Analysis of Geo-environmental Indicators for Coastal Zone Management of East Coast of the Bay of Bengal along Bangladesh

by

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Certificate of Validation

This is to certify that Ms. Saima Ahmad has completed the Ph.D thesis entitled "Analysis of Geo-environmental Indicators for Coastal Zone Management of East Coast of the Bay of Bengal along Bangladesh" under our joint supervision. This is her original work.

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Declaration

This is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Dedicated to my beloved Parents

Late Mesbahuddin Ahmad

&

Late Nasim Banu

Abstract

The present study area, the east coast of Bangladesh, stretched along the Bay of Bengal is characterized with unique geo-environment and biodiversity. The coastal zone, endowed with a rich pool of diverse, complex and dynamic Terrestrial and Coastal & Marine Ecosystem, has been increasingly confronting with the deteriorating geo-environment owing to escalating unscrupulous anthropogenic interventions. Consequences were observed in the changes of geomorphic features, such as shoreline movement, deterioration of environmental quality of soil and water, as well as changes or loss in terrestrial and coastal and marine biodiversity. The consequent geo-environmental degradation such as, the extremely polluted river estuaries, rapid shoreline change, as well as the declaration of the Teknaf coast, Cox's Bazar district as the 'Ecologically Critical Area (ECA)' by the Government of Bangladesh in 1999 enthused to select the eastern coastal zone, starting from the Feni River up to Inani beach, Teknaf coast as the study area of the present research.

A research gap regarding an integrated study about the 'Cause and Effect' relationship between the geo-environmental state and anthropogenic activities were revealed from the previous literatures. Hence, the main theme of the study was to analyze the selected geo-environmental features as study indicators and to incorporate them into the existing ICZMP (1999) and future development plans and policies.

Accordingly the study attempted to develop a Strategic Policy Framework (SPF) to incorporate the present study geo-environmental indicators into the existing ICZMP (1999) of Bangladesh, as well as into the future development plans like- the Sustainable Development Goals (SDGs, 2015-2030), 7th and 8th Five Year Plans (FYP, 2016-2020 and FYP 2021-2025), Bangladesh Delta Plan, 2100, and into the UNESCO's Ocean Science Decade (2021-2030) declaration.

The main theme and objectives of the study were to analyze the state of selected geo-environmental indicators of the east coast to provide them as development indicators for existing and future Coastal Zone Management (CZM) plans and policies for the east coast.

Soil, water and mollusk shell samples were collected, processed, measured and analyzed to reveal the geo-environmental state of the study area. The 'Net Shoreline Movement' (NSM) of the sample area coastlines was measured; heavy metal concentration and physio-chemical quality

of soil and water samples from the point sources of pollution along the study area were measured. Further, floral and faunal bio-diversity changes of the study area were explored by measuring two parameters, such as the 'Vegetation Coverage', and concentration of five heavy metals and $CaCO_3$ in the mollusk shells. Maps were created from six radiomterically corrected Temporal Landsat Images with ArcGIS to illustrate the location of the study area and sample areas, the chronological shoreline movement pattern and the vegetation coverage depletion pattern of the sample areas.

To reveal the geomorphic condition of the study area, the 'Shoreline Extraction and Accuracy Assessment' method was used to achieve a comparative assessment of the coastline or shoreline movement along east coast, within a time span of twenty five years (1990 to 2015). The 'Digital Shoreline Analysis System (DSAS)' was applied upon the sample area coastlines to get the previous shoreline positions (1990-2015). The 'Modified Normalized Difference Water Index (MNDWI)' and 'Single Operator' methods were applied to extract the 'Land-Water boundary' from the satellite images. Transect lines were created perpendicular to user-defined 'Base Line' to calculate the 'Net Shoreline Movement (NSM)'.

The EPR graphs and NSM map revealed that, the shorelines of the Feni River and the Bakkhali River estuaries, and the shoreline of the Marine drive sample area have experienced noteworthy changes during the study time (1990 to 2015). However, the field survey (March, 2018) accentuated that, the Feni River estuary has become accretion dominated, after the completion of the Muhuri Closure Dam (MCD) upon the Feni River. The decreased tidal force at downstream of the closure dam, huge logging along the shores and deposition of massive amount of silts, carried down through the vast Ganges-Brahmaputra-Jamuna River system are the major causes of accretion. The Jalkadar khal was comparatively stable as the shorelines were protected by the coastal protection dams on both sides. However, the huge garbage disposal from the fish market, boat construction and repairing factories, ice factories were observed to narrow down the estuary width. The EPR graphs and NSM map of the Bakkhali River estuary sowed that, the river estuary became erosion prone due to strong waves created by the frequently commuting passenger speed boats, and the big fishing trawlers since 2016. However, converse situation was observed in 2018 while huge accretion was observed at both shores of the estuary mouth. For instance, the Kasturi ghat and Nuniarchara fishery ghat area were going under land reclamation process for the extension of Cox's Bazar Airport, construction of Fishing Community Rehabilitation project, and Khurushkul Bridge by dumping huge amount of municipal wastes and river sediment carried down from the Meghna River. On the other hand, the EPR graphs and NSM map of the Teknaf coast along Marine drive (1990 to 1995) depicted massive erosion process. The coastline along Himchari and Sonarpara has eroded and moved east wards, almost near the Marine drive. Though the time span from 2010 to 2015 illustrated complete erosion activities along the entire study area, the field survey during March 2018 observed a gradual siltation process occurring within the geo-sand bag and cemented tetra- pod protected areas.

The environmental condition of the sample areas was assessed by measuring the concentration of five heavy metals, two non-metals or nutrients and four physio-chemical parameters of the soil and water. The concentration of Fe was the highest followed by the concentration of Pb, which were alarmingly higher than the world average in most of the soil and water samples. The untreated industrial wastes and huge municipal garbage were detected as the main point sources of pollution. During the field survey in 2018, the eastern side of the Bakkhali River sample area was observed to be filled up with huge municipal garbage to construct the Khurushkul Bridge, allowing seepage of toxic effluents from these wastes to contaminate the soil and water of the study area. Further, the heavy metal concentration of sample mollusk shells was measured to examine the adverse effect of them upon the faunal bio-diversity. Added to these, the $CaCO_3$ content of the sample mollusk shells depicted a declining concentration (42.5% - 91%) of $CaCO_3$ in comparison to the world standard content (95% - 97%). The Normalized Difference Vegetation Index (NDVI) and vegetation coverage maps were prepared to assess the vegetation depletion at the sample areas. The study showed that, vegetation coverage at Bakkhali river estuary reached a negative scale (- 0.1).

Recognizing the deteriorating geo-environmental state of the study area, the present study attempted to develop a policy framework for sustainable management plan. A Pressure-State-Response (P-S-R) model was formulated basing upon the findings of the present study to portray the 'Cause and Effect' relationship among the present study indicators. In the P-S-R index, the Pressure indicators (industrial effluents, municipality wastes, and illegal encroachment, construction of river dams and coastal embankments, and rapid deforestation) exert negative impacts upon the study area. The Response indicators (Local and national stakeholders, Government plans and policy frameworks) were observed to play a partially functional role in confronting, mitigating, as well as, developing the coast in a sustainable approach. Basing upon the present study P-S-R model, incorporation of a SPF for CZM was attempted. The recommendations of the concerned stakeholders, like-the Cyclone Preparedness Programme (CPP) and Forest Divisions of Chattogram and Cox's Bazar; the Fisheries Research Institute, Cox's Bazar; the BWDB, Chattogram, Upazila Chairman and local journalists were included into the framework.

Finally, the present study advocates to create a strong integration among all the local stakeholders, as well as to incorporate the proposed SPF for the fully-functional implementation of the existing ICZMP, along with the future coastal zone management plans and policies to form a sustainable coastal zone in Bangladesh.

Acronyms and Abbreviations

AAS : Atomic Absorption Spectroscopy

AMSL : Above Mean Sea Level

BBS : Bangladesh Bureau of Statistics

BCAS : Bangladesh Center for Advanced Studies

BDL : Below Detection Level

BFRI : Bangladesh Fisheries Research Institute

BWDB : Bangladesh Water Development Board

CARS : Centre for Advanced Research in Science

CDS : Coastal Development Strategy

CZP : Coastal Zone Policy

CZM : Coastal Zone Management

CPP : Cyclone Preparedness Program

DoE : Department of Environment

DPSIR : Driver-Pressure-State-Impact-Response

ECA : Ecologically Critical Area

EEZ : Exclusive Economic Zone

ESA : Ecologically Sensitive Area

ESCAP : Economic and Social Commission for Asia and the Pacific

FAP : Flood Action Plan

FGD : Focus Group Discussion

icddr,b :International Centre for Diarrhoel Research, Bangladesh

KII : Key Informative Interview

MoWR : Ministry of Water Resource

MoDMR: Ministry of Disaster Management & Relief

PSR : Pressure-State-Response

UNEP : United Nations Environment Program

WARPO: Water Resource Planning Organization

WB : World Bank

Operational Definition

Coastal Area and Coastal Zone

FAO (1998) defined the coastal area as the interface or transition area between land and sea and the coastal zone as an area along the coastline of a bay, sea, or ocean which has been defined for management purposes.

Sustainable Coast

Sustainable coast is a coast where all its biotic and abiotic components are preserved as much as possible in their natural habitat, while exploiting and utilizing the coastal resources. In 1987, World Commission on Environment and Development stated that, sustainable development is "to meet the needs of the present without compromising the ability of future generations to meet their own needs". Three main perspectives those summarize the idea of Sustainable development, are: i) Economic development to improve the quality of life of people, ii) Environmentally appropriate development, and iii) Equitable development. Sustainable coast thus, indicates a coast where, all the above mentioned standpoints are met.

In 1987, the United Nations World Commission on Environment and Development defined sustainable development as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs

ICZMP

The term Integrated Coastal Zone Management Planning**,** coined at Earth Summit, 1992, is a method of the management of the coastal zone by an integrated approach, concerning all aspects of the coastal zone, including geographical and political boundaries, in an attempt to attain sustainability.

In Bangladesh, the GoB provided a characterization of ICZM in 1999 through a Policy note, prepared by the concerned ministries (MoWR, 1999b). The process was proved as an effective general framework for dealing with the conflicts aroused due to interaction within different users. The ICZM endeavors to co-ordinate development and management along the coastal zone of Bangladesh.

Coastal Zone of Bangladesh

Coastal zones are the interfaces of land and ocean balancing geosphere, atmosphere and biosphere (World Bank, 1993). The intermittent key players of hydrological cycles, the rivers and distributaries, the ocean currents and waves accumulate huge organic and geochemical substances to produce highly productive zones of food and raw materials, energy, minerals.

Based on three basic natural processes, those govern opportunities and vulnerabilities of the coastal zone of Bangladesh, such as- i) tidal fluctuations, ii) Salinity (soil, surface water or groundwater), and iii) Cyclone and Storm surge risk, the Inter-Ministerial Technical Committee (April, 2006) declared that, totally 19 Coastal Districts, comprising 147 upazilas and the Exclusive Economic Zone (EEZ) are categorized as the Coastal zone of Bangladesh (47,201 km^2; WARPO, 2006). Nevertheless, totally 48 upazilas of 12 Coastal districts, exposed to the river estuaries or the coast, are defined as the ***Exposed coast,*** while the rest 99 upazilas of the remaining 7 coastal districts are termed as the ***Interior coast***, since they are located at the rearward side of the Exposed coastal upazilas.

Coastal Ecosystem

Coastal ecosystems are regions of significant biological productivity, which provide a wide array of goods and services, like, hosting the commercial ports, producing fish & fisheries resources for both human and animal consumption; and functioning as the substantial source of fertilizer, pharmaceuticals, cosmetics, household products, and construction materials. Encompassing a broad range of habitat types and harboring a wealth of species and genetic diversity, coastal ecosystems store and cycle nutrients, filter pollutants carried down from the inland river systems, and help to protect shorelines from erosion and storms.

Ecosystem Diversity in Bangladesh

Basing upon the bio-geographic features, the ecosystems of Bangladesh are broadly clustered as: (a) Terrestrial, (b) Inland Water, and (c) Marine and Coastal Area (DoE, 2015).

Ecologically Critical Area (ECA) of the Study Area

The Ecologically Critical Areas are defined as ecosystems, affected adversely by anthropogenic interference. The Bangladesh Environment Conservation Act (BECA, 1995; cited in Rizwana, 2012) declares that, an Ecologically Critical Area (ECA) is an ecosystem, which is considered to be threatened to reach a critical state. However, in 1999, the DoE officially declared nearly 40,000 ha. area, within seven separate wetlands as the ECAs. According to the declaration, the Cox's Bazar-Teknaf Peninsula (20,373 hector) along the Coastal and Marine ecosystem of the east coast of Bangladesh was declared as an ECA site (DoE, 2015). The Teknaf peninsula is one of the four sample areas of the present research, characterized as the longest sandy beach ecosystems (80 km) in the world. The ECA sites contain biodiversity of global significance. The main purpose of the declaration was to address and remove all threats to biodiversity within its focal areas as well as to the wider 'Buffer zone' will be mitigated in order to provide additional protection for the 'Focal Areas' (Banglapedia, 2015).

Point-Source Pollution: Point source pollution occurs when pollutants from a single source, such as, toxic wastes coming from a discharge pipe attached to a factory, oil spill from water vehicles into the water body, or a discharge from a factory chimney. When point-source pollution enters the environment, the adjacent areas become the most contaminated site. For example, toxic wastes drained directly to the beach and coastal water through the huge pipes from the shrimp hatcheries at Himchari, Marine drive made the area a point source pollution site.

Bio-Diversity of Bangladesh

Bangladesh is considered as one of the ten global hot-spot areas (Nishat, et al., 2002).The different geographical locations, such as, the Hill ranges, Evergreen and semi-evergreen forests, Dry-deciduous and moist deciduous forests, Grasslands, Reed lands, Floodplains, Rivers, Low-lying islands (Char lands), Ox-bow lakes (Baors), River back swamps (Haors), Open woodlands (Village Grove), Low-lying deep depressions (Beels), Ponds/canals/ditches, Estuaries, Coastal mudflats, Coastal islands, Mangrove swamp, Coral-bearing island, and Marine ecosystems has ensured the wide diversity of avifaunal, aquatic and plant biodiversity species in the country.

Bio-ecological Zone of the Study Area

The terminology 'Bio-ecological Zone' was coined while preparing an atlas of Bangladesh on the biological diversity as well as ecological characteristics at national scale. To determine the bio-ecological zones of the country, the intricate interaction between the abiotic and biotic properties like –physiographic, climate, soil type, flooding depth and frequency, and their cumulative effect on the biotic elements, such as, the floral and faunal biodiversities at a specific delineated zone. The sample areas of the present study are within the Bio-ecological zone 8a (Nishat, et al., 2002), termed as Chattogram Coastal Plain (21°30′-22°56′ N. and 91° 25′ - 91° 56′E).

Bioremediation

This is a waste management technique that involves the use of microorganisms to remove or neutralize pollutants from a contaminated site. According to the EPA, bioremediation is a "treatment that uses naturally occurring organisms to break down hazardous substances into less toxic or non toxic substances". For instance, to clean up oil spills, bacteria are introduced to the area of the spill where they break down the hydrocarbons of the oil into carbon dioxide. Bioremediation technology modifies physical, chemical, biochemical, or microbiological environmental conditions by using microorganisms to destroy or detoxify organic and inorganic contaminants in the environment (EPA, 2013). The process can be applied above ground (ex situ) or below ground (in situ).

Modified Normalized Water Differentiation Index (MNWDI)

There are many several methods, such as, Water Indices (McFeeters 1996 and Xu 2006) and Manual Digitizing at Fixed Zoom-In Level by single operator (Dewan, et al., 2017), established for Shore line extraction and accuracy assessment of land-water boundary from satellite images. Water indices are the best to identify water body in Landsat sensor. Normalized Differentiate Water Indices (NDWI) was developed by McFeeters (1996) for MSS (Multi Spectral Sensor), was modified to be termed as Modified NDWI (MNWDI) by Xu, H. (2006).This is the most effective method for TM, ETM, and OLI sensor (Li et al.2013). All of these indices specially identify the wetland from the satellite images. Generally, these water indices use green and mid-infrared spectral bands of different range to identify land and water area. Usage of the band was shown to produce up to 96.9% accuracy (Frazier and Page, 2000).

Normalized Difference Vegetation Index (NDVI)

The NDVI is a standardized index which generates an image displaying greenness (relative biomass). The NDVI is used for global vegetation monitoring, as it helps to compensate the changing illumination conditions, surface slope, physiographic feature, and other extraneous factors (Lille sand, 2004).The NDVI process creates a single-band dataset that mainly represents greenery. The **Negative** values represent clouds, water, and snow, and values near **Zero** (0) represent rock and bare soil.

1.1 Introduction

Bangladesh, the largest delta in the world is mostly formed of vast floodplains. Nevertheless, the Precambrian Himalayan piedmont highlands lying in the north and north-west, the Pleistocene Table lands such as, the Barind Terraces in the north and the Madhupur Terrace in the central area of the country, the High hill ranges lying in the south-east, the Low Hill ranges lying in the north-east at Sylhet are the high elevated land surfaces of the country. The south and south east border of Bangladesh is demarcated by 710 km long coastline (CCC, 2016). The total coastal zone is extended over 47,150 sq. km., consisting of 19 coastal districts with 38.52 million populations (BBS 2011; cited in CCC, 2016). The coastal zone is affluent in geomorphic and biological diversity, such as the vast and dynamic river network, long uninterrupted coastline, sandy beach and sand dunes, and rich biodiversity. The coastal zone functions as the ground of diverse natural processes, intermingled with the anthropogenic activities such as shrimp cultivation, tourism, shipping and inland navigation, ship breaking, oil and gas exploitation. All these factors provide numerous tangible and intangible opportunities to the nation (CCC, 2016). On the contrary, the natural resources of the coastal zone has been confronting with multiple, as well as critical constraint such as non-sustainable use of resources (CCC, 2016), climate change induced natural calamities, and rapid geo-environmental deterioration, set within a human context of wide-spread poverty, lack of public awareness, institutional and legal limitations, cyclones (Deb, 2014). The DoE (2005) classified the coastal zone of Bangladesh into three physiographic regions such as (i) the stable Deltaic Western coastal region (Atlantic type), (ii) the Deltaic Central coastal region, and (iii) the Deltaic Eastern coastal region (Pacific type). The ‘Western coastal regions’ comprises comparatively more stable geomorphology, while the ‘Central coastal region’ experiences dynamic geomorphology of the Ganges-Brahmaputra-Meghna River network due to constant erosion and accretion processes.

However, the Eastern coastal region, stretched in north-south direction, is a coastal plain characterized with wide shallow continental shelves, laden with huge sediment depositions, mud plains, sandy beaches and sand dunes; along with the hilly ranges at the eastern flank (Chowdhury, 2012a) and low coastal relief ranging from 4-5 meters above mean sea level (AMSL) (CCC, 2016). Further, the east coast is rich biodiversity and dynamic Terrestrial, as well as Coastal and Marine ecosystems (Nishat, et al., 2002). Despite the prevailing opportunities, the east coast has been experiencing accelerated rate of coastal erosion and accretion, soil and water pollution, changes and loss of biodiversity, as well as ecological criticality caused mainly by anthropogenic interventions. All the aforementioned geo-environmental deterioration has been functioning as major hindrances against all types of development potentialities of the east coast. Accordingly, recognizing the prevailing opportunities and vulnerabilities, the present study has selected the east coast as the study area and selected several geo-environmental features of the east coast as the study indicators. The study mainly focused upon causes and consequences of deterioration of selected geo-environmental features of the east coast, as well as the ways to incorporate them into the existing ICZMP (1999) and other future development plans and policies.

1.2 Background of the Study

The distinctive geomorphic features endow the east coast with rich biological diversity. Being categorized as the 'Bio-Ecological Zone 8a' (Nishat, et al., 2002), the east coast consists of estuarine brackish water and soil, mangrove forests and diverse floral and faunal resources. All these geomorphic and biological resources turned the east coast in an effluent, complex and dynamic zone of 'Terrestrial' and 'Coastal and Marine Ecosystem' (Illustration 1.1 & 1.2).

From the socio-economic perspectives, the Cox's Bazar and Inani sea beaches are the major tourist zones of the country. Recently, as a part of the ongoing huge development plans, this coastal zone has been flourishing as the center of economic growth and hence, drawing a large number of permanent inhabitants. Further, since the 'Settlement of Maritime Border Dispute' between Bangladesh and the neighboring countries, the Government of Bangladesh (GoB) has been prioritizing the development initiatives in the sector of 'Blue Economy' along the coastal zone (Hossain et al., 2017). However, the all embracing scope of blue economic development, including the artisanal and industrial fishing, marine fish and fisheries cultivation, development of coastal and marine aquaculture, expansion of eco-tourism and trade, exploitation of renewable energy like oil, gas, and mineral; development of eco-friendly ship-building and recycling industries, human resource development and many other related sectors have been prioritized in the development initiatives of the entire coastal zone of Bangladesh. Despite all the aforementioned opportunities prevailing at the east coast, the geo-environmental vulnerabilities such as the coastline erosion and accretion, climate change induced (CCI) heavy monsoon rainfall often accompanied by hill slides, flash flood, and water logging; cyclonic storms and surges at different magnitudes; increased salinity, higher tidal inundation and saline water intrusion in fresh water zone due to sea lever rise (SLR) have been exerting adverse impacts upon the east coast. Added to these, the increased discharge of toxic effluents and pollutants generated due to unscrupulous anthropogenic activities has been deteriorating the 'Terrestrial' and 'Coastal and Marine Ecosystems'. All these aforementioned hindrances have been impeding the socio-economic developments, specifically the expansion of blue economy in the study area. Realizing the need to mitigate, as well as protect the geo-environmental state of the study area, the present study attempted to investigate the geo-environmental features, the comparatively less explored natural process discussed in coastal zone management plans. Accordingly, literatures regarding previous and existing coastal zone management plans, particularly the 'Integrated Coastal Zone Management Plan' (ICZMP, 1999) of Bangladesh and the geo-environmental state of the east coast was reviewed for the present study. The sample areas were selected basing upon the most vital geomorphic process functioning at the east coast, such as the erosion and accretion process along the sample river estuaries and coastlines, as well as the consequential effects of theses processes functioning at the east coast, such as the ecological criticality and biodiversity changes.

