


Figure 4.1: Tsunami wave reduced from approx. 12 m (at point a) to 2 m (at point c) by vegetation in NE Sri Lanka (Left). 3 villages in Orissa, India with different level of protection by mangroves and embankment (Right)

It is recognized that presence of dense and wide coastal vegetation belts serves to protect from impacts of cyclone by reducing wind velocity and attenuating wave surges created by such storms and coastal erosion (IUCN, 2007; Spalding et al., 2014). There is a world-wide trend of establishing Greenbelts along coastlines to act as barriers to mitigate these risks. Sri Lanka and Indonesia have initiated measures to establish Greenbelts along their coastlines in the aftermath of the December 2004 Tsunami. Philippines have taken similar actions in the wake of Typhoon Haiyan (Larano, 2013). Recent climate change processes are predicted to increase intensity of cyclones, storm surges, erosion and sea level rise. Thus the importance of coastal Greenbelts in mitigating the risks from such natural hazards is immense. However, there is no universal consensus on what should be the ideal widths of these zones. The recommendation on width varies depending on local conditions but it is accepted that the wider the Greenbelt the better protection it can provide.

Several experiments employing numerical models have been used to find out the effectiveness of greenbelt in reducing storm surge height and wind velocity of cyclones. McIvor et al. (2012) have reported reduction of surge height by 0.05-0.5 m and surface wind waves by 75% by a kilometer of mangrove belt. Studies in Japan and Australian coast showed wave energy is reduced by a factor of 2 within the first 50m of the mangrove belt hence wave height is attenuated by a factor of square root of 2 (Massel et al., 1999). In Bangladesh, Kabir et al. (2006) found reduction in wave height of about 10cm by 133m wide mangrove belt and 45cm by 600m wide belts in Hatia, simulating with the wave height of 17 past cyclones. Rahman and Rahman (2013) conducted laboratory based experiment for Sandwip and found that wave height is reduced by 46% behind the vegetation barrier, 43% within and 41% in front of the barrier for wave period of 1.6 sec when vegetation is placed 1m from embankment.

A meeting organized by Food and Agriculture Organization (FAO, 2007) of the United Nations was held in 2006 in Thailand on the role of greenbelt in protecting coastal region. The theme of the meeting "Coastal protection in the aftermath of the Indian Ocean Tsunami: What role for forests and trees" was one of the most comprehensive technical workshop of its kind with government participants from Bangladesh, India, Indonesia, Malaysia, The Maldives, Myanmar, Sri Lanka, and Thailand. It also included representatives from various government and non-government agencies from Thailand, Japan, USA, Malaysia, India,

Indonesia, Switzerland, Austria, UNDP, UN/ISDR, WWF, Wetland International, and IUCN, and a significant number of resource persons. A complete list of attendees is provided in annex 4.1. The discussants at this workshop suggested greenbelt as an effective measure of protection from various coastal hazards and the following as a possible effective width of greenbelt for each type of coastal hazards (FAO, 2007):

Typhoon: 100 – 300 meters

Typhoon waves: 500 – 1000 meters

Strom surge: 200 meters

Tsunami: 500 – 2000 meters

In the aftermath of Typhoon Haiyan, Philippines government passed a bill in 2014 (Senate Bill 2179, 2014) that will enforce creation of a 100 m wide Greenbelt along its coast. They have recommended building 20-50 m wide Greenbelts in the riverbanks that are in proximity to the coast and often carry the storm surges inland.

4.2. Current Land Cover Map

The land cover map of 2015, prepared for Bangladesh Forest Department was used in this study to identify the land cover classes that falls within the proposed greenbelt zone. The primary purpose was to characterize lands that are required for plantation, types of plantation existing on them, and the types of plants, such as mangroves and non-mangroves, they will support. The primary utility of the map was to provide information on the forested areas within and adjacent to the greenbelt. These areas would be included in the proposed greenbelt as necessary but would not be part of the new greenbelt development plan. From the perspective of plant suitability the land cover classes of particular interest was mudflats, sandy beaches and bars, intertidal areas and raised stable lands, all of which has a bearing on selecting the types of plant species that are most suitable on those land cover. This map also will be helpful in future during the implementation phase of the greenbelt by identifying land cover that may need to be prepared or modified.

The mapping activity was supported by NFI (National Forest Inventory), DECCMA (Deltas, Vulnerability and Climate Change: Migration and Adaptation), and UN-REDD. It was prepared using FAO land cover classification system and SPOT satellite images of 2015. The eCognition software was used to segment (creating image objects) the images. After segmentation, the image objects were exported into ESRI shape files and those shape files were classified in ArcGIS environment using visual interpretation. Post processing techniques were applied to create the final land cover map.

The identification of the land cover classes have been done from the analysis of the diagram of the National Reference System (NRS). Figure 4.2 shows SPOT image of a part of the study area with few representative land cover classes.



Figure 4.2: Different Land Cover (LC) features as recognizable on unclassified SPOT 6 image (2015)

4.2.1. Image acquisition

The SPOT 6 and 7 multi-spectral ortho images of 6m ground resolution with bit depth of 12 bits were acquired for the land cover mapping of 2015. Maximum cloud coverage of 10% was considered as acceptable for any given image scene.

The selected image scenes were mosaicked in MosaicPro of EARDAS Imagine. No color correction or stretch option was applied to the image during the mosaicking process.

Segmentation

The mosaicked image was then uploaded in eCognition Developer and the multi-resolution segmentation algorithm with scale parameter 30 was used for segmentation. The weight factor one was given to green, red and NIR bands of spot image and the weight factor zero was given to blue band of the image for segmentation process. The attributes such as mean value of each band, brightness, NDVI and Length/Width ratio which are suitable for further analysis were added with the image object table and it was exported into ESRI shape file. The shape file was uploaded in ArcGIS and the Simplify Polygon tool was used to smooth the line boundaries of each object to reduce the vertex density and the consequent file size. After the generalization was applied, a clip with the original district boundary was performed to ensure topological consistency between districts.

4.2.2. Interpretation

In this phase, the land cover codes were assigned to each image object (polygon) using visual interpretation technique. The shape file of each district was overlaid on the mosaicked image in the ArcGIS Environment. Based on spectral characteristics, expert knowledge, available ancillary data at Resource Information Management System (RIMS) office, the land cover class codes were assigned. In addition to SPOT data, free available multispectral Sentinel-2 images and Landsat-8 images were also used as ancillary data for land cover map preparation. After interpretation, thematic and topological consistency of the interpreted districts was checked.

4.2.3. Final land cover data

At the final stage, all individual districts were appended together. Before that, the inconsistency on contiguous land features of neighboring districts was checked. A critical review of bordering edges of the districts was performed and some changes in codes and in geometries were needed to re-establish contiguity of land features. A final topological error check was performed on the appended land cover data to ensure that the final dataset is error free. Then, a dissolve was applied to remove boundaries between districts and the final dataset was prepared, statistics on the area coverage of each land cover class were calculated and metadata was prepared. Figure 4.3 shows a part of land cover map of the study area. The area statistics of each land cover class within the study area districts derived from satellite image is given in the Table-4.1.

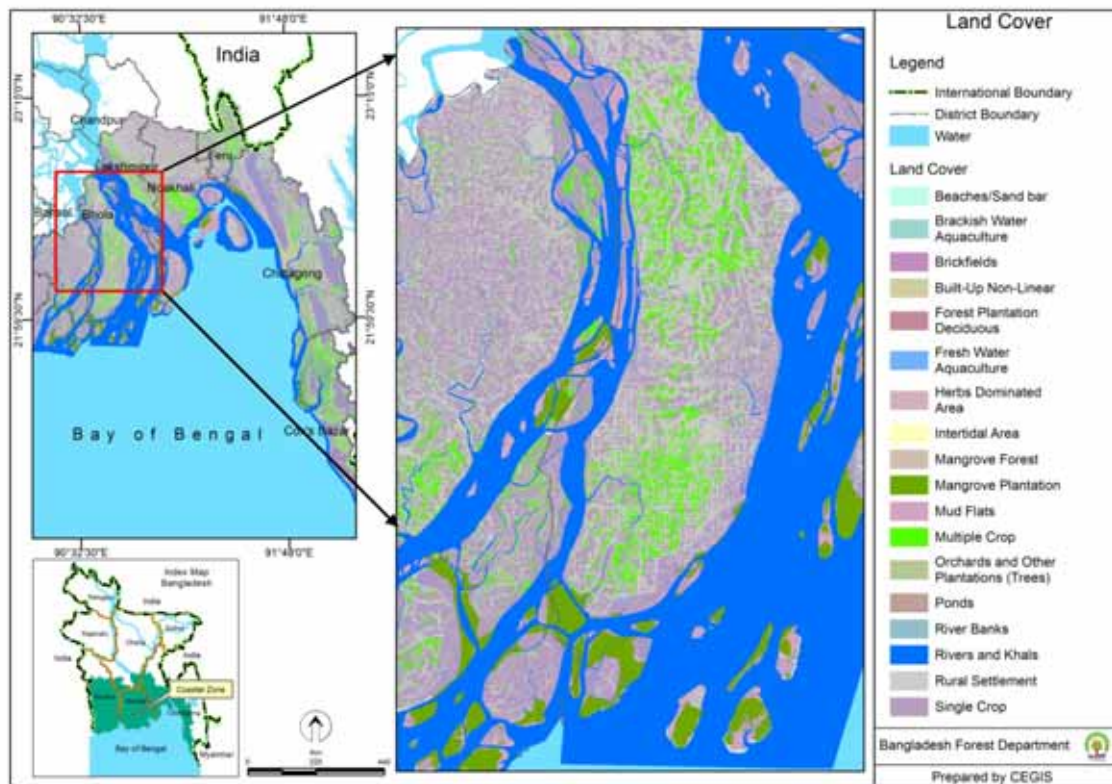


Figure 4.3: A representative Land cover map derived from SPOT satellite images of 2015

Table 4.1: Land Cover Statistics of the study area districts derived from Land Cover Map of 2015

Class Name	CODE	Area (Hectare)
Natural Vegetation (Terrestrial)		
Herbs Dominated Area	H	5,571
Shrub Dominated Area	S	122,123
Mangrove Forest	NMF	2,457
Cultivated Vegetation (Terrestrial)		
Forest Plantations	FP	70,267
Rubber Plantation	FP _r	7,755
Orchards and Other Plantations (Shrubs)	OS	4,988
Orchards and Other Plantations (Trees)	OT	1,473
Multiple Crop	PC _m	152,154

Class Name	CODE	Area (Hectare)
Single Crop	PCs	617,012
<i>Cultivated Vegetation (Acquatic)</i>		
Mangrove Plantation	FMp	52,539
<i>Natura Abiotic Surface</i>		
Beaches/Sand bar	BS	4,373
Intertidal Area	IA	2,269
Mud Flats	MF	64,717
River Banks	RB	245
<i>Artificial Abiotic Surface</i>		
Air Port	Ap	546
Brickfields	B	2,684
Built-Up Non-Linear	BNL	18,452
Salt Pan	SP	45,043
<i>Natural Water Bodies</i>		
Baor	Ba	120
Perennial Beels/Haors	BH	79
Rivers and Khals	R	557,124
<i>Artificial Water Bodies</i>		
Brackish Water Aquaculture	BWa	569
Fresh Water Aquaculture	FWa	6,827
Lake	L	1,361
Ponds	Po	1,343
<i>Cultivated Vegetation and Built-up Area</i>		
Rural Settlement	RS	535,890

4.3. Design criteria of Greenbelt

Greenbelt area should be designed in such a way so that it can reduce the risks from climate change induced coastal hazards such as cyclones, storm surges, coastal erosion and mitigate the adverse impacts of natural coastal hazards on human lives and livelihoods. Geometry of greenbelt is one of the key factors in determining the success of the greenbelt in providing protection from these hazards. Width of the greenbelt is the most important component of the geometry. All published research and scientific conferences clearly stated that wider greenbelt zone provides more effective protection than the narrower strip. So the challenge is to determine the width and there is no clear prescription for this. As suggested in literatures the Greenbelt oriented at right angles to the cyclone track provides better protection and this will be ensured during designing of greenbelt (Fritz and Blount, 2007). Besides, a proper greenbelt design also provide opportunities to conserve the biodiversity of coastal zone, provide livelihood support for coastal communities through horticulture, fishery and forestry crops, afford shade for various human activities, and can contribute to recreation and scenic beauty as well.

Selection of apposite Greenbelt trees is also very crucial for Greenbelt design as the trees are the elements of the greenbelt that will provide protection against hazards, livelihood support to the nearby communities, and useful benefits including carbon sequestration, ecosystem restoration, land stabilization, etc. Benefits also include the improvement of biodiversity that will create habitat corridors for wildlife that can be used for conservation activities, for ecotourism development and aesthetic pleasure. The suitability of the trees primarily depends on their ability of resilience and resistance to strong wind and waves associated with cyclones. Therefore, selection of suitable site specific trees needs to be examined using different parameters of the tree profile such as depth of its root, growth rate, height, salinity and flood tolerance level, their ecological suitability and economic value, and above all acceptance by local community. The planting design for the greenbelt should be chosen such that it can effectively provide the desired protection. The trees of the greenbelt will be planted continuously in a zigzag pattern along the coastline so no gaps exists that

could be the zone of weakness through which storm surges could make pathways to the embankments and inland. A separate chapter of this report addresses selection of suitable tree species and planting design of the proposed greenbelt.

4.3.1. Greenbelt Width determination

As the greenbelt will be continuous across the entire coastline of Bangladesh the design criteria discussed henceforth have been used primarily to determine the width of the belt at various locations along the coastline. In determining the width of the Greenbelt this study considered five primary factors; (i) characteristics of the hazards the greenbelt should strive to protect, (ii) the degree of vulnerability faced by different parts within the coastal region, (iii) presence or absence of embankment, (iv) presence of critical infrastructure, and (v) presence of forests.

Cyclone induced storm surges is the hazard that causes most damages in the coastal areas of Bangladesh. Though category 4 and higher cyclones occurs at irregular intervals they are the leading cause of fatalities and economic loss because of the associated storm surges, strong wind and heavy rainfall. A study on tsunami and storm surge inundation was carried out by Institute of Water Modelling (IWM) under the Comprehensive Disaster Management Programme (CDMP) funded by European Commission, Department for International Development (DFID), and United Nations Development Programme (UNDP) in 2009 (CDMP, 2009). The study took the average record of storm surge height and areas inundated by past 18 major cyclones between 1960 and 2007 and prepared an inundation risk map (Figure 4.4). These inundations proceeds inland by breaching or overtopping the embankments, by surging through the open river channels and are also bolstered by heavy rainfalls associated with cyclones. Strong winds associated with the cyclones generally follow the same track of the surges but unlike water flow through channels the wind flows all across the coastal plains. Singularly these surges and strong winds present the biggest threat to the inhabitants of the coastal region and the greenbelt must be designed to reduce the surge heights and energy.

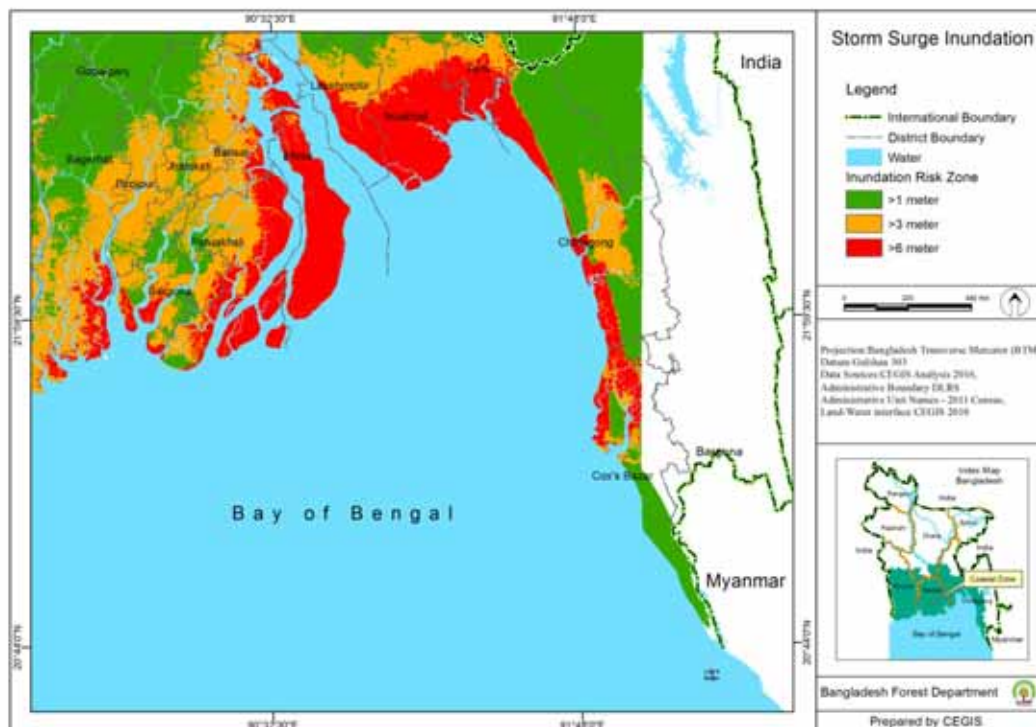


Figure 4.4: Inundation risk map from storm surges (modified after CDMP 2009)

Not every area along the Bangladesh coastline is equally impacted by the same disaster event. Many factors including the characteristics of the hazard, nature of the coastline at local scale, and socio-economic condition of the impacted area plays an important role in dictating the degree of damage sustained. The degree to which an area and its inhabitants are exposed to a hazard and the ability of the population to recover from it is an important factor in designing the protective measure, i.e., greenbelt. Coastal Vulnerability Index (CVI) is a measure of the degree of vulnerability of the coastal communities in the face of the hazards that threatens them. A CVI map has been created to assess the vulnerability of the upazilas within the study area. The CVI map preparation method as discussed in chapter 3 produced a six class vulnerability map which has been given the next priority in determining how wide the greenbelt should be.

Existence of embankment in the coastal upazilas within the study area is an important design criterion for Greenbelt establishment. Embankments are the 'hard' protection that continues to provide protection against the coastal hazards. It is expected that the areas in the coastal region where embankments already exists provides more protection towards the live and livelihoods compared to the areas which lack any embankment. The coastlines where embankments have not been built yet are very vulnerable and are areas of great concern that requires the maximum protection from a wide greenbelt. The presence or absence of embankment has been taken into consideration in calculating width of greenbelt at a particular location.

Critical infrastructure like seaports, airports, and power stations are built with huge investments and any damage or loss to them stresses the local and regional economy significantly. 2 ports in Chittagong and Payra lies near the coastline within the zone of impact of cyclones. 2 airports in Chittagong and Cox's Bazar are also within striking distance of cyclones. Six power plants (proposed and under construction) are also located near the coastlines within the study area. Their presence and need for additional protection against damaging cyclones have been taken under advisement in the design criteria of the greenbelt. The area where these critical structures already exists or proposed to be established needs greater degree of protection and the width of the greenbelt needs to be greater in the sea-facing side of these infrastructures.

If dense forests already exists along the coastline of the study area then areas behind those forests are already benefiting from the protection provided. The Sunderbans, a natural greenbelt just west of the study area has repeatedly acted as barriers against past cyclones and areas behind them suffered less damages compared to areas without forest cover. The existing forest land, natural or planted, is already working as natural Greenbelt by protecting human habitation, lives, properties, and agricultural crops from extreme weather events resulting from climate change. Therefore, there is no need to develop greenbelt in those areas where such forest already exists. However, the species composition of the existing forests is helpful in determining which plants will be ideal for the new greenbelt to be built in adjacent areas.

Erosion and accretion in coastal belt has also taken into consideration in making additional recommendation to the geometry and planting design of the greenbelt. Though, accretion is the dominant process in Meghna estuary region but at certain locations erosion creates risks for coastal communities there. Wave action and lack of protective vegetation cover combined with storm surges and intense upstream flooding promotes these erosive activities. Erosion-accretion process in Bangladesh's dynamic coastline constantly changes the geometry of the coastline. Erosion in some segments is quite severe putting the coastal community at risk and these areas will benefit from having a greenbelt along the coastline. Unfortunately, the morphological processes that govern the erosion usually do not leave enough spaces to plant greenbelt of significant width. Compared to the accreting coast generally the eroding coasts will have lesser amount of area available for the Greenbelt. Therefore, only a narrow strip in the sea-facing side will be available where species that can help in arresting erosion are recommended for planting. On the other hand in accreting

areas new lands are available to establish greenbelt and the ecological conditions are also favorable. These islands have natural mangroves growing and the recommendation that these lands be added to the design of the greenbelt as accretion processes continues to add lands.

4.4. Decision Rules for Greenbelt Width

A decision rule is the procedure by which criteria are selected and combined to arrive at a particular evaluation, and by which evaluations are compared and acted upon. It typically contains procedures for combining criteria into a single composite index and a statement of how alternatives are to be compared using this index (Eastman 2006). Establishment of Greenbelt along Bangladesh coastline will take into account the width determination criteria discussed above. In the outset it has been decided that the maximum width of the greenbelt will be 1000m and the minimum width will be 100m. This determination is based on results of scientific research as published in peer-reviewed journals; recommendation made in the FAO organized conference in 2006; by International Union of Conservation of Nature (IUCN, 2007), and greenbelt width in other countries. To determine the Greenbelt width within this range (1000m-100m) at specific locations along the coastline surge inundation height, coastal vulnerability index value, presence/absence of embankment, critical infrastructure, and forested land were used.

4.4.1. Decision Rule 1

Among the width determination criteria the highest importance has been given to surge inundation height as this is the primary destructive force associated with cyclones and has been the leading cause of most deaths and maximum damage in the past cyclones that has affected Bangladesh. The CDMP map on surge height was classified into 4 groups; (i) greater than 6m, (ii) 4-6 m, (iii) 2-4 m and (iv) 1-2 m and formed the basis of the first criteria in selecting the greenbelt width. The decision rule was set up so that the maximum greenbelt width of 1000m is assigned to all areas that have experienced greater than 6 m of surge in past cyclones. In such cases, the CVI value, existence of embankment, critical structure, forested lands, erosion and accretion of land will not have any impact on determining the Greenbelt width. The reason for developing greenbelt in the landward direction beyond the existing embankment is that the average height of the embankment in the coastal region is lower than 6 m. When surges greater than 6m height will strike these embankments they will be overtopped and then the greenbelt inside the embankment will provide protection by reducing the surge height and absorbing the energy of the waves. This will reduce the threat and provide more time for inhabitants to take mitigating measure. The same protective role of greenbelt will come in to play if the embankment is breached. Two studies of Yasuda et al (2006) and Badola and Hussein (2005) quoted earlier, have clearly indicated how dense forest have helped in reducing the impact and damage from storm surge and tsunami waves.

4.4.2. Decision Rule 2

After this initial determination using surge height only, other width classes were chosen for locations inundated by less than 6 m surges in combination with the CVI values calculated for those areas. CVI values have been grouped in to 6 categories; Very High, High, Medium High, Medium Low, Low and Very Low. The decision rule has been set up so that for areas affected by 4-6 m surge height their CVI values will be taken into consideration and based on those values the greenbelt width will be established and the width will be reduced in incremental fashion as the CVI values go down. In the same way the CVI value will determine the width for the next class of surge height; 2-4m. This decision rule set is presented in Table 4.2.

Table 4.2: Decision rule set using surge inundation and CVI

Inundation (m)	GB Width (m) Decision Rule 1	CVI	GB Width (m) Decision Rule 2		
6 or greater	1000	VH	1000	VH	Very High
	1000	H-MH	1000	H	High
	1000	ML-L	1000	MH	Medium High
	1000	VL	1000	ML	Medium Low
4 to 6	In combination with CVI	VH	1000	L	Low
	In combination with CVI	H-MH	800	VL	Very Low
	In combination with CVI	ML-L	600		
	In combination with CVI	VL	400		
2 to 4	In combination with CVI	VH	800		
	In combination with CVI	H-MH	600		
	In combination with CVI	ML-L	400		
	In combination with CVI	VL	200		
1 to 2	In combination with CVI	VH	600		
	In combination with CVI	H-MH	400		
	In combination with CVI	ML-L	200		
	In combination with CVI	VL	100		

4.4.3. Decision Rule 3

The presence or absence of embankments was considered next in deciding the greenbelt width. If embankments were present the rule was to accept the width determined by using surge height and CVI values. The logic being the presence of embankment would be the 'hard measure' behind the greenbelt and would not have any negative impact; hence no change in the previously derived width of greenbelt. The reasoning for extending the greenbelt landward beyond the embankment has been explained in the discussion of decision rule 1. However, if there is no embankment at the location then the area is considered very vulnerable to hazards and the rule is to develop greenbelt with maximum width of 1000 m changing, as necessary the width obtained from surge height-CVI value combination. This condition will over rule the decisions derived earlier by combining rule 1 and rule 2. This can be considered as 'soft rule' as opposed to the 'hard rule' set up by combining surge height and CVI value.

4.4.4. Decision Rule 4

The protection of critical infrastructures has been considered next and another 'soft rule' was applied to determine the width of greenbelt between the coastline and the structure. To provide maximum protection to these structures such as seaports, airports and power plants the decision rule was set to establish maximum width of greenbelt (1000 m) at those locations regardless of the value obtained by combining surge height, CVI, and embankments.

4.4.5. Decision Rule 5

The impact of existing forest was accounted for by integrating the forested areas as part of the greenbelt and planting trees only in areas where the required greenbelt width exceeded the width of the existing forest. For example if based on the four rules discussed above the greenbelt width has been calculated as 600 m at a location where a 300 m wide strip of forest exists then new plantation will be developed only in the remaining 300 m that does not have forest in it and the addition of the new and existing forest would total the recommended width.

4.4.6. Additional Recommendations

For areas being eroded currently it is not possible to extend the greenbelt into the intertidal areas by planting mangroves because the foreshore area is very narrow and not suitable for most varieties of mangrove. The recommendation in such cases is to plant tree varieties along edge of the coastline with root systems that works as erosion control. The most common example of that is Nipa palm (*Nypa Fruticans*) which is environmentally suitable for most of these areas but has not been planted by BFD in the past.

For accreting areas width of available land is continuously in a flux hence determination of a firm width of greenbelt is difficult. The recommendation here is to develop greenbelt at width derived from the four rules stated above and then add the new lands to that width as they continue to accrete. The reason is these lands are not suitable for any other use and the greenbelt trees will help in stabilizing these lands for future use in addition to the protection provided against coastal hazards. Table 4.3 summarizes results of all five decision rules and two 'soft recommendations' which helps to determine the width of the greenbelt at all locations along Bangladesh coastline.

Table 4.3: Decision rules and resulting width of greenbelt

Greenbelt Width Determination							
Inundation (m)	CVI	GB Width (m)	No Embankment	Critical Infrastructure	Forested Lands	Eroding	Accreting
Rule 1	Rule 2		Rule 3	Rule 4	Rule 5	For these conditions no change in width but recommendation as below	
6 or greater	VH	1000	No Change	No Change	Subtract Forest Width	Select appropriate plants	Add new lands to GB
	H-MH	1000	No Change	No Change	Subtract Forest Width	Select appropriate plants	Add new lands to GB
	ML-L	1000	No Change	No Change	Subtract Forest Width	Select appropriate plants	Add new lands to GB
	VL	1000	No Change	No Change	Subtract Forest Width	Select appropriate plants	Add new lands to GB
4 to 6	VH	1000	No Change	No Change	Subtract Forest Width	Select appropriate plants	Add new lands to GB
	H-MH	800	1000	1000	Subtract Forest Width	Select appropriate plants	Add new lands to GB
	ML-L	600	1000	1000	Subtract Forest Width	Select appropriate plants	Add new lands to GB
	VL	400	1000	1000	Subtract Forest Width	Select appropriate plants	Add new lands to GB
2 to 4	VH	800	1000	1000	Subtract Forest Width	Select appropriate plants	Add new lands to GB
	H-MH	600	1000	1000	Subtract Forest Width	Select appropriate plants	Add new lands to GB
	ML-L	400	1000	1000	Subtract Forest	Select appropriate	Add new lands to GB

Greenbelt Width Determination							
Inundati on (m)	CVI	GB Width (m)	No Embank ment	Critical Infrastruct ure	Forested Lands	Eroding	Accreting
					Width	plants	
	VL	200	1000	1000	Subtract Forest Width	Select appropriate plants	Add new lands to GB
1 to 2	VH	600	1000	1000	Subtract Forest Width	Select appropriate plants	Add new lands to GB
	H-MH	400	1000	1000	Subtract Forest Width	Select appropriate plants	Add new lands to GB
	ML-L	200	1000	1000	Subtract Forest Width	Select appropriate plants	Add new lands to GB
	VL	100	1000	1000	Subtract Forest Width	Select appropriate plants	Add new lands to GB

4.5. Delineation of Greenbelt Zone

The greenbelt map has been prepared on the basis of the design criteria and the decision rules discussed above. Two separate greenbelt maps were produced using different methods to fulfill two different objectives. The reasoning behind that is the outer boundary of the greenbelt zone is delineated from the coastline which changes rapidly in time across the dynamic Meghna estuary region where erosion-accretion process continuously redefines the coastline. The first approach is based on current shoreline as drawn from 2015 Landsat imagery. The greenbelt zone delineated using ArcGIS software on this coastline can be used with some updating for immediate establishment of the greenbelt and detailed maps of greenbelt accompanying this report is based on this method. The other method is integrated within the DSS component of this study and will allow planners flexibility to modify and redefine greenbelt zone at a future time taking in to account the land configuration of the time.