The main theme and objectives of the study were to analyze several geo-environmental features of the east coast and provide these as development indicators for existing and future Coastal Zone Management (CZM) plans and policies. Accordingly, several geo-environmental features of the study area were chosen as the measuring 'indicators' to reveal the state of the east coast.

1.3 Rationale of the Study

The coastal zone of Bangladesh is extended over about 32 percent of the total land area and sustains the livelihoods of approximately 28 percent of the total population of Bangladesh (Islam, 2004).The major sources of livelihoods in the coastal zone are agriculture, fishing and fishery; salt farming, industrial and agricultural labor; and extraction of forest resources. Nevertheless, the GDP from the coastal zone is lower than that of the national standard. According to a report, nearly 12 million people live in poverty at the coastal zones of Bangladesh (World Bank, 2016).

Despite the hindrances mentioned above, the diverse opportunities prevailing at the study area provides the strength to flourish as a zone of massive socio-economic development. These are - (i) the longest uninterrupted east coastline; (ii) the wide estuaries with rich biodiversity; (iii) great potentiality of coastal and marine fish and fisheries cultivation; (iv) utilization of the salts and mineral resources;(v) the coral eco-systems around the Inani beach; (vi) great potentiality of exploitation of both on-shore and off-shore natural gases and oil; and (vii) thriving economic development. Hence, the growing industrial sectors, fish and fisheries resource farming, salt cultivation, development of the huge 'Fishermen Rehabilitation Area', construction of highways, bridges and railways, along with the consequent socio-cultural advancement of the local community people has enhanced the necessity of immediate fully-functional implementation of the Integrated Sustainable Coastal Management (ICZMP, 1999), associated with the Sustainable Development Goals (SDGs) for the east coast. The construction of mega development projects along the study area such as the Muhuri Irrigation Project (MIP) in 1986, the largest economic zone of Bangladesh ‘Mirsharai Special Economic Zone’ and the ‘Mirsharai Upazila Development Project’ (2017-2020)(MoH&PW,2017), the ongoing mega project of railway construction in Cox’s Bazar district, modification of the Cox’s Bazar Airport into international standard and Airport extension, Khurushkul Extensive Shelter project (the Fishermen Rehabilitation project), Khurushkul bridge construction, and Sabrang economic zone at Teknaf has been pulling a huge population to settle in this zone. Consequently, the unplanned, unscrupulous anthropogenic activities of the local people have been deteriorating the terrestrial as well as the coastal and marine ecosystems of the study area. The entire coastal zone is becoming prone to land erosion and accretion, diurnal tidal surge, increased salinity in soil and water, infiltration of toxic wastes into the lithosphere, hydrosphere and biospheres, and the climate change induced (CCI) atmospheric hazards, such as seasonal storms and cyclones, associated with storm surges. All these vulnerabilities have been gradually turning the coastal dwellers more vulnerable to natural, as well as, socio-economic disasters, causing deceleration of the entire socio-economic development of the coastal zone. The GoB (2005) has identified the area as the ‘agro-ecologically disadvantaged area’ (Islam and Ahmad, 2004).However, the escalating degradation of these geo-environmental potentialities and diversities due to the increasing anthropogenic activities along the east coast motivated to conduct the present study. The present study attempts to measure the state of the selected geo-environmental features and incorporate these as the development ‘indicators’ to establish an area-specific, realistic and fully-functional CZM plan for the study area.

1.4 The Geo-Environmental Indicators of the Present Study

Basing upon the opportunities and vulnerabilities prevailing at the east coast of Bangladesh, the following geo-environmental indicators were selected to evaluate the geo-environmental state of the study area (Fig.1.1).

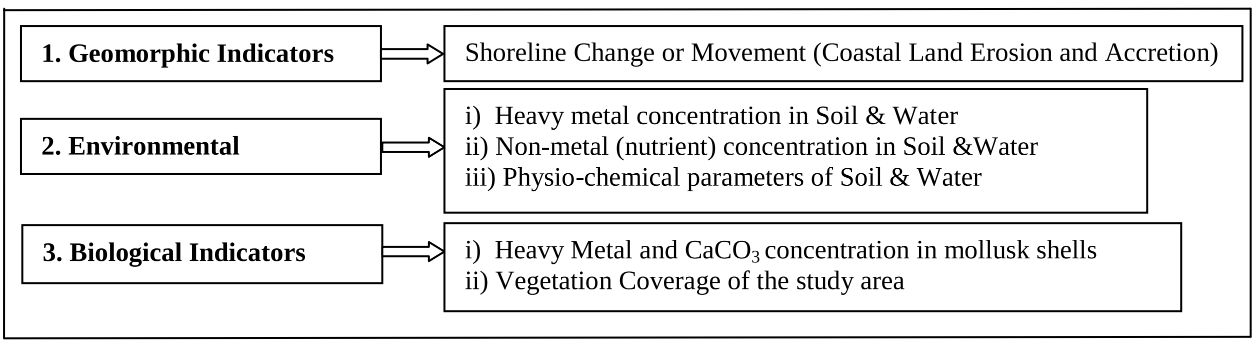


Fig.1.1: The Geo-Environmental Indicators of the Present Study

Source: Present Study, 2018

1.5 Problem Statement and Central Research Question of the Present Study

In Bangladesh several sustainable coastal zone development and management plans, and policies or frameworks were formed from the early 1960s. The major initiatives were- (i) the systematic development of large-scale embankments for flood control from the 1960s; (ii) the afforestation project (1995 to 2002) to build ‘Coastal Greenbelt’, and (iii) land reclamation project, which started with the Meghna Cross-Dam I (1957) and Meghna Cross-Dam II (1963-64) (Banglapedia 2015) along with several community based management and delta development projects. The previous plans and policies embraced the sustainable development and management of the Terrestrial and Coastal & Marine ecosystem, as well as, the CCI disasters. Nevertheless, though the previous literatures generated a huge data pool regarding the physiography, geomorphology, environment, bio-ecological diversity and CCI disaster, discussion about the ‘cause and effect' relationship between these features and the anthropogenic activities remained insignificant. Nevertheless, for further CZM plans and policy frameworks for the east coast, the incorporation of the present study geo-environmental indicators in a SPF was considered as a vital issue in the present study. Hence, the central research question of the present study was to investigate the ways to formulate a Strategic Policy Framework (SPF) to incorporate the study indicators into the existing and future CZM and development plans and policies, like-the ICZMP (2002), the SDG (2015-2030), the 7th & 8th Five Year Plans (FYP, 2016-2020 & 2021-2025), proposed Bangladesh Delta Plan: 2100, and the UNESCO’s Ocean Decade (2021-2030).

1.6 Main Theme and Objectives

The main theme of the study was to analyze the selected geo-environmental features as indicators to incorporate them into the existing ICZMP (1999) and future development plans and policies.

Objectives

To accomplish the main theme, five objectives were chosen like below:

1) Identify the Net Shoreline Movement (NSM) pattern
2) Determine the environmental quality of soil and water
3) Assess the faunal biodiversity change
4) Appraise the floral biodiversity change
5) Attempt to formulate a ‘Strategic Policy Framework’ to incorporate the geo-environmental indicators into the existing and future plans and policies of the eastern coastal zone.

1.7 Structure of the Thesis

The First chapter is the introductory chapter, where the background and rationale of the study; selected geo-environmental indicators, and main theme and objectives of the present study; problem statement and central research question; the structure and the limitation of the present study were discussed.

The Second chapter is a compilation of the literatures reviewed and the synthesis of the literatures. Further, a compilation of previous and existing international and national Coastal Zone Management Plans and Policies; Coastal Embankment Protection measures taken by the Government of Bangladesh to develop a sustainable coastal zone, as well as, the key challenges to achieve the full functionality of the existing ICZMP (1999) at the east coast have been discussed.

The Third chapter is an illustration of the natural and socio-economic features of the study area. The chapter is a narrative of the concept of coastal zone of Bangladesh, location of the selected study area and sample areas, the physiographic, geomorphic, and geologic structure, the hydrology and hydraulics, climate, bio-ecological zones, geo-environmental indicators, the indicators for P-S-R, socio-economic structure, such as the demographic and economic structure of the sample areas, land use and land cover transformation pattern, and the opportunities and vulnerabilities prevailing in the study area has been narrated in this chapter.

The Methodology of the present study was discussed elaborately in the Fourth chapter. The findings of the present research work was presented in the Fifth, Sixth and Seventh chapters. In Fifth chapter, the result of historical shoreline change pattern of the sample areas was illustrated by the 'Net Shoreline Movement (NSM)' method to reveal the geomorphic changes.

In the Sixth chapter, the results showing the concentration of five heavy metals, two non-metals, and four physio-chemical parameters of soil and water samples was discussed to portray the environmental condition of the indicators.

Added to these, in the Seventh chapter, the biodiversity change pattern of the present study area was elaborated. The state of the faunal indicator- the $CaCO_3$ content in the sample mollusk shells, and the floral biodiversity indicator-the Vegetation coverage of the study area was revealed. The 'Vegetation coverage' maps and a 'Vegetation Index' of the sample areas have been illustrated. The Chapter Eight discussed the 'Findings' of the study work, basing upon the 'Results' of the research work. This chapter efforts to compare the findings of the present research work with that of the previous ones, and to point out the knowledge gaps regarding the coastal zone management in Bangladesh. The chapter attempted to structure a 'Pressure-State-Response (PSR)' model to illustrate the 'Cause and Effect' relationship between the geo-environmental state and the anthropogenic interventions. Further, the chapter concluded with an endeavor to formulate a 'Strategic Policy Framework (SPF)' with a view to incorporate the study indictors into the existing ICZMP (1999 & 2002), as well as into the future coastal zone management at the east coast.

In Chapter Ten, conclusion was drawn for the present study. The chapter concluded with specific observations about the significance of the study geo-environmental indicators for coastal zone management, key lessons learned,\ on geo-environmental indicators, the limitations in their integration with coastal zone management framework and future direction of research.

1.8 Limitations of the Study

Several limitations had to be confronted during literature review and field surveys in the study area. These are as follows:

1. Insufficient data about the point sources of pollution,
2. Conservative attitude of the stakeholders in providing data,
3. Non-conducive rules and regulations of the stakeholders for restricted data, and
4. Inadequate records regarding institutional coastal zone management plans and policy frameworks.

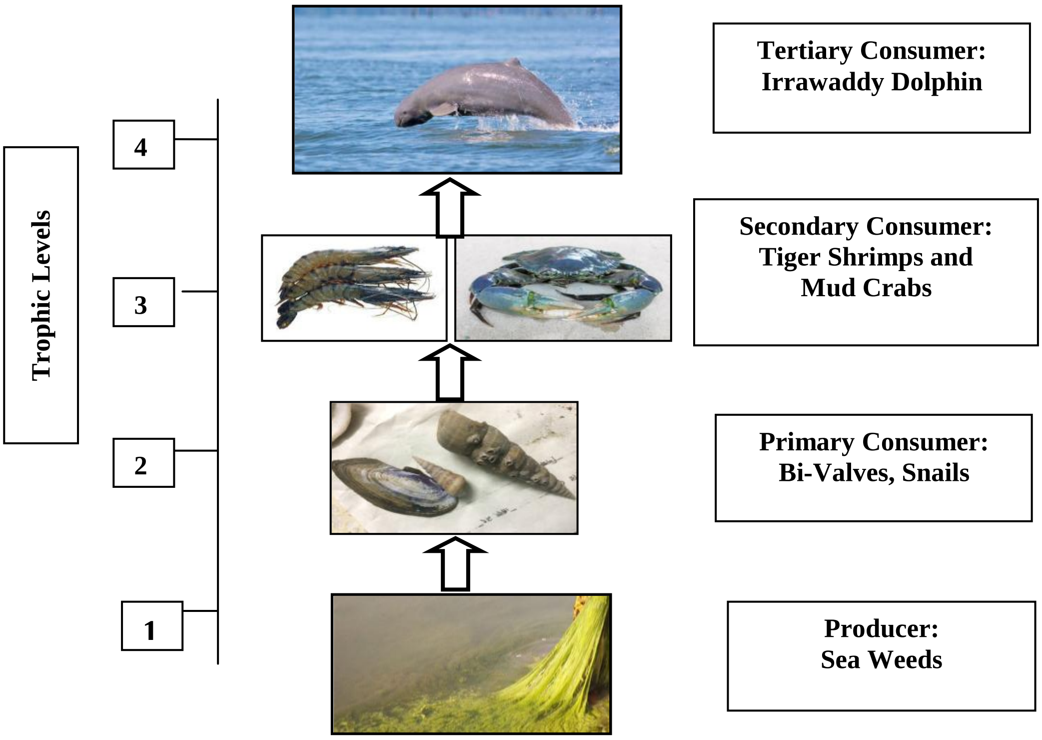


Illustration 1.1: Marine and Coastal Ecosystem of the East Coast

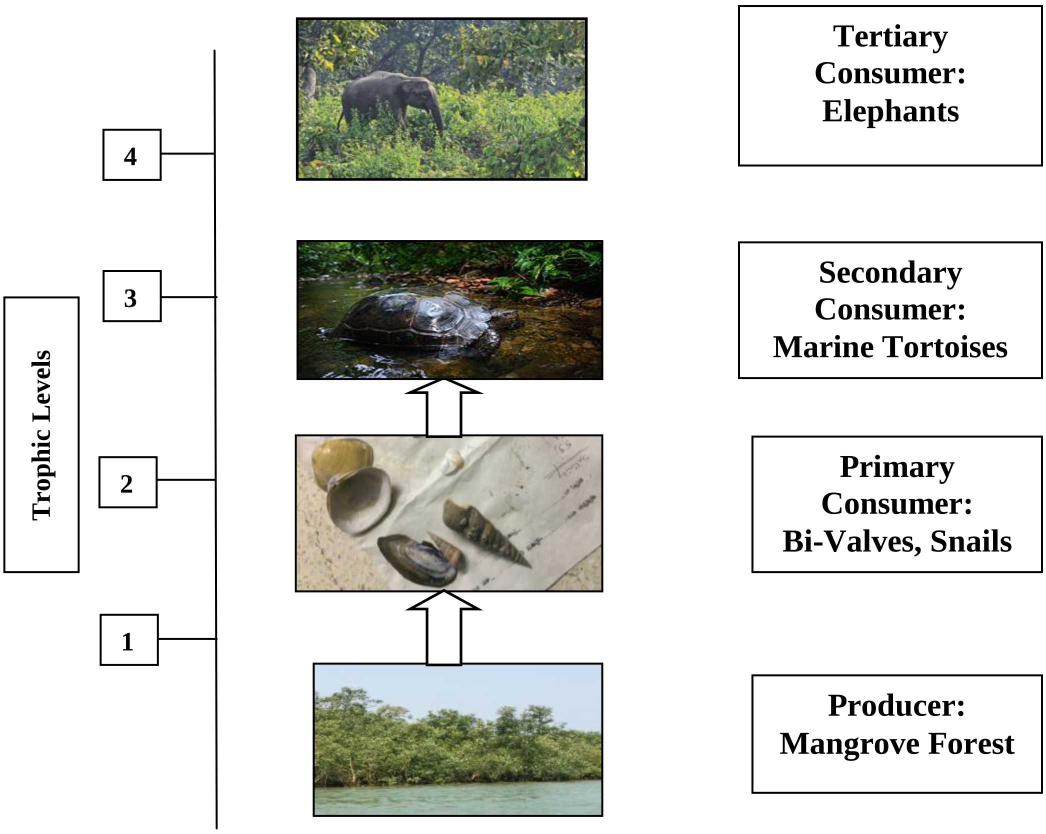


Illustration 1.2: Terrestrial Ecosystem of the East Coast

2.1 Introduction

The scholarly journal articles, research books, government reports and web materials regarding the success and /or failure of the coastal zone management plans and policy frameworks, as well as the opportunities and vulnerabilities of the physical, hydrological, environmental, biological and socio-economic processes of the coastal ecosystems; achievement of the 'Driver-Pressure-State-Impact-Response (DPSIR)' model application for coastal zone management at global and national arena has been reviewed as well. The following sections depict the knowledge which enriched and facilitated in identifying the relevant issues on geo-environmental parameters, their measurements and research approaches.

2.2 Coastal Zone Management Plans

The present study reviewed the literatures regarding 'Coastal Zone Management (CZM)' plans and frameworks to appraise the existing CZMs at global and national level. However, a concise discussion of the concept 'Sustainable Development' has been mentioned herewith, as this concept put forth a profound impact upon the formation of 'CZM' concept at national and international arena. Following the sustainable development concept, literatures regarding CZM plans and frameworks developed at international level were reviewed. Secondly, the literatures about all the initiatives of coastal development in Bangladesh were reviewed. Finally, the 'Integrated Coastal Zone Management Plan' (ICZMP, 1999) developed for Bangladesh and its key outputs such as (i) the Coastal Zone Management Policies (CZMPo, 2005) and (ii) the Coastal Development Strategy (CDS, 2006) has been reviewed for acquiring a clear concept about the processes of CZM in a sustainable way.

Brundtland (1987) developed the concept of 'Sustainable Development' articulated by the World Commission on Environment and Development (WECD). The report titled 'Our Common Future', also known as the 'Brundtland Report' defined sustainable development as an 'idea that human societies must live and meet their needs without compromising the ability of future generation to meet their own needs' (Brundtland, 1987). Nevertheless, in the Coastal Zone Management Act (1972) the USA first coined the term 'Coastal Zone Management' (CZM) and acted as the pioneer in CZM at international arena (Sorensen, 1993). Pernetta and Eldar, 1993 (cited in FAO, 1998) defined the coastal zone management as ‘a multifaceted management of coastal resources which combines every human, physical and biological aspects of the coastal zone within a single framework’.

Chua, et al. (1997) mentioned about the ICZM project in Xiamen coast of China, which started in 1994 as a successful regional program for the ‘Prevention and Management of Marine Pollution’ in the East Asian Seas. The purpose of applying ICZM process at Xiamen was to test a working model for the application of an integrated coastal management system for mitigating marine pollution and rapid economic development. The paper outlined the successful institutionalization at local level through the establishment of strong decision-making mechanisms based on consensus building among major stakeholders. Further, the framework targeted at the introduction of scientific knowledge and technology, the legislative improvement and enforcement, cross-sectoral marine pollution monitoring, development of sustainable financing options, enhancement of public awareness and participation, and capacity building towards ICM goals.

Marit and Lisette (2009) mentioned about the significance of the coasts as ‘an area of increasing human settlement and socio-economic activities’, as well as ‘the zone of global climate change’ projected by the ‘Inter Governmental Panel on Climate Change IPCC’ (2007). The report stated that, the coastal nations should develop long-term (decades to centuries) and large-scale ($10–10^2$ km^2) management program for sustainable coastal zone management. The United Kingdom Coastal Authorities have forecasted a coastal evolution with a time span of 100 years, with a sustainable ‘Vision’ of the coast.

Afterwards, the European Commission (1997) defined Integrated Coastal Zone Management (ICZM) as ‘a dynamic, continuous and iterative process designed to promote sustainable management of coastal zones which covers full cycle of information collection, planning, decision making, management and monitoring of implementation’.

2.3 International Initiatives for Coastal Zone Management

From the early 1960s until the present days the global coastal zone management plans and frameworks modified from a sectoral to a comprehensive and integrated approach;

from the protection of the coastal and marine ecosystems to the concept of integrated sustainable development. The Intergovernmental Oceanographic Commission (IOC) originated from a programme of UNESCO in 1960.Functioning as a separate unit of UNESCO, the IOC aimed at improvement of knowledge about oceans and increasingly directed towards the issues of responsible ocean management and sustainable development. The programme emphasized upon conducting trainings and disseminating education, as well as developing mutual assistance in the field of ocean sciences for preparing the ‘Capacity Building’ for global programs in international arena.

Though the Stockholm Conference (1972) was the first United Nation’s (UN) conference on human environment, the concept of Integrated Coastal and Ocean Management (ICOM) approach to address multi-sectoral sea use conflicts was emerging in international fora’ from the late 1970s (Chao, 1999). The ICOM approach involved principles, management strategy, approaches, methods and techniques (Cicin-Sain and Knecht, 1998). The two broad categories of ICOM were the (i) principles related to environment and development prescribed by Earth Summit, and (ii) principles related to the special character of oceans and coasts (Cicin-Sain and Knecht, 1998).

United Nations Conference on the Human Environment (1972), known as the ‘Stockholm Conference’ was the first United Nation’s (UN) conference on international environmental issues. The Stockholm Conference was initiated by Sweden, and arranged by the UN, back in 1968 to study the environmental problems, as well as, to identify the required international cooperation to solve them. Besides reflecting growing interest in environmental conservation issues, the conference initiated the ‘Global Environmental Governance’ concept. The conference produced the ‘Framework for Environmental Action,’ with an action plan containing 109 specific recommendations related to human settlements, natural-resource management, pollution, educational and social aspects of the environment, development, and international organizations. The final declaration of the Stockholm Conference was the ‘Finite nature of Earth’s Resources and the necessity for Humanity’ to protect them. The Stockholm Conference also led to the creation of the United Nations Environment Programme (UNEP) in December 1972 to coordinate global efforts, to promote sustainability, and safeguard the natural environment (Brisman, 2011). However, the ‘Convention on the Law of the Sea (UNCLOS, 1982)’ was the foundation of the new regime for the governance of the oceans of the world (Sabha, 1998).

In the late 1990s, the United Nations conference on Environment & Development (Rio Conference, 1992) fully supported the Stockholm declarations (1972) and emphasized upon the emerging concerns related with the environmental issues due to the rapid socio-economic development. A set of six important output documents like- (i) the Rio Declaration on Environment and Development, (ii) the UN Framework Convention on Climate Change (UNFCCC), (iii) the Convention on Biological Diversity, (iv) the World Summit on Sustainable Development (WSSD, 2002), (v) Agenda 21 and consequent Millennium Development Goals (MDGs, 2000-2015), and (vi) the call for Sustainable Development Goals (SDGs) for the post-2015 period at the Rio+20 Conference (2012) increased the arena of ocean and marine environmental concerns globally. Nevertheless, the principles of UNCLOS, and the Rio Declaration, especially Agenda 21-chapter 17, provide a legal basis for coastal and marine resources management (Cicin-Sain and Knecht, 1998).

The first international water project known as the ‘Prevention and Management of Marine Pollution in the East Asian Seas’ (PEMSEA,1993), a joint program of 14 East Asian costal countries, was supported by the Global Environment Facility (GEF,1993) and implemented by the United Nations Development Programme (UNDP). Executed by the International Maritime Organization (IMO), the project addressed some of the key marine pollution management problems of the East Asian region. The project focused on the prevention and management of marine pollution by setting up two pilot sites for integrated coastal management (ICM) in Xiamen (PR China) and Batangas Bay (Philippines); mobilizing sub-regional efforts (Indonesia, Malaysia and Singapore) to address marine pollution problems in the Straits of Malacca and Straits of Singapore; and strengthening capacity development, especially developing countries such as Cambodia, PR China, DPR Korea, Indonesia, Philippines, Thailand and Vietnam. The key significant progress of the project was- (a) the successful development of working models on the application of integrated coastal management (ICM) in addressing land-based sources of pollution; and (b) the measurement of risk assessment and risk management methodologies for addressing pollution in the Straits. The project developed the concept of 'Paradigm Shift', an approach and methodology in addressing the mounting environmental pressure caused by increasing marine pollution loads (Chua Thia-eng, 1997). The successful completion of the first project led to the second phase project named the 'Partnerships in Environmental Management for the Seas of East Asia (PEMSEA)' (October 1999–2007). Focusing on building intergovernmental, interagency and multi-sectoral partnerships in environmental management, major objectives of the project were- (i) to formulate and adopt integrated approaches to manage land and water uses; (ii) to develop human resources in areas of planning and sustainable management through innovative capacity building; (iii) demonstrate ICM as a systematic and effective approach for coastal areas, and scaling up of ICM initiatives; and (iv) development and adoption of a sustainable regional mechanism to protect and manage the coastal and marine environment of the Seas of East Asia. The PEMSEA used to operate in a self-sustaining operating mechanism through its SDS-SEA strategy to work with national and local governments, companies, research and science institutions, communities, international agencies, regional programs, investors and donors. In 2003 the PEMSEA endorsed the decade long 'Sustainable Development Strategy for the Seas of East Asia' (SDS-SEA, 2007-2017), which outlined a shared vision, as well as the collective strategies and approaches to achieve the goals of sustainable development for the region. Later, the 'SDS-SEA Implementation Plan, known as the 'SDS-SEA IP (2018-2022)' was introduced with 3 Priority Management Programs and 3 Governance Programs. The Priority Management Programs included the (i) Biodiversity Conservation and Management; (ii) Climate Change and Disaster Risk Reduction and Management; and (iii) Pollution Reduction and Waste Management. On the other hand, the cross-cutting Governance Programs included the (ii) Ocean Governance and Strategic Partnerships; (ii) Knowledge Management and Capacity Development; and (iii) Blue Economy Investment. To ensure regular monitoring of progress and gaps, progress/achievements of partners and collaborating organizations, national and regional ocean events, PEMSEA produces the State of Oceans and Coasts (SOC) Report and arranges a triennial congress known as 'East Asian Seas (EAS) Congress. This congress is an intellectual melting pot of the various stakeholders, partners and collaborators, where policy directions, as well as knowledge exchange activities and discussions targeted at specific sectors, promoting priority programmes and various mechanisms for 'Sustainable or Green business' mechanisms are discussed.

Later in the late 1990s, integration of all the previous relevant policy areas, sectors, and levels of administration was precisely incorporated within the ICZM approach. The International Integrated Coastal Zone Management (ICZM) Planning concept was developed in 1992 during the UN Conference on Environment and Development (the Earth Summit); and the policy regarding ICZM was set out within the Agenda 21, (Chapter 17). The Agenda 21 of the UNCED, known as the 'Rio Declaration' on Environment and Development, and the 'Statement of principles for the Sustainable Management of Forests' were adopted by more than 178 governments at the Rio Conference 1992. While aiming at achieving global sustainable development in the 21st century, the agenda attempts to ensure that every local government should to draw its own local Agenda 21. The full implementation and the programme for further implementation of Agenda 21 and the commitments to the Rio declaration were strongly reaffirmed at the World Summit on Sustainable Development (WSSD, 2002) held in Johannesburg, South Africa.

The ICZM aimed at creating balanced environmental, socio-economic, cultural and recreational objectives, over a long-term period. The integration of all the terrestrial and marine components of a selected area with the development instruments such as all relevant policy areas, sectors, and levels of administration in spatio-temporal perspective was the main theme of an ICZM plan. Cicin-Sain & Knecht (1998) stated that, the CZM strategy got recognized as 'Integrated Coastal Zone Management' (ICZM) or 'Integrated Coastal Management' (ICM) at global platform during the late 1990s. The research discussed that, though stating nearly similar plan, none of the terms (ICM/ICZMP/ICOM) are "one size fits all" concept. Rather, the researchers recommended that, the themes of the ICZMP have to be modified and adapted according to the designated area; as each area is characterized by its unique geo-environmental features.

Thia-Eng, C. (1993) defined ICZM as ‘a resource management system focused on integrative, holistic approach and an interactive planning process in addressing the complex management issues in the coastal area’. Sorensen (2000) attempted to define integrated coastal management as a “multi-disciplinary process that unites levels of government and the community, science and management, sectoral and public interests in preparing and implementing a program for the protection and sustainable development of coastal resources and environments”. The paper also illustrated a chronological history of global ICM process development. According to the paper, in the first decade, the practice was confined to the United States, Australia and UNEP's Regional Seas Programme, with a limited expansion of national and sub-national ICM efforts in both developed and developing nations. Later, in the mid-eighties ICM processes stared with an escalation into a common global practice. In the 1980s, coastal zone management practice begun to proliferate, particularly within South East Asia, the Mediterranean and South America.

However, C. Shi. et al. (2001) proposed an integrated coastal zone management (ICZM) framework, addressing anthropogenic activities as the main hindrances for the Shanghai coast in China. The framework emphasized the implementation of (i) cross-sectoral management, (ii) strategic environmental assessment, (iii) systematic scientific research, and (iv)public involvement. The paper concluded with the statement of conductive management approaches at the local level for sustainable development.

The European Commission (2006) defined ICZM as “a dynamic, multidisciplinary and iterative process to promote sustainable management of coastal zones.

However, Rupprecht Consult & International Ocean Institute (2006) defined ICZM as ‘a comprehensive strategy for an integrated approach to planning and management at spatio-temporal scales, involving stakeholders in a participative way and ensuring good communication among governing authorities (local, regional and national)’. The approach addresses all three dimensions of sustainability, such as the socio-economic, cultural, and environmental.

Godschalk (2009) stated that, following the Rio Conference (1992) the ICZM concept became the dominant paradigm for coastal management, which approaches the sustainability of environmental, ecological, and socio-economic sustainability. The author stated that, the ICZM requires the planning and management area or zone comprised of: 1) coastal and estuarine waters, 2) the adjoining and complete inter-tidal area, 3) and the supra-tidal coastal lands. The overall goal of ICZM is to improve the quality of life of the communities that depend on coastal resources, as well as providing for needed development (particularly coastal dependent development); while maintaining the biological diversity and productivity of coastal ecosystems in order to achieve and maintain desired functional and/or quality levels of coastal systems, and to reduce the costs associated with coastal hazards to acceptable levels (Godschalk, 2009).

La Sara (2011) discussed about the evaluation of the success of the programs implemented. The research revealed that, the intensive exploitation of the coastal and marine resources by the local communities for their livelihood, as well as, open access to all made it difficult to control the over exploitation, as well as, misuse of the resources. The paper discussed about the over exploitation of the coral reefs of Indonesia. The subsistence and commercial fishing, destructive fishing practices, poor land use practices and runoff of pollutants, and removal of coastal mangrove forest has posed significant threats to coral reef ecosystems. The Government of Indonesia has established an integrated coastal zone management (ICZMP) approach to manage the coastal issues based on scientific approach. However, the local community has no access to the programs. The research paper stated that, for proper monitoring and evaluation of the ICZMP programs, an appropriate set of governance, ecological and socio-economic indicators has to be developed to determine whether ICZMP interventions are achieving their intended goals.

Guanqiong, et al. (2014) stated that, proper indicators and measuring methods could be a useful tool kit to indicate the performance of ICM. The paper realized that, for long-term perspective, using indicators to monitor and measure the progress and effectiveness of ICM implementation is a key step towards adaptive management of the ICM process. The paper revealed that, despite the successful implementation of ICM plans in three coastal cities of China, the proper methods of evaluating the ICM performance are still lacking. The correlations between ICM governance, coastal environmental and socio-economic sustainability are analyzed using the ‘Drive force-Pressure-Status-Impact-Response (DPSIR)’ model in the paper. Finally, the authors ensured the implication of the evaluation indicators and methodologies for other coastal cities for ICM practice.

Guanqiong, Ye et al. (2015) selected three coastal cities for their case studies to test the effectiveness of ICM in China, where about 12% of China’s coastline has already been under the ICM governance framework. The researchers selected the ICM indicators in terms of governance, environment and socio-economic aspects for quantitatively evaluating the ICM performance over a 9-year period from 2004 to 2012.The results showed that ICM performance based on governance, coastal environment and socio-economic aspects in the three cities had improved, indicating the effectiveness of ICM program implementation for the sustainability of China’s coastal cities.

The following literatures described the coastal zone management issues in Bangladesh perspective.

Zhu and Hao (2018) discussed that, a paradigm shifts in an ICM system play a crucial role for the success of the ICM, taking the Successful ICM of Xiamen as the case study. Further, the authors attempted to divide the development process of ICM operational modality into three stages such as (i) decentralization of program management, (ii) primary establishment of the ICM system, and (iii) a stable and normalized ICM system. The paper structured a timeline of ICM system development as well as analyzed the development of main elements. Besides identifying the paradigm shifts implied in the development process, the institutional shift, vision shift, management approach shift, and management object shift has been discussed in the paper as well.

Wanfei, Qiu. et al. (2018) addressed the key drivers for implementing ICM programs in Xiamen, China were a growing level of public environmental awareness, multiple-use conflicts, and the need for more integrated coastal and ocean governance, driven by a clear vision and leadership from the Xiamen Municipal Government. The efforts for successful ICM initiatives in Xiamen demonstrated the importance of action plans, a legislative framework, financial sustainability, information management and dissemination, and capacity development in providing for an enabling environment for ICM activities. Nevertheless, the strong political will and leadership from the Municipal Government, has been emphasized as key factors for successful outcomes.

2.4 National Initiatives of Coastal Zone Management in Bangladesh

In accordance with the sustainable development strategies practiced in the world, Bangladesh also attempted to adopt the themes for coastal zone management in a sustainable approach from the early 1960s, when the landlord or *jaminders* used to build earthen dykes to protect the coast. The decade long perspective plans, namely, the Vision 2021 (2010-2020), the Sustainable Development Goals (SDGs), the 7th Five Year Plan (FY 2016 – FY 2020), the Bay of Bengal Large Marine Ecosystem (BOBLME) Project (2008-2013) and the future declaration of UNESCO's 'Ocean Decade (2021-2030)' are the major elements of the ongoing national development strategies of Bangladesh Government.

Bangladesh has taken several development initiatives while some are in the process of being initiated in different sectors, namely shipping, fisheries, environment, and researches to either boost economic growth or to manage the natural resources more sustainably. From the late 1970s GoB has been taking several initiatives to protect and pay safety and sustainable development for coastal communities (Table 2.1). Bangladesh was a signatory to the Ramsar Convention (1971) and the World Heritage Convention (1972) which act as the principal instruments to ensure the conservation of global natural heritages. Besides these development initiatives, the eastern coastal zone has been experiencing rapid development in socio-economic sectors such as the huge housing project termed 'Fishermen's Rehabilitation' at Khurushkul, Bakkhali River estuary and the construction of the 'Marine Drive' along Teknaf coastal zone (Present Study,2018). However, a sequential description of the initiatives taken for the CZM in Bangladesh has been given in the following section.

The Cyclone Preparedness Program (CPP) was established in 1972 as a joint programme with the then League of Red Cross after the devastating Bhola cyclone in 1970. Later, considering the significance of cyclone preparedness and management for the coastal communities, the programme was taken under the Ministry of Disaster Management & Relief (MoDMR) with effect from July, 1973.

Table 2.1: Bangladesh Coastal Zone Management Strategies (1977- 2006)

1.	Off Shore Islands Development Boards (1977-1982)
2.	Bangladesh National Conversation Strategy (1987)
3.	Coastal Environment Management Plan for Bangladesh (1987)
4.	Coastal Areas Resources Development Plan (1988)
5.	Special Parliamentary Committee on Coastal Area Development (1998- 1990)
6.	National Capacity Building Approach the ICZM Initiative (1991)
7.	Coastal Zone Policy (2005)
8.	Tsunami Vulnerability Map (2005)
9.	Coastal Development Strategy (2006)

Source: Hafez, 2019

Moreover, subsequent to the raging cyclone 1991, the CPP introduced training on disaster management through the Early Cyclone Warning dissemination, Search and Rescue, Evacuation, Sheltering, First Aid, Relief Distribution and Rehabilitation; as well as conducting training, demonstration and awareness building programmes for its officials as well as volunteers. At present, the CPP, in collaboration with the Bangladesh Red Crescent Society, has been disseminating the official Bangladesh Met Department cyclone warning signals to the communities in total 19 districts, with its 55,260 volunteers (gender ratio of 10:5). The CPP has reached its apex of excellence through its comprehensive knowledge and understanding of building an inclusive and resilient society and has been recognized as the 'Model of Cyclone Preparedness' in the world (CPP, 2018).

In the late 1987, the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) took the first major initiative for developing a coastal zone management policy in Bangladesh in the report titled 'Coastal Environmental Management Plan for Bangladesh' (UNESCAP, 1987). The document discussed the natural, human, socio-economic, infrastructure and institutional situation and processes in the coastal zone including 'baseline' information and relevant knowledge on different aspects of the Bangladesh coastal zone (Islam, 2004). Purpose of the profile was to bring existing data, information, experience and knowledge on coastal matters together and provide constructive inputs for the policy makers, planners, coastal managers, other government agencies, researchers, educators and communities.

Bangladesh Fisheries Research Institute, 1984 was established as an autonomous research organization for planning, coordination and conduct of fisheries research in Bangladesh. The major objectives of the institute is to carry out and coordinate basic and adaptive research for development and optimum utilization of all living aquatic resources; to develop low-cost, less labor intensive, environment friendly improved fish culture and management technologies; to develop technologies for commercially important aquatic products including shrimps; and to develop skilled technical manpower through training and demonstration.

The Bangladesh Environment Conservation Act (BECA, 1995) declared five Ecologically Critical Areas (ECA) in Bangladesh where ecosystem has been considered to be threatened to reach a critical condition. The Department of Environment (Islam, 2015) officially declared nearly 40,000 ha, within seven separate wetland areas, as ECAs. These sites were Hakaluki Haor, Sonadia Island, St. Martin's island, and Teknaf Peninsula (Cox's Bazar Sea Beach), Tanguar Haor, Marjat Baor (oxbow lake) at Jhenaidaha and outside of Sunderbans Reserved Forest at 10 km extent. One of the three ECA sites at Cox's Bazar - the western coastal zone of Teknaf Peninsula (10,465 ha) has been selected as a sample areas of the present study. The principal legislations that safeguard ECAs in Bangladesh were the Environment Conservation Act (1995), Environment Conservation Rules (1997), and the Constitution of Bangladesh. The Article 18A of the Bangladesh Constitution includes provisions regarding the protection and improvement of environment and biodiversity and states that, the State shall endeavor to protect and improve the environment and to preserve and safeguard the natural resources, bio-diversity, wetlands, forests and wild life for the present and future citizens.

In 1999 the GoB initiated the National Programme of Action (NPA) for the Protection of the Marine Environment from Land-based Activities (Fig.2.1). This program was to promote the integrated coastal management and to reduce the pressure on marine eco-systems (DoE, 2006). In this context, the Bangladesh NPA examined the previous coastal management strategies, introduced the procedures and arrangements that preceded the consolidation of this document and adopted the methodological framework suggested by the United Nations Environment Program (UNEP) (NPA, 1999). This program was to promote the integrated coastal management and to reduce the pressure on marine eco-systems.

The Millennium Development Goals (MDG, 2000-2015) was formed in the year 2000 after the Millennium Summit held by the United Nations, following the adoption of the United Nations Millennium Declaration (UNFPA, 2000). All 191 United Nations member states at that time, and at least 22 international organizations, committed to help to fulfill the eight international development goals by the year 2015.The goals related to the present study criteria were the goals to ensure environmental sustainability, and to develop a global partnership for development. The Millennium Development Goals **(**MDG) was replaced by the Sustainable Development Goals (SDGs) in 2016.

In 2006, the Bangladesh Vision 2021 was prepared to form a framework for future Bangladesh, which reflects the hopes and aspirations of the citizens of the country for an economically inclusive and politically accountable society (GED, 2012). With a view to achieve eight identified goals, a set of measures were taken for implementation of several short and medium-term initiatives and interventions. These goals were: (i) to become a participatory democracy; (ii) to have an efficient, accountable, transparent and decentralized system of governance; (iii) to become a poverty-free middle-income country; (iv) to have a nation of healthy citizens; (v) to develop a skilled and creative human resource; (vi) to become a globally integrated regional economic and commercial hub; (vii) to be environmentally sustainable; and (viii) to be a more inclusive and equitable society. These eight goals emerged from a one-year long activism of Bangladesh civil society throughout 2006 and were handed over at the Nagorik Forum organized in Dhaka on 9 December, 2006.

The GoB obtained an ‘Emergency Cyclone Recovery and Restoration Project (ECRRP)’ in 2007 after cyclones SIDR and AILA, to carry out the ‘Feasibility Study of the Coastal Embankment Improvement programme’. Conceived by the by the Bangladesh Water Development Board (BWDB), an outcome termed ‘Coastal Embankment Improvement

Project Phase-I (CEIP–I)' was developed, with an objective to increase resilience of coastal population to natural disasters and climate change.

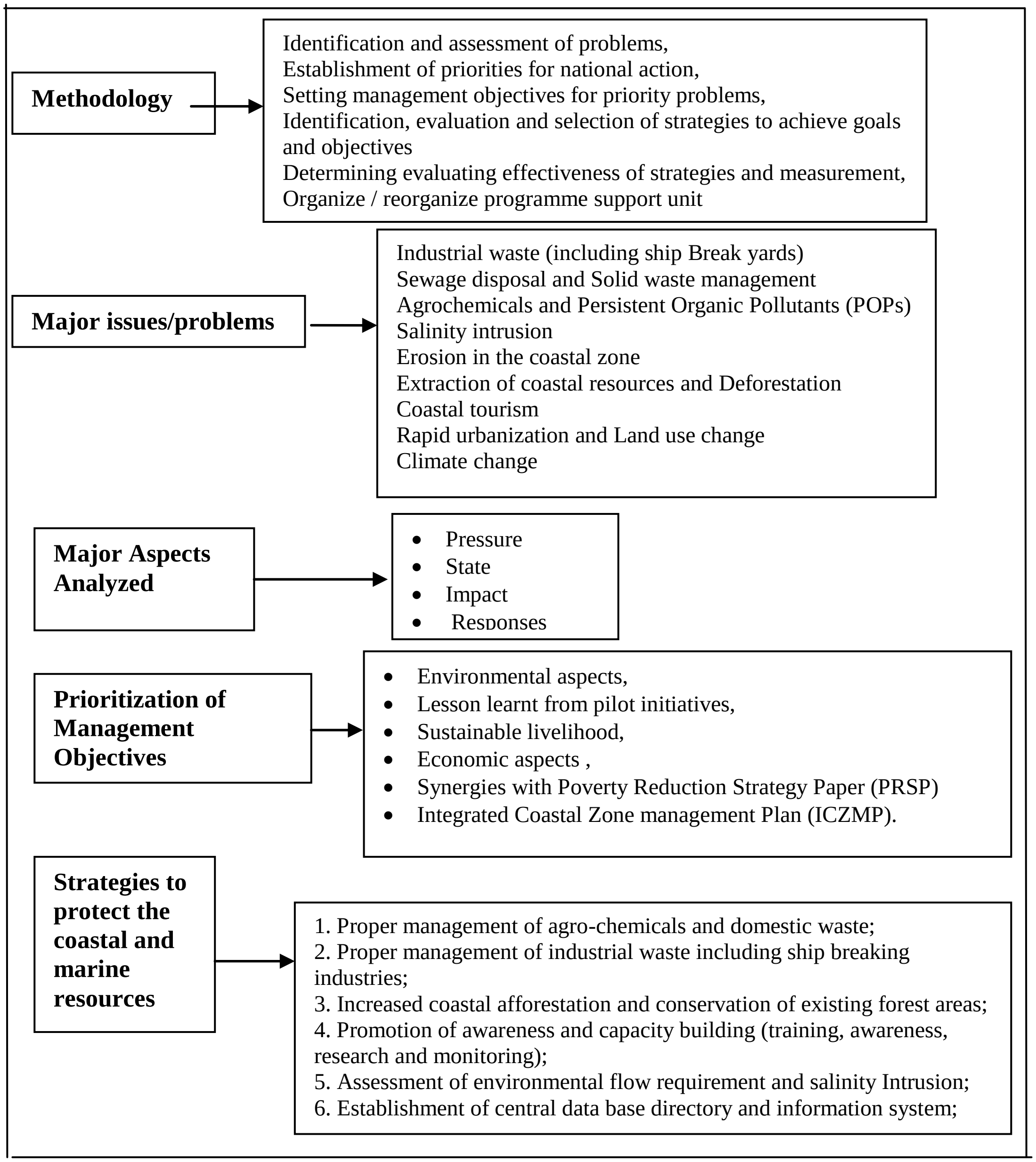


Fig. 2.1: Processes of National Programme of Action (NPA)
Source: NPA, 1999; MoEF, IUCN and BCAS, 2006

The project aimed at (a) increasing the protected areas in selected polders from tidal flooding and frequent storm surges; (b) reducing saline water intrusion to improve agricultural production in selected polders; and (c) improving the GoB capacity to prompt and effective response to crisis or emergency. Nevertheless, strengthening and upgrading embankments were the objectives to be achieved as part of an integrated approach to improve the polder system in the coastal area.