GIS data on study area, shoreline, storm surge inundation, coastal vulnerability index map, embankments, critical infrastructures, and forest maps were used in delineating the greenbelt. All data were in Shapefile format of ArcGIS software some of which were collected from secondary sources and others prepared by this study. The same dataset was used within the ArcGIS environment and the ILWIS software used to develop the DSS.

A spatial data layer of 37 coastal Upazila along with their attribute information was used to define the study area boundary. The source of this dataset is Police Station Maps published by Directorate of Land Record and Survey (DLRS), which were compiled within 1905-1945. The attribute information for this layer was derived from population census, 2011 published by Bangladesh Bureau of Statistics (BBS). This data layer has been collected from National Water Resources Database (NWRD, 2011), of Water Resources Planning Organization (WARPO).

CEGIS delineated shoreline for this study by interpreting good quality Landsat TM image of 2015 (30m pixel size) acquired between January to March of 2015 following the method described in section 2.4.

Storm surge Inundation was prepared from the inundation risk map of CDMP (2009) study prepared by IWM and BISR based on field collected data numerical model results. This map was converted to raster and vector format and used in delineating the greenbelt width.

The CVI maps prepared by CEGIS using BBS and other data was used as a design and decision parameter as described earlier.

Map of embankment within the study area built by Bangladesh Water Development Board (BWDB) has been collected from NWRD, WARPO. This database contained embankments in existence through 2012-13 periods. The embankments established later were identified using Google Earth images and were added to this data layer. The Marine Drive from Cox's Bazar to Teknaf has also been considered as embankment and added to this layer for analysis purposes.

Critical infrastructure map was prepared from hard copy map and verified using Google Earth image.

The forest data layer was extracted from the land cover map prepared for BFD under its NFI (National Forest Inventory) program.

4.5.1. Greenbelt delineation in ArcGIS

The greenbelt delineated within ArcGIS environment is a vector data model based system using 2015 coastline and several layers of spatial data as described above. Data collected from secondary sources underwent necessary GIS processing to adjust for projection, accuracy level, and removal of inconsistencies and make them compatible to the GIS format used by CEGIS. All datasets have been converted into the common projection system BTM_Gulshan303. Data accuracy and inconsistency has been improved using satellite images. Google image has been used for updating and checking data layers. Attribute information has been integrated in a relational database management system (RDMS) which allows efficient spatial analysis and increase performance of both spatial and non-spatial query.

4.5.2. Geospatial Analysis for Greenbelt Delineation

Based on decision rule, a number of geospatial analyses have been carried out to demarcate the potential greenbelt area. The green belt width has been demarcated along the shoreline through performing various spatial analysis operations including overlay, identity, attribute selection, intersect, erase etc.

The following steps were carried out to integrate data from all criteria layers inside the GIS prior to the greenbelt width delineation.

1. The greenbelt width criteria layers included surge height map, CVI map, embankment map, critical infrastructure map and forest maps. In several steps each of these layers was overlaid on the shoreline map and 'identity' operation was carried out between each of the criteria layers and shoreline layer to build the attribute table of the shoreline layer (may be add figure of attribute table).
2. 'Query' operation was run on this composite data layer on the basis of the decision rules on surge height, CVI, embankment and critical infrastructure to define the width of the greenbelt along the entire shoreline. 'Select by Attribute' operation was used to produce this output.
3. Once the width value was obtained several 'buffer' operations was then run on the landward side of the shoreline each with a unique width as derived from the query. These buffer outputs were then merged to create one composite greenbelt width map
4. On this greenbelt layer 'erase' operation was used to extract the existing forest by using the forest data layer.

Manual cross-checking and validation of data was done before and after running each of these GIS analyses steps. Figure 4.5 shows a representative section of the delineated greenbelt

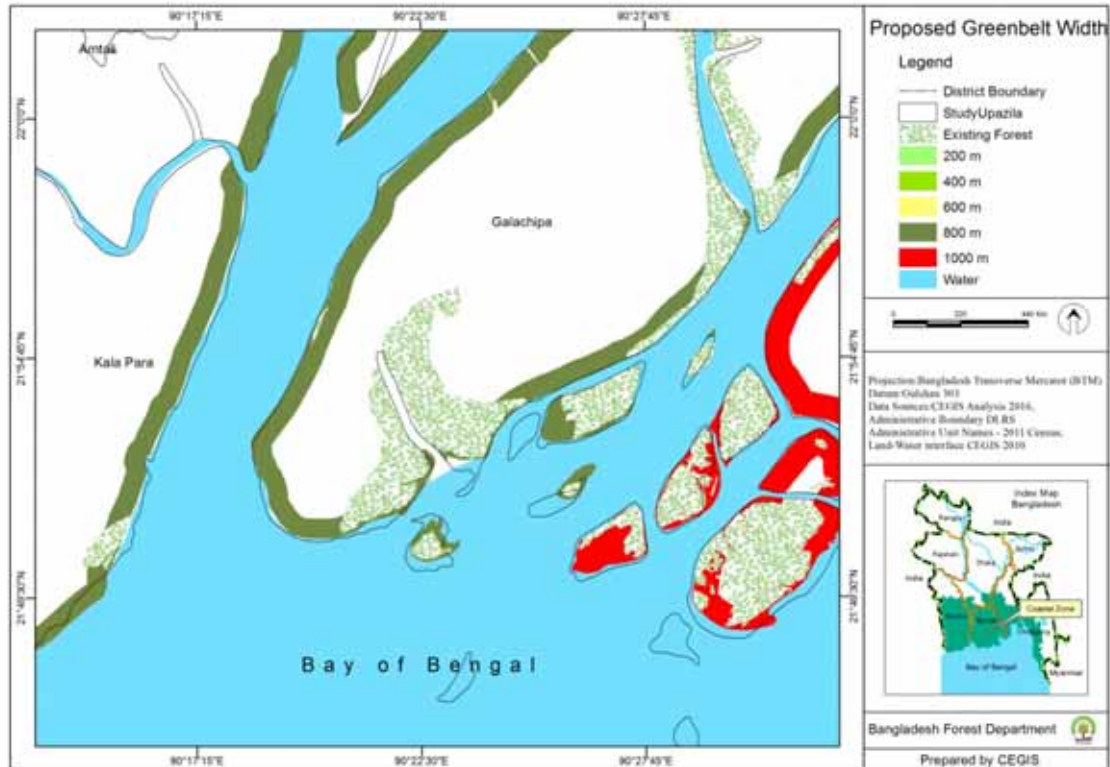


Figure 4.5: Map showing the proposed greenbelt; colors indicating various width as determined by the width criteria in part of the study area.

4.6. Greenbelt delineation in DSS

In the DSS, Greenbelt will be delineated based on utility function. The term "utility function" is a probabilistic decision usually measured on a scale of 0 to 1 to assign preference to a variable. The DSS method used the same dataset as in the ArcGIS method. However, the vector data used previously was converted to raster data model as required by the software. These data layers were then given utility values and given weights to identify criteria (called indicators in the DSS nomenclature) that would have precedence over other criteria. For example the storm surge inundation criteria are given the highest importance in delineating the width of the greenbelt for reasons discussed earlier. As the maximum greenbelt width has been set at 1000 m the DSS based greenbelt delineation method used the same maximum width.

The basic principle used in the DSS is not all areas within the greenbelt have the same priority. The priority is dependent on the criterion discussed earlier and how they impact each location within that 1000 m zone. All locations are evaluated as pixels of 25x25m raster grids. This pixel size was chosen to carry out a detailed analysis without tasking the system's computational capacity too much. For example priority or usefulness of developing greenbelt in a grid diminishes progressively as the distance between the grids increases from the shoreline (Figure 4.6). Similarly grids that are located within a >6 m surge inundation has higher priority than grids located within a lower surge inundation height zone. The term utility value is an expression of this priority. After combining the utility value of the different indicators (criteria) for a pixel the final priority of that pixel is determined and maps are produced that shows utility value of all grids within the 1000 m greenbelt zone (Figure 4.7). This map allows the planner to decide where the greenbelt needs to be built. A more detailed discussion of the DSS concept for greenbelt delineation is presented in the Annex 4.2 and a stand-alone report on the DSS is being prepared as a deliverable.

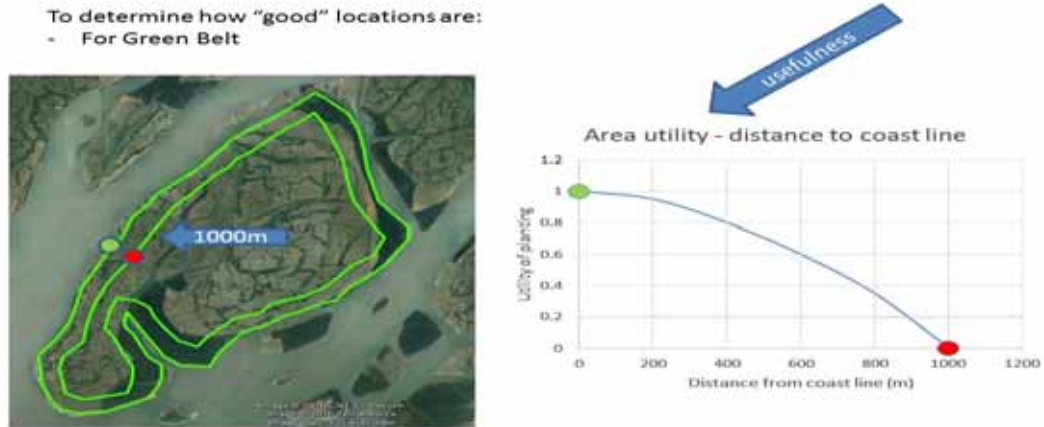


Figure 4.6. Utility curve for distance to shoreline, showing priority of greenbelt as highest (utility = 1) near the shore and lowest (utility = 0) after 1000 m inland.

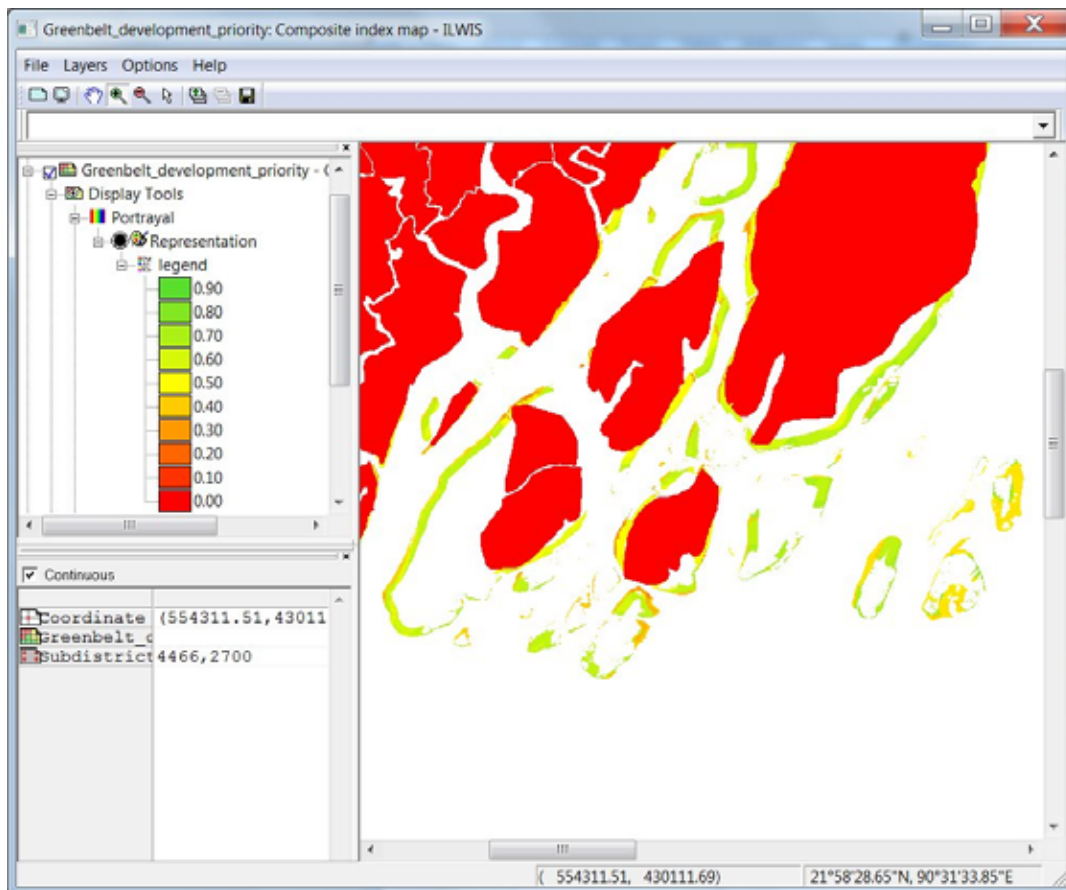


Figure 4.7. An example of the utility map for greenbelt prioritization

5. Selection of Plant Species

Selection of appropriate plant species for a particular site is very critical for developing the proposed greenbelt so that the belt can provide desired benefits while in harmony with the existing ecosystem. Two sets of consideration dominate this process of species selection. First the selected trees should have characteristics that match the requirement of an effective greenbelt and then whether these list of ideal trees are suitable for planting within the ecological conditions that prevails in the greenbelt location for which they are being considered. The ideal greenbelt trees should be tall enough to reduce the surge height and wind velocity; have wide trunk to dissipate the energy of the surging waves; have strong and deep roots for a firm hold to avoid being uprooted by strong winds; growing fast to reach the desired height quickly after planting; have high survival rate and natural to the ecosystem. The biological criteria that control the suitability of the trees at the location of planting would include: edaphic factors, types of sediments, water salinity and turbidity for the mangroves, land slope, drainage of surface waters etc.

One additional aspect in consideration was the economic benefit the chosen species can provide to both encourage the local population to actively participate in the development and maintenance of the greenbelt through time and offset the cost of establishing the greenbelt.

These factors have been considered in prescribing the suitable mangrove and non-mangrove tree species for planting in the proposed greenbelt. However, lack of data has limited the study to consider only soil texture, soil salinity, water salinity and sediment type as the selection criteria for the biological suitability.

5.1. Existing Plant Species

The study began by assimilating information on the trees that naturally grows in the coastal zone of Bangladesh. They are the natural candidates for planting in the greenbelt as they belong to the local ecosystem and could be planted without bringing any adverse impact to it. Information on the plants that grows well within the study area were collected by field visits and discussion with local inhabitants, through discussions with the BFD officials with work experience in the region and from published literatures.

Both mangroves and non-mangroves thrive in the coastal region of Bangladesh. Mangroves thrive in the sea facing lower lands that are inundated in varying frequency by tides and non mangroves occupy the higher stable lands that are mostly above the tidal ranges.

Aside from the natural mangrove of Sunderbans, most of the mangroves found along the coastal region have been planted by Bangladesh Forest Department. They have raised large scale plantations mainly with *Sonneratia apetala* (Mangrove Apple or Kewra) in zones and patches along the coastal belt to create a green shelterbelt (Islam and Rahman, 2015). Presently, *S. apetala* alone accounts for about 94.4% while *Avicennia officinalis* (Indian Mangrove or Bain) accounts for only 4.8% of the total established mangrove plantations (Siddiqi and Khan, 2004). The varying degree of water salinity, range of tidal inundation and sediment types has resulted in this difference in mangrove species composition in different locations of coastal area. *S. apetala* prefers the soft mud and silt of the Meghna estuary at a relatively lower salinity whereas *A. officinalis* is better suited at a higher salinity of the southeastern coast of Chittagong. *Sonneratia caseolaris* (Crabapple Mangrove or Ora) exists as associated species with *S. apetala* at Meghna Estuary and its surrounding areas where water salinity is comparatively low. *Nypa fruticans* (Nipa Palm or Golpata) is the palm species which grows well in soft mud and slow-moving creeks of coastal rivers of Meghna estuary, Sunderbans and Moheshkhali Island. Other less abundant species including *Heritiera fomes* (Sunder Tree or Sundaree), *Excoecaria agallocha* (Blinding Tree or Gewa), *Xylocarpus mekongensis* (Cedar Mangrove or Passur), *Bruguiera gymnorrhiza* (Black

Mangrove or Kankra) are also found in coastal mangrove vegetation of this area where land has become higher and the frequency of inundation is significantly less.

Among the non-mangrove mainland tree species *Cocos nucifera* (Coconut or Narikel), *Phoenix sylvestris* (Date Palm or Khejur), *Pithecellobium dulce* (Manila Tamarind or Khai Babla), *Acacia nilotica* (Gum Arabic Tree or Babla), *Samanea saman* (Rain Tree or Rendi Koroi), *Albizia richardiana* (Chambol), *Albizia procera* (White Siris or Sada Koroi), *Areca catechu* (Areca Nut or Supari), and *Swietenia mahagoni* (Mahogany) are prevalent all over the coastal area. *Borassus flabellifer* (Palmyra Palm or Taal) exists on homestead platforms as well as in road side plantations. *Musa* Spp. (Banana opr Kola) is the prominent fruit yielding plant that constitutes a large amount of vegetation coverage. *Casuarina equisetifolia* (Coast She Oak or Jhau) have been massively introduced in coastal areas during last few decades as an ideal plant on sand dunes/sand beaches of Cox's Bazar, Teknaf and at Patuakhali coast. *Pongamia pinnata* (Indian Beech or Koroach) is a common water tolerant species often associated with both mangroves and non-mangrove vegetations at their transition zone along Patuakhali and Barguna coastline. Except these, each of the homesteads consists of some fruit yielding trees like *Mangifera indica* (Mango or Aam), *Syzygium cumini* (Blackberry or Jam), *Artocarpus heterophyllus* (Jackfruit or Kathal), *Citrus maxima* (Pomello or Jambura), *Litchi chinensis* (Litchi), *Ziziphus mauritiana* (Indian Plum or Boroi), *Psidium guajava* (Guava or Pyara) etc. The mainland plant species composition primarily depends on people's choice based on their economic benefits like providence of foods, timber, fuel etc.

A list of common non-mangrove and mangrove plant species that are found in the study area along with their average canopy height is presented in Annex 5.1.

CEGIS field teams found similar species composition during their field visits in October 2016. *S. apetala*, was the dominant mangrove species whereas *S. saman*, *C. equisetifolia*, *A. auriculiformis*, *C. nucifera* etc. were the major non-mangrove species found inside the proposed greenbelt area. Table 5.1 lists the species composition as observed by CEGIS field teams within the proposed greenbelt zone in different parts of the study area. A table of scientific, English and local names of the common plants are present in the study area is shown in Annex 5.2.

Table 5.1: Upazila wise existing species composition within the proposed Greenbelt as recorded by CEGIS field teams

Location Name	Mangrove		Non-Mangrove	
	Dominant Species	Associate Species	Dominant Species	Associate Species
Amtali	Mangrove Apple	Crabapple Mangrove, Nipa Palm, Blinding Tree	-	-
Barguna Sadar	Mangrove Apple	Nipa Palm, Crabapple Mangrove	Rain Tree	Gum Arabic, Coconut, Mango, Palmyra Palm, Mandar
Burhanuddin	Indian Mangrove	-	Chambol, Mahagoni	Coast She Oak, Areca nut
Char Fasson	Keora	Crabapple Mangrove,	Areca nut	Rain Tree, Coconut, Chambol, Mango, Mehogony
Companiganj	Blinding Tree	Indian Mangrove, Uri grass	Rain Tree, Coast She Oak	Gum Arabic Tree, Palmyra Palm, Coconut
Dashmina	Mangrove Apple	-	Papuan Wattle, Coconut	Cattail, Palmyra Palm
Daulatkhan	-	-	Areca nut, Rain Tree	Mahagoni, Coconut
Hatiya	Mangrove	Blinding Tree	Coast She	Gum Arabic Tree, Rain Tree,

Location Name	Mangrove		Non-Mangrove	
	Dominant Species	Associate Species	Dominant Species	Associate Species
	Apple		Oak	Papuan Wattle, Rain Tree
Kala Para	Mangrove Apple	Crabapple Mangrove, Nipa Palm, Blinding Tree	Papuan Wattle	Rain Tree, Gum Arabic Tree, Chambol, Coconut, Banana, Palmyra Palm
Kamalnagar	Uri gash	-	Papuan Wattle	Coconut, Coconut, Palmyra Palm, Gum Arabic Tree
Lakshmipur Sadar	Uri gash	-	Rain Tree, Papuan Wattle	Coconut, Palmyra Palm, Gum Arabic Tree, Coconut
Lalmohan	-	-	Areca nut	Rain Tree, Mehogany, Chambol, Coconut
Manpura	Mangrove Apple	-	Rain Tree	Papuan Wattle, Rain Tree, Coconut, Gum Arabic Tree, Mahagoni, Areca nut, Palmyra Palm, Coast She Oak
Mirsharai	Mangrove Apple	Blinding Tree, Indian Mangrove, Lona Coast She Oak, Nipa Palm	-	-
Patenga	-	-	Coast She Oak, Rain Tree	Coconut, Papuan Wattle
Patharghata	Mangrove Apple	Crabapple Mangrove, Nipa Palm	Papuan Wattle, Chambol	Rain Tree, Gum Arabic Tree, Palmyra Palm
Ramgati	-	-	Rain Tree	Palmyra Palm, Coconut, Gum Arabic Tree, Coast She Oak
Rangabali	Mangrove Apple	Crabapple Mangrove	Mahagoni, Papuan Wattle	Rain Tree, Gum Arabic Tree, Palmyra Palm, Cattail
Sandwip	Mangrove Apple	Blinding Tree, Lona Coast She Oak, Indian Mangrove	Rain Tree	Papuan Wattle, Palmyra Palm, Coconut, Coconut
Sitakunda	Mangrove Apple	Blinding Tree	Rain Tree	Coconut, Papuan Wattle, Eucalyptus, Jahu
Subarnachar	-	-	Coast She Oak, Papuan Wattle	Gum Arabic Tree, Coconut, Palmyra Palm
Tazumuddin	-	-	Areca nut, Rain Tree	Mahagoni, Coconut, Mango, Velvet Apple

Source: CEGIS Field Visit, October, 2016

5.2. Criteria for Species Selection

5.2.1. Physical properties of the Plant

The various physical characteristics of a tree that would determine its suitability for planting in a greenbelt are: height, width, growth rate, survival rate, their adaptability to the local ecosystems, and economic benefits. In selecting the tree species for the greenbelt the physical characteristics of the common species of the coastal area were compared with the requirements of Greenbelt and common species that satisfied those needs were selected.

Physical characteristic of a plant species may vary in different environmental conditions. Information on different physical parameters was collected via discussion with BFD experts, field observations and literature review. The information unavailable from local sources was acquired from international publications. The information collected is shown in Table 5.2 and a brief description of the physical characteristics and the criteria threshold for species selection is presented in the following section.

Height

Height of a plant dictates how effective the tree will be in providing protection from inundation by storm surges and strong gale force winds when planted in a greenbelt. Taller trees are preferred as their protective cover can act as barriers against higher surges. In this regard, average height at five years age and maximum height of each plant have been collected. Average height of initially selected species varied from 1-28 m for different mangrove and non-mangrove species. As the maximum range of storm surge along Bangladesh coastline has been reported around 6 m height (CDMP, 2009), the ideal tree height threshold for greenbelt species selection has been put at 6 m by this study.

Tree stem Diameter

Diameter of a tree has been considered for the stability and strength against storm and surges. Wider tree trunks are blunt bodies that can absorb water wave energy as a result of wave induced reversing and unsteady flow around the vegetation (Wolanski, 2006). In this regards average DBH (Diameter at Breast Height) of 5 years age and maximum DBH of a species was considered. DBH of 15 cm and above after 5 years of age, and 50 cm and above as maximum DBH, was chosen as the threshold for this criteria.

Root depth

Root system of a tree provides the primary strength to a tree to stand upright on the ground. Trees with a deep root system are expected to withstand the force of storm surge and strong wind without being uprooted. Penetration of plant root inside the ground varies between species. Tap roots of a tree penetrates vertically in to the ground and fibrous root system grow horizontally and strength of a plant depend on root arrangement and depth of penetration. The ideal tree for the greenbelt should have greater penetration depth (for both tap and fibrous root system) as deeper roots provide greater strength to sustain against cyclones. For the purpose of Greenbelt, 1m of root depth is considered as the best choice and 0.5-1 m as the next best.

Growth rate

In the context of greenbelt growth rate of a species will dictate how rapidly the plant will reach the desirable height to play its role within a greenbelt in providing protection against hazards. Growth rate of a plant species is also a factor influencing its economic return. Planning for a functional greenbelt within 5 years after plantation, this study proposed a height growth rate of 1 m per year as ideal and 0.5-1 m as the next best option in selecting the species.

Survival Rate

Survival rate of a plant can vary significantly depending on the environmental characteristics at the location of planting, planting design, tolerance of the plants to the local ecological condition, and maintenance. Higher survival rate (or a lower mortality rate) is preferred for obvious reasons. It has been reported by Saenger and Siddiki (1993) that most mangroves planted in the coastal region of Bangladesh has variable survival rate between 30 to 70%. Based on their finding and personal communication with BFD executives the preferred survival limit has been put at 70% and the lower limit at 40%.

Economic benefit

In addition to physical characteristics, economic benefits of each species have been considered as they will encourage the local residents to take active interest in greenbelt

development and help sustain the Greenbelt through participatory management. It is less likely that local inhabitants will be interested to take care of plantation if they have no benefit from the Greenbelt. Economic benefits denote the importance of utilization from the plant. The plant species which provides more economic return like timber, fruits, fuel etc. are preferred by residents living in proximity to the greenbelt. Therefore, the species that can serve the purpose of the greenbelt while providing high economic benefit to the local population are more suitable species for plantation.

Life span

It is an important criterion for Greenbelt development as this is related with plant rotation for giving economic return to the local people as well as preparation of planting design. For example, *Borassus flabellifer* (Palmyra Palm) has a longer lifespan that may be considered for long rotation within the greenbelt and the economic outputs like fruit, molasses, fuel as well as home making materials from this plant will also continue for a longer time period. Likewise there are trees that are better suited as short rotation species in its role as a greenbelt tree with good economic benefit.

Few other criteria have also been considered during the species selection process. These included the compatibility (origin) of the species to the local ecosystem and erosion control capability. It is evident that species that are native to the local ecosystem would ecologically be most suitable for planting without fear of adverse impacts and were preferred during species selection. However, few introduced species (i.e: *Acacia auriculiformis*, *Albizia lebbbeck* etc.) bear high economic value as timber and were considered for planting in the greenbelt. Existing species composition as observed in the field was used as a good indication of the compatibility of the species to the location of planting.

Erosion-accretion analysis across a 40 year time span has identified locations along the coast that are erosion prone. Some mangroves have unique root system that traps sediments and speeds up accretion process which in turn deters erosion. Some of the common species within the study area that have this capability are *Nypa fruticans*, *Acanthus illicifolius*, *Bruguiera gymnorhiza* and *Xylocarpus mekongensis*.

Table 5.2: Physical and other relevant criteria of major plant species and greenbelt suitability thresholds

Plant Scientific Name	Plant English Name	Plant Type	Avg. height in 5 yrs. (m)	Max. Height (m)	Avg. DBH in 5 years (cm)	Max. DBH (cm)	Root Depth (m)	Height growth Rate (m/ year)	Survival Rate (%)	Origin	Erosion Control	Economic Benefit
Acanthus illicifolius	Holy Mangrove	Mangrove	0.75	1	2	2	0,5	0.2	50	Native	Yes	Low
Avicennia officinalis	Indian Mangrove	Mangrove	4	11	15	100	2	0.7	77	Native		Low
Bruguiera gymnorhiza	Black Mangrove	Mangrove	2	20	15	35	1-2	1	15	Native	Yes	Low
Excoecaria agallocha	Blinding Tree	Mangrove	6	15	20	30	1	1.5	74	Native		Moderate
Heritiera fomes	Sunder Tree	Mangrove	4	15	6	50	2	0.3	83	Native		Moderate
Nypa Fruticans	Nipa Palm	Mangrove	4	5	10	70	2	0.5	45	Native	Yes	High
Phoenix paludosa	Mangrove Date Palm	Mangrove	6	6	5.5	10	0.5	0.2	43	Native		Low
Sonneratia apetala	Mangrove Apple	Mangrove	6	15	15	50	2	1	80	Native		Moderate
Sonneratia caseolaris	Crabapple Mangrove	Mangrove	5	9	15	50	2	0.5	80	Native		Low
Xylocarpus mekongensis	Cedar Mangrove	Mangrove	3	18	8	100	2	0.3	83	Native	Yes	Moderate
Acacia auriculiformis	Papuan Wattle	Non-Mangrove	5	12	25	50	1.5	1.4	80	Introduced		High
Acacia nilotica	Gum Arabic Tree	Non-Mangrove	4	8	20	40	2	2	85	Introduced		Moderate
Albizia lebbek	Lebbek Tree	Non-Mangrove	5	30	20	100	2	0.7	46	Introduced		High
Albizia procera	White Siris	Non-Mangrove	4	11	20	60	2	0.85	33	Introduced		High
Areca catechu	Areca nut	Non-Mangrove	5	15	10	15	1-2	0.5	60	Native		High
Azadirachta indica	Indian Lilac	Non-Mangrove	3	14	8	30	1	0.5	40	Native		High
Borassus flabellifer	Palmyra Palm	Non-Mangrove	4	20	30	60	1.5	0.6	65	Native		Moderate
Casuarina equisetifolia	Coast She Oak	Non-Mangrove	6	30	15	50	1.5	1.5	90	Introduced		Moderate
Cocos nucifera	Coconut	Non-Mangrove	8	24	30	60	5	1	81	Native		High
Lagerstroemia speciosa	Queen Crape Myrtle	Non-Mangrove	3.5	14	10	40	1	0.8	60	Native	Yes	Low
Manilkara zapota	Sapodilla	Non-Mangrove	4	18	10	50	1.5	0.5	80	Native		High
Phoenix sylvestris	Date Palm	Non-Mangrove	5	15	30	40	1.5	0.6	82	Native		Moderate
Pithecellobium dulce	Manila Tamarind	Non-Mangrove	3	10	20	50	2	1.3	81	Introduced		Moderate
Pongamia pinnata	Indian beech	Non-Mangrove	4	9	15	50	2	1	92	Native		Moderate
Psidium guajava	Peyara	Non-Mangrove	3	10	10	25	1	0.5	55	Native		High
Samanea saman	Rain Tree	Non-Mangrove	6	15	25	200	3	1.5	32	Introduced		High
Swietenia mahagoni	Mahagony	Non-Mangrove	2.6	24	15	100	2.5	0.7	80	Introduced		Moderate
Terminalia arjuna	Arjun	Non-Mangrove	3	28	15	75	1.5	1	70	Native		Moderate
Selection Thresholds of the physical characteristics to determine suitable greenbelt Species	First Choice		5	6	15	50	1	1	70	Native	Yes	High
	Second Choice		4	5	10	30	0.5-1	0.5 - 1	40	Both	Yes	Moderate
	Third Choice		4	5	10	30	0.5-1	0.5 - 1	40	Both	No	Low

5.2.2. Environmental requirement of the plant

Trees that meet the requirements of the greenbelt must also be matched to locations that meet the environmental requirement of the trees themselves. For a tree to grow in its optimal condition it must have favorable environment. Only then it can be an effective component of the greenbelt and also produce economic benefits at an acceptable quality and quantity. These environmental conditions also demarcates areas that are either suitable for mangrove or for non-mangrove species. The environmental factors include soil properties like texture, salinity, and pH for non mangroves and water salinity, tidal conditions and sediment characteristics for the mangroves. However, soil data collected from Soil Resources Development Institute (SRDI) did not have pH data and extent and degree of tidal information was also unavailable.