The Bangladesh Climate Change Strategy and Action Plan (BCCSAP) was developed in 2009 to be implemented from the FY 2017-2018 to FY 2019-2020 (MoEF, 2009). The BCCSAP was a framework of the executive plan for 'Mitigation and Adaptation' prepared by the Ministry of Environment and Forests (MoEF, 2009). This framework was termed as the 'Knowledge strategy' formed after the 'National Adaptation Programme of Action (NPA)' during the years 2005 and 2009. The plan sets out 44 programmes to be conducted by Bangladesh, as the synergies with the government's Vision 2021. The plans had to be carried out within a strategic time frame of short, medium and long term over six strategic areas like (i) Food security, social protection and health, (ii) Comprehensive disaster management, (iii) Infrastructure, (iv) Research and knowledge management, (v) Mitigation and low carbon development, and (vi) Capacity building and institutional strengthening. All of these strategies focus upon the poor and vulnerable groups of people, specifically women and children. One of the Infrastructure programme (T3P8) was aimed at restoring the rivers and khals through dredging and de-siltation works and another Mitigation programme (T5P7) targeted the reforestation as well as afforestation. The project aimed to conduct total eleven activities within a time frame of three years (from FY 2017-2018 to FY 2019-2020), all of which were regarding the Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone under the CEIP-I; review of the coastal polder improvement works (polder strategy) in view of probable adverse impacts of sea-level rise due to climate change, storm surges, land subsidence, changes in tidal and sediment dynamics; variations in salinity boundaries due to different flow regimes under external drivers of change; water resources management for improvement of the coastal polders and morphological studies of river and estuaries in the changing climate and different future scenarios; detailed engineering design of the coastal embankments, drainage regulators, flushing inlets, drainage canals, river training works, and all other related works and construction of foundations in soft river deposits, including knowledge of the effects of scour and the prediction of flexibility of foundations, suitability of earth for construction of embankments; various modeling studies; dynamic behavior and environment of the coastal ecosystem, water management & Sunderbans; social and resettlement studies and management plans; exploring and investigation on the Tidal River and Sediment Management in coastal polders.

Bay of Bengal Large Marine Ecosystem (BOBLME) Project (2008-2013) was formed by eight countries encircled by the Bay of Bengal, namely the Maldives, India, Sri Lanka, Bangladesh, Myanmar, Thailand, Indonesia and Malaysia to work together and establish a coordinated programme of action planned to improve the livelihood of over 400 million people living in the countries (FAO,2019). The rapidly growing population, who was highly dependent on coastal and marine resources for their food, livelihood and security as well as increased land use, has resulted in over exploitation of fish stocks and habitat degradation along the coastal region. This has led to extensive degradation of Coastal and Marine ecosystem of the BOBLME countries, which in turn, has created uncertainty about its sustaining capabilities in future. Despite the numerous international, regional and sub-regional organizations operating in the Bay, none of them have the infrastructural capacity to support the confronting issues of the coastal communities of the BOB. Furthermore, many ineffective policies, strategies and legal measures at the National level were feared to impede the development of any regional arrangements. Nevertheless, other major constraints include weak institutional capacity at national levels, insufficient budgetary commitments, and lack of consultation and empowerment of the local communities as well as stakeholder. The Project has five components like below:

Component 1 was the formation of a ‘Strategic Action Programme’ for the long-term institutional and financial sustainability of the BOBLME Programme, including ‘Transboundary Diagnostic Analysis’; Component 2 discussed the ‘Development and implementation’ of regional and sub-regional collaborative approaches for ‘Coastal and Marine’ natural resource management and sustainable use and community-based integrated coastal management. The Component 3 discussed the ‘Improved large-scale processes and dynamics’ for the predictability of the BOBLME environment, marine protected areas in the conservation of regional fish stocks, improved regional and global environmental assessment and monitoring programmes. Further, the Component 4 described about the 'Maintenance of Ecosystem Health and Management of Pollution' by establishment of an effective ecosystem indicator framework designed to measure progress toward sustaining BOBLME health. Finally, the Component 5 explained about the establishment of cost-efficient project management, monitoring and evaluation, and knowledge management and information dissemination capacity.

The Coastal Towns Environmental Infrastructure Project (CTEIP,2014-2020) (Revised) reported that, the low lying coastal zone of Bangladesh, consisting of 19 districts with a total estimated population of 38.1 million, of which 8.6 million was urban; was highly vulnerable to Climate change (MoWR,2017). As a consequence of limited infrastructural capacities, the coastal towns or Pauroshovas faces challenges in the operation and maintenance (O&M) with the accelerating degree of climate change. Though containing high coverage of sanitation (up to 94% HHs have toilets), there was no seepage collection or treatment systems posing high risks for public and environmental health. Moreover, the local urban planning was in its infancy, with master plans and development control systems emerging without any concern about climate change. There was an urgent need to strengthen municipal management and public awareness to complement physical investments as part of an integrated approach for ensuring climate resilience and sustainability of coastal towns.

The increase in salinity in the water supply sources (both surface water, and shallow groundwater) of the coastal towns, caused by escalating risk of flooding and sea level rise will lead to the deterioration of water quality and the availability of potable water, with disproportionate impacts to women and the poor, including impacts on maternal health.

Hence, the CTEIP (2014-2020) project has been taken by the Local Government Engineering Department (LGED), Ministry of Local Government, Rural Development and Cooperatives (LGRD), GoB. Financed by the ADB, Strategic Climate Funds (SCF), Bill and Melinda Gates Foundation (BMGF), Urban Climate Change Resilient Trust Fund (UCCRTF) and GOB; the project has been designed to support 8 towns in 4 coastal zone districts, namely Amtali, Galachipa, Mathbaria, Pirojpur (Batch I) and Barguna, Bhola, Daulat Khan, and Kalapara (Batch II), with additional 2 towns (Bagerhat and Patuakhali). These towns were selected to study the level of vulnerability, population size, density, and level of past investments to achieve the (1) Improvement of climate-resilient municipal infrastructure, (2) Strengthening of institutional capacity, municipal governance, and community development, and (3) Project management and administration support.

The Bangladesh Oceanographic Research Institute was the first and sole national institute, established in 2015 at Ramu, Cox's Bazar under the Ministry of Science and Technology, GoB (BORI,2015). The research institute has been working for the development and sustainable use of the marine resources in Bangladesh as well as functioning as the focal point of the potentialities of 'Blue Economy' both in national and international arena. The objectives and goals of the BORI is to conduct its own research, along with offering assistance to the other organizations and educational institutions regarding oceanographic, climate change induced research and the Environment Impact Assessment of any maritime projects; creation, development and dissemination data from Oceanographic Data Centre; assessment of oil spill risk; providing sufficient and accurate data to ensure the sustainable extraction and use of oceanic resources; creating awareness about the coastal zone conservation through extensive training of the local communities and the local stakeholders; procurement of Research Vessel and its maintenance to conduct research with collaboration of other international organizations. The vision of the BORI framework was to conduct research, implement the findings in the sustainable planning strategies as well as regulate all allied activities. The mission of the BORI was to conduct research on the environment friendly as well as sustainable development in the sectors like minerals, agriculture, environment and industry; development of ocean literacy through training and researches to exploit and use the marine resources sustainably; addressing all kinds of marine disputes and solving them; conducting research on the Exclusive Economic Zones (EEZ), biodiversity, offshore islands, coastal zone, petroleum and mineral resources, hydrology, sedimentation, climatology, astrology, navigation and communication; maritime trade and business; maritime laws and rules; physiographic features.

Shamsuzzaman, et al. (2018) claimed that, the challenges faced by the Coastal and Marine ecosystems of Bangladesh coast has derived from both natural and anthropogenic sources. Hence, being aware of the pressures on the sustainability of the social and ecological system, the government has taken initiatives to enhance the ocean-based blue economy activities as well as the ways to achieve sustainable development goals through the ICZMP.

The Sustainable Development Goals (SDGs) set for the years 2015-2030 was a holistic and integrated framework that spans across socio-economic and environmental dimensions. The main theme of the SDG 14 was to develop a comprehensive conservation strategy for the coastal and marine environment. The researchers attempted to formulate a detailed conservation strategy including nine interrelated sectors, their objectives and the action plan towards achieving the objectives. The implementation of these strategies was the instrument for accelerated blue economy growth as well as sustainable development goals. The IPCC defined sustainable development as ‘development that meets the needs of the present and future generations’ through balancing economic, social and environmental considerations. Afterwards, the IPCC introduced the United Nations (UN) 2030 Agenda for sustainable Development, which set out 17 goals for sustainable development for all country by 2030. Although several SDGs were linked to coastal areas and ocean sustainability, the fourteenth SDG was directly related to ocean sustainability, which emphasizes conservation and sustainable use of ocean, seas and marine resources for ensuring sustainable development. Since 2015, Sustainable Development Goals were included in the Agenda 2030 (Roy, 2018). This was particularly true in the context of Bangladesh – a country that has repeatedly been cited as one of the most climate-vulnerable nations. In Bangladesh, some of the changes induced by climate change include rise in the sea level, intensified natural disasters, degraded natural resources and displacement of its population. The aftermath of these impacts spread across most social, economic and environmental sectors making it intrinsically linked to the achievement of all the other SDGs.

The Perspective Plan of Bangladesh (2010-2021) was developed as a strategic articulation of the vision, mission, and goals of the Government in achieving political and socio-economic prosperity in reality by 2021(GED,2012). The plan provided the road map for accelerated growth by eradication of poverty, inequality, and human deprivation through the two five-year plans such as the Sixth Five Year Plan (2011-2015) and the Seventh Five Year Plan (2016-2020). The Perspective Plan 2010-2021 set solid development targets to transform Bangladesh into a middle income economy. The development priorities included (i) ensuring broad-based growth and reducing poverty; (ii) ensuring effective governance and sound institutions but creating a caring society; (iii) addressing globalization and regional cooperation; (iv) providing energy security for development and welfare; (v) building a sound infrastructure and managing the urban challenge; (vi) mitigating the impacts of climate change; and (vii) promoting innovation in a knowledge-based society. These thematic approaches were considered as the agents of shaping and forming the foundation of specific strategies which will be developed over the period of two five-year plans (Sixth and Seventh Five Year Plans).

The Sixth Five Year Plan (FY11-FY15) achieved a firm progress, which were carried out in the Seventh Five Year Plan (FY16-FY20) with a target to complete the remaining agenda. The first integrated coastal and ocean governance and management policy framework for Bangladesh was proposed in the 7th Five Year Plan (2016-2020) of the country by the Planning Commission of Bangladesh. This framework included the ocean as part of integrated coastal and ocean management and considers the Integrated Coastal and Ocean Management (ICOM) as the umbrella of ocean and coastal issues, which were to be addressed and managed sustainably (Islam, 2015). This structure had the provision for further extension to include cross border and, regional collaborations, especially in the environment, river and island management, conservation and scientific research. Hence, among the central targets of 7^{th} FYP set in harmony with the vision and goals of the Perspective Plan, the 'Environmental Sustainability' was the sector of concern in the present study. The goals of 'Environmental Sustainability' of the coastal zone were: (i) to increase productive forest coverage to 20 percent; (ii) to promote Zero discharge of industrial effluents; (iii) to protect at least 15% of wetland as aquatic sanctuary; (iv) to establish and protect five (500) meters wide 'Permanent Green Belt' along the coast; (v) implementation of the completed 'Land zoning' for sustainable land/water; and (vi) integration of the climate change induced environmental disaster risk reduction processes.

Further, after the successful functional implementation of the MDGs, the timely incorporation of the 7th FYP (2016-2020) of Bangladesh which aimed at 'Environmental Sustainability', along with the SDGs enhanced the success rate of CZM in the country. After the inclusion of maritime area 118,813 sq. km. of waters extending up to 12 nautical miles of territorial sea and a further Exclusive Economic Zone (EEZ) of 200 nautical miles into the sea (Bhuiyan, et al., 2015), the coastal zone of the country has acquired a significant status as a 'hotspot of coastal and marine ecosystem' of the Bay of Bengal region.

The United Nations Conference on Sustainable Development (Rio+20 or Earth Summit 2012) focused mainly on Sustainable Development, where in depth attention and coordinated action to conserve the world's Oceans and Seas had been emphasized. The UNDESA meeting on Oceans, Seas and the Global Ocean Commission, the Global Partnership for Oceans and the prominence given to oceans and seas in the UN five-year Action Agenda 2012-2016 reflect the significance of blue economy. Bangladesh hosted the 'International Workshop on Blue Economy' in 2014, with an approach to provide significant contribution towards eradication of poverty, contributing to food and nutrition security, mitigation and adaptation of climate change and generation of sustainable and inclusive livelihoods. Further, the potentialities, challenges and constraints in the recent prosperous sector of 'Blue Economy' in Bangladesh have to be dealt with the coastal zone management plans and strategies. Hence, holistic approaches for achieving the full functionality of the terrestrial and coastal and marine ecosystems in Bangladesh has to be ensured through strong governance, public-private partnership, marine education and research, strong maritime surveillance, security, and development of Marine Spatial Planning (MSP) for Bangladesh in an integrated 'Sectoral Approach' (Hussain et al., 2018). Hussain et al. (2018) also discussed the future potentialities of Blue Economic activities such as the sustainable exploitation of marine resources; fish harvesting; brackish and marine aquaculture; seed production and mariculture; along with the application of scientific techniques like bio-remediation and bio-absorption.

Later, in 2019 the Ministry of Fisheries and Livestock and the Food and Agriculture Organization (FAO) of the United Nations jointly organized 'Bangladesh Blue Economy

Dialogue on Fisheries and Mariculture' (FAO, 2019). The dialogue convened representatives of key stakeholders and resource persons to identify, discuss and arrive at a consensus on (i) the essential enabling conditions; (ii) facilitators for fisheries and aquaculture to contribute meaningfully and sustainably to the blue economy of Bangladesh; (iii) potentialities of the Blue economy to meet sustainable development needs and leverage opportunities in Bangladesh; (iv) operationalization of the Blue Economy by enhancing sectoral performance in Coastal and Offshore Marine Fisheries and Aquaculture; (v) functionalization of the Blue Economy to add value to existing Value Chains; (vi) sustainable development of New Value Chains through Multi-Sectoriality; and (vii) mainstreaming of blue economy endeavors.

Bangladesh Delta Plan 2100, formulated in 2018 by the General Economics Division (GED), Bangladesh Planning Commission, GoB (GED, 2018) was an integrated and holistic plan for Bangladesh delta to ensure safe living and sound economic development. The proposed draft report of the future plan was targeted to provide a complete strategy for development in next 50 to 100 years. The Bangladesh Delta Plan 2100 comprised several specific objectives such as, (i) enabling a favorable socio-political climate to formulate and implement the BDP; (ii) create an inclusive knowledge base for the terrestrial, (iii) aquatic and biological resources, as well as (iv) develop a spatial planning for the Bangladesh delta, while (v) emphasizing on spatial and ecological development, environmental disaster management, agriculture and food security, economic growth, and public health using the knowledge base to carry out integrated analyses and scenario building with the main stakeholders; and (vi) to prepare a draft Act to develop and establish Delta Framework in an integrated, targeted, inclusive, broadly supported, and transparent manner. The BDP aimed at creating the vision, goals, and measures to develop an adaptive, inclusive, and transparent policy-making process including both the public and private sectors. The innovation of ideas and concepts were required to contribute to the BDP 2100 to promote short-term regional and sectorial developments for future governance upon natural resources as well as spatial planning in Bangladesh delta. The BDP 2100 searched to integrate the short to medium term aspirations of Bangladesh to achieve Upper Middle Income (UMIC) status and eliminate extreme poverty by FY2031 with the longer term challenge of sustainable management of natural resources in all environmental biomes in the context of their interaction with natural disasters and climate change. From the experience of the successful implementation of the 'Dutch Delta Management' project, the Government of Netherlands assisted Bangladesh to develop the BDP 2100.

Recently, the United Nations has proclaimed a 'Decade of Ocean Science for Sustainable Development (2021-2030)' in 2017 to support the efforts of prevent, mitigate, and reverse the cycle of decline in ocean health (UNESCO, 2017). The decade will focus upon gathering the ocean stakeholders worldwide behind a common framework to ensure full support of ocean science in creating improved conditions for sustainable development of the ocean. The marine realm was the largest component of the Earth's system that stabilizes climate and support life on Earth and human well-being. Nevertheless, the oceans were found to be seriously degraded, with changes and losses in the structure, function and benefits from marine systems during the First World Ocean Assessment in 2016. UNESCO emphasized upon creating scientific knowledge base about the ocean's responses to pressures and management action for sustainable development. Hence, the decade project impelled the necessity of ocean observations and research to predict the consequences of change, design mitigation and guide adaptation. The Intergovernmental Oceanographic Commission (IOC) of UNESCO will coordinate the global ocean community to plan for the next ten years in ocean science and technology to make the Ocean decade successful. The 7 Principles of Ocean Literacy are- (i) the Earth has one big ocean with many features;(ii) the ocean and life in the ocean shape the features of Earth;(iii) the ocean was a major influence on weather and climate; (iv) the ocean made Earth habitable, (v) the ocean supports a great diversity of life and ecosystems; (vi) the ocean and humans are inextricably interconnected; and (vii) the ocean was largely unexplored.

Based on the Concept of Ocean Literacy Network in the United States, and following the Great Lakes Literacy framework as a model, the first version of 'Bay of Bengal Literacy' in Bangladesh perspective was formed in 2019 (Samakal,2019).

2.5 Status of Coastal Embankment Protection in Bangladesh

- In the early l900s, the earthen dyke embankment system was introduced by the Zamindars (landlords) to protect agricultural lands from tidal flooding (World Bank, 2005).
- By 1954, the infrastructure of the coastal dykes ceased and deteriorated, due to lack of operation and maintenance (World Bank, 2005).
- The Coastal Embankment Project (CEP) was the first major project implemented by the Government from the 1960’s to early 1970’s, to construct polders and embankments along the entire coastal belt (World Bank, 2005).
- After 1970 Bhola cyclone, Coastal Area Rehabilitation Project (Cr 339-BD) was formed with the assistance of the World Bank (World Bank, 2005).
- After 1987 cyclone, Bangladesh Coastal Embankment Rehabilitation Project (CERP) was initiated, which was approved in 1995 and was closed in 2003 (World Bank, 2005).
- After the April, 1991 cyclone, the project name was changed to the Coastal Embankment Rehabilitation Project (CERP) in 1993 (World Bank, 2005).

The objectives of CERP were to- (a) provide cyclone protection, improvement of livelihood of the community people, decline the number of infrastructural damages, minimize the loss of crops and livestock; (b) improvement of agricultural production and cropping patterns, by preventing saline inundation and reduced cyclone risks; and (c) to design, construct and maintain the coastal embankments with improved technology.

The Social Forestry program, known as the Coastal Green Belt project (1994-95) was financed by Asian Development Bank. This was an Afforestation and Nursery Development Projects theme, comprising 10 coastal districts. The objective of the project was to reduce loss of life and damage to property caused by cyclones through increased vegetative cover in the project area. The tree plantation process was done through a participatory approach between community people and the non-government organizations (NGOs) (Ali, 2015).

Recognizing the worsening state of the coastal and marine ecosystem, the GoB developed several plans and policies, strategies and frameworks to upgrade the prevailing constraints to sustainable development. Despite the enormous potentialities of the zone, the present research revealed the partial implementation of the initiatives due to the lack of strong linkage between the policy makers, implementing authorities and local stakeholders. The most fundamental issue for the failure of the full functional activities of the existing plans and policies were found to be ignorance at community level about the potentialities, vulnerabilities as well as sustainability of the rich coastal and marine ecosystem of the country. Hence, the present study advocated including several management strategies into the existing ICZM framework, considering both short-term and long-term programs of several years or even a number of decades. Finally, the ICZM Plan framework needs to be developed and implemented with skilled proficiency to keep pace with the rapidly changing geo-environmental as well as socio-economic situation.

The success story of all these plans and policies were different as all of these were not fully functional regarding the implementation and after evaluation. The lack of proper coordination, poor infrastructural facilities, inadequate financial and resource allocation, inappropriate framework, poor after monitoring, and most importantly, lack of strong and proper linkage among the GoB, local stakeholders and community people resulted into the different degree of failure of the above mentioned CZM approaches. Hence, the GoB issued a Policy Note in 1999 regarding the formulation of the ICZM Plan for Bangladesh (Islam, 2012).

Though Bangladesh instituted legal as well as planning instruments for the management of the coastal zone, these generally lacked adherence. Failure of executing the coastal zone related laws often instigate unregulated structural development along the coast (Islam, 2002). Consequently, the need for an area specific management program in the coastal zone of Bangladesh was recognized in a number of government initiatives, such as, the earlier policies and programs of different government agencies. Though numerous national initiatives for sustainable developments in the coastal zone of Bangladesh were attempted even from the early 1960s, the accelerated socio-economic progress, as well as, the increased anthropogenic intrusions into the study area resulted into the deterioration of its coastal and marine ecosystems. Hence, the formulation of the ICZM Plan (1999) by the GoB for the exploitation and utilization of the natural resources in a sustainable way became a vital concern for the nation. The ICZMP (1999) planned a transform from the ‘open access to all’ approach, which was causing unsustainable exploitation of resources, low level of transparency, and little stakeholder participation in resource management, to a ‘desired future’, characterized by sustainable, structured, rational, and transparent marine and coastal zone management. The plan further aimed at low degree of resource conflict, high level of stakeholder participation, and a skilled, supportive administration (CZMPo, 2005). The main theme of the ICZMP (1999) initiative was to address the vital problems of the Bangladesh coastal zone, while emphasizing the need for integrating the socio-economic and environmental issues. This was a widely accepted approach at all levels of governance, aiming at “establishing a policy framework that defines and directs the development of the coastal zone” through the harmonization of government policies and their implementation (ICZMP, 1999). The Policy Note on declared that, “ICZM offers a means of balancing the competing demands of different users of the same resource and of managing the resources to optimize the benefits that was consistent with the country’s goals….it has to prove to be an effective general framework for dealing with conflicts arising from interactions of the various uses of coastal areas. It aims at coordinated development and management.” The policy note defined four stages for generating the ‘Coastal Development Framework’ such as (i) Policy formulation,(ii) Strategic planning, (iii) Program development, and (iv) Implementation (Table 2.1).

Table 2.2: Framework of Stages in the Generation of an ICZMP

1: Policy formulation	2: Strategy planning	3: Program development	4: Implementation
Creation of a Policy Framework to establish goals and to authorize and guide the ICZMP program	Potential impacts of ICZMP policy action are explored where benefits are evaluated and data are accumulated and where general strategy is created and recommendations are made for organization	Once the strategy plan is accepted by policy makers, development of the ICZMP program can commence and details master plan for its implementation to be created	Once the master plan is approved and a budget and staff are authorized. The implementation stage can commence

Source: PDO-ICZMP, 2002 and Hafez, 2019

Later, in 2000 the ICZMP project was modified and operated by the Water Resources Planning Organization (WARPO), Ministry of Water Resources (MoWR). The goal of the modified ICZMP in 2000 is “to create circumstances through which the communities of the coastal area will be able to cope with the multiple vulnerabilities they face and realize the zone’s development potentials” (PDO-ICZMP, 2002). The project addressed the national concerns for coastal waters and natural habitats (mangrove, coral reef, and sea grass) and adjacent coastal areas. Three main outcomes of the project were the (i) Coastal Zone Policy (CZPo, 2005), (ii) Coastal Development Strategy (CDS, 2006) and (iii) Priority Investment Program (PIP, 2006) reports (WARPO, 2006). The main objectives of these outcomes were to alleviate poverty and enhance economic growth through the reduction of the prevailing and forthcoming coastal zone vulnerabilities and utilization of the opportunities in a holistic and sustainable approach, equitable distribution of resources, ensuring gender equality and empowerment of women folk and conservation of the critical ecosystems while pursuing their restoration. The CZPo (2005) framework explains of the rationale of coastal zone management, its goals and policies, concept of ICZMP and the issues in coastal zone management in Bangladesh.

The objectives and methodologies of the CDS report (WARPO, 2006) were consistent with 'National Strategy for Accelerated Poverty Reduction' (PRSP document) which support the ICZMP (WARPO, 2004). The emerging trends, such as, the increasing urbanization, changing pattern of land use, declining land and water resources, unemployment and visible climate change impacts has been taken into account in the CDS (WARPO, 2006).

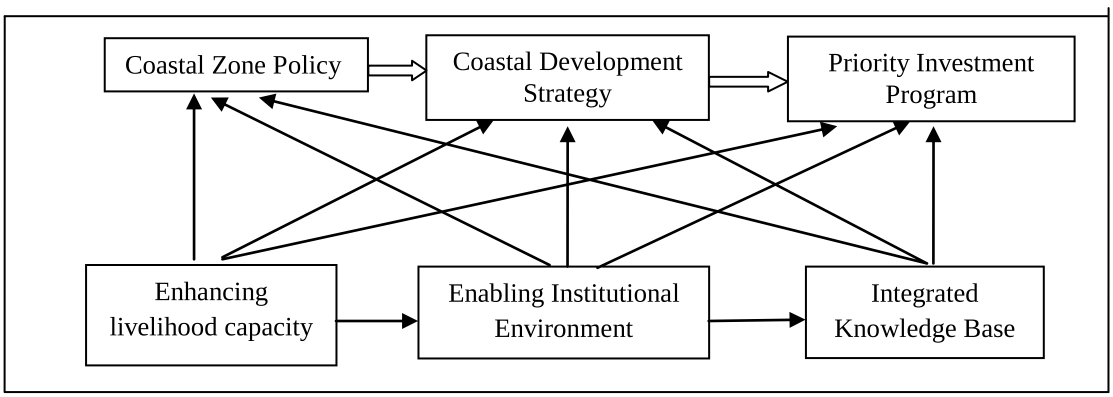


Figure 2.2: Relationship among ICZMP Outcomes in Bangladesh
Source: WARPO,2005

The other three key outcomes of ICZMP were- (iv) the ways to enhance livelihood capacity, (v) the techniques to enable institutional environment and (vi) to create integrated knowledge base. These themes are destined to generate all embracing knowledge pool and build capacities to define and implement the first three outputs in a more effective method. The relationship among the six outputs has been shown diagrammatically in Figure 2.2.

The diagram reflects the approach taken for coastal development, with the core process based on a transformation from 'Policy' to 'Strategy', and then to a 'Priority Investment

Program' on the top line and three sets of activities those support this core process on the bottom line. The ICZMP targets to provide the best long-term sustainable use of coastal natural resources with the continuous maintenance of the natural environment. The plan integrates the government, local communities, different stakeholders with different sectors of interests for the protection and development of coastal ecosystems and resources in an effective way. The ICZMP,1999 achieved partial success due to weak governance, lack of strong linkages among the policy makers, local stakeholders and communities; low awareness; absence of scientific knowledge and technologies; lack of expertise and disintegrated as well as exclusionist 'ICZMP approach' (Islam et al., 2009 and Hafez, 2019). However, the limitation of the ICZMP lacks in precise preference to be addressed to deal with both natural and anthropogenic disasters and vulnerabilities. Further, obvious guidelines about the collaborative approaches within the local communities, stakeholders and government were not recognized. The ineffectiveness of ICZMP was- (i) the failure to incorporate professionals qualified in Coastal Zone Management, (ii) the unreasonably land-centric view of the coastal zone, and (iii) the failure to assemble a regular workforce.

Accelerating rate of internal population migration from rural to coastal areas for residential, industrial and commercial purpose forced coastal development initiatives. The disorganized, unplanned and unregulated settlement growth in coastal area represents a growing threat to sustainability of the fragile coastal ecosystems. Hence, to avoid irreparable damage of natural ecosystems, both rural and urban growth policy was considered to be closely coordinated by integrated planning management of the coastal zones. Hence, the GoB initiated the ICZMP in 1999, and modified in 2000. The CZMPo (2005), one of the three key outputs of ICZM mentioned about three reasons for the development of ICZM plan, such as (i) lag of socio-economic developments along coastal zone, (ii) poor management initiatives to cope with different disasters and gradual deterioration of the environment, and (iii) to utilize great potentials for notable contribution in national development.

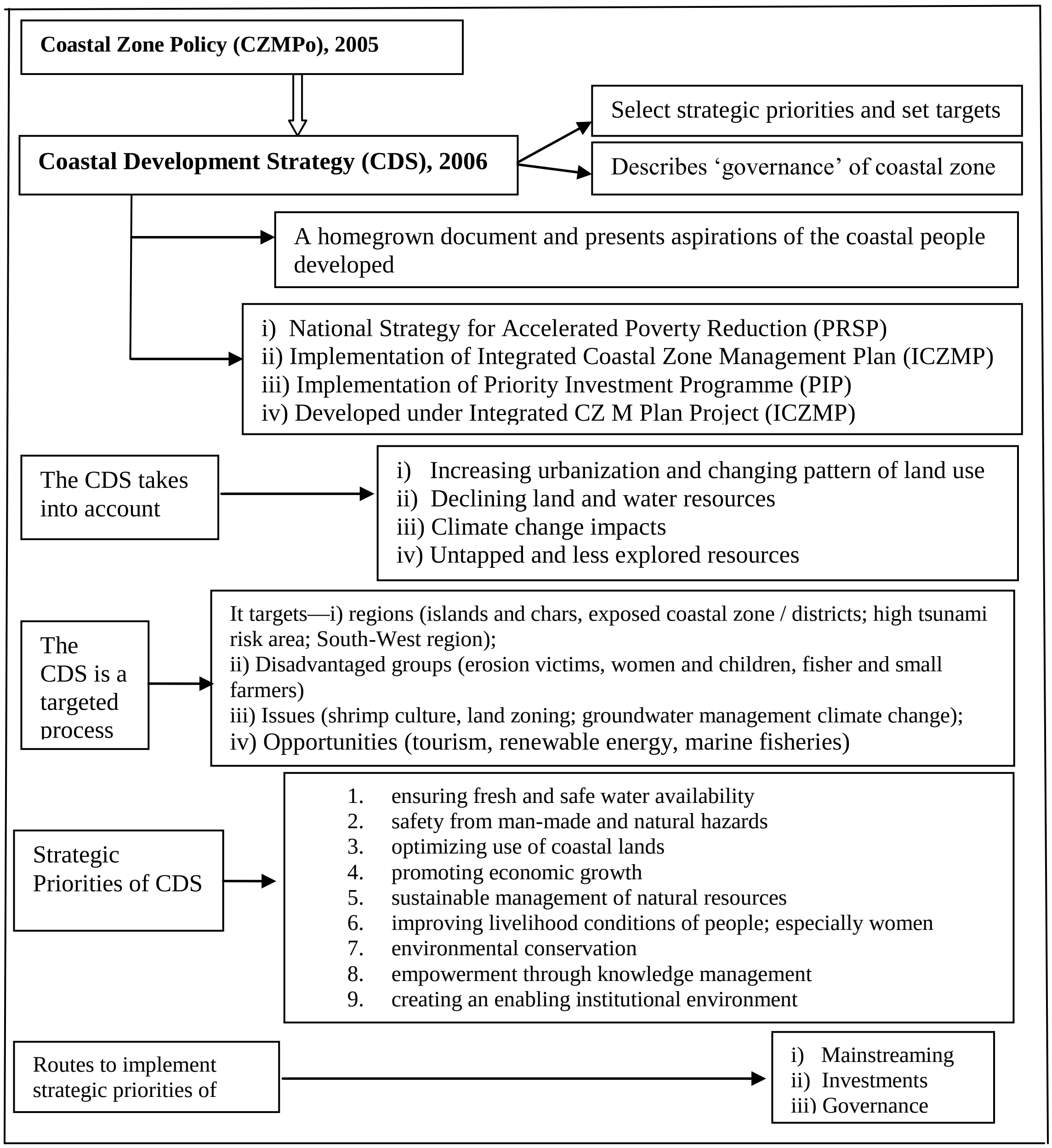


Figure 2.3: Framework of Coastal Development Strategy (CDS), 2006

Source: Water Resources Planning Organization (WARPO), February, 2006

The ICZMP aims at environmental or ecological gain, as well as providing resilience to millions living at coastal zone. Hence, ensuring mitigation techniques against adverse effects of natural and anthropogenic disasters, as well as, providing opportunities for sustainable resource utilization was the main goal of ICZMP. The formulation of ICZMP for Bangladesh coast was to explain the rationale of coastal zone management, the issues to be measured, along with plans, policies, strategies and framework to be developed for sustainable development and management of the east coast. The major key outputs of ICZMP were (i) the Coastal Zone Policy (CZPo, 2005), (ii) the Coastal Development Strategy (CDS, 2006), and (iii) the Priority Investment Programme (PIP, 2006). The CZMPo provides directives and framework for the development and implementation of ICZMP, while the CDS focuses on the strategies to implement the CZPo (WARPO, 2005). Figure 2.2 illustrates the 'Framework of Coastal Development Strategy (CDS)'.

The CZPo (2005) focused on 'Pro-Poor Growth' in view of the environmental management and equity, such as (i) Economic growth, (ii) Meeting basic needs and creating livelihood opportunities, (iii) Reduction of vulnerabilities and enhancement of coping capacities, (iv) Equitable distribution of resources and economic benefits across social strata, (v) Empowerment of coastal communities, (vi) Women's advancement and promotion of gender equality, (vii) Sustainable management of natural resources, and (viii) Preservation and enhancement of critical ecosystems (WARPO,2005).

The CDS (2006) explored potentialities of the coastal zone to mitigate the natural and anthropogenic hazards and to preserve, restore and enhance coastal ecosystems. Three strategic priorities of the CDS were (i) mainstreaming, (ii) investment and (iii) governance (WARPO, 2006).

The main concern areas of PIP (2006) were -(i) Mitigation of natural disasters, safety and protection, (ii) Environment management through protection and regeneration of the environment, (iii) Water resources management, (iv) Rural livelihoods and sustainable economic opportunities for coastal communities, (v)Productive economic activities and focused development of tourism and fisheries sector, (vi) Infrastructure development, and (vii) Social development including health and nutrition, education, and water and sanitation (WARPO,2006).

Table 2.3: Initiatives and Challenges in Key National Coastal Management Programs, Policies and Plans in Bangladesh

Key National Programs, Policies and Plans	Initiatives	Challenges
1) Area-specific CZM plans from late 1970s to late 1990s 2) ICZM (1999) 3) National Land Use Policy (NLUPo, 2001) 4) Program Development Office for ICZM (2002–2006) 5) Coastal Zone Management Policy (CZMPo, 2005) 6) Coastal Development Strategy (CDS,2006)	1) Provided guidelines for water bodies and acquisition for non-productive use 2) Introduction of zoning concept as management tool 3) Plan for effective introduction of ICZM 4) CZMPo established delineation coastal zone and goals of ICZM in Bangladesh and harmonized different agencies active in the coastal zone	1) Unclear definitions of land to be set aside for conservation 2) Piecemeal efforts to address coastal management through policy 3) Implementation of policy and strategy directives remain poor, despite adoption of CZMPo (2005) and CDS (2006)

Source: Coastal Zone Policy, WARPO, 2005

2.6 ICZMP for the Eastern Coastal Zone Study Area

The eastern coastal zone has diverse natural and socio-economic opportunities, as well as vulnerabilities, such as mixed and multi use of land, unplanned and unorganized urbanization due to flourishing industrial and tourism development. Nevertheless, the unsustainable natural resource exploitation by different industrial sectors and by the local communities resulted into an imbalanced man-land ratio, accelerating frequency of natural hazards, as well as severe deterioration of major eco-systems. Consequently, lack of development, as well as implementation of appropriate plans and policies for natural resource conservation and utilization has instigated the necessity of an ICZMP for the east coast. The present research stated the condition of selected geo-environmental indicators to measure the functionality of existing plans, policies and strategies, as well as to provide ideas towards an improved ICZMP for the east coast of Bangladesh.

Iftekhar (2006) mentioned that, the tendency to adopt an exclusionist approach, a narrowly departmentalized administration and weak management are the limitations in the process of ICZMP in Bangladesh. On the other hand, Islam, et al. (2009) mentioned the inclusion of local stakeholders as a reason of successful implementation of ICZM in Xiamen, China.

Hussain, et al. (2018) elucidated the major opportunities and vulnerabilities of blue economy in Bangladesh. The paper termed the Bay of Bengal as the ‘Backbone of national economy' of Bangladesh. The objective of this paper was to highlight the major opportunities of economic sectors related to the development of blue economy in Bangladesh and touches the constraints in achieving this goal. The blue economy emphasizes in harnessing the full utilization of ocean based resources within the present maritime boundary of Bangladesh, with proper management and planning of the coastal zone. The technique to reach the goal of blue economy is an intersectoral coordination of public-private partnership with concerned stakeholders, intertwined with scientific knowledge. Nevertheless, exploitation of the untapped resources of the coastal and marine ecosystem to ensure food security and alleviation of poverty governed by the protection of coastal and marine environment, physiography, and biodiversity were considered as the main approaches of blue economy. The researchers concluded with some recommendations such as initiatives have to be taken in the field of marine education and research; strengthening the maritime surveillance and security and formulation of Marine Spatial Planning (MSP) for Bangladesh.

Hafez (2019) recognized the necessity of managing the complex and active coastal zone in an integrated holistic approach. The paper aimed at studying the background, scope, and rationality of coastal development, the environmental challenges and their impacts, management framework and future trends. The paper concluded stating about the implementation of ocean governance initiative already taken by the GoB.

The coastal zone of Bangladesh is a sector of multiple opportunities, consisting of several significant ecosystems like- mangroves, sea- grass, estuaries, beaches, sand dunes, and coral islands. All these ecosystems were facing vulnerabilities like- rapid deterioration due to excessive harnessing of the natural resources, while exploitation of the natural resources of the coastal zone in a sustainable way can ensure their prospects upon the national goals of poverty reduction and economic growth.

2.6 Pressure-State-Response (PSR) Model

The Pressure-State-Response (PSR) model indicated the 'Cause and Effect' relationship between the geo-environmental and anthropogenic parameters to assist the decision makers for planning a CZM. In a PSR model the causes are shown as the 'Pressure' indicator and the consequences are shown as the 'State' indicators. The negative or positive impacts of the pressure indicators upon the state indicators are illustrated in the model without obscuring the view of more complex relationships in ecosystems. The adjusted versions of PSR model is the ‘Driving force-State-Response (DSR)’ model, formerly used by the UN Conference on ‘Sustainable Development (UNCSD, 2012)’, also known as the ‘RIO, 2012’. Initiated by the OECD in 1993 (OECD, 2003), the structure works on the environmental policies and considers the anthropogenic activities as the ‘Pressure’ index; which brings changes to the environment considered as the ‘State’ index. The modified ‘Driving force-Pressure-State-Impact-Response (DPSIR)’ model developed by the European Economic Area (EEA, 1999) used the climate change, eutrophication, acidification, toxic contamination, biodiversity, wastes, water resources, forest resources, fish resources, and soil degradation (desertification, erosion) as the environmental indicators for the DPSIR model.

Tao Lin, et al. (2007) analyzed temporal changes in regional coastal wetland ecosystem structure and functions from 1950 to 2005 at Xiamen, China with a ‘Drivers-Pressures-State-Impacts-Responses (DPSIR)’ model. The study results show that anthropogenic drivers causing coastal wetland degradation in the Xiamen coast increased substantially since 1950s, and these drivers are linked with a decline in coastal wetland function over the same period.

Edward R. Carr, et al. (2007) criticized the DPSIR framework mentioning that, the framework is not appropriated to address the impact of aggregated, informal responses on the drivers and pressures related to environmental problems and sustainability challenges. The researchers stated that, the DPSIR framework-centered approach is not a new direction for development within international organizations. Rather, the current approaches of DPSIR framework was described as a reproduction of existing inequalities between actors and stakeholders. Hence, the researchers recommended that, DPSIR has to be applicable for the assessment of sustainable development at the national, regional and global scales; while finding a way to incorporate the aggregated impacts of local, informal responses on drivers, pressures and states. This was suggested to be conducted by establishing linkages between qualitative and quantitative data, reconsidering the hierarchies within development process and embracing the complexity of the connections between human well-being and the environment. Hence, the practitioners of the DPSIR model was suggested to deal with the social and technical challenges as an opportunity to review new directions in development thoughts with better outcomes.

Karen et al. (2012) reviewed several studies with criticism and drawbacks of the DPSIR framework. Based on the studies and their own experiences in applying the DPSIR framework in an EU project to develop a decision making tool, the researchers developed two criteria crucial for policy relevant research, such as (a) the development of conceptual models integrating knowledge from different disciplines, specialists and policy makers, as well as those affected by their decisions; and (b) the potential to explain the results and analysis of research to different disciplines, specialists, stakeholders and the public and to demonstrate alternatives and provide decision options. The researchers found that, out of the total 21 studies, only a few targeted specific government authorities as users of research results; eight applied trans-disciplinary research concepts and integrated broad ranges of stakeholder opinions and values into the research; nine presented alternative outcomes to decision makers and used the valuation of these outcomes by stakeholders to add further support to the decision-making process. The different positive and negative implications of the DPSIR framework were discussed with reference to research that supports policy making. Finally, the researchers concluded by stating that, the DPSIR model might be effective if criteria basing upon knowledge integration, stakeholder involvement and the provision of alternatives are provided into the framework. In this way, the DPSIR is a useful tool to support decision making if visible alternatives and decision options are included, rather than by presenting predetermined solutions.

Sirak, et al. (2015) discussed the evolution of DPSIR from the Stress-Response to the Cause-effect framework. Though the research mentioned about discrepancies in the definitions of the DPSIR's information categories; the framework was explored both as a discrete tool and combined with other methods for different coastal and estuarine systems and biodiversity. Recommendations were suggested to improve the framework to overcome its limitations and updated the DPSIR framework is a useful adaptive management tool for analyzing and identifying solutions to environmental problems.

2.8 Environmental Indicators

The significance of the present research lies in the approach of illustrating the causes and consequences of deterioration in the Coastal and Marine ecosystems of the study area in a 'Cause and Effect' approach. The escalating environmental degradation caused chiefly by the unscrupulous anthropogenic activities and lack of proper implementation of the existing plans and policies was discussed by the preceding researchers. In this section of literature review, the quality of soil and water of the east coast of Bangladesh has been discussed by measuring and analyzing the concentration level of heavy metals, non-metals/nutrients and the physio-chemical parameters of soil and water of their designated study areas.