Soil texture and sediment characteristics

Information on Soil texture in proposed Greenbelt Zone has been acquired from SRDI's Soil Texture Map, (2009). The soils of the coastal area have been grouped in to six soil texture classes. These are:

- a. Clay
- b. Clay Loam
- c. Loam
- d. Sandy Loam
- e. Sand and
- f. Silty Loam

According to texture profile, most of the leguminous trees (i.e. *A. procera*, *A. lebbeck*, *S. saman*, *A. auriculiformis*, *P. dulce*, *B. flabellifer*, *P. sylvestris* etc.) adapts well with wide range of soil texture whereas *C. equisetifolia* prefer sandy texture of soil. Other species like *S. mahagoni*, *C. nucifera*, *M. zapota* grow better in loam type soil texture (Table 5.3). Soil Texture of some area in Greenbelt zone was not available in SRDI map. This was more common in the dynamic areas around the islands where accretion process has created new lands since the soil survey was conducted. In such situation textural information of the immediate vicinity was used to fill the gaps. In some cases texture information noted during field visit was used as well.

There is notable variation in preferred sediment type and inundation condition within the mangroves common in Bangladesh coastline. Among the common mangrove species of Bangladesh, *Sonneratia* and *Avicenia* adapts best in newly accreted soft mudflats where regular tidal inundation occur twice a day but without drainage congestion. The site should have at least 0.3 m thickness of mud/silt deposition. The depth of tidal water between 0.75m and 0.9 m is considered to be beneficial for *Sonneratia* plantation (CEIP I, 2012), On the other hand, *Nypa* prefer the depressed inter-tidal area of canal/river bank which is flooded by shallow water. Other mangroves like *Heritiera*, *Xylocarpus*, and *Excoecaria* grow well in the intertidal area where the land is inundated by regular tidal effects in monsoon but water does not reach the forest floor in dry season. No comprehensive map of the sediment type along the coastline was available for this study to use. The landcover map produced for NFIP from interpretation of 2015 SPOT image was used to serve this need as it has delineated newly accreted mudflats, beaches/sand bars, intertidal muddy and intertidal sandy area. Another class identified in the landcover map as herb dominated areas are also essentially underlain by muddy sediment similar in nature to mudflats and are suitable for some mangrove species described above. This information was used to create a sediment type map that guided the selection of site specific mangrove species. A small part of the study area within the Meghna estuary was not covered by the NFIP output and these gaps were filled by taking information from Landsat 8 images of 2015.

Table 5.3: Suitable Soil condition for the preliminary selected species

Plant Scientific Name	Soil Texture	Sediment Type/Landcover
<i>Acanthus illicifolius</i>	N/A	Mudflats or Intertidal Muddy or Herb Dominated Area
<i>Avicennia officinalis</i>	N/A	Mudflats or Intertidal Muddy or Herb Dominated Area
<i>Bruguiera gymnorhiza</i>	N/A	Stable raised land
<i>Excoecaria agallocha</i>	N/A	Stable raised land
<i>Heritiera fomes</i>	N/A	Stable raised land
<i>Nypa Fruticans</i>	N/A	Mudflats or Intertidal Muddy or River and Khal
<i>Phoenix paludosa</i>	N/A	Stable raised land
<i>Sonneratia apetala</i>	N/A	Mudflats or Intertidal Muddy or Herb Dominated Area
<i>Sonneratia caseolaris</i>	N/A	Mudflats or Intertidal Muddy or Herb Dominated Area
<i>Xylocarpus mekongensis</i>	N/A	Stable raised land
<i>Acacia auriculiformis</i>	Clay/Clay Loam/Loam/Sandy Loam/Silty Loam	Beaches/Sand bar
<i>Acacia nilotica</i>	Clay/Clay Loam/Loam/Sandy Loam	N/A
<i>Albizia lebbeck</i>	Clay/Clay Loam/Loam/Sandy Loam	N/A
<i>Albizia procera</i>	Clay/Clay Loam/Loam/Sandy Loam	N/A
<i>Areca catechu</i>	Clay Loam/Loam/ Sandy Loam/Silty Loam	N/A
<i>Azadirachta indica</i>	Clay/Clay Loam/Loam/Sandy Loam/Silty Loam	N/A
<i>Borassus flabellifer</i>	Clay/Clay Loam/Loam/Sandy Loam/Silty Loam	N/A
<i>Casuarina equisetifolia</i>	Sand/Sandy Loam	Beaches/Sandbar or intertidal moist sand
<i>Cocos nucifera</i>	Clay/Clay Loam/Loam/Sandy Loam	N/A
<i>Erythrina ovalifolia</i>	loam/clay loam/Sandy loam	N/A
<i>Lagerstroemia speciosa</i>	loam/clay loam/Sandy loam	N/A
<i>Manilkara zapota</i>	Clay Loam	N/A
<i>Phoenix sylvestris</i>	Clay/Clay Loam/Loam/Sandy Loam/Silty Loam	N/A
<i>Pithecellobium dulce</i>	Clay/Clay Loam/Loam/Sandy Loam	N/A
<i>Pongamia pinnata</i>	Loam/Sandy Loam	N/A
<i>Psidium guajava</i>	Clay Loam/Loam/Silty Loam	N/A
<i>Samanea saman</i>	Clay Loam/Loam/Sandy Loam	N/A
<i>Swietenia mahagoni</i>	Loam/Sandy loam	N/A
<i>Terminalia arjuna</i>	Clay Loam/Loam/Sandy Loam/Silty Loam	N/A

Note: N/A=Not Applicable

Salinity

All soils contain some water soluble salts and this salt is absorbed by the plant as their nutrient, however, excessive accumulation of soluble salt in soil suppresses plant growth. As soil and water of coastal area are prone to salinity intrusion this is an important consideration for plant species selection. As with the other environmental parameters tolerance to soil or water salinity differ between species. For the mainland non-mangrove species, suitability is determined by soil salinity. On the other hand surface water salinity is a major parameter for the mangrove species as this type of plant are influenced by the tidal regime. Soil salinity of coastal area has been acquired from SRDI Soil Salinity Map and Surface water salinity has been acquired from a joint IWM and CEGIS (2007) study. As indicated earlier the gaps in SRDI soil salinity has been filled partially on the basis of neighborhood analysis. Gaps also exists in the surface water salinity data due the same reason of rapid accretion process where new lands now occupy areas previously part of the sea. Additionally the IWM and CEGIS study did not extend to the Chittagong coast in the southeast. These 'no data' areas were filled by some field data collected by CEGIS field team and by using proximity operation within GIS environment. Information on suitable soil salinity limit for each preliminary selected species has been collected from various literatures. Table 5.4 show the suitable soil salinity and surface water salinity limits for the common non-mangrove and mangrove species of the region.

Table 5.4. Soil and water salinity tolerance range for Common plant species in the study area

Non Mangroves		Mangroves	
Plant Scientific Name	Tolerable Soil Salinity Class	Plant Scientific Name	Suitable Water Salinity (ppt)
<i>Acacia auriculiformis</i>	Very Strongly saline	<i>Acanthus illicifolius</i>	15
<i>Acacia nilotica</i>	Strongly saline	<i>Avicennia officinalis</i>	13-31
<i>Albizia lebbbeck</i>	Strongly saline	<i>Bruguiera gymnorrhiza</i>	8-26
<i>Albizia procera</i>	Very Strongly saline	<i>Excoecaria agallocha</i>	15-30
<i>Areca catechu</i>	Very slightly saline	<i>Heritiera fomes</i>	4-15
<i>Azadirachta indica</i>	Very Strongly saline	<i>Nypa Fruticans</i>	1-10
<i>Borassus flabellifer</i>	Moderate Saline	<i>Phoenix paludosa</i>	15-27
<i>Casuarina equisetifolia</i>	Very Strongly saline	<i>Sonneratia apetala</i>	3-18
<i>Cocos nucifera</i>	Strongly saline	<i>Sonneratia caseolaris</i>	0-15
<i>Erythrina ovalifolia</i>	Strongly saline	<i>Xylocarpus mekongensis</i>	15-27
<i>Lagerstroemia speciosa</i>	Very slightly saline		
<i>Manilkara zapota</i>	Moderate Saline		
<i>Phoenix sylvestris</i>	Very slightly saline		
<i>Pithecellobium dulce</i>	Very Strongly saline		
<i>Pongamia pinnata</i>	Very Strongly saline		
<i>Psidium guajava</i>	Very slightly saline		
<i>Samanea saman</i>	Very Strongly saline		
<i>Swietenia mahagoni</i>	Slightly Saline		
<i>Terminalia ariuna</i>	Very Strongly saline		

Note: Tolerable Soil Salinity (Ds/m) Classes: 2-4= Very Slightly Saline, 4-8=Slightly Saline, 8-12=Moderate Saline, 12-15=Strongly Saline, >15=Very Strongly Saline

5.3. Selection of Suitable Plant Species

To select the ideal greenbelt trees the collected data on physical characteristics of the plant species (Table 5.2) were compared against the thresholds chosen such as the minimum height requirement or diameter at breast height (DBH), high economic benefit etc. These thresholds are also appended at the end of Table 5.3. A filtering operation was run on this table on the basis of these thresholds to select those species that matches the requirement

of the ideal greenbelt tree. The first run with all of these filters did not select any tree from the list of species. Only 1 tree species was selected when filters were run again but without erosion controlling capability as a parameter for the ideal tree. Then the filtering conditions were modified as shown on Table 5.5 and 1 tree was selected that met all of the criteria with this second choice threshold and 13 species were selected as suitable when erosion control was removed and introduced species were included in the second choice thresholds. Finally, a third run of the filter was performed with low economic benefit included in the filter and 15 species were found as suitable. These selected species are shown in Table 5.5 that also indicates which round of filtering selected them with the associated thresholds. It is evident that very few trees have erosion control capabilities and that has limited selection of more trees in the first rounds of filtering therefore it is also a useful approach to treat the erosion areas as 'hot spots' and develop a customized species selection method. The DSS based approach is more suited for such tasks.

Table 5.5: Selected Species for Greenbelt Development

Plant Scientific Name	Plant English Name	Selection Phase				
		1st Choice with Erosion Control	1st Choice without Erosion Control	2nd Choice with Erosion Control	2nd Choice without Erosion Control	3rd Choice without Erosion Control
<i>Avicennia officinalis</i>	Indian Mangrove					√
<i>Excoecaria agallocha</i>	Blinding Tree				√	√
<i>Nypa Fruticans</i>	Nipa Palm			√	√	√
<i>Sonneratia apetala</i>	Mangrove Apple				√	√
<i>Sonneratia caseolaris</i>	Crabapple Mangrove					√
<i>Acacia auriculiformis</i>	Papuan Wattle				√	√
<i>Acacia nilotica</i>	Gum Arabic Tree				√	√
<i>Albizia lebbeck</i>	Lebbek Tree				√	√
<i>Borassus flabellifer</i>	Palmyra Palm				√	√
<i>Casuarina equisetifolia</i>	Coast She Oak				√	√
<i>Cocos nucifera</i>	Coconut		√		√	√
<i>Manilkara zapota</i>	Sapodilla				√	√
<i>Phoenix sylvestris</i>	Date Palm				√	√
<i>Pithecellobium dulce</i>	Manila Tamarind				√	√
<i>Pongamia pinnata</i>	Indian beech				√	√

Note: "√"= Selected Species

5.3.1. Preparation of site-specific species suitability map

This shortlist of suitable species was then matched with their preferred environmental condition of soil texture and salinity for non-mangroves and water salinity and sediment types for mangroves. This produced tree or group of trees that were suitable for plantation at each location within the greenbelt.

The species suitability map preparation was done within ArcGIS software where data layers on soil texture, soil salinity, water salinity, and sediment type/landcover were integrated in one composite layer. A species suitability map of a part of the greenbelt zone is shown in Figure 5.1.



Figure 5.1: Species suitability map of a part of the greenbelt zone

The steps used in producing the species suitability map are as follow. Manual cross-checking and validation of data was done before and after running each of these GIS analyses steps.

- Overlay operation was done using landcover, surface salinity, soil salinity, and soil texture data layer on previously generated green belt layer to create a composite data layer that integrated attribute data from all layers. This was done in several steps when each of these layers was overlaid on the greenbelt map and 'identity' operation was carried out between each of the criteria layers and greenbelt layer to build the attribute table of the greenbelt layer.
- 'Query' operation was run on this composite data layer on the basis of the criteria selected as 'ideal for greenbelt' (Table 5.2). 'Select by Attribute' operation was used to produce this output.
- Applied attribute selection method in GIS to determine suitable species for every location within the proposed Green belt.
- Combine all species suitable for one location to create group species maps for that location
- 'No data' polygons were filled primarily by using 'polygon neighbors proximity analysis' (200m). Areas that still contained 'no data' polygons were then filled by using species composition noted during CEGIS field team visits.

5.4. Tree species Comparison within DSS

Tree species selection is also a component of the DSS that will allow modification and addition of new species as deemed necessary in a future scenario where the existing environmental may change under a changing climatic condition. This selection process follow

a similar 'utility value' approach as discussed in the greenbelt delineation with DSS topic in Chapter 4.

Tree species needs comparison in two manners. First they need to be compared in terms of their suitability to meet the requirement of the greenbelts including to protect and also to produce benefits. These will shortlist the trees. Then, if they were in principle suitable to serve in greenbelts, each tree species on the short list needs a comparison in terms of suitability at each location so that in a location only the more suitable trees are planted.

A list of tree species from the Species Profile Database was placed in a spreadsheet and filtered to a shortlist of suitable trees according to the criteria in Table 5.2. These criteria were the same ones as discussed earlier that included tree height, width, growth rate, root type, economic benefit etc.

In as far as the suitability analysis of locations for different tree species is concerned; the same methods and DSS tool was adopted as the greenbelt development prioritization, spatial multi-criteria evaluation. Now a single generic evaluation model (Figure 5.2) was developed to be used for all trees in the short list. Only the settings of utility graphs and weights could differ according to environmental conditions in which the specific tree species would thrive.

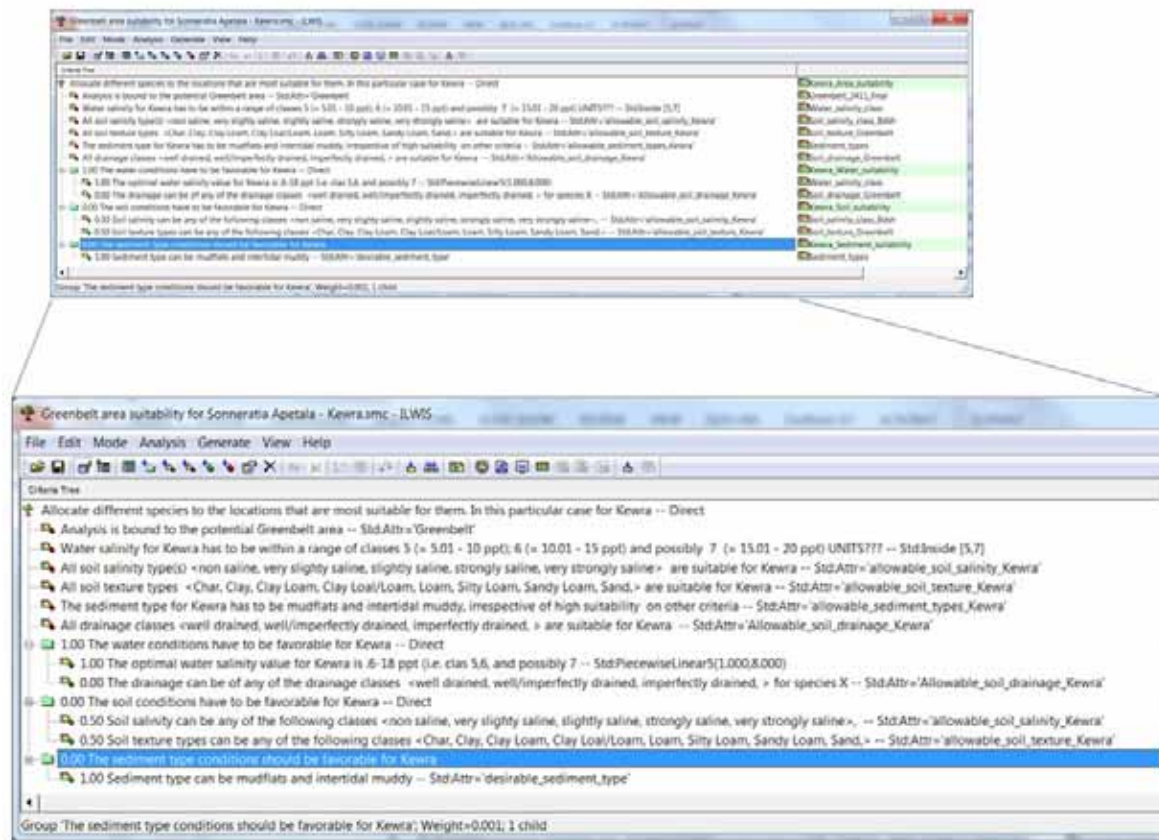


Figure 5.2. Criteria tree template for to be used by all tree species shortlisted for greenbelt development

An example of species selection using DSS is shown in Figure 5.3 using a hypothetical tree 'A' where green color indicates areas where this species would be most suitable with a utility value of 1.00 and orange area where it is least suitable with an utility value of 0.25.

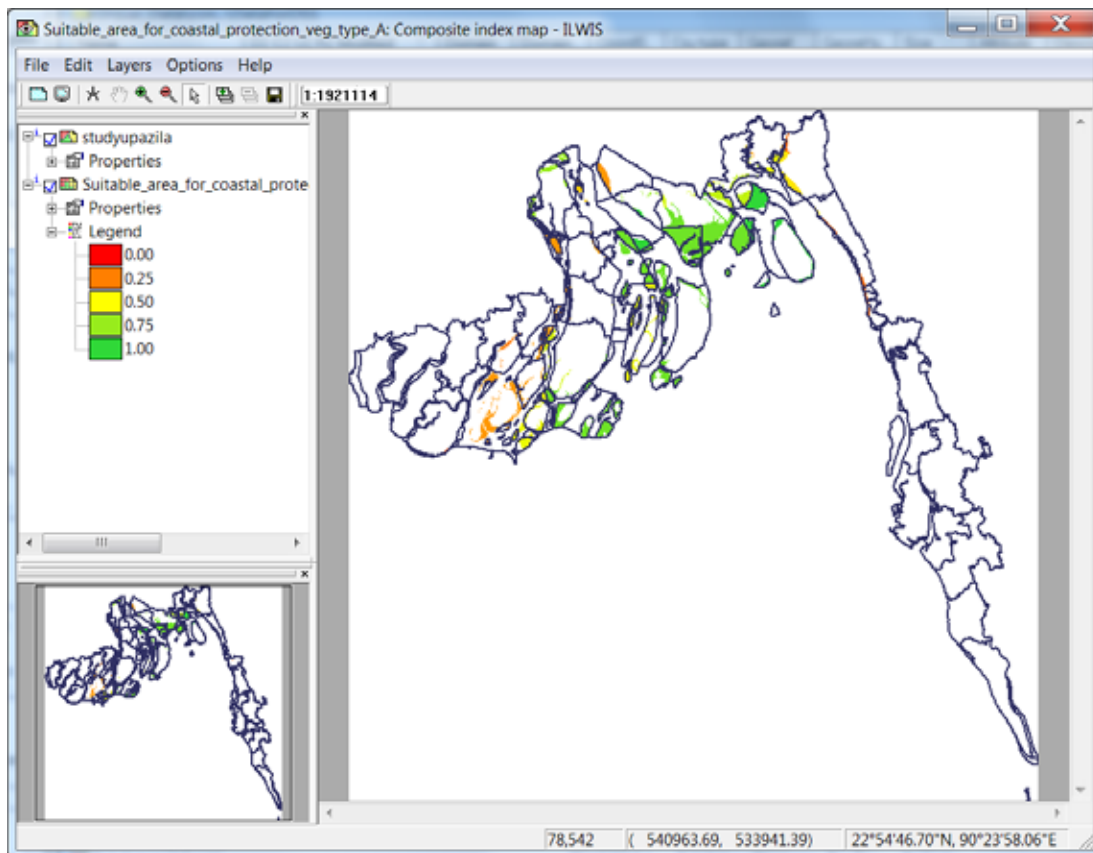


Figure 5.3: Example of Tree suitability calculation within the DSS

5.5. Planting Design

The selected list of mangroves contains very few species and their suitability is limited by the environmental condition. Hence there is not much flexibility in preparing a planting design for them. However, among the non-mangroves alternate choices are available for planting in the same location and a planting design can be useful in getting optimum economic return. A design for planting the selected non-mangrove species inside the Greenbelt has been prepared to achieve the primary 'protective' objective of the greenbelt and the 'productive' economic benefit goal to encourage local participation and to offset the cost of greenbelt establishment.

The following are the criteria which were considered in the planting design of the proposed Greenbelt development:

- Species arrangement according to land condition
- Rotation period of selecting species
- Spacing between saplings
- Economic return

The species arrangement for the mangrove and non-mangrove on the basis of land (slope and sediment/soil) condition is presented in Figure (5.4).

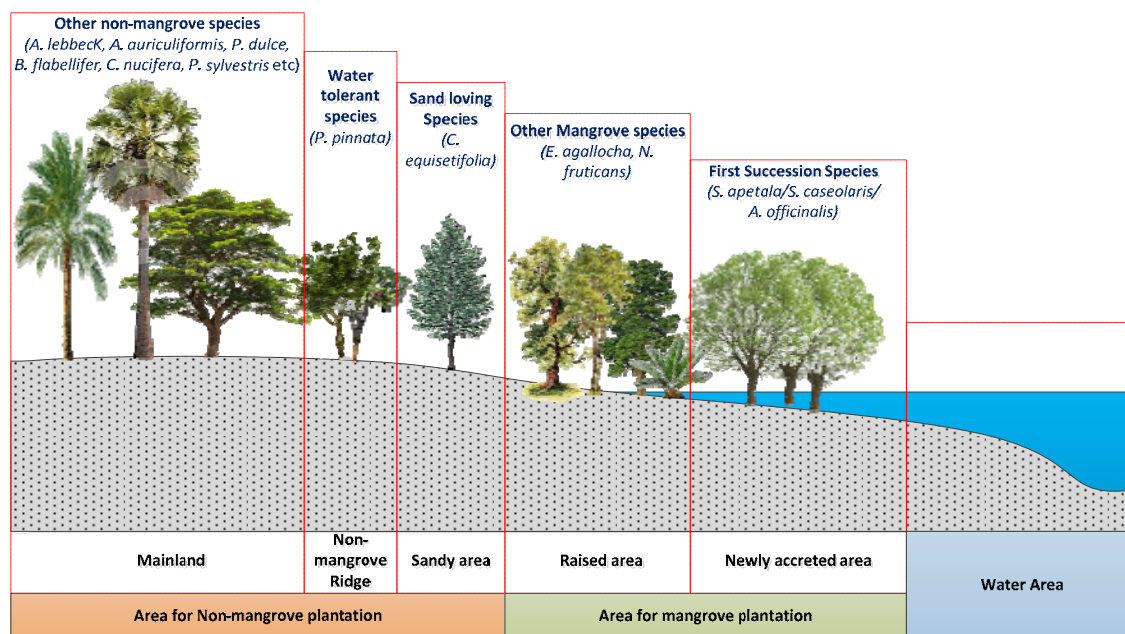


Figure 5.4: Species arrangement according to land condition

Plant rotation is the successive felling of different species in a specified order on the same land. This is usually done to ensure a healthy forest when old trees are cleared to plant new ones. It also provides economic benefit when timber of the felled trees generates monetary income. For the proposed greenbelt, 2 types of plant rotation is being proposed, a group of short rotation trees to be replaced in 15 years and a set of long rotation trees lasting 25 years. The rotation is designed such that the felling by rows of trees would never impair the greenbelts ability to provide protection. The water tolerant species, *Pongamia pinnata* is will be a long rotation tree to be planted at the transition zone between mangroves and non-mangroves (at non-mangrove ridge). Rotation period of different non-mangrove species are listed in table 5.6:

Table 5.6: Rotation period of non mangroves species

Rotation Period	Species Name
Long Rotation (25 Years)	<i>Borassus flabellifer</i> , <i>Cocos nucifera</i> , <i>Manilkara zapota</i> , <i>Phoenix sylvestris</i> , and <i>Pongamia pinnata</i>
Short Rotation (15 Years)	<i>Acacia auriculiformis</i> , <i>Acacia nilotica</i> , <i>Albizia lebbeck</i> , <i>Casuarina equisetifolia</i> , and <i>Pithecellobium dulce</i>

Presently, Bangladesh Forest Department implements planting with spacing of 1.5X1.5m for mangrove plantations and 2.0X2.0m for non-mangrove and Nipa Palm plantations. For the mangrove portion of the Greenbelt, the existing spacing is 1.5 will be followed which will result into 4,444 of mangrove seedlings to be planted in one hectare.

To provide economic benefit to the local people to encourage participatory management, planting spacing is proposed at 3.04 m (10 ft) for non-mangrove in the mainland area. Figure 5.5 and 5.6 shows an idealized planting design created for a 100 m x 100 m block within the non-mangrove part of the greenbelt. This design is to be repeated throughout the greenbelt with some variation in tree choices from the list of suitable trees based on local environmental condition. The proposed wider spacing of planting will provide room for shallow canals to be dug between the rows where culture fishery will be implemented inside the Greenbelt. Canal width and depth is considering 1.52m (5ft) and 0.914 m (3ft) respectively to culture the fishes those required shadow and shallow depth of water (Figure 5.5 and 5.6). *Heteropneustes fossilis* (Stinging Catfish), *Clarias batrachus* (Freshwater

Catfish) and *Anabas cobojus* (Gangetic Koi) is suitable for such environment in shallow depth and covered by the shade of the greenbelt trees (Das, 2016 personal communication)

Additional innovative part of the planting design includes planting of palms (*C. nucifera*, *B. flabellifer*, *P. sylvestris*) in 3 consecutive rows where the narrow canopy of the palms will allow enough sunlight to practice horticulture in those three rows to keep provision for vegetable cultivation within the plants rows. These three rows will be repeated three times within 100 m allowing 9 rows for vegetable gardens (Figure 5.5). Shaded area within the two rows of long rotation and short rotation trees will be used to cultivate shade tolerant spices like Turmeric and Ginger where the environmental condition is suitable for these economically beneficial crops. Where the palm species are unsuitable only aquaculture and spice planting will be practiced (Figure 5.6). It is believed that the inclusion of fishery, horticulture and spice planting within the greenbelt will generate sufficient income to attract the poorer segment of the coastal community to be highly enthusiastic about participation in establishing and maintaining the greenbelt through perpetuity. Additionally this will add to the economic benefit to be derived from the greenbelt to offset cost of building it without jeopardizing its protective role.

The planting design also recommends that each successive row will have a measured offset of 0.762m (2.5 ft) creating a zig-zag pattern so that within 100 m. a wall of trees without any gaps is created. This will prohibit water and wind surges to proceed inland further enhancing the 'protective' capacity of the greenbelt against cyclones. Roads are also considered in this planting design to provide vehicular communication from the inner boundary of the greenbelt to the seashore after every 1-5 Km. Besides everyday access these roads will also allow tourists to visit the seashores.