Ashraful et al. (2009) measured the heavy metal contents (Cd, Pb, Zn, Cu, Mn and Fe) in littoral sediments of the Bay of Bengal coast by Sediment Quality Guidelines (SQG) method. The study aimed at determining the level, as well as, reveals the seasonal distribution of heavy metal concentrations in the sediment and on the inter-metal correlation. The hotspots of pollution around the coast such as river, industrial region, and uncontrolled domestic wastewater discharge areas were selected as sample areas. The researchers stated that, in comparison between heavy metal concentrations (2006-2007) of the coastal water samples compared with that of the Environmental quality standards (EQS) of Bangladesh (EQS, 2001); the concentration of Cd, Pb, Zn and Fe were high at Matamuhuri, Moheshkhali and Bakkhali Rivers. According to the study, the metal pollution had affected the aquatic ecosystem, mainly at Matamuhuri, Moheshkhali and Bakkhali River sites by domestic wastes, industrial effluents, and household garbage. The Cox's Bazar municipality receives around twelve tones of household wastes into the water bodies daily of which more than half of them end up in the Bakkhali River (DoE, 2014). The Department of Environment (DoE) found that, the level of dissolved oxygen (DO), total dissolved solids (TDS) and biological oxygen demand (BOD) in the Cox's Bazar Municipality area vary greatly in comparison to the standard values (Dhaka Tribune,7th August,2014). In 2013, the level of TDS was 9,110 ppm (standard value below 2,100 ppm) in the river's middle wharf area, which accentuates the gradual contamination of the river water (DoE, 2014). The Local officials at the DoE suggested the need for a coordinated approach by the Cox's Bazar municipal authorities, district administration and environmental groups to combat the problem.

Rashid et al. (2013) in another research paper titled 'Ocean Acidification in the Bay of Bengal' dealt with adverse impacts of ocean acidification upon the environment of the Bay of Bengal. The study revealed that, the average pH of water in the Bay of Bengal was around 7.75 and has fallen by 0.2 units between 1994 and 2012 (pH 7.95). The study inferred that, reduction of pH has adverse effects on calcifying organisms such as sea shells, oyster and coral reefs. The lower pH (7.75) might have made the mollusks vulnerable and fragile as average calcium carbonate composition of the calcifying organisms was found to be 80% which was 17% lower than the standard composition.

Rashid, et al. (2015) focused on the adverse effects of toxicity due to the escalation heavy metal concentration in saline sea water, sea sediment, sea shells, and on oyster along the east coast of the Bay of Bengal. The hierarchy of heavy metals in sea sediment of the bay showed as: Fe > Zn > Ni > Cr > Pb > Cd. The study showed that the concentration of Cd, Fe, Pb and Cu in sea and a considerable amount of heavy metals (0.035%) such as Zn, Pb, Cu, Fe, and Mg in sea shells, and oyster may cause toxicity.

Raknuzzaman, et al. (2016) aimed to provide baseline information on the toxic trace metal concentration in different coastal environment of Bangladesh. Seven trace metal concentration, such as, Cr, Ni, Cu, Zn, As, Cd and Pb was determined in water and sediment samples collected from four coastal sites of Bangladesh, namely Bakkhali river estuary, Cox's Bazar, Karnaphuli river, Chattogram, Meghna Estuary and Sunderbans. The study confirmed that, a wide range of metal concentration was observed among the sampling sites. Various factors such as salinity, SS, pH, Temperature, geomorphic situation, and terrestrial runoff might have diversified the concentration of trace metals. The No.6 Fishery Ghat at Bakkhali River was detected as the main source point of pollution. The trace metals in water samples of Cox's Bazar hatchery site showed the highest levels of Zn (1,390 μg /L), Cu (510 μg /L) and Pb (109 μg /L), which ascribe the huge discharge of different chemical compounds from the hatcheries and fish processing industries. However, the mean concentrations of sediment samples followed a decreasing order of Zn > Cr > Pb > Ni > Cu > As > Cd. The study stated about the obscurity in identifying the metal pollution sources as Bangladesh is a downstream riverine country with more than 230 rivers receiving huge industrial effluents from neighboring country as well as inland sources and dumping up through the Bhola estuary to the Bay of Bengal. Besides, there are approximately 8,542 industries along the coastal area, which also release the entire untreated industrial effluents directly to the Bay of Bengal.

Wang et al. (2016) stated that, the environmental parameters in Karnaphuli river estuary fluctuate seasonally. The main objective of the present study was to assess heavy metal contamination in sediment in recent years by the Contamination Factor (*CF*) and Pollution Load Index (*PLI*) methods. To meet the objective, the depth-distribution of core sediment composition, grain-size parameters, TOC content and Pb radioactivity in the Karnaphuli River estuary was measured. The variations of all core sediment properties showed an abnormal sediment layer (8–20 cm) below the surface. The attributed data suggest that the surface sediment of Karnaphuli River estuary is contaminated with Cr and Pb. However, the researchers stated that, the catastrophic events, such as, landslides, cyclones, and heavy rainfall, between 2007 and 2008, led to the changes in source materials and depositional environment of estuary, and thus altered metal accumulation in sediments. In general, heavy metal enrichment in Karnaphuli River estuary is likely to be associated with accelerated urban and industrial growth in recent 30 years, including catastrophic events in the area. The pollution of aquatic ecosystems by heavy metals is emerging as a serious issue in Bangladesh.

Khan et al. (2017) measured the concentrations of major (Si, Al, Ca, Fe, and K) and minor (Cd, Mn, Ni, Pb, U, Zn, Co, Cr, As, Cu, Rb, Sr, and Zr,) heavy metals/elements in the surface sediments along the Bay of Bengal coast. The objectives of this work were to reveal the spatial distribution of major and minor elements in the study area and to evaluate the metal concentration using Contamination Factor (CF) and Pollution Load Index (PLI). In 2014, ten sampling points at Salimpur Union, Chattogram, were chosen for surface sediments sampling at the coast of the bay during the winter season. It was revealed that, majority of the trace elements infiltrate into the Bengal marine from the riverine flows, carrying the effluents from the industries, ship breaking yard, gas production plant, and urban wastes, which generally decreased with distance from the coast. The study observed that, the heavy metal concentrations in the sediments were within the international marine sediment quality standard. However, both the CF and PLI values suggested the escalation of some metals concentrations in the region, which might release back into the water column. Hence, constant monitoring and recording of the water quality along Bengal coast was recommended to be done with a view to minimize the health risk of the local population and the detrimental impacts upon the aquatic ecosystem.

2.9 Geomorphic Indicators

The Net Shoreline Movement (NSM) of the present research sample areas was examined to reveal the changing pattern of the shorelines in a time span of twenty five years (1990-2015). One of the significant geomorphic factors, the shoreline change pattern, was selected to be investigated for the present research. The investigation was done in five steps, of which the Digital Shoreline Analysis System (DSAS), Modified Normalized Difference Water Index (MNWDI), Net Shoreline Movement (NSM) and the End Point Rate (EPR), the main methods to find out the total shoreline change as well as the changes at five years interval. To meet the objective of investigating the shoreline change pattern, as well as the appropriate method of detecting the changes of present research study area the following literatures were reviewed.

Stroeve (1993) analyzed the influence of advanced design methods, considering the distinction between monsoon and cyclone conditions as these two generates two different hydraulic situations. The objective of this study was to examine the influence of various improved design methods and the consequential morphological changes since the year 1983. Besides studying the different indicators to examine the influence of improved designs, such as, the hydraulic loading conditions and the wave climate; huge amount of sediment carried and deposited by the lower Meghna River was measured as well.

Islam et al. (1999) focused upon the land loss due to beach erosion, caused by sea level rise in the eastern coastline of Bangladesh. Three distinct areas, such as, a) the Bakkhali river valley b) the Southern beach plain, and c) the Nhilla-Teknaf plain along with the Moheshkhali channel area were taken as the study area. These points were interpolated to define the coastline profile. Real world geographical location of each point was captured using Geographical Positioning System (GPS) and subsequently the shoreline profile was coupled with a GIS system. Bathymetric information was drawn from admiralty charts from which height (depth of water) and width of the continental shelf were determined. Brunn's formula (Islam et al.,1999) was applied to evaluate the values for shoreline recession for 30 cm and 75 cm sea-level rise in the year 2030 and 2075, respectively.

The findings of the study projected that, about 5,800 ha area along the shoreline would be lost in 2030, and 11,200 ha would be recessed in 2075. An estimation showed that, about 13,750 and 252,000 tons of food grain production would be lost in 2030 and 2075, respectively, due to shoreline erosion.

Kankara, et al. (2014) carried out a study on shoreline change along a 25 km long stretch of Chennai coast. Besides using the Landsat satellite images, field survey was conducted using Arc-Pad GPS instrument for 2011. Three methods, i.e., End Point Rate, Linear regression Rate and Weighted Linear Regression were employed to calculate shoreline change rate for 1990-2013. From the long term analysis it was clearly visible that, the northern portion of the Chennai port was eroding and the southern portion of the port was accreting. Thus, the combined use of satellite imagery and Wafer Level Reliability (WLR) testing is the reliable statistical method for shoreline change analysis.

Allison and Kepple (2001) attempted to find out whether the Ganges-Brahmaputra river basin has been sinking extensively due to the huge sediment load. The measurement of 137 Cs activity and radiocarbon in the sediment was done to reveal the spatio-temporal rate of sediment accumulation at the Ganges-Brahmaputra river mouth. The study revealed that, there is still a significant depocenters for riverine sediment, which show a trend of declining accretion with growing distance inland from the Bay of Bengal.

Li, et al. (2014) mentioned that, Modified Normalized Difference Water Index (MNDWI) Method (McFeeters, 1996 and Xu, 2006) is the best system for identifying water body with Landsat sensor and is the most effective method for Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager (OLI) sensor.

Matin and Baig (2006) stated that, if the water flow of a tidal channel is obstructed for a long time by water control structure, heavy siltation occurs at that channel. The researchers have taken two variables to determine the predicted accretion height, which influences the siltation to study and analyze the siltation condition at the Feni estuary below the closure dam. The researchers applied the bathymetric field data below the closure, with regression analysis to correlate the rate of accretion with the depth and distance of the channel from the closure dam and the correlation coefficient is found satisfactory. The analysis shows that, after the construction of Feni closure dam of Muhuri Irrigation Project (MIP), a rapid siltation have occurred, enhancing the height of the area about 4m in the first year followed by 0.6m in the second year. The authors measured the accretion ratio with that of the predicted accretion by an adjustment factor, which indicates the impact of dam construction on siltation or in other words effective percentage of inundation time for siltation. The major source of sediment in the Feni estuary is silt carried by the seawater (Eysink, 1983). It is found that the concentration towards the regulator site below the Feni closure is gradually reduced and average sediment concentration during high water flow condition is about 400 mg/l. At the outfall of the estuary, higher value of sediment concentration is observed.

Van, et al. (2008) attempted to measure the shoreline change at one of the eight estuaries of the Mekong River, the coastal zone of Cuu Long estuary. The clayey and silty soil of the estuary turned the river shoreline subject to both accretion and erosion processes. The main objective of this paper was to detect the spatial changes as well as quantify the results of shoreline change in Cuu Long estuary. The methodology used for the research was the Spectral Band Rationing of the Multispectral Remote Sensing Satellite Imageries (Landsat and Aster satellite images), by applying the satellite remote sensing technology and GIS. However, rationale of the study lies in the direction for the sustainable integrated management plan of coastal zones by detecting and measuring the shoreline change for environmental monitoring. The paper mentions waves, tides, winds, periodic storms, sea-level change as the geomorphic process of erosion and accretion; along with the anthropogenic interference as the driving forces of shoreline change (cited from Selvavinayagam, 2008). Three shoreline change maps of three time periods: 1989, 2001 and 2004 of the study illustrates that, the accretion and erosion are inverse processes. The accretion increases the size of the area as well as obstructs the water ways by sedimentation. Conversely, erosion causes loss and destruction. In conclusion, the existing situation along with the future prediction with the integration of Remote Sensing and GIS was highlighted.

Sarwar and Woodroffe (2013) measured the shoreline change and stated that, although abundant sediment supply has resulted in accretion on some parts of Bangladesh coast, others are experiencing rapid erosion. In this research, Bangladesh was identified as one of the most vulnerable places in terms of climate change and sea-level rise. The objective of this paper was to assess the rates of shoreline change in a systematic manner for the entire coast of Bangladesh, by applying the mapping comparison approach of Mikhailov and Dotsenko (2007). By this approach the study aimed at providing a synoptic view of shoreline change for a 20-year time period (1989-2009). The study revealed that, devastation of the mangrove fringe caused by the landfall of Cyclone Sidr in November 2007 accelerated erosion towards seaward margin of the Sundarbans in western Bangladesh, though a retreat rate up to 20 m/yr is common along this shoreline. However, the study observed that, erosion exceeded accretion in the Barguna Patuakhali coastal zone, most of which eroded at up to 20 m/yr, but with truncation of the southern tip of the Patharghata Upazila at up to 100 m/yr. According to the study results, the erosion rate along much of the Bhola coast was up to 120 m/yr. Distinct characteristics were found along the Noakhali Feni coastal zone, where despite the similar rates of erosion, rapid accretion of the main promontory by more than 600 m/yr brought a balance in the area

Hossain, S. (2015) stated that, the natural sediment load in Bakkhali estuary is comparatively higher, with a significant change in deposition rates. According to the study, huge amount of sediment and sand is carried down to the river estuary in the monsoon period. The researcher also observed that, the rubber dam in the Bakkhali River causes siltation in the upstream of the Bakkhali River. Added to this, huge garbage disposal as well as illegal structures by land grabbers is gradually narrowing down the river width. Nevertheless, the human interference was stated as the obstacle for the normal flow velocity as well as the natural transportation of sediment load through the estuary. As a result the deposition intensity in the Bakkhali estuary is decreasing as well as affecting the process and characteristics of estuary evolution.

Dewan et al. (2016) assessed the channel changes of the Ganges River flowing through Bangladesh. The study mentioned the changes of the river channel as a growing concern for Bangladesh due to the climatic variability, land use change, and agricultural intensification as well as the anthropogenic interventions, creating adverse environmental and social consequences. The researchers mentioned that, the construction of a barrage at the upstream along the Indo-Bangladesh border adversely affected the Ganges reach in Bangladesh. The research aimed at quantifying the planform dynamics of the Ganges-Padma system in Bangladesh. The objectives of this paper were - (i) to examine the nature and extent of bank line movements of the Ganges and Padma rivers; (ii) to quantify channel patterns through sinuosity, width, and braiding index calculations; (iii) to estimate the volume and location of both erosion and deposition in the river channel; (iv) to explore the factors responsible for channel changes, and (v) to investigate the effect of floods. Nevertheless, the research paper attempted to provide some insights into the impact to the riparian population through reaching the objectives of the study. The planform changes of the Ganges and the Padma within Bangladesh was analyzed over the period 1973 to 2011, using multi-temporal Landsat images and long–term flow data in eight epochs with an average duration of 4.5 years (1973 to 2011). The channel planform evaluation indicated that, both the Ganges and the Padma experienced contraction, expansion and readjustment in configuration over the last 38 years. The relationship between bank curvature and erosion/accretion of the river banks for both rivers was analyzed and the results contradicted with the established meander theory. In this paper, the bank curvature, classified as concave, convex or straight, was recorded at the end of each transect for two epochs to investigate the relationship between the erosion / accretion patterns and classic meander theory.

2.10 Bio-Diversity Indicators

The literature review done for the biodiversity shows that, though situated within the Oriental region, and having a rich Gene pool, Bangladesh has been facing a rapid decline in bio-diversity. The following section is the discussion of the literatures reviewed for the present study regarding bio-diversity of Bangladesh.

Nishat, et al. (2002) illustrated the Bio-geographic condition of Bangladesh. The report stated that, Bangladesh is situated in the Oriental region (cited in Morin, 1984).The report used the parameters like, Physiography, Soil, Temperature and Rainfall, Floral and Faunal Diversity, and Flooding Depth to categorize Bangladesh into twelve Bio-ecological zones. The study area selected for the present research work comprises the Bio-Ecological zone 8a, also termed as the Coastal Plains (8a).

The Fifth National Report to the Convention on Biological Diversity (2015) prepared by Department of Environment (DoE) highlights the status of conservation as well as sustainable use of the biological resources of the country. According to this report, Bangladesh is situated at the juncture of Indo-Malayan and Indo-China sub-regions of the Oriental region. The country is a biological corridor of the wildlife among the neighboring countries. The Ganges-Brahmaputra-Meghna river system ecologically connected and integrated the floral and faunal species with its neighboring countries. Being one of the most ecologically significant and biologically diverse countries, Bangladesh consists of a wide range of gene pool. Moreover the distinct climate variability brings species richness. Basing upon the biophysical characteristics, the ecosystem of Bangladesh has been categorized broadly into three types, namely, (i) the Terrestrial, (ii) the Inland water, and (iii) the Marine and Coastal ecosystems.

Almost half of Bangladesh is of wetland type (among 64 Marine Ecosystem in the world). The country is a part of Bay of Bengal Large Marine Ecosystem (BOBLME,2015). The eastern coast of Bangladesh, one of the three coastal regions, is comparatively more stable. The east coast is highly important breeding ground for marine turtle, with the only coral ecosystem lying at the Inani coast. The east coast is highly rich in marine algae and mollusk diversity, with a moderate density.

Added to these, the coast of Bangladesh has a great potentiality to naturally harvest as well as culture the sea weeds (50 species of Brown Algae, 82 species of Red algae, and 26 species of Green algae (Zia,2009) and 5 species of sea grasses (Kamal and Short, 2009, in DoE,2015) in captive environment. Total 301 species of marine mollusks, 442 species of Fish, 58 species of Shrimps and Lobsters, 16 species of Crabs, 336 species of Mollusks and Sea Turtles (5 species) are the significant species of the coastal zone of

Bangladesh (DoE,2015). According to the Red List of Threatened Animals, totally 201 species are threatened (IUCN, 2000).

Sajal (2018) mentioned about the 1992 National Conservation Strategy of Bangladesh, where total 31 areas were identified as Environmentally Critical Areas (ECAs). The Bangladesh Environment Conservation Act (BECA, 1951) declared the ‘Cox’s Bazar-Teknaf Peninsula’ (20,373 ha.) as a zone of Coastal and Marine ecosystem in Cox’s Bazar on 19/04/1999. In 2016 the Government adopted the ‘Ecologically Critical Areas Management Rules’, which provide different committee systems for the management of ECAs from the national to village level. The Department of Environment (DoE) and the National Committee plays a pivotal role in the management of ECAs. The principal government agencies responsible for overall protection and improvement of Environment are under the Ministry of Environment & Forest.

Rashid et al. (2015) have focused upon the heavy metal concentration in sea water and sea sediment in the saline Bay water and sediment at the continental shelf at the north-eastern part of the Bay of Bengal along Bangladesh. The study aimed to find out the adverse toxic effects of the heavy metals upon the sea shells, and oysters along the east coast of the Bay of Bengal.

The findings of this study showed that, the concentration of Cd, Fe, Pb and Cu in sea water were relatively higher than the standard concentration. The hierarchy of heavy metals in sea sediment of the bay showed as: Fe > Zn > Ni > Cr > Pb > Cd. Moreover, the study showed a considerable amount of heavy metals, such as, Zn, Pb, Cu, Fe, and Mg in sea shells and oysters, which are apprehended to turn the mollusks toxic. The consequence of toxicity was considered to be the reason of reduced growth of the sea shells and oysters.

Though many studies were conducted on water pollution in rivers of Bangladesh, the present thesis work measured the concentration of five heavy metals, such as, the Cd, Cu, Fe, Pb, and Zn of the estuarine areas of the Feni River, the Bakkhali River, and the Jalkadar River along with the three sources of pollution along the Marine Drive.

The earlier literatures, investigating the environmental condition of the Feni River, Bakkhali River and Marine Drive were quite insignificant. Moreover, despite the geo-strategically vital location of the Jalkadar River, flowing between the two large coastal upazilas, such as, the Banshkhali and Gondamara; sufficient data has not yet been found about the environmental condition.

Khan et al. (2017) stated that, the Mud crab (*Scylla* spp.) fishing and culture has become a major source of income, and next to shrimp, is the second most important cultured species in the coastal Bangladesh (cited from Hoq et al., 2014). It is the most popular crab species because of its size, meat quality, high price and export potential. Nevertheless, mud crab farming in hatchery and production of crab seed is needed for the further development. The main dwelling of the Mud crabs is the coastal rivers of Cox's Bazar, Chattogram, Noakhali, Barisal, Bhola, Patuakhali, Bagerhat, Khulna, Satkhira swamps of the Sundarban Reserve Forest (SRF) and traditional shrimp ghers (cited from Shafi and Quddus, 1982).

Though the Mud crab aquaculture technique is not yet developed in Bangladesh, the experiment was conducted from November, 2015 to January, 2016 in a soft-shell crab farm of Nuniarchara at Cox's Bazar Sadar Upazila and the farm was located on the bank of Bakkhali river estuary. In that context, present study was carried out in nylon net hapas in an earthen pond with the aim to explore the effects of different feeds on survival rate and growth of crablets, *Scylla* species (Bangladesh Fisheries Research Institute, 2018).

Recently, the seaweeds are regarded as a major commercial marine biota for its diverse use. However, this paper mentioned the species *Hypnea* sp. as the most common seaweed at Bangladesh coast. Due to its tolerance over a wide range of water temperatures, salinities and light intensities (Hoq,2016; cited from Dawes et al. 1976), *Hypnea* cultivation might be initiated in Bangladesh for commercial purpose, such as, utilization as raw materials of bio-chemicals (agar, agarose, algin, carrageenan), dyes, food, feed, enzymes, drugs and hormones (Islam, 2017).

The seedlings of *Hypnea sp.*, collected from the St. Martin Island were transplanted in Inani and Bakkhali river site. The Saint Martin Island has sandy and rocky bottom, protected by the sloping coral reef .The wave action is weak, and provides a favorable environment for several seaweed species (Islam, 2017).

On the other hand, the Inani beach site has sandy bottom with boulders, pebbles, broken shells. Naturally occurring *Padina, Enteromorpha, Gracilaria, Hypnea* species were observed in this area (Islam, 2017). However, the Bakkhali river estuary site has sandy to muddy bottom with plentiful growth of different seaweeds (Islam, 2017). The winter season was recommended as the favourable time for sea weed culture at Bakkhali river estuary and Inani beach (Islam, 2017).

2.11 Ecosystem Diversity of Bangladesh

Basing upon the bio-ecological zones, the ecosystems of Bangladesh has been clustered into three major categories like- i) the Terrestrial, ii) the Inland waters, and iii) the Marine and Coastal ecosystem. However, in the present research, forest ecosystem within the Terrestrial ecosystem and the estuarine ecosystem within the Marine and Coastal ecosystem of the east coast of Bangladesh along the Bay of Bengal was studied (Islam,2014).