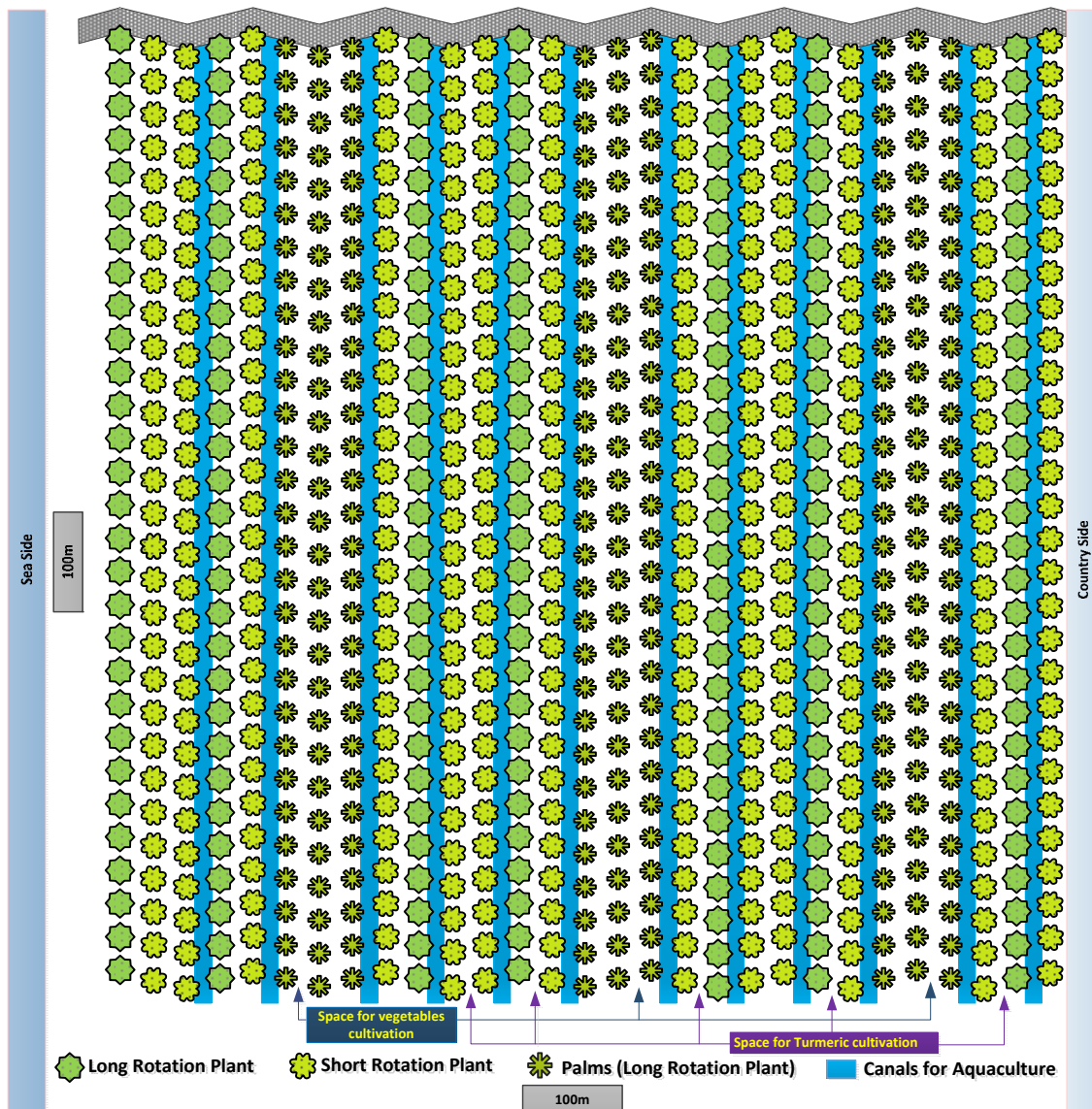


Figure 5.5: Typical planting design of non-mangrove mainland plantation with Palms for a 100m X 100m block of greenbelt

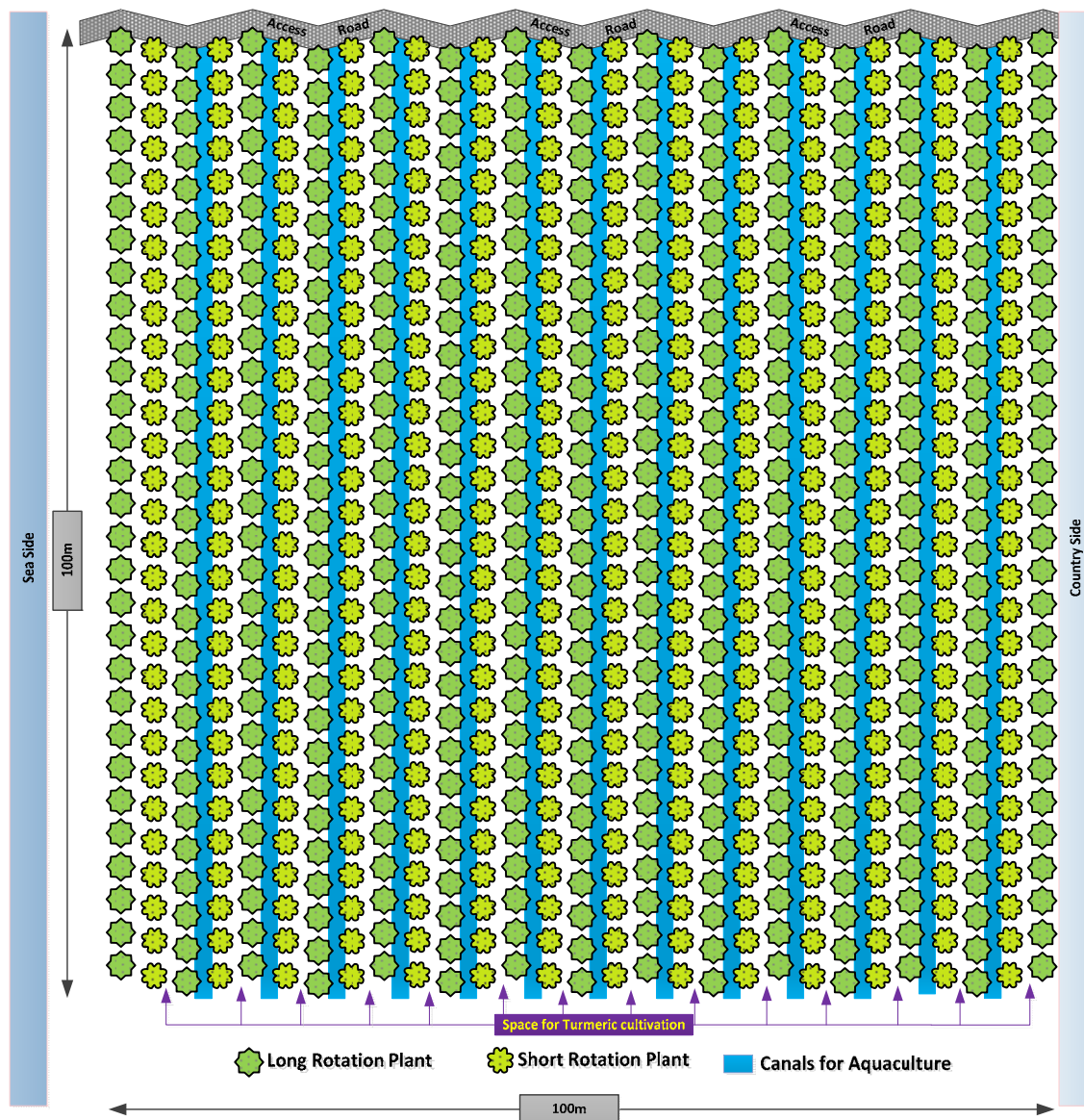


Figure 5.6: Typical planting design of non-mangrove mainland plantation without Palms for a 100m X 100m block of greenbelt

5.6. Sources of Planting Materials

Presently planting materials (seeds and seedlings) are collected from local sources. Existing mangrove forest patches of coastal area are the main source for seed and seedlings for mangrove species. Seeds of non-mangrove species are also collected from local markets and Forest Department's established nurseries. It was gathered from the discussion with Coastal Forest Department officials that local sources are capable of providing necessary seeds of all suitable species; both mangrove and non-mangroves. For the mangrove species the Department raises temporary nurseries at available foreshore areas near to the planting sites and produce required seedlings. But to achieve the massive plantation for the proposed Greenbelt development, it will be necessary to expand the existing nursery capacity of BFD or collect seedling from private nurseries. The general recommendation from BFD official is to maintain the seedling/sapling for 1 year at the nursery site to develop good tap roots which will allow the sapling become stronger when transplanted at their final location within the greenbelt.

5.7. Establishment of plant nurseries

Coastal Forest Divisions of Bangladesh raises 2 types of plant nurseries, a) Nursery for mangroves and b) Nursery for non-mangroves.

Generally, temporary nursery is established by Bangladesh Forest Department for mangrove species according to seedling requirement. Site for the nursery should be subjected to the tidal inundation throughout the year where having 0.3 m - 0.6 m. depth of silt deposition along the river or canal and connected with a natural canal for water drainage. The site should not be exposed to the direct action of sea water. The depth of tidal water should be between 0.75m and 0.9 m for good results (CEIP I, 2012). Natural regeneration of *Sonneratia* spp (Mangrove Apple and Crabapple Mangrove), *Oryza coarctata* (Dhanshi) etc. is an indication of suitable plantation site at river foreshore area subject to regular inundation and silt deposition. The ideal spacing of seed swing is 1.5m x 1.5m. After site selection, the area is to be surveyed, demarcated and a pre-planting map is to be prepared. The selected site is to be cleaned by cutting grass, removing debris etc. for a successful seedbed. Then collected seeds should be planted at the nursery site. The required land for mangrove nurseries will be selected at the available foreshore area near to the proposed planting sites considering above mentioned land criteria during one year timeframe for most of the suggested species.

Non-mangrove nurseries can be established at local private premises or at own premises of BFD's various Coastal Forest Division offices. Presently, BFD acquires non-mangrove seedlings through both ways most of which are prepared by polybag nursing.

6. Development of Investment Plan

6.1. Introduction

Coastal Greenbelt is a 'soft' measure considered to break cyclonic storm surges and wind speed, prevent coastal erosion, and reduce other natural hazards by creating mangrove (protective) and non-mangrove (productive) forests along the climate vulnerable coastal areas of Bangladesh. The Greenbelt investment plan is the process of development and clarification of Investment activities in specific vulnerable areas of coastal zone. With a view to provide protection against natural disaster in coastal zone forest development applying participatory planning and management method to establish greenbelt (mangrove and non-mangrove forests) has been planned. In this regards, expanding greenbelt, i.e., coastal afforestation program with mangrove planting in accreted land in the specified shoreline and non-mangrove forestry in land facing areas (behind the mangrove forest) will be established. Cost benefit analysis of the investment plan has been carried out accordingly,

6.2. Development of Project

A greenbelt will ideally represent a multipurpose investment, in terms of stabilizing a fragile and unconsolidated seafront in the coastal belt, while at the same time functioning as a wind barrier where necessary, providing shade and protection, enhancing the landscape for recreation, tourism and providing opportunities for economic returns to traditional coastal communities.

The scope of the investment aligns with the Bangladesh Climate Change Strategy and Action Plan in achieving climate resilient participatory afforestation and reforestation goals. It also matches with directives of the Forestry Master Plan (1993-2012) that calls for protection of the country against natural disasters.

The United Nations has published 17 Sustainable Development Goals (SDGs) to guide the role of public sector development. SDG 13 states 'Take urgent action to combat climate change and its impact (UNO, 2015)', which is relevant with the proposed project. As a soft measure to combat against climate change, afforestation and reforestation activities, the Bangladesh Forest Department (BFD) will establish Greenbelt to reduce the intensity of climate vulnerability (cyclones). Residents of the adjacent coastal community will be participating in the project.

6.2.1. Location of the Project

The investment activity will cover 37 upazilas of 9 coastal districts of Bangladesh. The area of this proposed greenbelt has been delineated as described earlier in Chapter 4 of this report.

6.2.2. Major Components

The project covers many aspects of Greenbelt establishment which concentrate around three major components with operationalised social forestry principle in all categories of afforestation activities. Thus a portfolio of a range of investment activities in the specific locations in the coastal zone is made. All spatial parameters used in developing the investment plan and performing economic analysis are presented in Table 6.1. The table highlights the major factors used in calculating the financial costs and benefits of the greenbelt. It includes the area to be covered by the greenbelt, the ownership category of that land, the length of embankment behind the greenbelt, the types of plantation (mangroves and non-mangroves), income generating and livelihood diversification measures within the non-mangrove area based on the planting design discussed in chapter 5 and the cropped area

behind the belt. The data is presented for greenbelt portion along the coastline of each of the 37 upazilas.

Table 6.1: Greenbelt Forest and Land Distribution by Upazila

Location		Upazila Population	Embankment (km)	Embankment with reduced maintenance cost due to greenbelt (km)	Land Tenure (ha)						Greenbelt Area (ha)	Mangrove (Protective) Plantation (ha)			Non-Mangrove (Productive) Plantation Area Distribution (ha)						HYV AmanDamage Save area (ha)
District	Upazila				Khas	To be Acquired	% of acquired land	Private	Leased	Total		Mangrove (Protective) Plantation (ha)			Non-Mangrove plantation			Livelihood Diversification measures			
												Total Mangrove	Mangrove	Golpata	Total non-mangrove & Livelihood	Palm	Others	Fish Culture	Turmeric	Vegetable gardening	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Barguna	Amtali,	270,802	248	10	693	340	0	340		1,033	1,041	302	279	23	739	12	342	162	213	10	2,175
	BargunaSadar	261,343	260	23	868	605	0	605		1,473	1,473	100	90	9	1,373	111	541	294	333	95	1,389
	Patharghata	163,927	124	30	717	1,476	1	1,476		2,193	2,206	497	457	40	1,709	185	622	363	381	159	591
Pirojpur	Mathbaria	262,841	34	14	424	705	1	705		1,129	1,129	97	4	93	1,033	-	496	227	310	-	482
Bhola	BholaSadar	430,520	40	14	2,110	6,043	1	5,912	131	8,153	8,093	2,282	2,072	211	5,810	685	2,055	1,229	1,253	588	1,153
	Burhanuddin	233,860	12	12	986	3,132	1	3,034	98	4,118	4,038	914	825	89	3,124	437	1,031	656	625	375	834
	Char Fasson	546,437	100	38	6,067	6,607	1	6,535	72	12,674	12,764	4,623	4,163	459	8,142	186	3,708	1,778	2,309	160	570
	Daulathkhan	168,567	18	3	2,384	2,044	0	2,024	20	4,428	4,427	2,107	1,916	191	2,320	286	807	490	492	245	323
	Lalmohan	283,889	33	27	978	3,951	1	3,220	731	4,929	4,938	1,148	1,037	111	3,790	339	1,456	810	895	291	267
	Manpura	76,582	69	36	3,075	4,391	1	3,770	621	7,466	7,464	2,878	2,609	270	4,586	43	2,155	1,006	1,345	37	15
	Tazumuddin	126,940	11	5	6,957	1,366	0	1,366		8,323	8,321	2,991	2,729	262	5,330	607	1,908	1,129	1,165	520	116
Feni	Sonagazi	262,547	55	-	806	-	-			806	805	745	745	-	60	6	22	13	13	6	444
Lakshmipur	Kamalnagar	222,915	49	2	165	803	1	803		968	973	320	288	32	653	91	215	137	131	78	73
	Ramgati	261,002	40	8	2,144	1,791	0	1,791		3,935	4,001	940	846	94	3,061	343	1,101	649	673	294	111
Noakhali	Companiganj	250,579	75	6	3,476	1,504	0	1,504		4,980	4,981	2,969	2,935	34	2,011	-	965	442	603	-	1,073
	Hatiya	452,463	100	29	7,563	5,068	0	3,479	1,589	12,631	12,647	5,576	5,050	525	7,072	290	3,084	1,535	1,914	249	235
	Subarnachar	289,514	66	-	2,698	182	0	182		2,880	2,879	1,271	1,271	-	1,608	156	605	343	371	134	61
Patuakhali	Dashmina	123,388	95	16	2,216	2,173	0	1,821	352	4,389	4,390	1,653	1,489	164	2,736	101	1,205	595	749	87	77
	Galachipa	361,518	401	90	5,726	5,863	1	3,153	2,710	11,589	11,584	3,212	2,973	240	8,371	127	3,882	1,833	2,420	109	1,622
	Kala Para	237,831	307	32	2,880	219	0	219		3,099	3,099	346	326	20	2,753	105	1,209	598	751	90	8,741
Chittagong	Mirsharai	398,716	60	-	539	67	0		67	606	606	505	505	-	101	11	37	21	23	9	2,934
	Sandwip	278,605	44	-	4,811	3,649	0	3,649		8,460	8,459	5,491	5,490	1	2,968	-	1,425	653	890	-	145
Chittagong	Anwara	259,022	75	8	204	550	1	524	26	754	751	75	75	-	676	18	306	147	190	15	2,989
	Banshkhali	431,162	168	16	526	532	1	532		1,058	935	247	247	-	689	82	243	146	148	70	3,021
	Chittagong Port	208,260	7	2	127	-	-			127	127	63	63	-	64	7	24	14	15	6	4
	Halishahar	151,515	4	3	153	115	0	115		268	268	141	141	-	127	1	61	28	38	0	51
	Pahartali	190,637	4	1	57	-	-			57	57	22	22	-	36	2	15	8	10	1	11
	Patenga	132,677	15	8	429	409	0	409		838	838	149	149	-	689	96	227	145	138	83	134
	Sitakunda	387,832	51	12	1,467	1,586	1	1,494	92	3,053	3,052	740	740	-	2,313	1	1,110	509	693	1	1,372
Cox's Bazar	Chakaria	474,465	123	-	141	30	0	17	13	171	171	4	4	-	166	-	80	37	50	-	1,866
	Cox's bazar sadar	459,082	84	14	865	680	0	669	11	1,545	1,540	118	118	-	1,422	-	683	313	427	-	1,450
	Kutubdia	125,279	39	35	1,162	1,879	1	1,856	23	3,041	3,039	388	388	-	2,651	152	1,110	572	687	130	517
	Maheshkhali	321,218	100	12	796	763	0	661	102	1,559	1,527	431	431	-	1,096	108	411	234	252	92	1,181
	Pekua	171,538	105	12	245	574	1	563	11	819	813	172	172	-	641	90	211	135	128	77	2,398
	Ramu	266,640	20	-	149	-	-			149	149	6	6	-	143	-	69	31	43	-	2,975
	Teknaf	264,389	54	-	1,563	763	0	573	190	2,326	2,339	8	8	-	2,331	-	1,119	513	699	-	2,087
	Ukhia	207,379	8	-	585	241	0	241		826	825	40	40	-	785	-	377	173	235	-	2,247
Total		10,015,881	3,098	518	66,752	60,101		53,242	6,859	126,853	126,748	43,568	40,701	2,867	83,180	4,679	34,913	17,965	21,612	4,010	45,734

6.2.3. Economic Analysis

The main objective of the investment plan is to measure the worth of the coastal greenbelt development through participatory planning/monitoring and to contribute in the resilience of coastal communities to climate change. With a view to expanding the greenbelt in the shoreline and expanding social forestry program on khas and private lands is the main purpose of the plan. This analysis also attempts to estimate the potential economic value of mangrove and non-mangrove afforestation resources.

6.3. Investment Cost of the Greenbelt Establishment

The greenbelt with mangrove and non-mangrove plantation will be established in three phases using about 126,853 ha land for a period of seven years. The area comprises of 66,752 ha. of khas land, and 60,101 ha., either of private ownership or khas land leased by private owners. It may be mentioned here that single crop area benefit will be foregone due to land acquisition. It is estimated to be 1,784 BDT million (=benefit 29,680 BDT/ha x 60,101 ha) annually and to be continued for a period of 30 years (the time horizon of the plan). The lost benefit as cost to the greenbelt development and the same is included in cash flow analysis.

Total Investment cost of the plan is prepared and updated based on unit cost rate of mangrove and non-mangrove plantation using the data collected from government publication, field surveys, consultation with BFD officials, generated by this study, and from relevant current market rates constant at 2015 prices.

Two alternate investment plans has been produced in establishing the greenbelt. In both plans greenbelt development on khas lands will only require the actual cost of plantation and necessary preparatory activities. The two plans vary on the mechanism of how the private lands will be put under the greenbelt. The first plan is based on Public Private Partnership (PPP) concept where the ownership of 60,101 hectare of private land will remain with their owners and BFD will develop the greenbelt under a profit sharing agreement. In the second plan government will acquire and own all private lands within the proposed greenbelt and bear the cost of resettlement of the owners of the homestead. Total cost of the greenbelt development stands at 20,915 million BDT in the plan where land ownership remains with the original owners and 260,407 million BDT if government acquires and takes ownership of all private lands. In the subsequent text plan one is referred to as the 'without acquisition' plan and plan two as the 'acquisition' plan. The acquisition plan will cost 12.5 times more than plan without acquisition. Benefits are exactly the same for both plans as the productive (benefit generating) activities of the greenbelt will follow the same design presented in figure 5.5 and 5.6 regardless of the ownership type of the private lands. As the Land acquisition and resettlement component is the most significant cost of plan two (approximately 93% of the cost), plan one ('without acquisition' plan) is the preferred option and it is feasible and attractive according to all financial and economic indicators.

The 'without acquisition' plan will require the private landowners to forego the benefit they currently receive from their lands which are primarily single-crop land where HYV Aman is grown bringing in 29,680 BDT/year of earning per hectare of land. In return the same lands can produce earning of 139,000-160,000 BDT/year from aquaculture and horticulture, when greenbelt will be developed in those lands following the planting design recommended in figure 5.5 and 5.6. However, realistically these benefits will be available at the end of year three so the owners will have to be provided compensation at the rate of their foregone crop earning (29,680 BDT/yr) for the first two years of greenbelt development for the 50,189 hectares of cropland within the proposed greenbelt. On the other hand, per hectare benefit will rise even more by year 15 when palms and timber producing trees will become ready for harvesting. This compensation and the prospect of earning significantly larger sum from year three onwards through the life of the greenbelt should be a strong incentive for the landowners and encourage them to voluntarily join the 'without acquisition' plan of

establishing the greenbelt. Table 6.2 compares the annual earning to be had from one hectare of land through various income generating activities within the greenbelt as opposed to income from a single crop of HYV Aman as is the current practice.

Table 6.2: Benefit (per ha.) comparison from current single-crop landuse and diversified landuse within the proposed greenbelt

Benefit from landuse within greenbelt when 100% of the land is under same activity				
Activities	Direct Tangible Net Benefits (BDT/ha)			Assumptions Sources and Description of benefits.
	Financial	SCF	Economic	
Palm (from year 14)	338,000	0.902	304,876	Average number 65/year. Local price 20/coconut. Plantation cost BDT1125/ha. Expert opinion:
Timber output(from year 15)	87,799	0.902	79,194	Sale Taka/ha for 580 no. with short and long rotation After 15 and 25 years.
Fish culture (from year 3)	660,760	0.902	596,006	Net benefit. CEGIS expert's data.(culture of Kai needs 4 months duration and Magur 8 months duration).
Turmeric production (from year 3)	29,352	0.902	26,475	Net benefit per ha. Khanam (2009).
Vegetable production(fro m year 3)	132,000	0.902	119,064	Net benefit as per Field data and also from BARI.
Benefit accrued from Year 3 (based on recommended planting design – diverse activities)				
Without Palm				
Fish culture	145,367	0.902	131,121	Fish culture covers 22% of a ha.
Turmeric	8,806	0.902	7,943	Turmeric covers 30% of a ha.
Total	154,173		139,064	
With Palm				
Fish culture	138,760	0.902	125,161	Fish culture covers 21% of a ha.
Turmeric	5,870	0.902	5,295	Turmeric covers 20% of a ha.
Vegetable	15,840	0.902	14,288	Vegetable covers 12% of a ha.
Total	160,470		144,744	
Benefit from current practice of single-crop				
Single crop HYV Aman benefit 29,680 BDT per year	29,680	0.902	26,771	Crop land is about 50189 ha. single crop area.

For land acquisition, average of land price declared by the Government of Bangladesh (GoB) has been estimated from the proposed greenbelt covered mouzas of Tazimuddin upazila of Bhola District. The land price data has been collected from the Upazila land registration office. Resettlement cost has been prepared in reference to the rates of the Padma Multipurpose Project. Other relevant costs are estimated based on assumptions and information available. The costs also include those for land preparation, developing the plantation including nursery and maintenance, logistics and human resources monitoring and evaluation, and contingencies. In the next sections the cost and benefit details are reported in several tables for both plans. For ease of comprehension each table is presented

as a set of two, first one for the 'without acquisition' plan and next one for the 'acquisition' plan. Details of the investment costs are given in Table 6.3 and 6.4.

Table 6.3: Investment cost of the Greenbelt project – without acquisition plan

	Components	Unit	Quantity	Unit Cost BDT	1,000,000 Financial Cost BDT million	SCF	Economic cost BDT million	% of base cost	Assumptions/ Sources
A	Preparatory work of Greenbelt								
1	Crop Compensation	ha	50,189	59,360	2,979	0.902	2687		For first two years. @ 29680 BDT per ha /year
2	Survey and investigation	ha	126,748	100	13	0.902	11		
					0	0.902	0		With reference to Padma Bridge Project. Needs RAP Study
	Subtotal				2,992		2,699	14.57%	
B.	Plantation Development (including 3 year maintenance)								Sources:
1	Mangrove	ha	40,701	48,815	1,987	0.902	1792		DPP of CRPAR Project of FD
2	Goalpata (Nipa Palm)	ha	2,867	370,000	1,061	0.902	957		CEIP-I BWDB: Afforestation Report
3	Palm	ha	4,679	32,500	152	0.902	137		Consultants team of CEGIS
4	Non-Mangrove (Including Jhaw species)	ha	34,913	207,442	7,243	0.902	6533		DPP of CRPAR Project of FD
5	Ditch earthwork (avg 1531 m3/ha for 17965 ha)	m3	27,505,010	250	6,876	0.902	6202		Consultants team of CEGIS
	Subtotal				17,319		15,621	84.33%	
C.	Logistics								
1	Furniture	per FD	5	200,000	1	0.902	1		
2	Equipment and computers	per FD	5	500,000	3	0.902	2		
3	Speed Boat (1 boat for each of the concerned FD)	no	5	800,000	4	0.500	2		including tax 100% of cif value. Economic value is on cif
4	Jeep (1 jeep for each of the concerned FD)	each	5	8,500,000	43	0.42	18		including tax 140% of cif value. Economic value is on cif
5	Motor cycle	each	10	200,000	2	0.71	1		including tax 40% of cif value. Economic value is on cif
	Subtotal				52		24	0.25%	
D.	Human Ressources Development								
2	Local Training to FD officials (20 participants in each	batch	10	400,000	4	0.902	4		

	Components	Unit	Quantity	Unit Cost BDT	1,000,000 Financial Cost BDT million	SCF	Economic cost BDT million	% of base cost	Assumptions/ Sources
	of 5 coastal FD)								
3	Local Training for Beneficiaries	BDT/ha	126,748	200	25	0.902	23		
	Subtotal				29		26	0.14%	
E.	Monitoring and Evaluation								
1	Socio-economic survey (baseline) and Monitoring	BDT/U pazila	37	1,000,000	37	0.902	33		Monitoring is to be continuous.
2	Evaluation Studies	BDT/U pazila	37	1,000,000	37	0.902	33		
	Subtotal				74		67	0.36%	
F.	Consulting Services								
	International	BDT/ha	126,748	400	51	0.902	46		
	Local	BDT/ha	126,748	100	13	0.902	11		including support staffs
	Subtotal				63		57	0.31%	
G.	Recurrent costs								
	Incremental Staff costs (salaries and others)								To be in kind provided by FD
	Office running cost	BDT/year/FD	5	600,000	3	0.902	3		
	O&M of equipment and vehicle during implementation	BDT/year/FD	5	800,000	4	0.902	4		
	Subtotal				7		6	0.03%	
	BASE COSTS				20,536		18,501	100%	
	Physical contingencies (1 % of Plantation cost)				173	0.902	156		
	Price Contingencies (1 % of base cost)				205	0	0		
	TOTAL PROJECT COST				20,915		18,657		

Table 6.4: Investment cost of the Greenbelt project – acquisition plan

	Components	Unit	Quantity	Unit Cost BDT	1,000,000 Financial Cost BDT million	SCF	Economic cost BDT million	% of base cost	Assumpti ons/ Sources
A	Preparatory work of Greenbelt								
1	Land Acquisition	ha	60,101	1,059,828	63,697	0.902	57454		Avg of GoB land price estimated based on Greenbelt related mouzas of Tazimuddin upazila of Bhola District. Upazila land

	Components	Unit	Quantity	Unit Cost BDT	1,000,000 Financial Cost BDT million	SCF	Economic cost BDT million	% of base cost	Assumptions/ Sources
									registration office.
2	Survey and investigation	ha	126,748	100	13	0.902	11		
3	Resettlement cost (Settlement area)	ha	19,597	9,001,540	176,403	0.902	159116		With reference to Padma Bridge Project. Needs RAP Study
	Subtotal				240,113		216,582	93.19%	
B.	Plantation Development (including 3 year maintenance)								Sources:
1	Mangrove	ha	40,701	48,815	1,987	0.902	1792		DPP of CRPAR Project of FD
2	Goalpata (Nipa Palm)	ha	2,867	370,000	1,061	0.902	957		CEIP-I BWDB: Afforestation Report
3	Palm	ha	4,679	32,500	152	0.902	137		Consultant's team of CEGIS
4	Non-Mangrove (Including Jhaw species)	ha	34,913	207,442	7,243	0.902	6533		DPP of CRPAR Project of FD
5	Ditch earthwork (avg 1531 m3/ha for 17965 ha)	m3	27,505,010	250	6,876	0.902	6202		Consultant's team of CEGIS
	Subtotal				17,319		15,621	6.72%	
C.	Logistics								
1	Furniture	per FD	5	200,000	1	0.902	1		
2	Equipment and computers	per FD	5	500,000	3	0.902	2		
3	Speed Boat (1 boat for each of the concerned FD)	no	5	800,000	4	0.500	2		including tax 100% of cif value. Economic value is on cif
4	Jeep (1 jeep for each of the concerned FD)	each	5	8,500,000	43	0.42	18		including tax 140% of cif value. Economic value is on cif
5	Motor cycle	each	10	200,000	2	0.71	1		including tax 40% of cif value. Economic value is on cif
	Subtotal				52		24	0.02%	
D.	Human								

	Components	Unit	Quantity	Unit Cost BDT	1,000,000 Financial Cost BDT million	SCF	Economic cost BDT million	% of base cost	Assumpti ons/ Sources
	Ressources Development								
2	Local Training to FD officials (20 participants in each of 5 coastal FD)	batch	10	400,000	4	0.902	4		
3	Local Training for Beneficiaries	BDT/h a	126,748	200	25	0.902	23		
	Subtotal				29		26	0.01%	
E.	Monitoring and Evaluation								
1	Socio-economic survey (baseline) and Monitoring	BDT/ Upazil a	37	1,000,000	37	0.902	33		Monitoring is to be continuou s.
2	Evaluation Studies	BDT/ Upazil a	37	1,000,000	37	0.902	33		
	Subtotal				74		67	0.03%	
F.	Consulting Services								
	International	BDT/h a	126,748	400	51	0.902	46		
	Local	BDT/h a	126,748	100	13	0.902	11		including support staffs
	Subtotal				63		57	0.02%	
G.	Recurrent costs								
	Incrementa Staff costs (salaries and others)								To be in kind provided by FD
	Office running cost	BDT/y ear/F D	5	600,000	3	0.902	3		
	O&M of equipment and vehicle during implementation	BDT/y ear/F D	5	800,000	4	0.902	4		
	Subtotal				7		6	0.00%	
	BASE COSTS				257,657		232,384	100%	
	Physical contingencies (1 % of Plantation cost)				173	0.902	156		
	Price Contingencies (1 % of base cost)				2,577	0	0		
	TOTAL PROJECT COST				260,407		232,540		

6.4. Benefits of Greenbelt

6.4.1. Tangible Benefits

The estimated tangible economic and financial benefits for a unit area (ha) of the greenbelt development are considered for cost benefit analysis. The investment is planned, without alternative, for considering greenbelt development in climate vulnerable coastal areas to mitigate the cyclonic disaster. Initially the Total Economic Valuation (TEV) approach for

ecosystem service benefit was considered for calculating the benefits from greenbelt. However, the data requirements of the TEV framework were difficult to assimilate within the limited time frame of this study. The tangible benefits (direct and indirect use values) of the investment have been quantified for cost benefit analysis all of which are similar to what is considered in the TEV approach (Emerton, 2012). The economic and financial indicators are calculated accordingly for both plans. Tangible benefits per hectare are exactly the same for both plans and are presented in Table 6.5.

The unit benefit is applied to the total greenbelt development area. For the purpose of economic analysis, the costs and benefits are required to adjust to reflect their resource costs/values as those are affected by taxes, subsidies, and trade restrictions, monopoly etc. To convert their domestic market prices to border prices equivalent, a Standard Conversion Factor (SCF) is applied to these goods and services due to lack of specific conversion factors.

The Economic Internal Rate of Return (EIRR) and Financial Internal Rate of Return (FIRR) and other indicators have been estimated using 12% discount rate to the total investment cost and benefits based on the above unit area benefit from greenbelt. The physical activity of developing the greenbelt will be implemented for a period of seven years in three phases. Thus, the period of analysis (time horizon) is considered to be 30 years. The tangible total present value of financial benefit from the project over the 30 year analysis period is 105,813 million BDT and economic benefit is 474,343 million BDT for both plans.

Table 6.5: Tangible Net Benefit per hectare of Greenbelt – both plans

Components	Direct Tangible Net Benefits (BDT/ha)			Total Area (126,748 ha)	Total Benefits (BDT million)		Labour Utilization in greenbelt plantation (mandays/ha)	Labour Utilization in greenbelt plantation total mandays (million)	Assumptions Sources and Description of benefits.
	Financial	SCF	Economic		Financial	Economic			
Carbon Sequestration by Mangrove			1,717,232	40,701		69,893	20	0.81	Mangrove forests absorb carbon 97.57 tons of carbon per ha (UNDP, 2013). A total of 3,972,075 m tons of Carbon to be absorbed by greenbelt mangroves per year. Social cost of CO ₂ emissions USD 220/ton
Carbon Sequestration by Golpata (Nipa Palm)			1,717,232	2,867		4,926	54	0.15	Same as above. Nipa palm will absorb 279,733 m tons per year
Golpata (Nipa Palm)	50,000	0.902	45,100		143	129			Frond use in housing. BDT 20/plant. Total plants to be 2500
Golpata (Nipa Palm)	3,825,000	0.902	3,450,150		10,966	9,892			Value of Nipa palm sap for 2500 plants, avg 1.7 litre/plant in winter season (American Journal of Agriculture and Forestry) for 90 days, price 10 BDT/litre.
									Leaflets and midribs are used for producing of brooms, baskets, mats and sunhats.
									The white endosperm of immature seeds is sweet and jelly-like and is consumed as a snack.
									The various parts of Nipa palm material against toothache and headaches.
									Used in traditional medicine and others.
Palm	338,000	0.902	304,876	4,679	1,582	1,427	30	0.14	Average number 65/year. Local price 20/coconut. Plantation cost BDT1125/ha. Expert opinion:
Other (Non-Mangrove including Jhau) Protective benefits and Carbon Sequestration by Non-Mangrove			572,352	34,913		19,983	30	1.05	Non-Mangroves absorb about 32.52 tons/ha/yr. Greenbelt non-mangroves will absorb 1,135,371 m tons of Carbon per year. Social cost of CO ₂ emissions USD 220/ton
Timber output	87,799	0.902	79,194		3,065	2,765			Sale Taka/ha for 580 no. with short and long rotation After 15 and 25 years.
Fish culture	660,760	0.902	596,006	17,965	11,871	10,707			Net benefit. CEGIS expert's data.
Turmeric production	29,352	0.902	26,475	21,612	634	572			Net benefit per ha. Khanam (2009).
Vegetable production	132,000	0.902	119,064	4,010	529	477			Net benefit as per Field data and also from BARI.

Components	Direct Tangible Net Benefits (BDT/ha)			Total Area (126,748 ha)	Total Benefits (BDT million)		Labour Utilization in greenbelt plantation (mandays/ha)	Labour Utilization in greenbelt plantation total mandays (million)	Assumptions Sources and Description of benefits.
	Financial	SCF	Economic		Financial	Economic			
Embankment with reduced maintenance cost due to greenbelt (BDT)	321,680	0.902	290,155		167	150			Cost estimate of damage polder of Cox's Bazar rehabilitation of Embankment cost 8.042 BDT million/km. FPCO Guidelines (1992), it is to be 6% of construction cost, however, as per expert opinion, periodic maintenance has increased about 10% of the cost. Thus the maintenance cost per km seems to be reduced by 4% due to greenbelt protection.
Saving Value of HYV Aman crop damages (partial damage) due to greenbelt measures.	27,899	0.902	25,165		1,276	1,151			About 94% reduced damaged in 2007 cyclone compared to 1970 Cyclone damages.
Total benefit BDT in million					30,234	122,072		2.16	

The unit benefit is applied to the total greenbelt development area. For the purpose of economic analysis, the costs and benefits are required to adjust and then to reflect their resource costs/values as those are affected by taxes, subsidies, and trade restrictions. To convert their domestic market prices to border prices equivalent, a standard conversion factor (SCF) is applied to these goods and services due to lack of specific conversion factors.

The EIRR and other indicators have been estimated using 12% discount rate to the total investment cost and benefits based on the above unit area benefit from greenbelt. The mangrove forest is perpetual, however the non-mangrove forest is considered to be short and long rotational of (15 and 25 years) forest time period. The physical activity will be implemented for a period of seven years by three phases. Thus, the period of analysis (time horizon) is considered to be 30 years. Using discounted method of cost benefit comparison, the values of the indicators are estimated and the same are given in Tables 6.6 and 6.7 for the economic indicators for the two plans. The financial indicators for the plans are shown in Tables 6.8 and 6.9. Tables used in the calculations are listed in Annex A6.1 to A6.16.

Table 6.6: Values of the Economic indicators – without acquisition plan

Economic indicators	Values of the indicators	Decision Rules
Benefit Cost Ratio (BCR)	38.8:1.0	>1 is acceptable. The investment plan is economically viable and acceptable.
Net Present Value (NPV) (BDT million)	462,105	>0 is acceptable. Economically viable.
IRR	161%	>12% is acceptable. The plan is economically viable.

Table 6.7: Values of the Economic indicators – acquisition plan

Economic indicators	Values of the indicators	Decision Rules
Benefit Cost Ratio (BCR)	2.8:1.0	>1 is acceptable. The investment plan is economically viable and acceptable.
Net Present Value (NPV) (BDT million)	307,652	>0 is acceptable. Economically viable.
IRR	29%	>12% is acceptable. The plan is economically viable.

Table 6.8: Values of the financial indicators – without acquisition plan

Financial indicators	Values of the indicators	Decision Rules
BCR	8.6:1.0	Financially attractive
NPV (BDT million)	93,501	Financially attractive
IRR	63%	Financially attractive

Table 6.9: Values of the financial indicators – acquisition plan

Financial indicators	Values of the indicators	Decision Rules
BCR	0.6:1.0	Financially unattractive
NPV (BDT million)	-70,095	Financially unattractive
IRR	7%	Financially unattractive

As financial indicators include only the marketable products, benefits such as damage protection and carbon sequestration from the greenbelt is not part of the calculation in Table 6.8 and 6.9.

Social Benefits: apart from the cost benefit comparison a range of tangible social benefits is estimated due to participation of the beneficiaries. About 2.16 million man-days employment opportunity is expected to be created due to greenbelt establishment. Table 6.6 lists these social benefits.

Table 6.10: Creation of Employment Opportunities

Plantation type	Per hectare man-days	Plantation Area (ha)	Total man-days
Mangrove	20	40,701	814020
Nipa Palm	54	2,867	154818
Palm	30	4,679	140370
Non-Mangrove	30	34,913	1047390
Total			2156598

Poverty Reduction

Poverty reduces people's ability to respond to survive, and recover from the likely effects of climate change. Community participation through social forestry programme could be an effective measure for reducing poverty in the coastal areas. Moreover, awareness builds up through participation in the social forestry program (as per Social Forestry Rules) the beneficiary of the social forest would be selected within one km² of the forest.

Damage Reduction

It is anticipated that the greenbelt attributes to saving damage to lives, properties and infrastructures from different coastal hazards, main one being cyclones. Damage saving benefits of the investment can be estimated by assessing the possible savings resulting from the greenbelt establishment in response to damage protection of lives and properties against cyclone. Benefits from damage savings have been estimated based on frequency and return period (Statistical) analysis of time series damage data for the period 1970-2015 (Sarker, personal communication).

In this analysis, it is found an opposite relationship exists between return period and chance of occurrence of the cyclone. According to the mean return period (1 in 2.33 year recurrence interval) with 43% chance of occurrence cause to the damage values as estimated lower than the higher return period. Details are given in Table 6.11.

Table 6.11: Frequency analysis of Damage from Cyclone

Return Period (YR)	crops damaged Fully (acre)	Crops damage partially (acre)	No. of House damage fully	No. of House Damage (partially)	No. of Dead people	No. of dead Livestock (cattle and goats)	Road Damage Fully (km)	Road Damage partially (km)	No. of Damages Bridge / Culvert	Embkt. Damage (km)
2	24,701	94,170	51,057	41,950	1,923	33,098	40	131	21	36
2.33	83,669	193,321	137,116	81,130	8,824	84,545	108	355	66	100
5	339,853	624,078	510,996	251,346	38,803	308,051	406	1,327	257	375
10	548,511	974,922	815,515	389,985	63,221	490,094	649	2,119	414	600
20	748,660	1,311,461	1,107,618	522,970	86,643	664,714	881	2,879	563	815
50	1,007,733	1,747,076	1,485,715	695,106	116,960	890,742	1,182	3,862	757	1,094
100	1,201,872	2,073,508	1,769,045	824,098	139,679	1,060,118	1,408	4,599	903	1,303

Reduced cost of periodic maintenance of costal embankment

The greenbelt reduces the wind speed and tidal surge. As to that wear and tear of coastal embankment could be lower than without greenbelt protection. Costs saving in the maintenance of coastal embankment as consider being the benefits accrue to the investment. The amount is included in the cash flow of the investment.

Livelihood Improvement

Improving the socio-economic conditions of local coastal communities through green belt vegetation contributing to their livelihoods directly (e.g. through sale of fish, agricultural produce) or indirectly (e.g. by providing shade, coolness, shelter, visual enhancement, etc. for other revenue generating activities).

Reduction in death and damages

Greenbelt attenuates wave and wind energy reducing potential damage to human lives and properties from natural hazards such as Cyclones. Table 6.8 shows that compared to 1970 and 1991 cyclones, the number of death was less in 2007 and 2009 as they struck areas protected by the mangrove forest of the Sunderbans. Similarly damage to the houses was also lesser in areas with mangrove greenbelt.

Valuation of human life in coastal risk

The usual method for valuation of human life in a risky situation is called Discounted Future Earnings. This method can be used for a particular individual as well as an average person representing a group of population. Based on the age of a person, and assuming he/she has a normal life expectancy, his/her expected future earnings and his contribution to the Gross Domestic Product (GDP) is estimated using available statistical data. The present value of the expected stream of future income is then computed using discounting methods and appropriate discounting rates. This calculated present value is assumed to be the average value of life for the person or an average person of the population under study (UNDP 2015).

The value of human life calculated is therefore sensitive to age of the person likely to become victim of the natural calamity, longevity of the people, discount rate used in the country and per capita income of the persons of the locality. Assumptions for Coastal Risk Analysis

Average Age of person losing life : 10 years

(Based on Coastal data collected)

Average Longevity in Bangladesh: 67.7 years

(Source: BBS)

Remaining productive Life Lost: 57, 7 years, say 58 years

Discount Rate used in Bangladesh: 12%

(Used by Planning Commission of Bangladesh)

Per Capita Income (2015): BDT103,149 (US \$ 1,314)(BBS)

Estimated Growth of Per capita income: 7% up to 2019, 8% from 2020-2030, 9% from 2030-40, 10% from 2040 -2073 (58 years)

(Based on current Growth Rates)

Estimated Value of a Human Life Lost in Coastal Area: **Tk2.8 million** (Calculations are not shown)

Table 6.12 shows the number of fatalities in three major cyclones that hit coasts of Bangladesh at different locations not protected by mangroves (1970) and protected by mangroves (cyclones Sidr and Aila). As the statistics on the number of death from various past cyclones have been tabulated over the entire coastal area this did not allow benefit calculation per unit area and was not included in cost-benefit analysis.

Table 6.12: Comparative Damage to Human lives and Property

Natural Disaster (Cyclone)	With mangrove		Without mangrove	
	Number of dead people	Fully damage to Houses	Number of dead people	Fully damage to Houses
1970			250,000	3,350,000
2007 (SIDR)	3363	564,967		
2009 (Aila)	190	243,191		

Source: DDM Data sheet personal communication, Sarker. N. C. D. (2016)

Increased rate of siltation

It is known that a positive impact occurs in protection of the shoreline against erosion by the greenbelt vegetation which stabilizes the soil increasing resistance to wave action. It also enhances the rate of land accretion by trapping sediments at a faster rate within its root system. However, quantification of this rate of increase was not possible to calculate within the time span of the study.

6.4.2. Intangible Benefits

Landscape for recreation

The greenbelt will be creating landscapes that are aesthetically pleasing in the coastal area, of scenic value, while providing shade where necessary, and promoting ecotourism, recreation and other activities.

6.5. Prioritization

An attempt has been made to identify priority upazilas where greenbelt establishment will begin first. Two factors have been used in setting up of this priority of implementation; coastal vulnerability index (CVI) value and availability of khas land in the respective upazilas. Multi-Criteria Analysis has been done for calculation of priority index. In the analysis higher weight was given to more vulnerable upazilas ($w=0.55$) and to upazilas where more khas land was available ($w=0.45$) to start development of greenbelt with less investment. Calculated priority index of all 37 upazilas are shown in Table 6.13. The 10 upazilas with the highest priority index values are being recommended for greenbelt establishment in phase I, the next 10 upazilas will be developed in phase II and the remaining 17 upazilas will be developed in phase III.

Table 6.13: Phases of Greenbelt Establishment based on priority index

Location		Total Land required	Khas land (ha)	% of khas land	CVI	Score Card (Weighed Average Value)			Phase
District	Upazila					0.45	0.55	Priority index	
						% of Khas land x 0.45	CVI x 0.55		
Noakhali	Subarnachar	2880	2698	94%	1.083	0.422	0.596	1.017	I
Noakhali	Hatiya	12631	7563	60%	1.289	0.269	0.709	0.978	
Bhola	Tazumuddin	8323	6957	84%	1.038	0.376	0.571	0.947	
Feni	Sonagazi	806	806	100%	0.835	0.450	0.459	0.909	
Lakshmipur	Ramgati	3935	2144	54%	1.180	0.245	0.649	0.894	
Chittagong	Sandwip	8460	4811	57%	1.104	0.256	0.607	0.863	
Patuakhali	Kala Para	3099	2880	93%	0.754	0.418	0.415	0.833	
Noakhali	Companiganj	4980	3476	70%	0.909	0.314	0.500	0.814	
Bhola	Daulathkhan	4428	2384	54%	0.940	0.242	0.517	0.759	
Bhola	Char Fasson	12674	6067	48%	0.970	0.215	0.534	0.749	
Bhola	Bhola Sadar	8153	2110	26%	1.061	0.116	0.584	0.700	II
Chittagong	Pahartali	57	57	100%	0.410	0.450	0.226	0.676	
Patuakhali	Dashmina	4389	2216	50%	0.813	0.227	0.447	0.674	
Patuakhali	Galachipa	11589	5726	49%	0.813	0.222	0.447	0.669	
Bhola	Burhanuddin	4118	986	24%	0.955	0.108	0.525	0.633	
Barguna	Amtali,	1033	693	67%	0.565	0.302	0.311	0.613	
Cox's Bazar	Pekua	819	245	30%	0.850	0.135	0.468	0.602	
Pirojpur	Mathbaria	1129	424	38%	0.760	0.169	0.418	0.587	
Bhola	Lalmohan	4929	978	20%	0.895	0.089	0.492	0.582	
Cox's Bazar	Ramu	149	149	100%	0.224	0.450	0.123	0.573	
Cox's Bazar	Kutubdia	3041	1162	38%	0.710	0.172	0.391	0.562	III
Cox's Bazar	Chakaria	171	141	82%	0.327	0.371	0.180	0.551	
Cox's Bazar	Ukhia	826	585	71%	0.410	0.319	0.226	0.544	
Cox's Bazar	Cox's bazar sadar	1545	865	56%	0.529	0.252	0.291	0.543	
Bhola	Manpura	7466	3075	41%	0.570	0.185	0.314	0.499	
Barguna	Barguna Sadar	1473	868	59%	0.420	0.265	0.231	0.496	
Barguna	Patharghata	2193	717	33%	0.633	0.147	0.348	0.495	
Chittagong	Chittagong Port	127	127	100%	0.055	0.450	0.030	0.480	
Cox's Bazar	Maheshkhali	1559	796	51%	0.425	0.230	0.234	0.464	
Chittagong	Mirsharai	606	539	89%	0.073	0.400	0.040	0.440	
Lakshmipur	Kamalnagar	968	165	17%	0.658	0.077	0.362	0.439	
Cox's Bazar	Teknaf	2326	1563	67%	0.184	0.302	0.101	0.404	
Chittagong	Anwara	754	204	27%	0.428	0.122	0.235	0.357	
Chittagong	Halishahar	268	153	57%	0.177	0.257	0.097	0.354	
Chittagong	Banshkhali	1058	526	50%	-0.032	0.224	-0.018	0.206	
Chittagong	Patenga	838	429	51%	-0.066	0.230	-0.036	0.194	
Chittagong	Sitakunda	3053	1467	48%	-0.436	0.216	-0.240	-0.024	
9	37	126,853	66,752						

6.6. Phasing of Investment

The plan is to be implemented in three phases. Bangladesh Forest Department (BFD) will implement the Greenbelt following existing policy guidelines of the department. As per implementation plan of the greenbelt plantation, based on climate vulnerability index, and the capacity of BFD, and flow of financial resources, the implementation of greenbelt is considered to be a period of seven years. Mangrove and non-mangrove plantation and maintenance for a period will be done by Forest Department. Community participation approach in non-mangrove forestation will be applied. Overall schedule of activities are given in Table 6.14.

Table 6.14: Overall schedule of activities.

Major Activity	Fiscal Year							Responsible Agency
	1	2	3	4	5	6	7	
<i>Preparation Phase</i> DPP preparation and Finalization	■							Forest Department (FD and Ministry of Environment and Forest (MoEF)
DPP Approval	■							Planning commission (PC)
Loan proposal submission and negotiation	■							MoEF, ERD
ADP approval	■							PC
Fund Release		■						Ministry of Finance
Fund Disbursement		■						MoEF and Project Director (PD) of FD
Formation of Social Forestry Management committee.	■	■						FD (Field Division office) if necessary with the support of NGO
Land preparation for plantation		■	■	■	■	■		FD (Field Division office)
Nursery Development (Mangrove)		■	■	■	■	■		FD (Field Division office)
Nursery Development (Non-Mangrove)		■	■	■	■	■		FD (Field Division office) and Management committee
Mangrove plantation (% of work)		5%	15%	30%	30%	10%	10%	
<i>Phase I (2 years)</i>		■	■	■				FD (Field Division office)
<i>Phase II (3 years)</i>			■	■	■	■		FD (Field Division office)
<i>Phase III (4 years)</i>				■	■	■	■	FD (Field Division office)
Turmeric and Vegetable plantation				■	■	■	■	DF and Management committee if necessary support from DAE
Fish culture in ditch		■	■	■	■	■	■	Management

Major Activity	Fiscal Year						Responsible Agency
	1	2	3	4	5	6	
(for 6 months in to Non-Mangrove forest							committee with necessary support from DoF
Monitoring supervision and reporting							FD (Field Division office) and Management committee and PD

6.7. Economic Analysis in DSS for Alternate Scenarios

A web based application will be developed to view all information collected and generated under this project. It will also help to display the output of the desktop based DSS. One of the outputs of DSS is a priority map showing the maximum green belt area in three classes (very high priority, high priority and medium priority). This map will be intersected with land cover and land tenure map to extract corresponding information of the suitable green belt area. The resultant map will be uploaded in the PostgreSQL database. Another output of DSS is a table containing one criteria tree per short listed species showing suitability in three classes (very suitable, suitable and unsuitable). Again, unit value of cost and benefit parameters for each upazilla will be derived and formatted as tables. These tabular information will also be uploaded into the database. All these information stored in the database will be used by web based application to perform cost benefit analysis.

One of the components of web based application will allow users to calculate alternatives for investment planning. The application will have a user-friendly interface from where user will be able to select different cost parameters such as acquisition, preparation, plantation, nursery, maintenance, fish culture, fish nursery, fruit orchard, vegetable gardening etc. to calculate the cost of the area suitable for greenbelt implementation. First, user will select a particular area which is suitable for greenbelt implementation. After then, user will select different cost parameters. Unit cost of the selected parameters will be extracted from the database and displayed in the web interface. Unit cost of a particular parameter depends on the different sub-parameters such as land tenure (Private, Public, Lease), land cover (Agriculture, Nature, Settlement), selection of species etc. Total cost will be calculated by multiplying the summation of the cost with the total area of the selected region. Table 6.15 shows an example of cost analysis of a particular location X.

Table 6.15: Cost Analysis of Location X

Cost Parameter	Cost/Acre in Taka
Acquisition	C1
Preparation	C2
Plantation	C3
Nursery	C4
Maintenance	C5
Fish Culture	C6
Fish nursery	C7
Fruit Orchard	C8
Vegetable gardening	C9
Total	C_x

If the area of X is AX hectare, then the cost of total area will be calculated as follows:

Cost of Total Area = Total Cost per acre * Total Area of X = C_x* AX Taka = AXC_x taka

The system will have the facilities to change the parameter and recalculate the costing. As for example, user can change the species for plantation and the costing will be recalculated for new selection. User can also select a new area and repeat the same analysis.

Web application will also help to calculate the benefit of implementing greenbelt at the selected region. In the same way as done for cost analysis, user can select different parameters for benefit (tangible and intangible) analysis. Parameters that user can select for benefit analysis are life saved, land saved, crop saved, infrastructure saved, income generation, reduced embankment cost, reduced embankment maintenance cost, carbon sequestration, fish production, fruit production, vegetable production etc. Based on user selection, corresponding economic value will be loaded from the database and total benefit will be calculated. Table 6.16 shows an example of benefit analysis for location X.

Table 6.16: Benefit Analysis of Location X

Benefit Parameter	Economic Value/Acre
Life Saved	B1
Land Saved	B2
Crop Saved	B3
Infrastructure Saved	B4
Income Generation	B5
Reduced Embankment Cost	B6
Reduced Embankment Maintenance Cost	B7
Carbon Sequestration	B8
Fish Production	B9
Fruit Production	B10
Vegetable production	B11
Total	B_x

Benefit can be recalculated by changing parameter selection. Total benefit of area X will be calculated as follows:

Benefit of Total Area = Total Benefit per acre * Total Area of X = $B_X * A_X = A_X B_X$

Following the same process user can calculate the cost and benefit for other locations. Assume that cost and benefit of location Y and Z are calculated and obtained information are shown in Table 6.17.

Table 6.17: Cost and Benefit Analysis of Location Y and Z

Location	Cost	Benefit	Area	Total Cost	Total Benefit
Y	C_Y	B_Y	A_Y	$A_Y C_Y$	$A_Y B_Y$
Z	C_Z	B_Z	A_Z	$A_Z C_Z$	$A_Z B_Z$

After calculating cost and benefit analysis of different locations, a tabular as well as a graphical representation will be displayed in the web application. A probable output of tabular information is shown in Table 6.18. Corresponding graphical representation could be similar as shown in Figure 6.1.

Table 6.18: Cost and Benefit Analysis of Different Locations

Location	Total Cost	Total Benefit
X	$A_X C_X$	$A_X B_X$
Y	$A_Y C_Y$	$A_Y B_Y$
Z	$A_Z C_Z$	$A_Z B_Z$

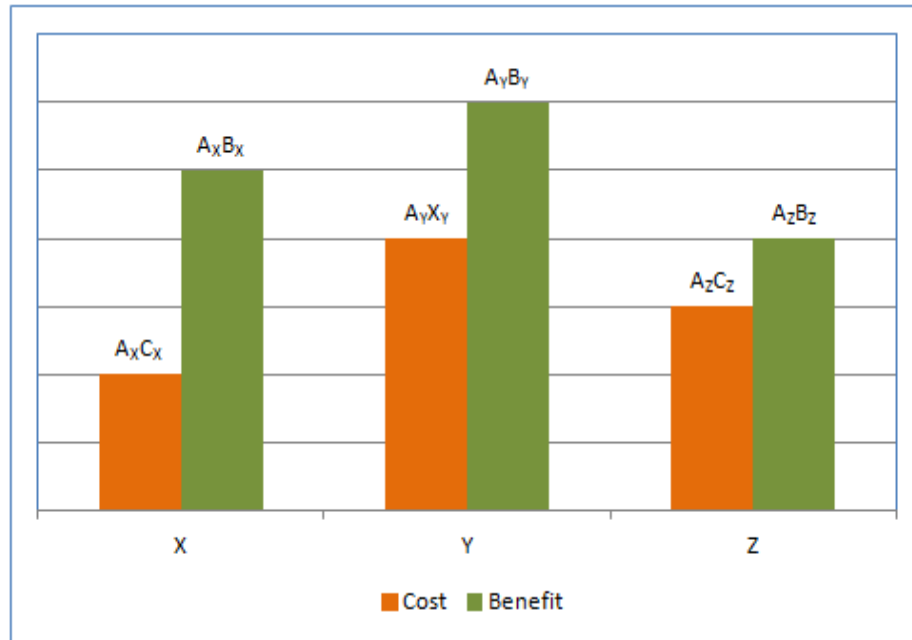


Figure 6.1: Cost and Benefit Analysis of Different Locations

Analyzed information can also be displayed as a map (Figure 6.4). Based on this cost and benefit analysis, users (planner, decision maker) will make planning for future investment. They could be able to prioritize the location and could decide which area would be selected first for the investment.