Terrestrial Ecosystem: Forest Ecosystem

The forest resources of the country has been distinguished into five different categories, such as, i) the tropical wet evergreen, ii) the tropical semi-evergreen, iii) the tropical moist deciduous, iv) the tidal, and v) the planted forests. The total forest area in Bangladesh including the unclassed state forest land is about 2.25 million ha (DoE, 2015).

Coastal and Marine Ecosystem: Wetland Ecosystem

According to Sarkar (1993) and Nishat (1993), the wetlands (total area 74,822 km^2) in Bangladesh, are divided into two major ecosystems like- i) the Estuarine ecosystem, comprising the brackish water and mangrove swamp areas (total area 68,722 km^2) and ii) Closed Freshwater system (total area 6,100 km^2) (cited in Islam, 2010).

2.12 Extinct and Threatened Wildlife in Bangladesh

Many wildlife species were exterminated in Bangladesh, while many more are under threat of extinction. The list of extinct animals of Bangladesh has been prepared on the basis of published data and habitat management. The country has lost 10% of its mammalian fauna, 3% avifauna and 4% reptiles over the last 180 years. More than 50 species are critically endangered in Bangladesh of which 23 species are already declared as endangered in the Red Data Book of IUCN (International Union for Conservation of Nature). In addition, 83 species are threatened and are included in the appendices of Convention on International Trade in Endangered Species (CITES). Among them the most endangered species are : Elephant (*Elephas maximus*), Tiger (*Panthera tigris*), Wildcat (*Felis chaus*), Leopard (*Panthera pardus*), Dolphin (*Peponocephala electra*), among mammals; Whitling duck (*Cairina scutulata*), Knobbilled duck (*Sarkidiornis melanotos*), Black partridge (*Perdicula manipurensis*), among birds and Crocodile (*Crocodylus, porosus*) Python (*Python molurus*), Monitor (*Varanus bengalensis*), River Terrapin (*Batagur baska*), Roffed turtle (*Kachuga dhongoka*), Softshell turtle (*Chitra punctata*) and all marine turtle among reptiles. A total of 706 bird species recorded in Bangladesh represent 7.2% of the world's total species. Of these, 383 are resident species, 218 winter visitors, 11 summer visitors and 94 vagrants (DoE, 2015).

2.13 Marine Fish and Fisheries Bio-diversity

The marine water bodies (within 200 nautical miles off the coast) of Bangladesh is the habitat of totally 442 number of fish species, more or less 36 number of marine shrimps, around 336 species of mollusks, which comprise totally 151 number of genera; were identified from the Bay of Bengal. In addition, several species of crabs, 24 species of turtles and tortoises, 168 kinds of seaweeds, 3 kinds of sponges, 15 kinds of crabs, 3 kinds of lobsters, 10 kinds of frogs, 3 kinds of crocodiles, 24 kinds of snakes, 3 kinds of otters, 1 kind of porcupine, 9 kinds of dolphins, and 3 kinds of whale species are found in the coastal aquatic environment of Bangladesh.

The east coast of Bangladesh is an important breeding ground of four species of marine turtles associated with high diversity and moderate density of marine mollusks. In the present research, the biodiversity depletion of the Chelonians, as well as the mollusks has been studied to indicate the biodiversity status of the east coast. The natural snail populations in the wetland areas of the country are the exclusive source to meet up such high demands (DoE, 2015). As a result over exploitation without any scientific management of the snail population is causing the biodiversity depletion.

2.14 Bioremediation and Bioabsorption Process for Decontamination of Toxic Materials

The knowledge and practice globally adopted for remediation of toxic materials from environment shows a great potential for the future research on bioremediation in Bangladesh. The global research aspects discussed in the present review along with the local investigation cascades would largely inspire advanced research on bioremediation as well as implementation as far as possible.

Igwe, J. C. and Abia A.A. (2006) studied about the removal of heavy metals from the environment as the presence of heavy metals in the environment is of major concern because of their toxicity, bio-accumulating tendency, and threat to human life and the environment. The researchers stated that, the process of decontaminating of the wastewater is now shifting from the use of conventional adsorbents to the use of biosorbents. In recent years, many low cost sorbents such as algae, fungi bacteria and lignocellulosic agricultural by-products was investigated for their biosorption capacity towards heavy metals. In this paper, emphasis has been given upon demarcating the occurrences and toxicology of heavy metals; while evaluating the successful functionality of the biosorption capacity of biosorbents compared to conventional adsorbents. The role of cell structure, cell wall, micropores and macropores was evaluated in terms of the potential of these biosorbents for metal sequestration. The sorption behavior of some biosorbents with various heavy metals was summarized, their relative performance evaluated and a bio-separation process flow diagram for heavy metal removal from wastewater using bio-sorbents was proposed in the research paper.

Kumar, et al. (2011) defined the term bioremediation as "the process of using biological agents to remove toxic waste from environment". The researchers mentioned 'Bioremediation' as the most effective management tool to manage the polluted environment and recover contaminated soil. Bioremediation has been used at a number of sites worldwide, mainly in Europe, with varying degrees of success. The paper discussed that, Bioremediation, both in situ and ex situ experienced a strong scientific growth, in part due to the increased use of natural attenuation, caused by biodegradation. Bioremediation has been described as a solution for emerging contaminant problems, such as landfill stabilization, mixed waste bio-treatment and biological carbon sequestration. The research paper stated the ‘Microbes’ as very helpful to remediate the contaminated environment. Number of microbes including aerobes, anaerobes and fungi are involved in bioremediation process.

Rashed et al. (2017) mentioned the effluent discharges, trashes, garbage, oil spills, chemicals, and sewages as the major sources of environmental pollution. The paper suggested the application of bioremediation, which has long been known as the supreme eco-friendly biotechnological method. However, like many other developing countries, the applicability of bioremediation is still obscure in Bangladesh, though a wide-ranging environmental cleanup is needed for the country. According to the researchers, (i) a group of arsenic resistant bacterium was identified to remove arsenic from the contaminated soils in Chuadanga district; (ii) bioremediation techniques for chlorofluorocarbons (CFCs) was also conducted locally; (iii) the halophytic plants to remediate salinity was also conducted; (iv) two chromium resistant bacteria to be capable of reducing Cr (VI) to Cr (III) from the chromium contaminated water along with the aquatic lives, land, vegetables farming, and crops coming from the leather processing industries at Hazaribagh (2011).

Bhakta, et al. (2019) stated that, the contamination, pollution and degradation of air, water, and soil environments by geogenically and anthropogenically generated various pollutants are serious global problems. The researchers mentioned bioremediation as the most potential eco-friendly approach in the field of environmental remediation technology, playing a pivotal role in solving the menacing problems of environmental pollution. According to Bhakta (2019), several innovative and advanced bioremediation technologies were developed using genomics and metagenomics, proteomics, transcriptomics and metabolomics in order to overcome the limitations concerning the process. The researchers attempted to briefly discuss the advancement of bioremediation in respect to significant biotechnological improvement for applying as green technology in order to eco-friendly cleaning the air, water, and soil environments. Further, Sultana (2013) discussed that, there are several methods for treatment of waste effluent Like (i)

Absorption; (ii) Reverse osmosis; (iii) Ultra filtration; (iv) Ozonation; (v) Multiple effect evaporation; and (vi) Electrochemical technique.

2.15 Conclusion

The literatures discussed the chronological development of the CZM concept at global level, as well as evaluated the success and /or failure, global applicability and appropriateness of indicators and frameworks for ICZMP, institutional management and policy initiatives, weak and disintegrated approach in governance; lack of knowledge, expertise and manpower to execute the plans and policies at coastal areas; negative or 'no access' of local communities into the ICZMP Plan; and inadequate linkages between policy makers and local stakeholders and local communities due to the 'Exclusionist' approach of ICZMP Plan of Bangladesh. The ICZMP (1999) did not delve into the geo-environmental and biodiversity indicators into the policy and strategic frameworks.

A small number of studies regarding the CZM, geo-environment and biodiversity of the east coast of Bangladesh were found as most of the literatures discussed about the western and central coast of Bangladesh. This directed to the selection of the east coast of Bangladesh as the study area, the zone endowed with unique geo-environment, rich bio-diversity and flourishing socio-economic potentialities.

Further, research gaps were found regarding the identification of the 'cause and effect relationship' between these parameters and the adverse impacts of anthropogenic interventions. Accordingly, the study attempted to identify the human interventions as the causes (Pressure index) of geo-environmental and biodiversity deterioration (State index) at the study area. The institutional approaches such as the national plans and policies were discussed as the 'Response indicators' to develop a coastal zone management plan. The literatures lacked in detailed study about the geographic, environmental, biological and social processes of the eastern coastal zones of Bangladesh. The studies regarding the significant coastal geo-environmental and biological parameters like- the erosion and accretion processes at the major river estuaries and the ecologically critical coastlines; increased toxicity and pollution in the terrestrial and coastal and marine ecosystems; degradation of the physio-chemical quality of the estuarine brackish soil and water; the consequent decline and change in faunal and floral bio-diversity were quite limited.

Further, the 'Cause and Effect' relationships between the aforementioned geo-environmental and anthropogenic interventions; the consequent declination of the ecosystems; bio-diversity loss /or changes; development of scientific methods to restore, as well as conserve the deteriorating state of the study area has been attended the least. Accordingly, the present study selected several geo-environmental and biological indicators to measure and explore the vulnerabilities and opportunities of the study area to develop the coastal zone in a sustainable approach.

3.1 Introduction

The eastern coastal region of Bangladesh is formed by both fluvial and marine geomorphic processes (Alam, et al., 1999). The physiographic features formed by fluvial geomorphic processes are the gently sloping piedmont plains and the floodplains along the rivers like the Feni, the Karnaphuli, the Jalkadar, the Bakkhali, the Halda and the Sangu; the world’s longest uninterrupted coastline along with the tidal flats or mud flats and sand dunes are along the coastal zone. Further, rich Terrestrial and Coastal and Marine ecosystems are the natural habitats of diverse floral and faunal biodiversity. Added to the natural opportunities, the socio-economic features like the all these aforementioned opportunities have been providing the coastal communities with diverse sources of livelihoods. Nevertheless, in recent years, all these opportunities of the east coast have been getting deteriorated due to anthropogenic interventions like agriculture, fishing, fish and fisheries farming, salt faming, as well as industrial and other structural development.

The literature review and reconnaissance survey at the study area revealed the need to harness every potentialities of the east coast in a sustainable way. , the present study attempted to investigate several selected geo-environmental features like the shoreline movement functioning along the river estuaries and coastline; the causes of deterioration of environmental and biological condition at the east coast was also been analyzed. The following sections have discussed about the coastal zone, the geology, geomorphology, hydrology, hydraulics, climate, biodiversity, as well as the socio-economic features of the study area-the eastern coastal zone of Bangladesh.

3.2 The Coastal Zone of Bangladesh

The delineation and definition of the coastal zone in Bangladesh have been done by different agencies for different perspectives and purposes. For instance, the Soil Resources Development Institute (SRDI) delineated the coastal zone as the “area affected by tidal changes in water level in the Bay of Bengal, extends up to 150 km from the coast”. The SRDI definition incorporates the Bhola, Barisal, Patuakhali, Jhalkhati, Barguna, and Satkhira districts and part of the Cox’s Bazar, Chittagong, Feni, Noakhali, Lakshmipur, Pirojpur, Bagerhat and Khulna districts (SRDI, 2001).

In the GoB Policy Note on ICZM plan (MoWR,1999), the land area of the 16 sea and estuary facing districts in Chattogram, Noakhali, Barisal, Patuakhali and Khulna along with the Exclusive Economic Zone (EEZ) has been delineated as the 'Coastal Zone' of Bangladesh.

Abu et al. (2003) mentioned that, coastal zone as the "land affected by its proximity to the sea and that part of the sea affected by its proximity to the land". In the working paper WP 005, PDO-ICZMP Abu et al. (2003) defined the coastal zone as the area where the land-sea interactive processes functions in the most intensive manner. Further, the report discussed about three basic natural system processes and events that govern opportunities and vulnerabilities of the coastal zone of Bangladesh. These are- (i) tidal fluctuations; (ii) salinities (soil, surface water or groundwater); and (iii) cyclone and storm surge risk (Abu et al., 2003). Considering these three natural processes, total 19 districts comprising 147 Upazilas and the Exclusive Economic Zone (EEZ) along the coast was defined as the 'Coastal zone' of Bangladesh (Abu et al.,2003). Total 48 Upazilas were categorized as the 'Exposed Coastal Zone' as these are open to the sea and /or lower estuaries. The remaining 99 Upazilas were termed as the 'Interior coast', lying behind the exterior coast of the country (Abu et al., 2003) (Map 3.1).

The coastal zone of Bangladesh has been divided into three geomorphic regions such as (i) the deltaic Eastern region (Pacific type),(ii) the deltaic Central region, and (iii) the stable deltaic Western region (Atlantic type) (ESCAP/UN, 1987; cited in Abu, et al., 2003 and Hafez, 2019).These are discussed below:

(i) The Deltaic Eastern Region (Chattogram Coastal Plain / CCP)

The deltaic eastern region of Bangladesh coast is stretched from the big Feni River up to the Badar Mokam (southern tip of the mainland), Chattogram (PDO-ICZMP, 2005). The region is classified as the 'Pacific type' coast, which runs parallel to the young Tertiary folded hill ranges (Abu, et al., 2003 and Hafez, 2019).

(ii) The Deltaic Central Region (Meghna Deltaic Plain / MDP)

The central region starts from the Tetulia River up to the big Feni River estuary at the east, including the Ganges-Brahmaputra-Meghna river confluence zone (Abu, et al., 2003 and Hafez, 2019).

(iii) The Stable Deltaic Western Region (Ganges Tidal Plain East /GTPE)

The western region covers the coastline from the west of the Tetulia River, westward up to the Hariabangha River. The region is covered mostly with dense mangrove forests with deeply scoured tidal channels of the tidal plain overlapping abandoned Ganges delta (Abu, et al., 2003 and Hafez, 2019).

3.3 Study Area

The reconnaissance field survey and literature review revealed that, the east coast of Bangladesh has diverse natural and socio-economic opportunities, such as the world's longest uninterrupted coast, the distinct physiographic features formed by the dynamic geomorphic processes, rich and unique terrestrial and coastal and marine ecosystems. Nevertheless, all these opportunities have been hindered by the vulnerabilities, such as rapid shoreline movement or change, intense soil and water pollution, notable biodiversity change and / or loss, and substantial ecological criticalities owing to unscrupulous anthropogenic interventions. Hence, the present study selected the east coast as the study area to investigate the deteriorating state of selected geo-environmental features caused by anthropogenic interventions at the east coast. Classified as the 'Chattogram Coastal Plain' (CCP) of the 'Deltaic Eastern Region' (Banglapedia, 2015), the east coast has been included into the 'Exposed Coastal Zone' category of the coastal upazilas of Bangladesh (Abu, et al., 2003) (Map 3.1).

Further, the reconnaissance field survey and literature reviews revealed that, the 121 km long uninterrupted coastline (Brammer, 2012) along the Teknaf peninsula comprises diverse natural and socio-economic opportunities for the east coast. Added to this geomorphic and hydrologic uniqueness, the significance of the east coast is enhanced by the brackish soil and water of the river estuaries. The brackish soil and water of the estuaries are the habitats, breeding round and nursery of rich terrestrial as well as coastal and marine biodiversity. However, the geo-environmental state of the river estuaries and the ECA (DoE, 1995) areas of the Teknaf coast have been experiencing the worst consequences of deteriorating geo-environmental state owing to anthropogenic interventions.

Hence, the estuaries and the ECA area of Teknaf coast along Marine drive, experiencing the maximum intensity and occurrences of the aforementioned geo-environmental vulnerabilities were selected as the sample areas. The sample areas are listed below:

3.4 Sample Areas

The study selected four geo-environmentally vulnerable locations of the east coast as the sample areas for the present study. The areas are (i) the Feni River estuary (ii) the Jalkadar River estuary (iii) the Bakkhali River and channel estuaries and (iv) the Ecologically Critical areas along Marine drive (Maps 3.2, 3.3, 3.4, and 3.5). The chronological pattern of shoreline change and /or movement, heavy metal concentration and physio-chemical qualities of soil and water qualities, the biodiversity change and /or loss at the sample areas of the present study has been measured and analyzed to reveal the geo-environmental state of the east coast.

i) Feni River estuary

The Feni River is 116 km long from its origin at Tripura up to its estuary at the Bay of Bengal. The river flows between the Sonagazi upazila of Feni district and Mirsharai upazila of Chattogram district, Bangladesh and falls into the Bay of Bengal (Chowdhury, 2012b).

ii) Jalkadar River estuary

The Jalkadar River (or Jalkanda canal, Banglapedia, 2015) flows between the Khankhanabad and Pekua unions of Banshkhali upazila, Chattogram district and falls into the Bay of Bengal (Banglapedia, 2015).

iii) Bakkhali River estuary

The flashy Bakkhali River is the most important waterway of Cox’s Bazar Sadar Upazila of Cox’s Bazar district. A number of small streams originating in the south-eastern hills of Mizoram meet at Naikhongchhari upazila of Bandarban district to form the 67 km long Bakkhali River. Flowing through Naikhongchhari and Ramu upazilas of Cox's Bazar district the river falls into the Moheshkhali channel adjacent to the Bay of Bengal (Banglapedia, 2015).

iv) Marine Drive Expressway, Cox’s Bazar and Ukhia Upazilas

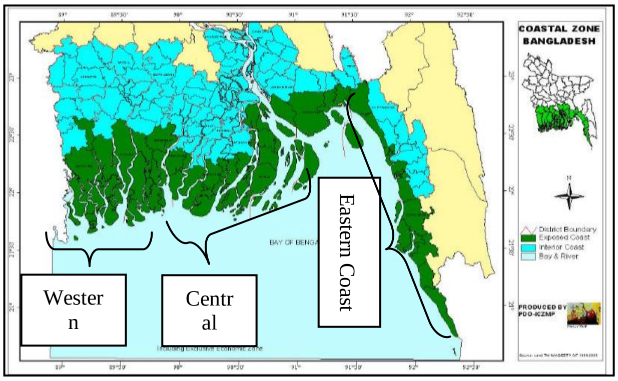
The source points of pollution such as the Himchari and Sonarpara Shrimp hatchery areas of Cox’s Bazar Upazila, and Inani beach tourist spot of Ukhia Upazila were selected as sample areas. The sample areas were located along the 80 km long Marine drive expresses way of the 80 km. long coastline of Teknaf peninsula, Cox’s Bazar (Islam, 2015).

3.5 Geology and Geomorphology

Bangladesh occupies major part of the Bengal basin and has developed due to uplift of the Himalayan mountain range. The country developed by huge sediment deposition carried by the broad fluvial front of the Ganges-Brahmaputra-Meghna river system.

3.5.1 Geology

Geologically, Bangladesh is divided into three major tectonic units such as, (i) the Stable Precambrian Platform in the northwest; (ii) the Geosynclinal Basin in the southeast; and (iii) the narrow northeast-southwest trending zone, known as the 'Hinge Zone', which separates the above two units almost through the centre of the country (Khan,1991). (i) The stable Precambrian platform occupies Rajshahi, Bogra, Rangpur, and Dinajpur areas and is characterized by limited to moderate thickness of sedimentary rocks above a Precambrian igneous and metamorphic basement. The Precambrian platform is divided into (i) northern Rangpur Saddle, a shallow Precambrian basement (130m to 1,000 m) and (ii) southern Bogra Shelf, a basement at moderate depth (1 km to 6 km). The sedimentary layers in the Bogra shelf dip very gently towards the southeast until it reaches the 'Hinge zone' at a 15° to 20° slope, where the shelf plunges into the Geosynclinal basin to the southeast (Khan, 1991). (ii) The Geosynclinal basin is subdivided into two parts such as, (i) the folded belt at east and (ii) the foredeep at west. The folded belt is characterized with folded sedimentary layers into a series of anticlines forming the hills, and synclines forming the valleys at the eastern Chattogram-Cumilla-Sylhet regions. Nevertheless, the intensity of the folding is greater towards the southeastern part of Bangladesh, which is termed as the 'Folded flank of Chattogram Trough' (Khan, 1991). However, the eastern part of Chattogram Trough is known as the 'Chattogram Hill Tracts' (Quazi, 1986 and Chowdhury, 2015a). (iii)The Hinge zone is a 25 km wide, stretching along northeast-southwest, which separates the 'Precambrian platform' from the Geosynclinal Basin (Khan, 1991) (Map 3.6). The eastern part of the country, the Chattogram division is an uplifted hilly region, which is formed due to collision of the Indian plate with the Assam plate (Chowdhury, 2015a).



Map 3.1: Coastal Regions (Zones) of Bangladesh

Source: WARPO, 2005

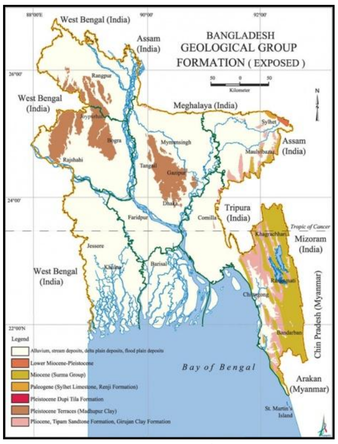
Map 3.2: Mirsharai Upazila

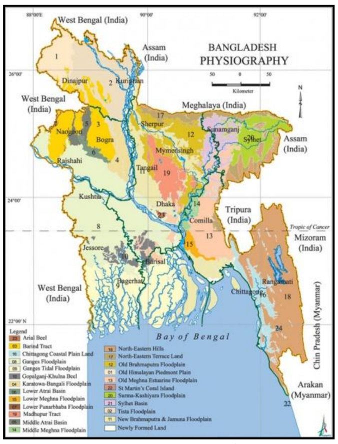
Map 3.3: Banshkhali Upazila

Map 3.4: Cox's Bazar Sadar Upazila

Map 3.5: Ukhia Upazila

Source: Banglapedia, 2015





Map 3.6: Geology of Bangladesh

Map 3.7: Physiography of Bangladesh

Source: Harun-er Rashid, 1991

The folded flank of the Chattogram Trough is sub-divided into three subzones, namely (i) the Western most gentle subzone of box-like structures, (ii) Middle subzone of asymmetrical and faulted structures, and (iii) Eastern subzone of highly compressed and disturbed structures (Quazi, 1986). (i) The study area is within the **Western subzone** of the folded flank of Chattogram trough. This subzone of the east coast of the Bay of Bengal includes Dakhin Nhila, Inani, Jaldi, Sitakunda, Semutang and Patiya anticlines and their corresponding synclines. The dip on either flank of the structures range from 45° to 55 ° (Quazi,1986).