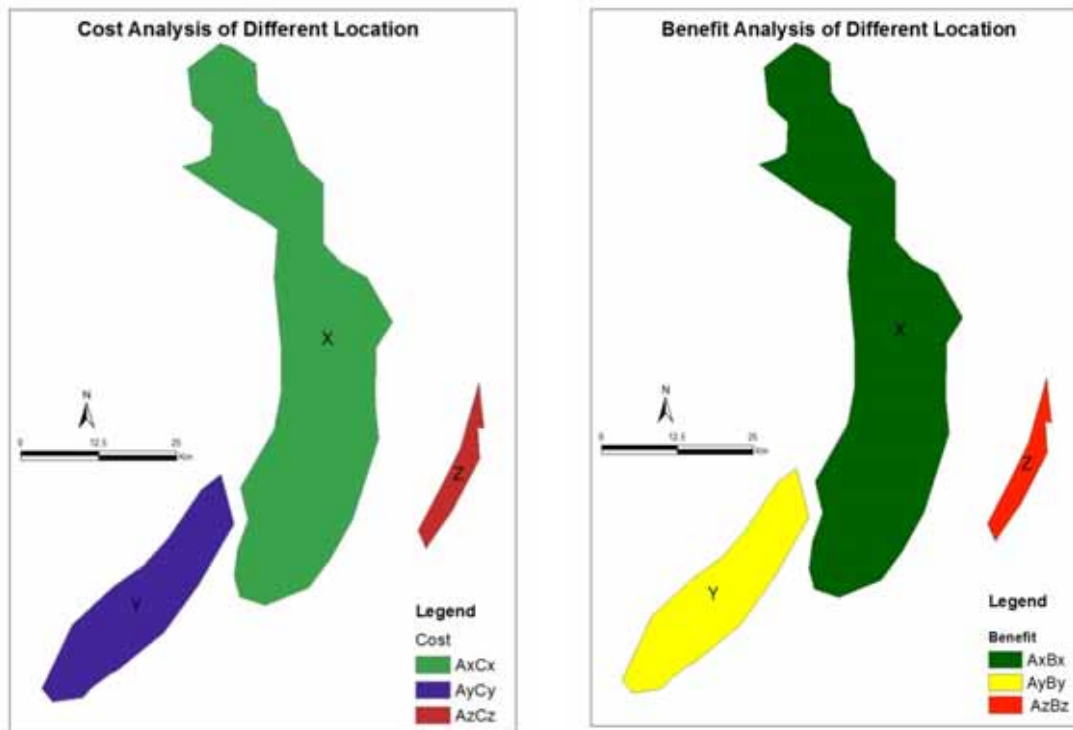


Figure 6.2: Maps Showing Cost and Benefit Analysis of Different Locations

7. Implementation Modalities

7.1. Introduction

The ability to implement the Greenbelt programme efficiently and to evaluate the results is of critical importance for the success of the program. Proper implementation of the program would require attention to various governance issues like legal framework, land tenure system, institutional architecture, funding mechanism, capacity building, sustainability, monitoring and evaluation etc. It is evident that without fundamental improvement in the above mentioned implementation modalities, attainment of benefits of the project will be compromised.

7.2. Legal Frameworks

7.2.1. Forest Act

The Forest Act (1927; amended in 2000) provides the necessary legal back-up for their management, protection and conservation. The Forest Act has also been providing legal support for bringing additional land under reserved forestry notified under Section 4 of the Forest Act. The Act has been giving legal cover for resolving conflicts on existing reserved forestry land. It may be mentioned here that the sub-judicial ownership for the land under title suits and questionable ownership of the land notified under Section 4 are serious hurdles in programme formulation, which in turn undermines the sustainability of forests, and forestry programme in Bangladesh (Forest Act, 1927).

Greenbelt erection will require public lands (known as Khas lands), leased lands from government authority as well as private lands obtained through acquisition. The public lands belong to particular government authorities. There is a need of prior permission for using these lands for any other purpose. Obtaining a lease from the appropriate authority or acquiring private land for afforestation activities is difficult and time consuming. Under the existing system, Deputy commissioner of the district gives lease to Forest Department for a period of 20 years for purpose of developing the land and when lands is developed, the land needs to be handed back to Deputy Commissioner's office for onward lease to needed citizens for agriculture, fishing, residential or any commercial purposes. Sometimes, Deputy Commissioner's office lease land before it is developed. This creates several types of problems. Firstly, there will be additional complexity of getting back the land from the present lease for erection of greenbelt for example. Secondly and more importantly, land does not become compacted and may be subject to erosion or depletion in near future. Therefore, District authorities should follow the existing rules and procedures in this regard.

7.2.2. Social Forestry Rule

Social Forestry Rule (2004) was enacted to allow and regulate plantations in public forest. It may be noted here that people in Bangladesh did not have any proprietary rights on public forest till 2004 when the "Social Forestry Rule-2004" was enacted. Under the rule, the Government may assign to any village community, the rights of Government to or over any land which has been constituted as a reserved forest. All forests so assigned shall be called village forests. The Government may make rules for regulating the management of village-forests, prescribing the conditions under which the community to which any such assignment is made may be provided with timber or other forest-produce or pasture, and their duties for the protection and improvement of such forest. On any land which is the property of the Government or over which the Government has proprietary rights, and on any other land assigned to the Government by voluntary written agreement of the owner for the purpose of afforestation, conservation or management through social forestry, the Government may

establish a social forestry programme under sub-section (2). A social Forestry programme is established when the Government by one or more written agreements assigns rights to forest-produce or rights to use the land, for the purposes of social forestry, to person assisting the Government in management of the land.

7.3. Suggested changes in Legal Framework

7.3.1. Forest Act

In case of greenbelt, land has to be perpetually used in greenbelt to provide necessary protection to men and properties exposed to tidal wind and surge in the coastal belt. This would require that land has to permanently handed over to the authority responsible for maintaining greenbelt, e.g., Forest Department. To allow such transfer of greenbelt forestry, necessary changes need to be incorporated in the Forest Act. These changes in the Act will allow Forest Department to own and maintain the greenbelt perpetually. Also, after a passage of time, there may be new land accretion beyond the greenbelt. In such cases, private land used for greenbelt may be returned back to them for them to use as they find suitable. To allow such return, necessary amendments in the Forest Act may be necessary.

7.3.2. Social Forestry Rule

Unlike, other type of forests, greenbelt forestry has the main purpose of protecting the locality from cyclonic winds and tidal surge. These are, therefore different from roadside or other type of social forestry which has mainly livelihood and income earning objectives. Nevertheless, greenbelt can be used for some income generation by the local community so long this does not compromise the protective nature of the greenbelt in short, medium or long term. To allow community participation in non-mangrove greenbelt forestry, appropriate changes need to be incorporated in the Social Forestry Rule.

7.4. Land tenural issues

Land tenure security is of paramount importance for making medium to long term investment in forestry sector. Community, individual or any organization will be hesitant to invest in forestry on lands of uncertain tenure. Greenbelt would require using public land, leased land and land acquired from the private citizens. The greenbelt land is supposed to be used for perpetuity. Therefore, there is a need for land tenure adjustments from private, leased and khas lands to greenbelt lands. Government can consider setting up special legal provisions so that land acquisition and tenure adjustment for greenbelt development can be done quickly so that the greenbelt can be established efficiently.

7.5. Funding Mechanism

Currently, Forest Department expenditures are met from Development Budget included in the Annual Development Program (ADP). However, under the present system, when there is no project, there is no funding for forestry activities specially for maintenance. Thus every time, a project comes to an end after 4 or 5 years, all benefits are lost because of discontinuity. Similar things may happen to greenbelt project. The funding crisis is the most serious problem for the Forest Department in achieving sustainability.

In this event, long term plans like the country's Five Year Plans need to make provision for year-wise funding for Greenbelt. Necessary resource allocations in the country's Medium Term Budgetary Framework (MTBF) need also to be ensured. Besides ADP, Forest Department should have to access to Revenue budget of the Government for greenbelt funding. Forest Department additionally require to have a window of multi-lateral donor funding financed by world-wide Green Climate Funds or similar global funds.

7.6. Implementation Method

Coastal greenbelt forest will need to be implemented through participation of the local stakeholders along with government agencies and NGOs. Forest Department will be the lead agency for implementing the Coastal Greenbelt project. Bangladesh Forest Department will need to coordinate with other government agencies, like local DC's office, Ministry of Land, and other relevant organizations for suitable policy decisions and implementation plans. A project steering committee may be formed at central and local level according to the suitable location of the principal project implementation authority. At the local level the union council and citizens living in proximity to the greenbelt can be integrated in the implementation under the authority of the local BFD executives.

The implementation process will ensure a result based Monitoring and Evaluation (M&E) through experts' opinion and opinion of local stakeholder (discussed in next chapter).

The implementation will involve the following steps:

- Forest Department will take the allotment of the belt from the Authorities owning the land,
- NGO may be engaged for carrying out motivation of local people whose lands will become part of the greenbelt and landless people and in formation of groups (10-15 participants per group),
- Allocation of greenbelt lands among the groups,
- Plantation establishment and cultivation of agricultural crops (inter-crops) by the groups on the strip land under the guidance of the Forest Department,
- Forest department provides seeds, seedlings and daily wages to the groups at the time of planting,
- Responsibility given to the groups for post-planting maintenance, management and supervision, and
- Agreement between the Forest Department, private land owners, plantation and maintenance Group, Land Owning Authority and Local Union Council on distribution of benefits.

The implementation activities are the following:

- a) Establishment of Nursery
- b) Preparation of Land and plantation in Greenbelt
- c) Care and Maintenance of Plantation
- d) Setting up Benefit Sharing Agreement
- e) Technical and Management Assistance

7.6.1. Establishment of Nursery

The establishment of a nursery will be an essential part in the implementation of an afforestation program. Forest Department will host nurseries for mangroves in their own lands. They will also provide assistance to develop the nurseries by the local residents. NGOs may provide necessary assistance to the groups in this regard. If seedlings /saplings are grown by the groups, a substantial amount of income would be added to their daily earnings from selling the seedlings.

7.6.2. Preparation of Land and Plantations in Greenbelt

In some locations the lands will require some pre-planting preparation including leveling and correcting the slope. These will be done by local group of participants under BFDs guidance. Then plantating of the seedlings will be carried out in the same manner

7.6.3. Care and Maintenance of Plantation

Proper maintenance such as, weeding, cleaning, watering is required immediately after planting and these would be carried out by the Group members. Damage by the domestic and wild animal cannot be avoided without continued physical presence at the plantations site. Social conflict may also cause damage to the plantations. In order to ensure accountability of the members, one group member will be selected as caretaker in charge of a number of seedlings. This approach will secure people's participation and responsibility in the greenbelt program. This system will also create short-term employment opportunities for the group members.

7.6.4. Setting up Benefit Sharing Agreement

The sustainability of the program will require signing of agreement between the Group members, Forest Department, Land Owning Authority and Local Union Council. The agreement would set the percentage of the benefit. Usually, the Group gets majority share and rest are distributed over the Forest Department, Land-owning authority and local Union Council.

7.6.5. Technical and Management Assistance

A successful plantation will also depend on proper management and appropriate technical assistance to the group members. Technical assistance will be given in case of seed collection, germination technique, thinning and pruning, intercropping, pest and disease control etc. Also, from a management point of view, it is important to make sure that activities such as, resources collection assistance to the preparation of the plan, distribution of responsibilities among the groups are timely executed.

7.7. Gendetr role in greenbelt forestry

In Bangladesh about half of the population is women. But the conventional wisdom tells that in Bangladesh, women are in a disadvantaged position. Women's contribution to the family and national economy is substantial and largely unacknowledged. Equal access to jobs, education, training, technology and access to resources is generally denied. Gender inequality is also a significant factor for poverty in Bangladesh.

Greenbelt forestry can be a tool of engaging the poor women as daily laborers in raising nurseries and plantations. Later they could be included in the sustainability program.

8. Monitoring and Maintenance

8.1. Monitoring

Monitoring is the key to accountability. In case of Greenbelt project, participatory monitoring involving local level stakeholders like Forest Department, Land owning authority, Group in charge of conservation and income generation, Local Union Council and NGO involved in conscientization would be useful. For result-based monitoring, log frame of the project activities will have to be used. Appropriate input, output and outcome monitoring forms will have to be developed.

For purpose of smooth monitoring, there is a need for

- I. ensuring that necessary data is generated in a timely and reliable fashion,
- II. the data is examined adequately to shed insights on the progress, and
- III. the findings are disseminated to all relevant state and non-state actors so that better public policies are formulated and implemented to support the progress.

The Monitoring and Evaluation (M&E) framework should be a dynamic process. Considering data and capacity limitations, the M&E process will evolve and become mature over time. Lessons from international experience on good practices will be helpful in starting the process in the right direction.

8.2. Institutional arrangements for monitoring and supervision

Some of the important schedule and responsibilities/ Institutional Arrangements and Coordination are illustrated in Table 8.1.

Table 8.1: Schedule and responsibilities among institutions.

Nature of Activities	Concerned Organization	Concerned Ministry/Office
Developing suitable institutional architecture for coordination of Forest Department, Group entrusted with conservation, local Union Council and NGOs activities for purpose of long term productive and secure utilization of the Greenbelt.	Forest Department	Ministry of Environment and Forests
	Local Government	Ministry of Local Government, Rural Development and Cooperatives (LGRDC)
Ensuring suitable land tenure system for the Greenbelt and newly accretion land.	Land Reforms Board	Ministry of Land
Providing research support on growth of newer species of plantations resistant to pest, temperature, salinity, erratic rainfall etc. resulting from climate change adversities.	Forest Research Institute	Ministry of Environment and Forests
	Horticulture breeding organizations like BARI, BINA etc.	Ministry of Agriculture
Promoting integrated forestry, fisheries and fruits that might allow higher net earnings to the community organizations tasked with maintenance of the Greenbelt.	Forest Department	Ministry of Environment and Forests
	Interested NGOs/ NGOs Forum	NGO Affairs Bureau
Promoting non-mangrove timber and fruit tree plantations in line with soil/ land development.	Forest Department	Ministry of Environment and Forests
	Forest Research Institute	Ministry of Environment and Forests

8.3. Towards a Ten Steps results based M&E System

Result based monitoring and evaluation is suggested to be used for proposed greenbelt project. This would help Government and Donor entity to track and monitor progress with implementation of the respective targets and take corrective actions when major gaps or divergences emerge. This would require (i) the necessary data is generated in a timely and reliable fashion; (ii) the data is examined adequately to shed insights on the progress; (iii) the findings are disseminated to all relevant state and non-state actors so that better public policies are formulated and implemented to support the progress.

The Logical framework for Greenbelt sustainability as shown in Table 8.2 may be used for developing monitoring and evaluation formats.

Table 8.2: Logical framework for Greenbelt sustainability.

Narrative summary	Objectively Verifiable Indicators (OVI)	Means of Verification (MOV)	Important Assumptions (IA)
Goal: Institutional capacity building for Forest Department (FD), Local government -Union Council , NGOs and Beneficiary Groups.	GDP increase through saving of human life and property at national and local level	National Statistics of GDP Evaluation studies	Agreement implemented towards a common goals
Outcome: Skill and expertise developed in the FD, Local Government-Union council and NGOs and Beneficiary groups , to ensure safety from natural hazards and earning Livelihood	Enhanced coastal afforestation performance by the FD, Union Council, NGO and Beneficiary Groups	Safeguard to life and property ensured	Institutional policy support
Outputs: Sustainable Greenbelt in coastal areas	Number of skilled manpower created in related ministries and local level organizations	Indicators for greenbelt plant growth and sustenance, income generation activities, poverty, health, soil and water quality, disaster management etc. of local people.	Active participation of the officials and group members
Inputs: Investment and o & m expenditure for greenbelt	Government Budget allocation for carrying out the relevant activities	Budget (ADP and non-ADP) Expenditure on greenbelt project	Authority willingness for expenditure

8.4. Monitoring and Evaluation Framework

Monitoring and evaluation framework based on the log-frame as shown in Table 8.3, may be used for input monitoring, output monitoring and impact monitoring and evaluation. Additional indicators will be subsequently added based on lessons learnt.

Table 8.3: Framework for monitoring and evaluation.

Type of Monitoring	Indicators of Monitoring and Evaluation
Input Monitoring	Fund disbursed, Seedling, Sapling, Other Inputs supplied, Group formations, Group meetings, Project steering committee meetings etc.
Output Monitoring	Plantation growth, Cyclonic surge and wind protection capacity developed, Soil compaction, etc.
Impact Monitoring	Income Generation from timber and non-timber, Livelihood sustainability, Secured life and property, coastal GDP

8.4.1. Project Steering Committee

A Project Steering Committee (PSC) will be formed at central level. The PSC will include members from various Ministries/Departments linked with the project and representatives from local government institutions, NGOs and donors. Members of the PSC will be responsible for meeting and review progress regularly to achieve the projects goals and objectives. To ensure the formal linkage with other central ministries and donor agencies, an Inter-Ministerial Co-ordination Committee (IMCC) may be formed to review the progress of the project implementation.

8.5. Risks and Mitigations

8.5.1. Risks

Risks and mitigations likely to be related to the project are mentioned below:

- Risk 1: Technical Risk: During construction of greenbelt, there may arise technical faults for reasons beyond the control of implementing authority. Possible reasons may be cyclones of unprecedented scale combined with storm surges damaging the infrastructures created by the project. These “damages” unless rectified might affect the overall performance of the project.
- Risk 2: Social Risk: The project interventions will need some tasks to be carried out with active community participation. If local stakeholders are not involved in the project or do not get adequate incentives from the project, they may not participate in the project work.
- Risk 3: Financial Risk: The implementation of the project would require regular maintenance of the greenbelt. Funds would be required for close monitoring and supervision of the works.
- Risk 4: Commercial Risk: The production cost of various income generating activities within the greenbelt will be a major variable for the profit maximization of local inhabitants. Increase in cost of production and inflation will in turn increase financial risk. Inadequate marketing facilities for agricultural output will also involve risk.
- Risk 5: Climate Change Risk: Climate change is likely to increase sea level which might ultimately result in greater submergence of land under greenbelt and saline water intrusion. This scenario might affect carrying out income generating activities within greenbelt. The problem would be further exacerbating with reduced down stream flow due to greater extraction of the waters flowing from upper riparian countries.

8.5.2. Mitigation

- Risk 1: Technical Risk: Appropriate technical design of work in consultation with the stakeholders, risk may be mitigated by adopting safeguards during the implementation of the project so that damage from the natural calamities might be minimized through participation of the community organisation. Moreover

contingency measures have been taken in the project cost so that damages can be rectified quickly so as to reduce the sufferings of the people.

- Risk 2: Social Risk: Social risks arising of the project may be mitigated by greater involvement of the local people during the pre-construction and construction and Operation and Maintenance (O&M) phase. Consultation meetings may be arranged so as to suggest measures for overcoming the likely adverse effects as far as possible. The local members of the parliament, chairmen and members of the local government institutes and key elites of the local area need to be involved for minimizing the risk.
- Risk 3: Financial Risks: Financial risks may be minimized by Government making allocations for some of the O&M cost of the project.
- Risks 4: Commercial Risk: Commercial risks may be mitigated by increasing the profitability of the farmers through starting value chain activities. Farmers' co-operative activates may mitigate commercial risks.
- Risk 5: Climate Change Risk: Climate risk may be avoided by taking up necessary adaptation measures like growing of saline tolerant crops, designing of appropriate inter-cropping pattern capable in generating high revenues from the greenbelts etc.

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ANNEXES

Annex 1

Table A1.1: List of coastal afforestation projects implemented by Bangladesh Forest Department.

Sl. No.	Name of the project	Starting year	Completion year
1.	Afforestation in the coastal belt and offshore islands	1960–61 1965–66	1964–65 1969–70
2.	Afforestation Project in the coastal regions of Chittagong, Noakhali, Barishal and Potuakhali	1974–75	1979–80
3.	Mangrove Afforestation Project	1980–81	1984–85
4.	Second Forestry Project	1985–86	1991–92
5.	Forest Resources Management Project-FRMP	1992–93	2001–2002
6.	Extended Forest Resources Management Project	2002–03	2003–04
7.	Coastal Embankment Rehabilitation Project (CERP)	1997	2003
8.	Coastal Green Belt Project-CGP	1995–96	2001–02
9.	Forestry Sector Project	1997-98	2005-06
10.	Sundarbans Biodiversity Conservation Project (SBCP)	1999-2000	2004-05
11.	Char Development and Settlement Project (CDSP)	2000-05	2005-10
12.	Coastal Char Land Afforestation Project	2005–06	2009–10
13.	Management Support Project for Sundarban Reserve Forest	2005–06	2009–10
14.	Plantation of BWDB's Embankment in the Coastal Belt and its adjacent Char Areas	2009-10	2011-12
15.	Afforestation in the Coastal Areas to Mitigate Adverse Effect of Climate Change Project	Nov, 2010	June, 2013
16.	Community Based Adaptation to Climate Change Through Coastal Afforestation Project in Bangladesh	July, 2009	June, 2014

Source: Bangladesh Forest Department (BFD), 2012

Annex 2

Table A 2.1: District wise erosion accretion from 1973 to 2015.

District	Accretion (km ²)	Erosion (km ²)	Net Accretion (km ²)	Accretion rate (km ² /yr)
Bagerhat	10	9	1	0.0
Barguna	40	27	13	0.3
Barisal	165	175	-10	-0.2
Bhola	412	366	46	1.1
Chandpur	46	76	-30	-0.7
Chittagong	293	112	181	4.3
Cox's Bazar	82	11	71	1.7
Feni	32	11	20	0.5
Jhalokati	4	9	-4	-0.1
Lakshmipur	54	134	-79	-1.9
Noakhali	622	170	452	10.8
Patuakhali	282	149	133	3.2
Pirojpur	8	9	-1	0.0
Shariatpur	28	19	9	0.2
Total	2,076	1,275	801	19.1

Table A 2.2: District wise erosion accretion from 1973 to 1984.

District	Accretion (km ²)	Erosion (km ²)	Net Accretion (km ²)	Accretion rate (km ² /yr)
Bagerhat	12	12	0	0.0
Barguna	25	24	1	0.1
Barisal	132	88	44	4.0
Bhola	160	189	-29	-2.7
Chandpur	16	53	-37	-3.4
Chittagong	85	47	38	3.5
Cox's Bazar	85	2	82	7.5
Feni	12	5	7	0.7
Jhalokati	4	6	-2	-0.2
Lakshmipur	43	72	-29	-2.6
Noakhali	242	104	138	12.6
Patuakhali	89	178	-89	-8.1
Pirojpur	12	3	9	0.8
Shariatpur	20	7	13	1.2
Total	936	790	147	13.3

Table A 2.3: District wise erosion accretion from 1984 to 1996.

District	Accretion (km ²)	Erosion (km ²)	Net Accretion (km ²)	Accretion rate (km ² /yr)
Bagerhat	15	13	1	0.1
Barguna	34	14	20	1.7
Barisal	83	128	-45	-3.8
Bhola	174	137	37	3.1
Chandpur	41	45	-5	-0.4
Chittagong	78	64	14	1.1
Cox's Bazar	5	45	-41	-3.4
Feni	20	7	13	1.1
Jhalokati	5	6	-1	-0.1
Lakshmipur	70	37	32	2.7
Noakhali	199	106	93	7.7

District	Accretion (km ²)	Erosion (km ²)	Net Accretion (km ²)	Accretion rate (km ² /yr)
Patuakhali	268	71	197	16.4
Pirojpur	3	5	-2	-0.2
Shariatpur	13	10	3	0.2
Total	1,006	689	317	26.4

Table A 2.4: District wise erosion accretion from 1996 to 2006.

District	Accretion (km ²)	Erosion (km ²)	Net Accretion (km ²)	Accretion rate (km ² /yr)
Bagerhat	11	9	2	0.1
Barguna	16	12	4	0.3
Barisal	99	104	-5	-0.4
Bhola	202	147	55	4.6
Chandpur	34	46	-12	-1.0
Chittagong	132	48	84	7.0
Cox's Bazar	25	11	14	1.2
Feni	10	7	3	0.2
Jhalokati	3	3	1	0.1
Lakshmipur	39	65	-26	-2.2
Noakhali	175	116	60	5.0
Patuakhali	109	60	49	4.1
Pirojpur	2	4	-3	-0.2
Shariatpur	7	26	-19	-1.5
Total	865	657	207	17.3

Table A 2.5: District wise erosion accretion from 2006 to 2015.

District	Accretion (km ²)	Erosion (km ²)	Net Accretion (km ²)	Accretion rate (km ² /yr)
Bagerhat	6	9	-3	-0.3
Barguna	6	19	-13	-1.4
Barisal	83	88	-5	-0.5
Bhola	137	154	-17	-1.8
Chandpur	46	23	23	2.6
Chittagong	120	74	46	5.1
Cox's Bazar	21	6	15	1.7
Feni	5	8	-3	-0.4
Jhalokati	2	4	-2	-0.2
Lakshmipur	30	86	-56	-6.3
Noakhali	246	84	162	18.0
Patuakhali	46	70	-24	-2.7
Pirojpur	1	5	-5	-0.5
Shariatpur	21	10	12	1.3
Total	770	640	130	14.4

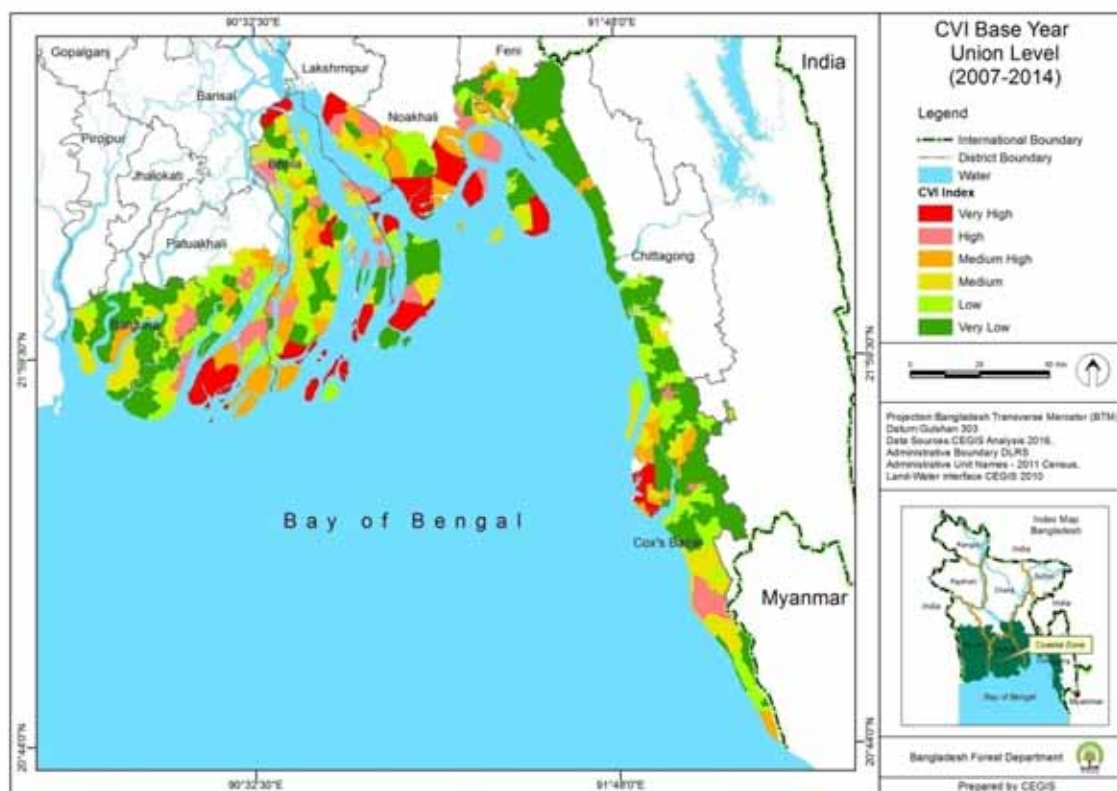
Annex 3

Table A 3.1: Data Sources of Identified Indicators for CVI Assessment.

Vulnerability Components	Sl. No.	Indicators	Unit	Data source
Exposure	1	Land elevation	cm	Prepared DigitalElevation Model(DEM) by CEGIS
	2	Inundation depth by monsoon flood	cm	IWM and CEGIS (2007)
	3	Erosion affected area	ha	GIS analysis (1973-2014) by CEGIS
	4	Soil salinity affected area	ha	SRDI (2009)
	5	Area under inundation surge (1m-3m)	ha	CDMP (2009)
	6	Area under inundation surge (3m-6m)	ha	
	7	Area under surge (>6m) inundation	ha	
	8	Surface water salinity (1 PPT) affected area	ha	IWM and CEGIS (2007)
	9	Surface water salinity (5PPT) affected area	ha	
Sensitivity	10	Population density	No. of person per sqkm	Population Census, BBS (2011)
	11	Dependent people	%	Population Census, BBS (2011)
	12	Disable people	%	Population Census, BBS (2011)
	13	Small scale farmer	%	Census of Agriculture (2008)
	14	Landless farmer	%	Census of Agriculture (2008)
	15	Livestock population	no.	Census of Agriculture (2008)
	16	Kutcha house	%	Population Census, BBS (2011)
	17	Length of road (Unpaved)	km	NWRD (2011)
	18	Poverty level	%	Population Census, BBS (2011)

Vulnerability Components	Sl. No.	Indicators	Unit	Data source
Adaptive Capacity	19	Literacy Rate	%	Population Census, BBS (2011)
	20	Embankment length	km	NWRD (2011)
	21	Length of road (paved)	km	NWRD (2011)
	22	Cyclone shelter	no.	NWRD (2011)
	23	Crop production	ton	Census of Agriculture (2008)

Map A 3.1: Union level CVI Map.



Annex 4

A4.1: List of Attendees participated in the Workop on “Coastal protection in the aftermath of the Indian Ocean Tsunami: What role for forests and trees”.

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A4.2: The concept of utility to delineate and prioritize greenbelt development

The potential greenbelt encompasses an area of over 2200 km². Not all areas along the coast and land inland will have the same priority in development. Closer to the coastline priority for development of a greenbelt is higher than land inland, and so is priority in more vulnerable areas, in areas of higher storm surge, areas with key infrastructure, and areas of land accretion. However, priority is less when protection is already provided by existing nearby forest. Consequently there will be a gradients and patches of priority of development.

Before explaining the concrete application of the DSS, we explain the relation between priority and greenbelt width with a simple example. Figure A 4.1 shows a greenbelt where as we move inland, the usefulness of a greenbelt, expressed in a dimensionless utility value between zero and one, drops. Over the first 400 meters from the coastline the usefulness (utility) drops slowly since a greenbelt is very useful close to the coast line.

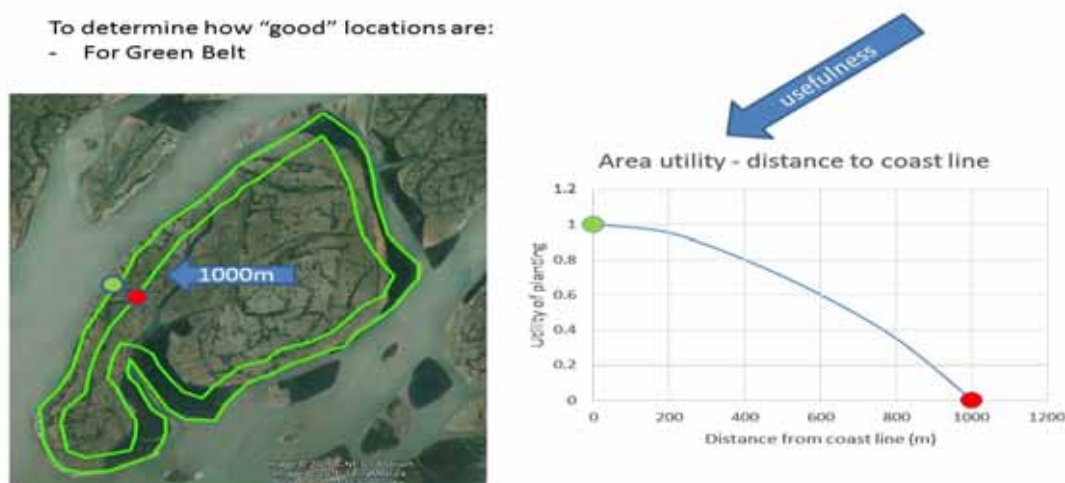


Figure A 4.1: Greenbelt with a utility curve for distance to the coastline, expressing usefulness for a greenbelt to be highest (utility = 1) near the shore and lowest (utility = 0) after 1000 meters inland.

Of course distance to shoreline is not the only concern in developing a greenbelt. Storm surge has an inland gradient where at the Southern tip (Figure A 4.2) it is highest (6 meters) and thus the utility for development of a greenbelt is highest (utility =1) too. On the other hand, more inland usefulness of a greenbelt diminishes as the surge dampens (utility = 0).

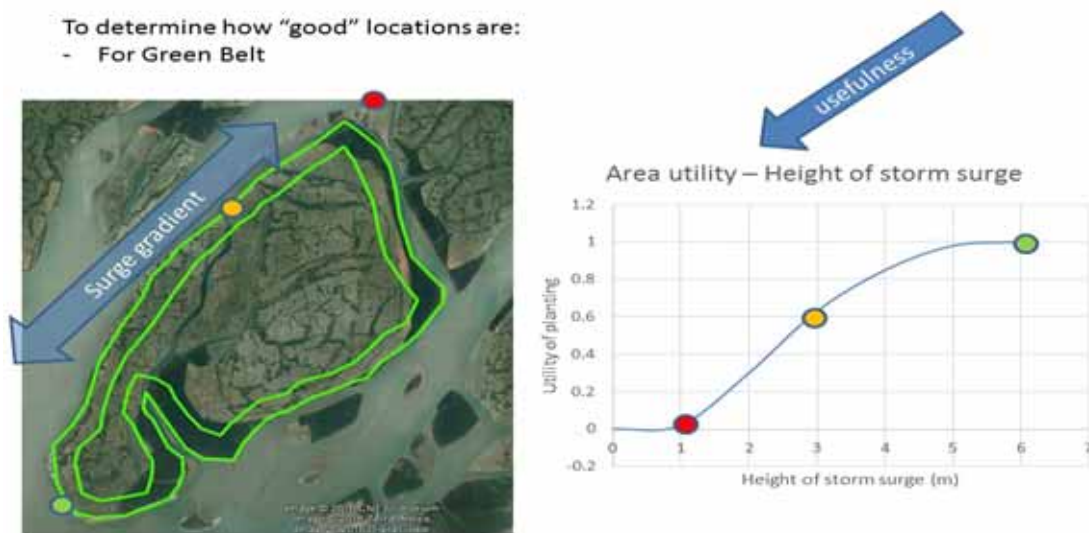


Figure A 4.2. Greenbelt with a utility curve for storm surge height, expressing usefulness for a greenbelt to be highest near the highest surge and lowest (utility = 0) inland.

In reality both distance to shoreline and surge height (and of course other considerations) are at play (Figure A4.3). If we now look at location X, we see a utility for distance to shoreline is zero, but since location X is almost at peak surge height a greenbelt would be very useful (utility = close to 1). Assuming that we consider concerns of surge height and distance to shore equally important the average utility would be approximately 0.5. Now if we look at location Y, we see that both utility from the perspective of protection against surge and distance to shore is zero. If we assume that where the surge is at maximum of 6 meters, we need a greenbelt that is developed over the full width of 1000m, we could say that whenever an area in the greenbelt has a utility between 0.5 and 1, it needs to be planted with trees. Therefore, if we follow the 0.5 utility dotted yellow contour line we see that the greenbelt width is maximum at the Southern tip and decreases as the storm surge decreases and the distance to shoreline increases. If we believe that surge height is more important to consider than distance to shore we could of course assign greater weight to that. For instance we could assign a weight to storm surge of 0.75 and weight of 0.25 to distance to shore. In that case utility for greenbelt development in location X would become $\text{weight}_{\text{surge}} \times \text{utility}_{\text{surge}} + \text{weight}_{\text{distance}} \times \text{utility}_{\text{distance}} = 0.75 \times 1 + 0.25 \times 0 = 0.75$.

If again we would take the 0.5 utility curve as the decision criterion, now that curve would be located more inland and the greenbelt would be wider.

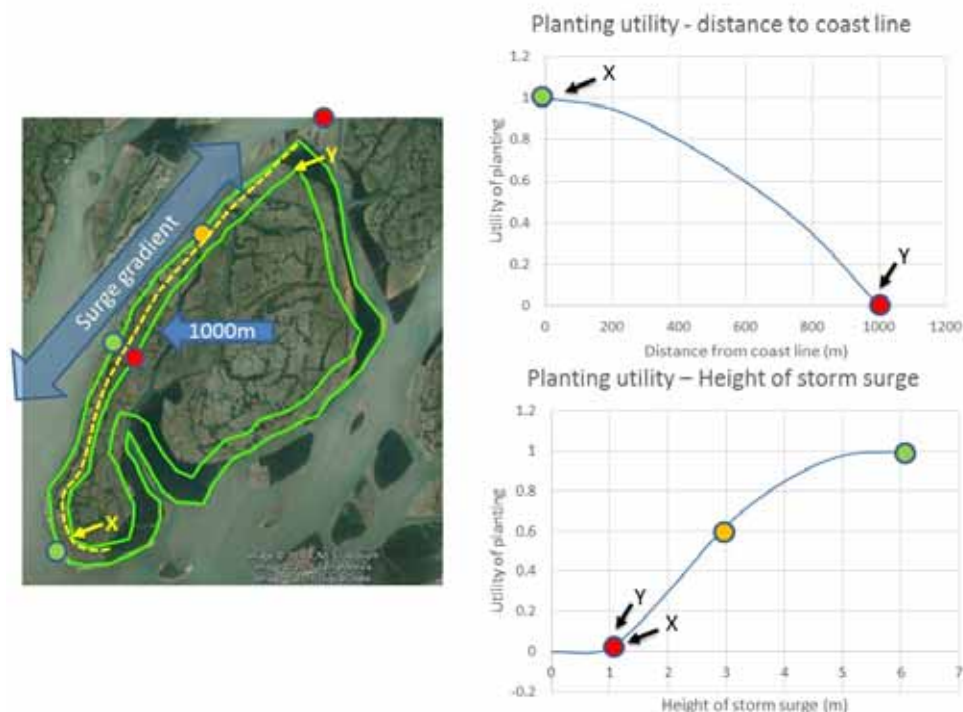


Figure A 4.3: Comparing utility in 2 locations X and Y in terms of two value functions of criteria “distance to coastline” and “height of storm surge” and deriving a width of greenbelt using a utility contour (yellow dotted line).

So we conclude that utility contour lines can help in determining the width of a greenbelt. However, this example shows to relatively simple gradients. Other phenomena are more patchy, for instance the presence or absence of existing embankments, or some areas along the coast having higher population densities and thus higher vulnerability and need for (utility) for development of a greenbelt.

Using ILWIS SMCE to create utility maps

A component of the DSS developed for BFD is the ILWIS (Integrated Land and Water Information System) GIS, which contains an operation called “Spatial Multi-Criteria Evaluation” (SMCE). ILWIS is freely available open source software. In this project the SMCE functionality is ported from version 3.8 to version 4 desktop client so that it benefits from the new modular structure in ILWIS 4 (Figure A4.4), in particular the connectors to PostGis and Python. With those connectors ILWIS SMCE in the desktop client will be able to provide data to the web-application part of the DSS through the PostGis data connector and if desirable adaptation of the DSS can be made in future through the python connector. Also a webclient for online SMCE is in research and development, and can be of future benefit for BFD.

The development of the DSS within only the 3 months of this study was possible only because the SMCE method already existed in ILWIS 3.8 so that while SMCE analysis could be done in ILWIS 3.8, software development could take place in parallel. At the time of writing of this report the SMCE images shown were still generated with ILWIS 3.8.

With the SMCE operation we evaluate each pixel of 25x25 meters in the whole potential greenbelt of maximum width of 1000 meters along the coast of Bangladesh, in the way it is done in the previous conceptual explanation with distance to shore and surge height

indicators. A more complex tree structure (a “criteria tree”) was developed, which integrates all relevant indicator maps, criteria to interpret the utility of the values (such as distances -in meters- to shore or heights - in meters - of surge) in the indicator maps, in view of objectives to be achieved with the development of a greenbelt.

The SMCE operation allows users to define their own evaluation problem, i.e. write their criteria tree, change indicator maps they want to use, define or change utility curves (as in Figures A 4.1, A 4.2, and A 4.3) and change weights of different criteria. Therefore, the evaluation model discussed here can re-evaluate the priorities as new insights into the problem or new policies at BFD develop over time.

The SMCE analysis generates an overall utility map for the entire potential greenbelt zone (Figure A4.4), where high utility means high priority for development. Utility values range from 0 (red) to 1 (green). Perfect utility does not exist where all factors are present at maximum urgency. Nevertheless one of the factors, e.g. surge height, may overrule all others. Unlike the ILWIS 3.8 implementation of SMCE, the ILWIS 4 implementation will have the possibility to force certain criteria to a maximum priority (Utility is 1), for instance when surge height is above a certain threshold, priority will be set to maximum utility of 1, irrespective of low utility of any of the other criteria. This feature is still under development at the time of writing.

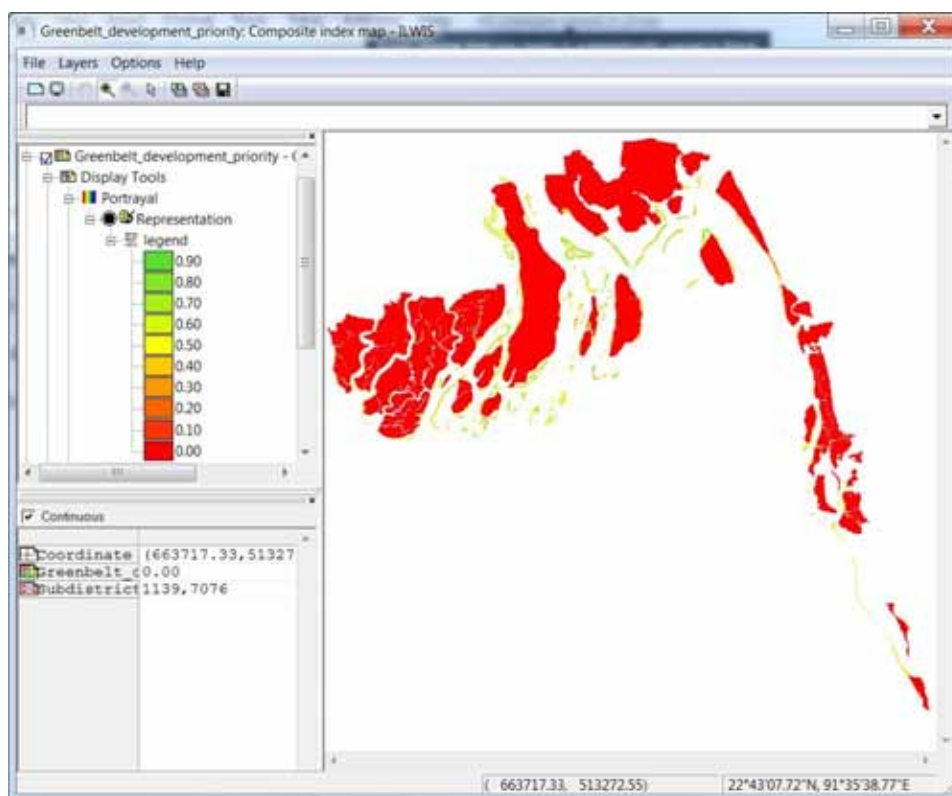


Figure A 4.4: A sample Utility map for greenbelt development for the entire study area considering selected objectives, criteria and indicator maps. Red areas are embankment areas which have been treated as constraints that put the utility to zero, assuming that inside embankments greenbelt is not necessary.

Zooming in to a particular area we see the spatial variation of greenbelt utility within the maximum greenbelt zone (Figure A4.5). For instance we see that close to coastline colors

tend to be greener (green representing higher utility values), given the utility graphs and weights defined in this analysis.

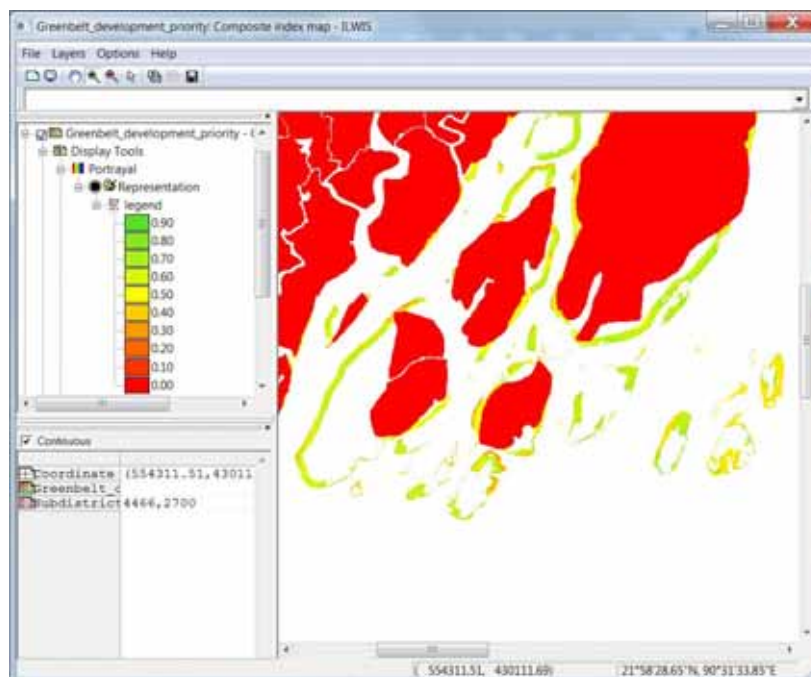


Figure A 4.5. Detail of the utility map for greenbelt prioritization.

The 25x25 meter pixel map that shows overall utility we can slice according to a series of utility thresholds, for instance at the 0.25, 0.5 and 0.75 utility threshold. These thresholds can be displayed as a vector map (Figure A4.6). Such a vector map we can overlay on for instance a satellite map to assist in the identification of intervention areas.

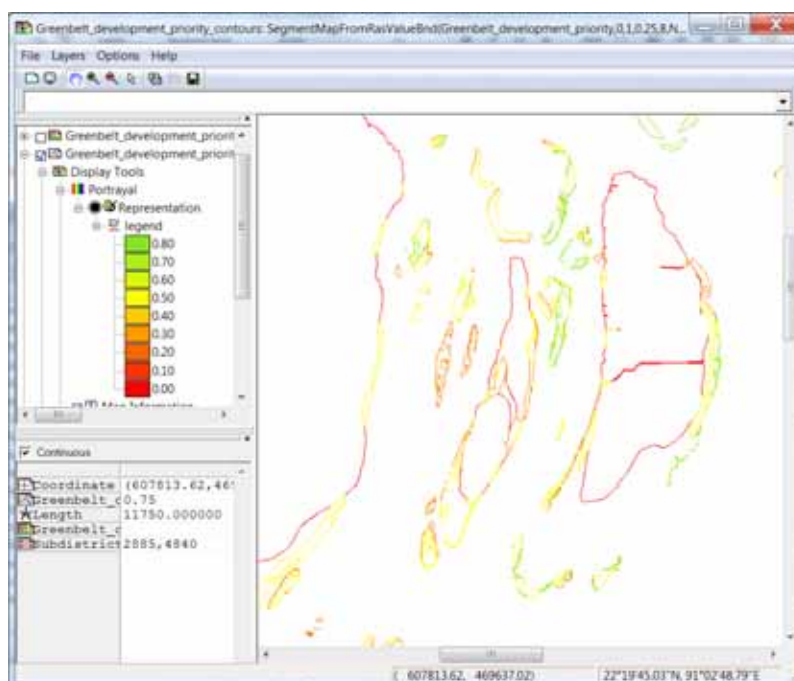


Figure A 4.6. Detail of the utility contour lines (beyond red > 0 utility, orange > 0.25 utility, yellow > 0.5 utility and green > 0.75 utility).

Of course a detailed understanding of overall utility can be obtained by considering the sub-objective maps (Figure A4.7) that, after weighted summation make the overall utility map (Figure A4.4).

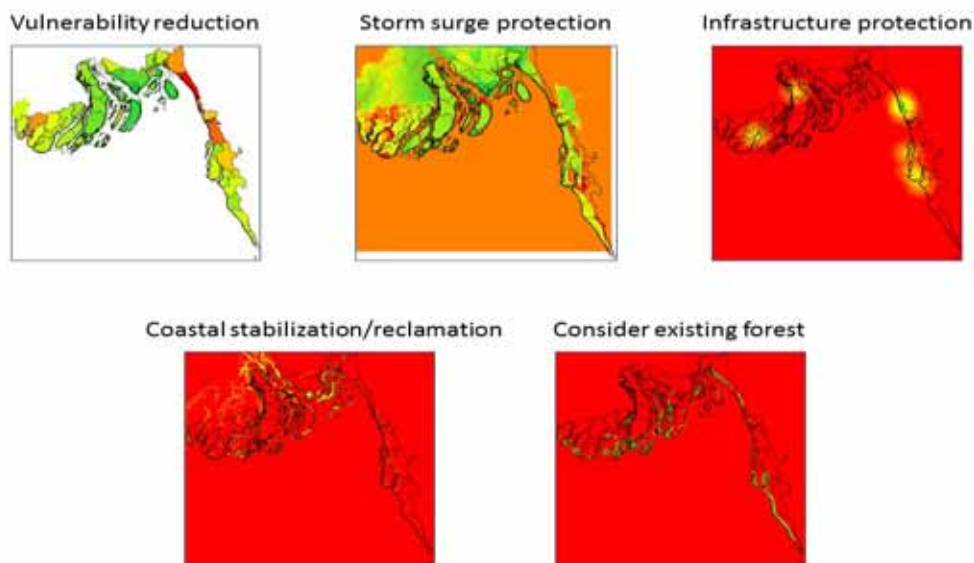


Figure A 4.7. Utility per sub-objective, which after weighting and summation contribute to the overall utility map (Figure A 4.6).

Interpretation of utility

Note that utility is a relative measure! As said the most urgent place where all criteria come together to create highest need of utility 1. Of course one could think that for instance highest storm surge would overrule any other concern. However, if the area has zero vulnerability because people do not live there, then building a greenbelt is not a necessity. Therefore, users of the DSS have to be careful to assign one of the criteria to be overruling.

So if the highest utility in a map is for instance around a value of 0.75 it does not mean that greenbelts are not so urgent but it means that there is always a less urgent criterion at play but in terms of the other criteria a greenbelt can be very urgent. So the comparison is relative between the pixels. The analysis prioritizes the pixels, one against the others. The highest pixel value is, in terms of the given indicator values, utility graphs, and weights of criteria, the pixel where development is most urgent.

The user should also note that utility is not a prescription of what to do where and neither is the utility map a result of a decision model. It is the result of a decision support model that can help and guide planners. But they have to make their own decision considering the information provided by the decision support system, and also consider other information they can avail of. Locations or trees can be preferred over others, yet these preferences are influenced by the changing state of the environment such as development of more intense storm surges due to climate change scenarios. Not only as time progresses, scenarios can also be developed in anticipation of possible changes, and consequences for greenbelt development assessed. A detailed discussion of this methodology of building the DSS is provided in a separate report on DSS.

Annex 5

Table A 5.1: List of common non-mangrove and mangrove plant species that are found in the study area along with their average canopy height.

Avg. Canopy Height (m)	Non-Mangrove Plant species	Mangrove Plant Species
>15	<i>Albizzia richardiana</i> (Chambol)	-
	<i>Samanea saman</i> (Rain Tree)	-
	<i>Borassus flabellifer</i> (Palmyra Palm)	-
	<i>Cocos nucifera</i> (Coconut)	-
14-12	<i>Bamboosa</i> spp (Bamboo)	<i>Sonneratia apetala</i> (Mangrove Apple)
	<i>Phoenix sylvestris</i> (Date Palm)	-
	<i>Swietenia mahagoni</i> (Mahogany)	-
	<i>Areca catechu</i> (Areca nut)	-
11-8	<i>Acacia auriculiformis</i> (Papuan Wattle)	<i>Avicennia officinalis</i> (Indian Mangrove)
	<i>Syzgium cumini</i> (Blackberry)	<i>Sonneratia caseolaris</i> (Crabapple Mangrove)
	<i>Artocarpus heterophyllus</i> (Jackfruit)	<i>Xylocarpus mekongensis</i> (Cedar Mangrove)
	<i>Pongamia pinnata</i> (Indian beech)	<i>Excoecaria agallocha</i> (Blinding Tree)
7-5	<i>Diospyros blancoi</i> (Velvet Apple)	<i>Nypa fruticans</i> (Nipa Palm)
	<i>Mangifera indica</i> (Mango)	-
	<i>Citrus maxima</i> (Pomelo)	-
	<i>Litchi cinensis</i> (Litchi)	-
<5	<i>Syzgium samarangense</i> (Malay apple)	<i>Acanthus illicifolius</i> (Holy Mangrove)
	<i>Ziziphus mauritiana</i> (Indian Plum)	-
	<i>Musa</i> spp (Banana)	-
	<i>Psidium guajava</i> (Guava)	-

Source: CEGIS archives from different EIA Study at coastal area

Table A 5.2: Lists of the plant species with local names

Plant Scientific Name	English Name	Local Name
<i>Acanthus illicifolius</i>	Holy Mangrove	Hargoza
<i>Avicennia officinalis</i>	Indian Mangrove	Bain
<i>Bruguiera gymnorhiza</i>	Black Mangrove	Kankra
<i>Excoecaria agallocha</i>	Blinding Tree	Gewa
<i>Heritiera fomes</i>	Sunder Tree	Sundaree
<i>Nypa fruticans</i>	Nipa Palm	Golpata
<i>Phoenix paludosa</i>	Mangrove Date Palm	Hental
<i>Sonneratia apetala</i>	Mangrove Apple	Kewra
<i>Sonneratia caseolaris</i>	Crabapple Mangrove	Ora/Choilla/Cholom
<i>Xylocarpus mekongensis</i>	Cedar Mangrove	Passur
<i>Acacia auriculiformis</i>	Papuan Wattle	Akashmoni/Acacia
<i>Acacia nilotica</i>	Gum Arabic Tree	Babla
<i>Albizia lebbek</i>	Lebbek Tree	Kala Koroi/Sirish
<i>Albizia procera</i>	White Siris	SadaKoroi
<i>Albizia richardiana</i>	-	Chambol/Raj Koroi
<i>Areca catechu</i>	Areca Nut	Supari
<i>Azadirachta indica</i>	Indian Lilac	Neem
<i>Borassus flabellifer</i>	Palmyra Palm	Taal

Plant Scientific Name	English Name	Local Name
<i>Casuarina equisetifolia</i>	Coast She Oak	Jhao
<i>Cocos nucifera</i>	Coconut	Narikel
<i>Lagerstroemia speciosa</i>	Queen Crape Myrtle	Jarul
<i>Manilkara zapota</i>	Sapodilla	Sofeda
<i>Phoenix sylvestris</i>	Date Palm	Khejur
<i>Pithecellobium dulce</i>	Manila Tamarind	KhaiBabla/Pyra/Jilapi
<i>Pongamia pinnata</i>	Indian beech	Koroach/Koronja
<i>Psidium guajava</i>	Guava	Peyara
<i>Samanea saman</i>	Rain Tree	Rendi Koroi
<i>Swietenia mahagoni</i>	Mahogany	Mahagoni
<i>Terminalia arjuna</i>	Arjun Tree	Arjun

Annex 6

Table A6.1: Upazila wise Settlement and Cropland Area inside the proposed Greenbelt

District	Upazila	Settlement Area (ha)	Cropland Area (ha)
Barguna	Amtali	155	500
	Barguna Sadar	422	904
	Patharghata	633	1,001
Bhola	Bhola Sadar	1,773	3,018
	Burhanuddin	936	1,732
	Char Fasson	1,722	5,934
	Daulatkhan	488	1,544
	Lalmohan	971	2,607
	Manpura	958	3,798
	Tazumuddin	968	4,315
	Anowara	236	288
	Banshkhali	113	137
	Chittagong Port	6	35
	Halishahar	1	22
	Mirsharai	0	28
	Pahartali	0	2
	Patenga	-	170
	Sandwip	1,027	1,882
	Sitakunda	1,205	954
Cox's Bazar	Cox's Bazar Sadar	326	65
	Kutubdia	713	424
	Maheshkhali	131	178
	Pekua	123	28
	Ramu	34	19
	Teknaf	805	1,104
	Ukhia	142	331
Lakshmipur	Kamalnagar	280	270
	Ramgati	1,117	1,497
Noakhali	Companiganj	180	1,383
	Hatiya	1,393	5,517
Noakhali	Subarnachar	84	967
Patuakhali	Dashmina	679	1,523
	Galachipa	1,296	6,117
	Kala Para	637	1,796
Pirojpur	Mathbaria	44	96
Total		19,598	50,189

Table A6.2: Unit Cost of Mangrove Afforestation

Sl. No.	Activity	Investment Costs					
		Unit	Unit cost (1st year) Taka	Unit cost (2nd year) Taka	Unit cost (3rd year) Taka	unit cost (4th year) Taka	Unit cost Total Taka
1	2	3	4	5	6	7	8
1	Nursery: 40'X4' bed, Tk.1.95/seedling, 5000 seedlings for planting of 4444/ha.	ha	9,750	-	-	-	9,750
1	Planting 4444 seedling/ha (1.5mX1.5m spacing)	ha	7,085	-	-	-	7,085
2	Community Watching (1st yr 6 months and 2 yr, 12 months)	ha	2,405	4,810	-	-	7,215
3	Maintenance {vacancy filling (VF) 2nd yr 40%= 1800 seedling/ha}	ha	-	3,510	-	-	3,510
4	Beating up 40% and 3 weeding	ha	-	11,700			11,700
5	Maintenance (VF 3rd yr 20%= 900 seedling/ha)	ha	-		1,755		1,755
6	Beating up 20% and 2 weeding	ha	-		7,800		7,800
Sub-total/ha.			19,240	20,020	9,555	-	48,815

Table A6.3: Unit Cost of Non-mangrove Afforestation

Sl. No.	Activity	Investment Costs					
		Unit	Unit cost (1st Year) Taka	Unit cost (2nd Year) Taka	Unit cost (3rd Year) Taka	unit cost (4th Year) Taka	Unit cost Total Taka
1	2	3	4	5	6	7	8
1	Nursery: 7"X5" bag, Tk8.05/seedling, raising 1760 seedlings for planting of 1600 seedlings/ha	ha	13,156				13,156
1	Planting 1600 seedling/ha	ha	172,394				172,394
2	Maintenances (VF 1 yr 10% =160 seedling/ha	ha		1,196			1,196
3	Beating up 10% and 3 weeding	ha		11,700			11,700
4	Maintenance (VF 2 yr 10% = 160 seedling/ha)	ha			1,196		1,196
5	Beating up 10% and 2 weeding	ha			7,800		7,800
Sub-total			185,550	12,896	8,996	-	207,442

Table A6.4: Unit Cost of Jhao (Non-mangrove) Afforestation

Sl. No.	Activity	Investment Costs					
		Unit	Unit cost (1st Year) Taka	Unit cost (2nd Year) Taka	Unit cost (3rd Year) Taka	Unit cost (4th Year) Taka	Unit cost Total Taka
1	2	3	4	5	6	7	8
1	Nursery: 7"X5" bag, Tk7.475/seedling, raising 2750 seedlings for planting of 2500 seedlings/ha	ha	13,156				13,156
1	Planting 2mX2m:2500 seedling /ha	ha	172,394				172,394
2	Maintenance (VF 1yr 10%=250seedling/ ha	ha		1,196			1,196
3	Beating up 10% and 3 weeding	ha		11,700			11,700
4	Maintenance (VF 2yr 10% = 250 seedling /ha)	ha			1,196		1,196
5	Beating up 10% and 2 weeding pruning	ha			7,800		7,800
	Sub-total		185,550	12,896	8,996	-	207,442

Table A6.5: Unit Cost of Golpata (Mangrove) Afforestation

Sl. No.	Activity	Investment Costs					
		Unit	Unit cost (1st Year) Taka	Unit cost (2nd Year) Taka	Unit cost (3rd Year) Taka	Unit cost (4th Year) Taka	Unit cost Total Taka
1	2	3	4	5	6	7	8
1	Nursery: 40'X4' bed, Tk 14/seedling, raising 638seedling/ ha for planting 10000 seedling/ha	ha	8,932				8,932
1	Plantation: 580 seedlings/ha	ha	8,120				8,120
2	Watcher and boat hire , planting 0yr.=(save seedling from fishing push net)	ha	5,460	10,920			16,380
3	Maintenance (VF 1yr 10% = 10,000 seedling/km.	ha		1,000			1,000
4	Beating up 10% and 2 weeding	ha		7,800			7,800
5	2nd year maintenance: weeding and cleaning	ha		-	3,900		3,900
	Sub-total		22,512	19,720	3,900	-	46,132

Table A6.6: Unit Cost of Palms (Non-mangrove) Afforestation

Sl. No.	Activity	Investment Costs					
		Unit	Unit cost (1st Year) Taka	Unit cost (2nd Year) Taka	Unit cost (3rd Year) Taka	Unit cost (4th Year) Taka	Unit cost Total Taka
1	2	3	4	5	6	7	8
Coconut							
1	Nursery	Per/Plant	52				52
2	Plantation	Per/Plant	33				33
3	Maintenance	Per/Plant	-	20	10	10	40
	Sub-total		85	20	10	10	125
Areca Nut							
4	Nursery	Per/Plant	8	-			8
5	Plantation	Per/Plant	8	-			8
6	Maintenance	Per/Plant	-	8	5	5	18
	Sub-total						34
Palmyra							
7	Nursery	Per/Plant	20				20
8	Plantation	Per/Plant	10				10
9	Maintenance	Per/Plant	-	7	4	4	15
	Sub-total						45
Date Palm							
10	Nursery:	Per/Plant	8	-			8
11	Plantation	Per/Plant	8	-			8
12	Maintenance	Per/Plant	-	8	5	5	18
	Sub-total						34

Table A6.7: Total Greenbelt Area and Financial Unit Cost per ha.

Sl. No.	Items	Total Area in ha	Financial Cost BDT/ha					Development Period																													
			Plantation	Maintenance	Maintenance	Maintenance	Total BDT/ha																														
	Time horizon (Year)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30						
1	Total Greenbelt area (ha)	126,748																																			
2	Mangrove (ha)	40,701	19,240	20,020	9,555	0	48,815																														
3	Goalpata (Nipa Palm)	2,867	112,750	107,250	102,000	48,000	370,000																														
4	Palm (260 number/ha)	4,679	21,970	5,070	2,704	2,704	32,448																														
5	Non-Mangrove (Jhao and others)	34,913	22,512	19,720	3,900	0	46,132																														
	Sub-total		176,472	152,060	118,159	50,704	497,395																														
6	Ditch earthwork (avg. 1531 m3/ha for 17453 ha)	17,965																																			
7	Turmeric (ha)	21,612																																			
8	Vegetable (ha)	4,010																																			

Table A6.8: Financial Cost Benefit Analysis for Greenbelt (Without Acquisition Plan)

Item	Total Area in ha.	SCF	Time Horizon (Year)																														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
			Financial cost BDT/ha					Economic cost (adjusted value) BDT/ha.																									
			Plantation	Maintenance	Maintenance	Maintenance	Total BDT/ha	Plantation	Maintenance	Maintenance	Maintenance	Total BDT/ha																					
Total Greenbelt area (ha)	126,748																																
Mangrove (ha)	40,701		19,240	20,020	9,555	0	48,815																										
Golpata (Nipa Palm)	2,867		112,750	107,250	102,000	48,000	370,000																										
Palm (260 number/ha)	4,679		21,970	5,070	2,704	2,704	32,448																										
Non-Mangrove (Jhau and others)	34,913		22,512	19,720	3,900	0	46,132																										
Subtotal			176,472	152,060	118,159	50,704	497,395																										
Ditch earthwork (avg 1531 m3/ha for 17453 ha)	17,965																																
Turmeric (ha)	21,612																																
Vegetable (ha)	4,010																																
% of Greenbelt Dev			5%	10%	10%	20%	20%	20%	15%																								
Items of Investment Cost	Quaintly	Financial Cost																															
% of crop compensation/year			5%	10%	10%	20%	15%	10%	10%	10%	10%																						
Crop compensation	50,189	2,979	149	298	298	596	447	298	298	298	298																						
Survey & Investigation		13	0.6	1.3	1.3	2.5	1.9																										
Plantation Development Cost	126,748	17,319	866	1,732	1,732	3,464	3,464	3,464	2,598																								
Ditch earthwork m3 million	28																																
Logistics	1 lot	52	52																														
Training	1 item	29	1	3	3	6	6	6	4																								
Monitoring and Evaluation	1 item	74	4	7	7	15	15	15	11																								
Consultants services	1 item	63	3	6	6	13	13	13	10																								
Recurrent costs	1 item	7	0.4	0.7	0.7	1.4	1.4	1.4	1.1																								
Base cost		20,536	1,076	2,049	2,049	4,097	3,947	3,796	2,922																								
Physical contingencies (1% of plantation cost)		173							173																								
Price contingencies (1% of base cost)		205							205																								
Total Investment cost by year		20,915	1,076	2,049	2,049	4,097	3,947	3,796	3,300																								
Total Area ha.			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total cost			1,076	2,049	2,049	4,097	3,947	3,796	3,300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tangible Benefits																																	
% of Carbon sink by year					0	10%	30%	60%	70%	80%	90%	100%	90%	80%	70%	30%	10%	5%	10%	20%	40%	60%	80%	100%	100%	100%	90%	80%	70%	30%	10%	5%	
Mangrove		0				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Golpata (Nipa Palm)		11,111				1,111	3,333	6,667	7,778	8,889	10,000	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111		
Palm output		1,581								1,265	1,423	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581		
Other (Non-Mangrove including Jhau)		0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Other benefits build up					5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%		
Fish culture		11,871			594	1187	2374	3561	4748	5935	7122	8310	9497	10684	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871		
Turmeric production		634			32	63	127	190	254	317	381	444	507	571	634	634	634	634	634	634	634	634	634	634	634	634	634	634	634	634	634		
Vegetable production		529			26	53	106	159	212	265	318	371	423	476	529	529	529	529	529	529	529	529	529	529	529	529	529	529	529	529	529		
Timber output		3,065													2452	2759	3065	2759	2452										2452	2759	3065		
Embankment with reduced maintenance cost due to greenbelt (BDT)		167					33	50	67	83	100	117	133	150	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167		
Value of save human lives																																	
Saving Value of HYV Aman crop damages (partial damage) due to greenbelt measures.		1,276					255	383	510	638	766	893	1021	1148	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276		
Total Tangible benefits		30,235	0	0	652	2,415	6,229	11,010	13,568	17,392	20,109	22,826	24,274	25,722	29,622	29,928	30,235	29,928	29,622	27,169	27,169	27,169	27,169	27,169	27,169	27,169	27,169	27,169	29,622	29,928	30,235		
Cash flow			-1,076	-2,049	-1,397	-1,682	2,281	7,213	10,268	17,392	20,109	22,826	24,274	25,722	29,622	29,928	30,235	29,928	29,622	27,169	27,169	27,169	27,169	27,169	27,169	27,169	27,169	27,169	29,622	29,928	30,235		
PV of Investment Cost		12,312																															
PV of Tangible Benefits		105,813																															
BCR		8.6																															
NPV (BDT in million)		93,501																															
EIRR		63%																															

Table A6.9: Financial Cost Benefit Analysis for Greenbelt (With Acquisition Plan)

Items	Total Area in ha.	SCF	Time Horizon (Year)																													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
			Financial cost BDT/ha					Economic cost (adjusted value) BDT/ha.																								
			Plantation	Maintenance	Maintenance	Maintenance	Total BDT/ha	Plantation	Maintenance	Maintenance	Maintenance	Total BDT/ha																				
Total Greenbelt area (ha)	126,748																															
Mangrove (ha)	40,701		19,240	20,020	9,555	0	48,815																									
Goalpata (Nipa Palm)	2,867		112,750	107,250	102,000	48,000	370,000																									
Palm (260 number/ha)	4,679		21,970	5,070	2,704	2,704	32,448																									
Non-Mangrove (Jhaw and others)	34,913		22,512	19,720	3,900	0	46,132																									
Subtotal			176,472	152,060	118,159	50,704	497,395																									
Ditch earthwork (avg 1531 m3/ha for 17453 ha)	17,965																															
Turmeric (ha)	21,612																															
Vegetable (ha)	4,010																															
% of Greenbelt Dev			5%	10%	10%	20%	20%	20%	15%																							
Items of Investment Cost	Quantity	Financial Cost																														
% of Land acquisition			3%	12%	43%	26%	17%																									
Land acquisition (ha)	60,101	63,697	1,976	7,375	27,173	16,304	10,869																									
Survey & Investigation		13	0.4	1.5	5.4	3.2	2.2																									
Resettlement cost (ha)	19,597	176,403	5,471	20,425	75,253	45,152	30,101																									
Plantation Development Cost	126,748	17,319	866	1,732	1,732	3,464	3,464	3,464	2,598																							
Ditch earthwork m3 million	28																															
Logistics	1 lot	52	52																													
Training	1 item	29	1	3	3	6	6	6	4																							
Monitoring and Evaluation	1 item	74	4	7	7	15	15	15	11																							
Consultants services	1 item	63	3	6	6	13	13	13	10																							
Recurrent costs	1 item	7	0.4	0.7	0.7	1.4	1.4	1.4	1.1																							
Base cost		257,657	8,374	29,552	104,181	64,958	44,471	3,498	2,624																							
Physical contingencies (1% of plantation cost)		173							173																							
Price contingencies (1% of base cost)		2,577							2,577																							
Total Investment cost by year		260,407	8,374	29,552	104,181	64,958	44,471	3,498	5,374																							
Total cost			8,374	29,552	104,181	64,958	44,471	3,498	5,374	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tangible Benefits																																
% of Carbon sink by year					0	10%	30%	60%	70%	80%	90%	100%	90%	80%	70%	30%	10%	5%	10%	20%	40%	60%	80%	100%	100%	100%	90%	80%	70%	30%	10%	5%
Mangrove		0				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Golpata (Nipa Palm)		11,111				1,111	3,333	6,667	7,778	8,889	10,000	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	11,111	
Palm output		1,581								1,265	1,423	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	1,581	
Other (Non-Mangrove including Jhau)																																
Other benefits build up					5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Fish culture		11,871			594	1187	2374	3561	4748	5935	7122	8310	9497	10684	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	11871	
Turmeric production		634			32	63	127	190	254	317	381	444	507	571	634	634	634	634	634	634	634	634	634	634	634	634	634	634	634	634	634	
Vegetable production		529			26	53	106	159	212	265	318	371	423	476	529	529	529	529	529	529	529	529	529	529	529	529	529	529	529	529	529	
Timber output		3,065													2452	2759	3065	2759	2452										2452	2759	3065	
Embankment with reduced maintenance cost due to greenbelt (BDT)		167					33	50	67	83	100	117	133	150	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	
Value of save human lives																																
Saving Value of HYV Aman crop damages (partial damage) due to greenbelt measures.		1,276					255	383	510	638	766	893	1021	1148	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	1276	
Total Tangible benefits		30,235	0	0	652	2,415	6,229	11,010	13,568	17,392	20,109	22,826	24,274	25,722	29,622	29,928	30,235	29,928	29,622	27,169	27,169	27,169	27,169	27,169	27,169	27,169	27,169	29,622	29,928	30,235		
Cash flow			-8,374	-29,552	-103,530	-62,543	-38,243	7,511	8,195	17,392	20,109	22,826	24,274	25,722	29,622	29,928	30,235	29,928	29,622	27,169	27,169	27,169	27,169	27,169	27,169	27,169	27,169	29,622	29,928	30,235		
PV of Investment Cost		175,908																														
PV of Tangible Benefits		105,813																														
BCR		0.6																														
NPV (BDT in million)		-70,095																														
EIRR		7%																														

Table A6.10: Economic Cost Benefit Analysis of Greenbelt (Without Acquisition Plan)

Items	Total Area in ha.	SCF	Time Horizon (Year)																													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
			Financial cost BDT/ha					Economic cost (adjusted value) BDT/ha.																								
			Plantation	Maintenance	Maintenance	Maintenance	Total BDT/ha	Plantation	Maintenance	Maintenance	Maintenance	Total BDT/ha																				
Total Greenbelt area (ha)	126,748																															
Mangrove (ha)	40,701	0.902	19,240	20,020	9,555	0	48,815	17,354	18,058	8,619	0	44,031																				
Golpata (Nipa Palm)	2,867	0.902	112,750	107,250	102,000	48,000	370,000	101,701	96,740	92,004	43,296	333,740																				
Palm (260 number/ha)	4,679	0.902	21,970	5,070	2,704	2,704	32,448	19,817	4,573	2,439	2,439	29,268																				
Non-Mangrove (Jhau and others)	34,913	0.902	22,512	19,720	3,900	0	46,132	20,306	17,787	3,518	0	41,611																				
Subtotal		0.902	176,472	152,060	118,159	50,704	497,395	159,178	137,158	106,579	45,735	448,650																				
Ditch earthwork (avg. 1531 m3/ha for 17453 ha)	17,965																															
Turmeric (ha)	21,612																															
Vegetable (ha)	4,010																															
% of Greenbelt Dev	126,748		5%	10%	10%	20%	20%	20%	15%																							
Items of Investment Cost	Quantity	Economic Cost																														
% of crop compensation/year			5%	10%	10%	20%	15%	10%	10%	10%	10%																					
Crop compensation	50,189	2,687	134	269	269	537	403	269	269	269	269																					
Survey & Investigation		11	2.3	2.3	2.3	2.3	2.3																									
Plantation Development cost	126,748	10,442	522	1,044	1,044	2,088	2,088	2,088	1,566																							
Ditch earthwork m³ million	28	6,876	344	688	688	1,375	1,375	1,375	1,031																							
Logistics	1 lot	24	24																													
Training	1 item	26	1	3	3	5	5	5	4																							
Monitoring and Evaluation	1 item	67	3	7	7	13	13	13	10																							
Consultants services	1 item	57	3	6	6	11	11	11	9																							
Recurrent costs	1 item	6	0.3	0.6	0.6	1.3	1.3	1.3	0.9																							
Base cost		20,198	1,035	2,019	2,019	4,035	3,900	3,764	2,890	269	269	0																				
Physical contingencies (1% of plantation cost)		156							156																							
Price contingencies (1% of base cost)		0							0																							
Total Investment cost by year		20,354	1,035	2,019	2,019	4,035	3,900	3,764	3,046	269	269	0																				
Total cost			1,035	2,019	2,019	4,035	3,900	3,764	3,046	269	269	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Transible Benefit																																
% of Carbon sink by year					0%	10%	30%	60%	70%	80%	90%	100%	90%	80%	70%	30%	10%	5%	10%	20%	40%	60%	80%	100%	100%	100%	90%	80%	70%	30%	10%	5%
Mangrove		69,893				6,989	20,968	41,936	48,925	55,914	62,904	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	
Golpata (Nipa Palm)		14,946				1,495	4,484	8,968	10,462	11,957	13,451	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	
Palm output		1,426								1,141	1,284	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	
Other (Non-Mangrove including Jhau)		19,983			0	1998	5995	11990	13988	15986	17984	19983	17984	15986	13988	5995	1998	999	1998	3997	7993	11990	15986	19983	19983	19983	17984	15986	13988	5995	1998	999
Other benefits build up					5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Fish culture		10,707			535	1071	2141	3212	4283	5354	6424	7495	8566	9637	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	
Turmeric production		572			29	57	114	172	229	286	343	401	458	515	572	572	572	572	572	572	572	572	572	572	572	572	572	572	572	572	572	
Vegetable production		477			24	48	95	143	191	239	286	334	382	430	477	477	477	477	477	477	477	477	477	477	477	477	477	477	477	477	477	
Timber output		2,765													2212	2488	2765	2488	2212									2212	2488	2765		
Embankment with reduced maintenance cost due to greenbelt (BDT)		150					30	45	60	75	90	105	120	135	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Value of save human lives																																
Saving Value of HYV Aman crop damages (partial damage) due to greenbelt measures.		1,151					230	345	460	575	691	806	921	1036	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151
Total Tangible benefits		122,071	0	0	588	11,658	34,058	66,811	78,599	91,528	103,458	115,389	114,697	114,004	115,524	107,807	104,087	102,811	103,534	103,320	107,317	111,313	115,310	119,306	119,306	119,306	117,308	115,310	113,312	107,531	103,810	103,088
Cash flow			-1,035	-2,019	-1,431	7,623	30,158	63,047	75,552	91,259	103,190	115,389	114,697	114,004	115,524	107,807	104,087	102,811	103,534	103,320	107,317	111,313	115,310	119,306	119,306	119,306	117,308	115,310	113,312	107,531	103,810	103,088
PV of Investment Cost		12,237																														
PV of Tangible Benefits		474,343																														
BCR		38.8																														
NPV (BDT in million)		462,105																														
EIRR		161%																														

Table A6.11: Economic Cost Benefit Analysis of Greenbelt (With Acquisition Plan)

Items	Total Area in ha.	SCF	Time Horizon (Year)																													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
			Financial cost BDT/ha					Economic cost (adjusted value) BDT/ha.																								
			Plantation	Maintenance	Maintenance	Maintenance	Total BDT/ha	Plantation	Maintenance	Maintenance	Maintenance	Total BDT/ha																				
Total Greenbelt area (ha)	126,748																															
Mangrove (ha)	40,701	0.902	19,240	20,020	9,555	0	48,815	17,354	18,058	8,619	0	44,031																				
Golpata (Nipa Palm)	2,867	0.902	112,750	107,250	102,000	48,000	370,000	101,701	96,740	92,004	43,296	333,740																				
Palm (260 number/ha)	4,679	0.902	21,970	5,070	2,704	2,704	32,448	19,817	4,573	2,439	2,439	29,268																				
Non-Mangrove (Jhau and others)	34,913	0.902	22,512	19,720	3,900	0	46,132	20,306	17,787	3,518	0	41,611																				
Subtotal		0.902	176,472	152,060	118,159	50,704	497,395	159,178	137,158	106,579	45,735	448,650																				
Ditch earthwork (avg. 1531 m3/ha for 17453 ha)	17,965																															
Turmeric (ha)	21,612																															
Vegetable (ha)	4,010																															
% of Greenbelt Dev	126,748		5%	10%	10%	20%	20%	20%	15%																							
Items of Investment Cost	Quantity	Economic Cost																														
% of Land acquisition			3%	12%	43%	26%	17%																									
Land acquisition (ha)	60,101	57,454	1,782	6,653	24,510	14,706	9,804																									
Survey & Investigation		11	0.4	1.3	4.9	2.9	2.0																									
Resettlement cost (ha)	19,597	159,116	4,935	18,424	67,879	40,727	27,151																									
Plantation Development Cost	126,748	15,621	781	1,562	1,562	3,124	3,124	3,124	2,343																							
Ditch earthwork m3 million	28																															
Logistics	1 lot	24	24																													
Training	1 item	26	1	3	3	5	5	5	4																							
Monitoring and Evaluation	1 item	67	3	7	7	13	13	13	10																							
Consultants services	1 item	57	3	6	6	11	11	11	9																							
Recurrent costs	1 item	6	0.3	0.6	0.6	1.3	1.3	1.3	0.9																							
Base cost		232,384	7,530	26,656	93,972	58,592	40,113	3,156	2,367																							
Physical contingencies (1% of plantation cost)		156							156																							
Price contingencies (1% of base cost)		0							0																							
Total Investment cost by year		232,540	7,530	26,656	93,972	58,592	40,113	3,156	2,523																							
Crop benefit foregone due to Land acquisition			45	223	864	1,236	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
Total cost			7,575	26,879	94,836	59,828	41,603	4,645	4,013	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
Tangible Benefits																																
% of Carbon sink by year					0%	10%	30%	60%	70%	80%	90%	100%	90%	80%	70%	30%	10%	5%	10%	20%	40%	60%	80%	100%	100%	100%	90%	80%	70%	30%	10%	5%
Mangrove		69,893				6,989	20,968	41,936	48,925	55,914	62,904	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	69,893	
Golpata (Nipa Palm)		14,946				1,495	4,484	8,968	10,462	11,957	13,451	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	14,946	
Palm output		1,426								1,141	1,284	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	1,426	
Other (Non-Mangrove including Jhau)		19,983			0	1998	5995	11990	13988	15986	17984	19983	17984	15986	13988	5995	1998	999	1998	3997	7993	11990	15986	19983	19983	19983	17984	15986	13988	5995	1998	999
Other benefits build up					5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Fish culture		10,707			535	1071	2141	3212	4283	5354	6424	7495	8566	9637	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	10707	
Turmeric production		572			29	57	114	172	229	286	343	401	458	515	572	572	572	572	572	572	572	572	572	572	572	572	572	572	572	572	572	
Vegetable production		477			24	48	95	143	191	239	286	334	382	430	477	477	477	477	477	477	477	477	477	477	477	477	477	477	477	477	477	
Timber output		2,765													2212	2488	2765	2488	2212									2212	2488	2765		
Embankment with reduced maintenance cost due to greenbelt (BDT)		150					30	45	60	75	90	105	120	135	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	
Value of save human lives																																
Saving Value of HYV Aman crop damages (partial damage) due to greenbelt measures.		1,151					230	345	460	575	691	806	921	1036	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	1151	
Total Tangible benefits		122,071	0	0	588	11,658	34,058	66,811	78,599	91,528	103,458	115,389	114,697	114,004	115,524	107,807	104,087	102,811	103,534</													

Table A6.12: Estimation of Plant Numbers, Canals and Cultivation area and Earth volume for 1 hectare area of Greenbelt.

Estimation for Non-mangrove Plantation with Coconut		
Description	Measurements/Nos	% of Total
Area in ha.	1.00	
Spacing (m)	3.45	
No. of Rows	29	
No. of Column	29	
Total Required Saplings (Nos)	840	100
No. of Short Rotation Plant	377.00	45
No. of Long Rotation Plant	203.00	24
No. of Coconut Plant	260.00	31
No. of Canals	12.00	
Canal Width (m)	1.7	
Canal Depth (m)	1.00	
Total Area (Sqm) for Canal/ha	2,070.00	21
Earth Volume (m3)/Ha to be dug for Canal (1:2 slope)	1,470.00	
Space (Sqm) for Turmeric cultivation	2,000.00	20
Space (Sqm) for vegetables cultivation	1,200.00	12
Estimation for Non-mangrove Plantation without Coconut		
Area in ha.	1.00	
Spacing (m)	3.45	
No. of Rows	29	
No. of Column	29	
Total Required Saplings (Nos)	840	100
No. of Short Rotation Plant	405.00	48
No. of Long Rotation Plant	435.00	52
No. of Coconut Plant	-	-
No. of Canals	13.00	
Canal Width (m)	1.7	
Canal Depth (m)	1.00	
Total Area (Sqm) for Canal/ha	2,242.50	22
Earth Volume (m3)/Ha to be dug for Canal (1:2 slope)	1,592.50	
Space (Sqm) for Turmeric cultivation	3,000.00	30
Space (Sqm) for vegetables crops cultivation	-	-

Table A6.13: Cost and Return fromFish Culture (Per Hectare Greenbelt Area)

SI. NO	Major Species/ Fish Category												Return (million BDT)			Net Benefit (million BDT)	Remarks
		Fish fry cost			Feeding cost			Labor cost			Others (liming, netting etc. (million BDT)	Total Cost in million BDT	Production (kg/ha)	Price (BDT/kg)	Total revenue (million BDT)		
		Fish fry number	Price BDT/fry (including transport)	Fish fry cost in million BDT	Fish Feed (kg)	Price BDT/kg	Feed cost in million BDT	Labor number	Wage BDT/ day	Labor in million BDT							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 st period Koi	64,220	2	0.13	7410	40	0.30	125	400	0.05	0.04	0.51	3705	160	0.59	0.08	15-16 nos/kg and 15-20% mortality rate, Duration 4 months. Annual culture is based on rainwater harvesting.
2	2 nd period Koi	64220	2	0.13	7410	40	0.30	125	400	0.05	0.04	0.51	3705	160	0.59	0.08	Same as above
3	Shing	79040	2	0.16	9880	40	0.40	125	400	0.05	0.04	0.64	3458	300	1.04	0.40	18-20 nos/kg and 15-20% mortality rate. Duration 7-8 months. Annual culture is based on rain water harvesting.
4	Magur	39520	2		4940	40		125	400	0.05	0.04	0.09	2223	300	0.67	0.58	15-16 nos/kg and 15-20% mortality rate. Duration 7-8 months. Annual culture is based on rain water harvesting.
	Annual Maximum Return to be															0.66	

Table A6.14: Cost and Return fromFruit, Vegetables, Turmeric and other crops cultivation (Per Hectare Greenbelt Area).

Sl. No.	Major Plant Species/Crop Types	Investment Cost per ha.							Direct Tangible Benefits per ha.					Net Benefit (BDT Million/ ha)
		Cost/ Sapling or Seed cost/ha	Sapling number	Land Preparation cost (1 st Year)	Labour Cost (1 st Year)	Input Cost (1 st Year)	Sapling cost (1 st Year)	Total Cost	Yield (no/ha)	Price BDT/no	Return/ha	By product	Total Return /ha	
1	2	3		4	5	6	7	8	9	10	11	12	13	14
1	Coconut (Narikel)							32,500	16,900	20	338,000		338,000	0.31
2	Palmyra (Taal)	30	100	10,000	50,000	5,000	3,000	65,050	25	6,500	162,500		162,500	0.10
3	Date palm (Khejur)	10	100	100	50,000	5,000	1,000	55,150			190,000	2,000	192,000	0.14
4	For All types of vegetables	2,000		14,000	40,000	12,000	50,000	68,000	20	10,000	200,000		200,000	0.13
5	Turmeric							61,016					90,367	0.03

Source: BARI Survey (Compiled) 2014

Table A6.15: Data Sheet for Cyclone Damages to Lives and Properties in Bangladesh 1970-2015 (for a period of 46 years).

Year	Affected numbers of				Damages of Resources											
	District	Upazila	Family	People	Crops Damaged fully (acre)	Crops damage partially (acre)	No. of house damage fully	No. of house damage (partially)	No. of dead people	No. of dead livestock(cattle's and goats)	No. of damage institution (fully)	No. of damage institution (partially)	Road damage fully (km)	Road damage partially (km)	No. of damages bridge / culvert	Embankment damages (km)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1970	5	99	-	1,100,000	-	3,350,000	3,350,000	-	250,000	470,000	-	-	-	-	-	-
1971	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1972	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1973	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1974	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1975	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1976	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1977	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1978	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1980	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1981	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1982	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	9	30	-	167,500	39,500	86,590	10,095	7,135	10	2,020	-	-	32	-	11	10
Year	Affected numbers of				Damages of Resources											
	District	Upazila	Family	People	Crops Damaged fully (acre)	Crops damage partially (acre)	No. of house damage fully	No. of house damage (partially)	No. of dead people	No. of dead livestock(cattle's and goats)	No. of damage institution (fully)	No. of damage institution (partially)	Road damage fully (km)	Road damage partially (km)	No. of damages bridge / culvert	Embankment damages (km)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1986	7	30	-	238,600	17,800	84,837	1,116	3,446	12	1,050	2	47	132	-	-	1
1987	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1988	21	131	-	1,006,536	2,316,042	1,597,780	788,715	863,837	9,590	386,766	2,442	5,444	515	976	39	18
1989	33	71	-	346,087	38,712	38,629	12,173	20,008	573	2,065	74	166	-	-	-	-
1990	39	127	-	1,015,866	171,099	242,897	75,085	63,562	132	5,326	233	461	-	-	-	-
1991	33	102	-	13,919,504	145,032	800,346	854,399	903,024	138,958	1,061,054	3,927	5,952	-	764	496	707
1992	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	2	8	-	422,020	23,986	579,512	52,057	17,476	134	1,296	96	98	169	-	83	97
1995	28	67	-	305,953	2,593	42,644	22,395	44,664	91	1,838	127	537	-	-	-	-
1996	2	9	16,520	81,162	-	2,431	15,868	15,976	545	4,933	85	64	-	-	-	-
1997	10	66	743,467	3,784,916	254,755	59,788	290,320	452,886	127	7,960	1,824	3,000	174	1,527	527	122
1998	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1999	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2002	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	30	200	2,064,026	8,923,259	743,322	1,730,317	564,967	957,110	3,363	1,778,507	4,231	12,723	1,714	6,361	1,687	1,875
2008	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	11	64	948,621	3,928,238	77,486	245,968	243,191	370,587	190	150,131	445	4,588	2,233	6,621	157	1,743
2010	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A6.16: Value of Woodlot from Plantation.

Items	Return (BDT)
Block Plantation	
Plantation Area (Ha)	204
Timber (Cft)	136,678
Poles (no)	78,018
Fire wood (cft)	129,440
Total sale value (Tk)	77,202,562
Sale Taka/ ha for 2,500 no)	378,443
Sale Taka/ha for 1,600 no)	87,799

Source: Patuakhali Coastal Forest Division, BFD