(ii)The folding in the **Middle Subzone** is characterized by intensive appearances of tectonic forces and development of more complex structures. The southern portion of the subzone is occupied by large structures, while the northern part includes structures of smaller sizes (Quazi, 1986).

(iii)The **Eastern Subzone** comprises sharp faulted anticlines, which have dips of 70°-90° (Quazi, 1986).

3.5.2 Geomorphology of Bangladesh

The floodplains occupy 79 percent of the country's land area, which is composed of sediments deposited by the Brahmaputra-Jamuna, the Ganges- Padma, the Surma-Meghna, and the Chattogram river systems (Brammer, 2012). The hilly regions at the east, northeast and southeast part of the country occupies 12 percent and the uplifted blocks occupy the rest 9 percent (Brammer, 2012). The physiographic formation of Bangladesh is the consequence of several sequential geomorphic processes, such as upliftment of the Himalayan mountain range due to orogenic movement, huge sedimentation and subsidence of the Bengal basin with thick quaternary deltaic sediments eroded from the high lands on three sides of the Bengal basin and deposited by the major river systems (Rashid, 1991). Nevertheless, the delta building procedure is still under progress at the south into the Bay of Bengal, followed by the extensive fluvial front of the GBM river system (Rashid, 1991). The Bengal Delta Basin has been constantly going under the geomorphic process of both horizontal (seaward), as well as vertical (upward) growth at the coastal belt since its creation (Rashid, 1991 and Brammer, 2012). Located at the south and south-east, the Chattogram Hill Tract is an integrated uplifted zone of the frontal belt of the Indo-Burma ranges (Rashid, 1991). The Chattogram hills are the consequence of the subduction of an oceanic plate (Indian Ocean) under a continental plate (Burma) or the great Eurasian plate (Rashid, 1991). In the south, the country is bordered by the Bay of Bengal, where the basin surface slopes down into the Bengal Deep Sea Fan (Rashid, 1991, and Brammer, 2012). The literatures (Rashid, 1991, and Brammer, 2012) categorized Bangladesh into four distinct physiographic regions, each having distinguishing characters of its own (Map 3.7). Brammer (2012) classified Bangladesh into three distinct physiography regions, such as, (a) the Floodplains, (b) the Terraces, and (c) the Hills. The northern and eastern hilly regions of Bangladesh comprise two main kinds of topography (Khan,1991; Brammer,2012; Alam, 2015), namely, (i) the Low Hill Ranges (Dupi Tila and Dihing Formations), and (ii) the High Hills or Mountain Ranges (Surma and Tipam Formations).

(i) The low hill ranges are found in the southeastern region of Chattogram, the northeastern hills of Sylhet and highlands in the north and northwest rises steeply to narrow ridgelines (average 36 m wide), with elevation ranges between 600 m and 900 m above MSL(Chowdhury,2015a). In between the hilly ridges lie the valleys that generally run north to south. West part of the Chattogram hills is a narrow and wet coastal plain lying parallel to the coastline. The Chattogram region unit includes the Sitakunda and Mara Tong ranges (Highest elevation 113m). The elevation reaches 352m at Sitakunda peak at Sitakunda range. The northern high peaks on this range are Rajbari Tila (274m) and Sajidhala (244 m), while in the south, there is an abrupt fall, which results into the lower elevation of the Chattogram city (less than 92m). Subsequently, the main mass of hills goes down the Teknaf peninsula as the Teknaf range, which is comparatively lower (61m to 91m) at the north of the Reju khal (Rashid, 1991, and Brammer, 2012 and Alam, 2015).

(ii) High hill or mountain ranges have very steep slopes and are subject to landslide erosion. This sub-unit comprise an almost parallel ridge running approximately north-south and with summits reaching 300m-1000 m (Alam, 2015).

The contour map of Bangladesh shows a gentle slope from the northwestern hilly regions towards the Meghna estuary at south- centre. The elevation of the floodplains in the country is less than 10m above the average mean sea level (AMSL), which decline further towards the coastal zone at south (Brammer, 2012).Converse situation is seen at the northern and southeastern hilly regions, as the compact contour lines run almost in north-south direction, at an elevation from 300 m to 1000 m (Brammer, 2012)

3.6 Physiography and Geomorphology of the Study Area

The study area of the present research work, the Chattogram Coastal Plain (CCP), is a compound geomorphic unit comprising an area of 3690 sq. km. (Brammer, 2012).

Geomorphically, the present study area-the east coast is categorized as the 'Chattogram Coastal Plain (L)', stretched from the Feni River up to the mouth of the Matamuhuri delta (121 km) (Brammer, 2012). The CCP is mostly regular, although cut twice by two rivers namely, the Sangu and the Karnafuly, discharging in the Bay of Bengal (Brammer, 2012). Despite being the most stable coastal zone of Bangladesh, the east coast is still now geomorphically active. It comprises of gently sloping piedmont plains near the hills, river floodplains alongside the Feni, Karnaphuli, Halda and other rivers, tidal floodplains along the lower courses of these rivers, a small area of a young estuarine floodplain in the north, adjoining sub-regional young Meghna estuarine floodplain, and sandy beach ridges adjoining the coast in the south (Chowdhury, 2015). The unit comprises the piedmont plains, depicted with the rivers, tidal and estuarine floodplains, and old and young beach ridges along the coast (Brammer, 2012). However, the two sub-physiographic regions (Map 3.8) are the North Chattogram Tidal Floodplain (Lca) and North Chattogram Tidal Floodplain (Lcb) (Brammer, 2012). Geomorphically characterized as a low-elevated alluvial delta plain, the average land elevation of the east coast is about 4-5 meters AMSL (CCC, 2016). Stretched in the Cox's Bazar beach is 20 km wide and gradually narrows down to 3 km at the seaward end (Hossain, 2015). The shallow part (less than 20m) of the continental shelf off the Chattogram and Teknaf coast is covered by sand dunes and the intertidal areas show well-developed sandy beaches (Chowdhury, 2015b).

3.6.1 Geomorphic Features of the Feni River

The trans-boundary river Feni emerges from the eastern hills of Tripura and enters Bangladesh at Belchhari of Matiranga upazila of Khagrachhari district. Then it flows through Ramgarh (Khagrachhari), Fatikchhari (Chattogram) and then flows along the border of Chattogram (Mirsharai upazila) and Feni (Chagalnaiya, Feni, and Sonagazi upazilas) districts, to discharge into the Bay of Bengal near Sonagazi upazila. The length of the river is 108 km (Chowdhury, 2015c). The Feni River is one of the most geomorphically significant rivers in the south-east part of our country. The river separates the Bengal basin from the hilly landforms of Chattogram region in the southeast of Bangladesh (Chowdhury, 2015c).

Feni structure is a subsurface anticlinal structure. Tectonically, the structure is located in the folded flank of the Bengal foredeep between Hatiya Trough and Tripura uplift. Both east and west of the structure is separated by synclines from Sitakunda and anticlines of Begumganj respectively. The axis runs NNW-SSE direction (Baqui, 2015). The Muhuri Dam, constructed across the river near the estuary, connecting the Mirsharai Upazila, with the Fulgazi Upazila of Feni Noakhali has brought a drastic change in the geo-environmental characteristics of the river.

3.6.2 Geomorphic Features of Jalkadar River

The Jalkadar River, a meandering river (Jalkadar Khal/ Jalkanda Canal), branches off from the Sangu River, flows from the Kumurachara at the north of Banshkhali upazila, Chattogram to fall into the Bay of Bengal near Katkhali through Kutubdia channel. The branches of this rive are Jaliakhali, Chunti, and Chhanua (Biswas, 2011).

3.6.3 Geomorphic Features of Bakkhali River and Channel

The Bakkhali River is a major tidal river in the study area, which originates in the Arakan Mountains, flows north, and then turns to the west flowing past Ramu and Cox’s Bazar town, to fall into Moheshkhali channel adjacent to the Bay of Bengal (IWFM, 2008 and Chowdhury,2015d). The length of the river is 67km and has several tributaries. The Bakkhali River estuary is about 0.5 km wide and 10 m deep at its mid-point and directly influenced by semi-diurnal tides (Hena et al., 2007). This estuarine zone is characterized by the long intertidal mudflat, linked to the Bay of Bengal. The location of the leading tourist point of Bangladesh, the Cox’s Bazar sea beach, enhanced the geographic, geomorphic as well as socio-economic importance of the Bakkhali River and its channel. A huge amount of sediments (locally called as Charis) washes down the river during heavy monsoon rain, while in the dry season, the amount of the silt transport is very insignificant (Hossain, 2015 b).

However, the water retention capacity of the Bakkhali river catchment has been reducing gradually due to unanticipated siltation in the upper region of the dam, as well as huge garbage disposal. The bathymetric condition of the Bakkhali River mostly consists of muddy and sandy particles (IWFM, 2008).

3.6.4 Geomorphic Features of Teknaf Peninsula, Marine Drive

The Teknaf Peninsula, with an area of 388.68 sq km, is located at 20°87′ N. and 92°30′ E. and is the southernmost land of Bangladesh at a distance of 86 km to the south from Cox's Bazar (Banglapedia, 2014). Teknaf peninsula is one of the longest sandy beach (80 km) ecosystems in the world (Islam, 2015). One of the three sample areas, the Inani Beach is an 18 kilometer (11 miles) stretched clayey sea beach in Ukhia Upazila (Chowdhury, 2015). The whole beach is dotted with lots of coral stone of different sizes. The Inani structure is represented by NNW-SSE trending low hillocks attaining maximum elevation 54.86 meters (Baqui, 2015). Tectonically, Inani anticline is situated in the Chattogram Folded Belt of Bengal Fore deep, running along the coastline of the Bay of Bengal. The anticline is dissected into two parts by Reju khal, which flows from the hill ranges of North Arakan, traverse through the Cox’s Bazar district in a south-westerly direction to fall into the Bay of Bengal (Baqui, 2015).

3.7 Hydrology and Hydraulics

The Feni and the Bakkhali Rivers flows in east-west direction and the Jalkadar River flows in north-south direction. The Feni and Jalkadar Rivers fall directly to the Bay of Bengal. The Bakkhali River falls into the Moheshkhali channel to reach the bay. The Marine drive sample area is located along the longest uninterrupted beach (121 km, Brammer, 2012) from Cox’s Bazar to Teknaf upazila (Chowdhury, 2015).

The tides, waves, and winds are responsible for sediment deposition (Jena et al., 2008; cited in Komol, 2011). The major natural forces functioning behind the coastal erosion are the wave actions driven by the wind, water level change due to tidal fluctuation, wind, storm surge, and sea level rise (Morton, 2008; cited in Komol, 2011). The tides in the east coast are semi-diurnal in nature. However, the average daily rise in the tide is about two meters (Chowdhury, M., 2015), while Haque (2018) mentioned that, the average tidal range is 3.6 meters. The wave height ranges from 6 to 9 meters. The dominant floods of the east coast are (i) the Coastal Tidal Flood, and (ii) the Flash floods (Islam, 2004).

3.8 Climate

The east coast of Bangladesh is categorized under tropical maritime climate. The temperature varies from 12° C to 34° C and the rainfall ranges from 2290-2700 mm (Nishat et al., 2002). The two major wind streams prevailing at east coast are the south west monsoon and north east monsoon. The wind velocity varies from 4.5 to 5.5 knots during spring tide, which reduces to 2.3 to 3.9 knots during neap tide in summer monsoon (Hossain & Lin, 2007). In early summer (April and May) and in late monsoon (September- November) moderate to high intensity cyclones and associated storm surges strikes at the study area. The wind speed might increase up to 160 km/ h with about six meters high storm surges might crash with tremendous force in the coastal zone causing saline water inundation for several days along with huge loss of lives and properties (Alam, 2015). The climate change induced (CCI) adverse impacts such as, sea-level rise (SLR), cyclones and storm-surge intensification, declination of ecosystems have been occurring constantly in the east coast (Sahrdul,2003).

3.9 Biodiversity and Ecosystems

The study area is rich in floral and faunal biodiversity and has been categorized as the 'Bio-ecological zone 8a' by Nishat et al. (2002). The terrestrial ecosystem accommodates various types of floral and faunal species like tress, herbs, shrubs, mollusks, crabs, chelonians, mammals and the Coastal and Marine ecosystem consists of sea weeds, mollusks, crabs, chelonians, mammals, aquatic birds, reptiles and amphibians (DoE, 2015 and Nishat, et al., 2002).

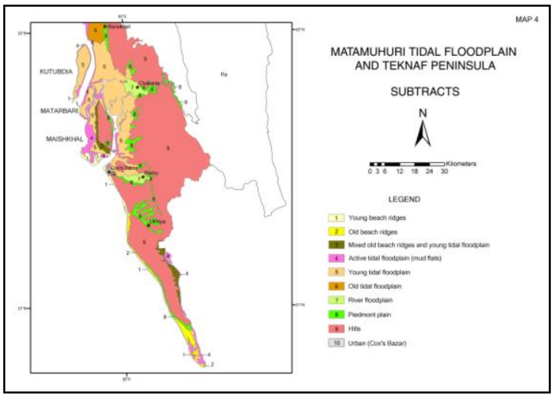
3.10 Bio-ecological Zones of Bangladesh

The bio-ecological zones of the country is a complex interaction between the abiotic and biotic properties, like physiographic, climate, soil type, flooding depth and frequency, and their cumulative effect on the biotic elements, such as, the floral and faunal biodiversities at a specific delineated zone.

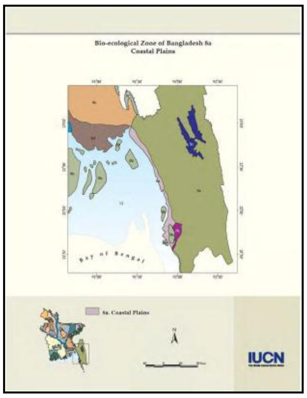
Bio-ecologically, the country is located within the Oriental Region, at the transitional zone between the Indo-Malayan and Indo-China sub-regions of the Oriental region (DoE, 2015). Interconnected by the huge river network of the Ganges-Brahmaputra-Meghna rivers system, the country acts as the ecological corridors of the wild lives among the neighboring countries like- Nepal, India and Bhutan. Bangladesh, endowed with diverse physiographic as well as climatic characteristics, is the most ecologically significant 'Gene Pool' of the wildlife species in the region. Nishat, et al. (2002) categorized Bangladesh into twelve major Bio-ecological zones on the basis of differentiation in soil, temperature, rainfall, physiography, flooding depth, diversity and distribution of flora and fauna species. The east coast has been categorized as the ‘Ecological Zone 8a’ within the Chattogram Coastal Plain (Map 3.9). Bangladesh is one of the most significant bio-ecological regions of the world in terms of migratory species, stepping stones, staging ground and flyways of wild life movement. Bangladesh is situated at the cross roads of two major international shorebird migration flyways, for instance, along the western edge of the East Asian-Australian flyway and eastern edge of the Central Asian Indian flyway. Bangladesh is considered as one of the ten global hot-spot areas (Nishat, et al., 2002).

	Bio-ecological Zones		
1.	Himalayan Piedmont Plain	7b.	Chakaria Sunderban
2.	Barind Tract	8a.	Coastal Plain
3.	Madhupur Shal Tract	8b.	Offshore Island
4a.	Teesta Floodplain	8c.	Narikel Jinjira Coral Island
4b.	Ganges Floodplain	8d.	Meghna estuarine Flood Plain
4c.	Brahmaputra-Jamuna Floodplain	8e.	Sandy Beach/Sand Dunes
4d.	Surma –Kushiyara Floodplain	9a.	Chattogram Hills and CHTs
4e.	Meghna Floodplain	9b.	Sylhet Hills
5.	Haor Basin	9c.	Lalmai-Tippera Hills
5b.	Chalan Beel	10.	Saline Tidal Floodplain
5c.	Kaptai Lake	11.	Major Rivers
6.	Gopalganj / Khulna Peat Lands	12.	Coastal and Marine Water
7a.	Sunderban		

Table 3.1: Bio-Ecological Zones of Bangladesh
Source: Nishat et al., 2002



Map 3.8: The Geomorphology of the Study Area
Source: Brammer, 2012



Map 3.9: Bio-Ecological Zones of Bangladesh
Source: Nishat, et al., 2002

3.11 Geo-Environmental Indicators of the Present Study

The Canadian Government started to develop the environmental indicator concept in the late 1980s, as an attempt to simplify the large quantities of new environmental data. In 1987, the Dutch government; followed by the G-7 power in 1989, took initiatives to develop environmental indicators, but all these attempts were ensued (Hammond, et al., 1995). In 1992, the United Nations Conference on Environment and Development, known as the 'Earth Summit' emphasized the need for sustainable development as well as the necessity of precautionary measures for environmental protection. In the Agenda 21, the conference called to develop indicators for sustainable development (UNCSD, 1992).

For the present study, a set of environmental indicators intermingled with the geomorphic and biodiversity indicators of the east coast were selected to conduct the research. The Geomorphic indicator for the study was Net Shoreline Movement (NSM) or Net Shoreline Change; the Environmental indicators were the elevated concentration of heavy metals and non-metals (nutrient) in soil and water, and the physio-chemical quality of soil and water; the Biodiversity indicators were the concentration of five heavy metals in mollusk shells, the $CaCO_3$ content in mollusk shells, and the vegetation coverage of study area.

3.12 Indicators for PSR Model

The study adopted three indicators namely the pressure, state and response indicators, developed by the OECD (2008) to develop a 'Pressure-State-Response' (PSR) model formed for the present study (Table 8.14). The rationale of developing a PSR model was to identify a 'cause and effect relationship' between the pressure indicators and state indicators at the east coast, as well as to depict the management approaches of the response indicators. The indicators of the present study have been discussed below:

1) The toxic industrial effluents, municipal garbage, heavy metal contamination from water vehicles, illegal land encroachment, construction of river dams and coastal embankments, and rapid deforestation were selected as the 'Pressure' indicators of the present study.

2) The shoreline change or movement, heavy metal contamination, decline in soil and water quality, and biodiversity change and/or loss was selected as the 'State' indicators of the present study.

3) The national and local administrative bodies and social institutions were selected as the 'Response' indicators of the present study.

3.13 Socio-Economic Structure

Agriculture, followed by the fishing, fish processing and salt cultivation is the major sources of livelihood at the coastal zone of Bangladesh. Alike the other two coastal zones of Bangladesh, low wages, poverty, increasing population density, soil and water pollution, biodiversity loss and climate change induced hazards has been accelerating the vulnerabilities of the east coast (Sahrdul,2003).

3.13.1 Demographic Structure

The demographic structure (Table 3.1) of the sample areas illustrates that, the socio-economic factors plays a significant role upon the population density of the sample areas. For instance, though consisting the largest area (482.88 km^2), the Mirsharai upazila has quite low density (826/km^2) as the area is less socio-economically developed. On the other hand, comprising the smallest area (228.23 km^2), the Cox's Bazar Sadar upazila contains the highest population density (2011/ km^2), as the area is the major tourist spot and business center of the country. The Sonagazi upazila comprises an area of 235.07 km^2 and the population density is moderate (1001/km^2). The Banshkhali upazila, a comparatively developed upazila of the region comprises an area of 376.90 km^2 and contains a high population density (1038/ km^2) (BBS, 2011 & Banglapedia, 2015).

Table 3.1: Demographic Structure of the Sample Areas

Sample Area	Area (km^2)	Population	Density /km^2
Mirsharai Upazila, Chattogram District	482.88	3,98,716	826
Sonagazi Upazila, Feni District	235.07	2,35,229	1001
Cox's Bazar Sadar Upazila	228.23	4,59,082	2011
Banshkhali Upazila	376.90	3,91,320	1038
Ukhia Upazila	261.80	1,55,187	592

Source: BBS, 2011 & Banglapedia, 2015

The area of the Ukhia upazila is 261.80 km^2 and consists of lowest population density among the sample areas (592/km^2).The upazila is the least socio-economically developed area of the study area.

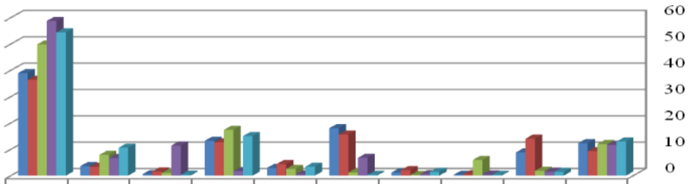
3.13.2 Main Sources of Income at the Sample Areas

The main source of income at the sample areas has been mentioned as the 'Agriculture' (Fig.3.1). The highest percentage of income comes from agriculture at Banshkhali upazila (58.73 %) followed by 54.40% at Ukhia upazila and the lowest at 36.40% at Sonagazi upazila (Banglapedia, 2015).

The second main source of income at the sample areas was from 'Commerce'. The highest percentage of income (17.29 %) from Commerce was at Cox's Bazar upazila, followed by the Ukhia upazila (15.05%) with the least at Banshkhali upazila (1.70%) (Banglapedia, 2015).

The 'Other' source of income came from various economic activities, which might be categorized as the third main source of income at the sample areas. The highest percentage of this category of income was found at Ukhia (12.95%) followed by 12.33% at Mirsharai upazila and the lowest at Sonagazi upazila (9.27%) (Banglapedia, 2015).

The lowest source of income was from 'Religious Services' ranging from 0.34 % at Mirsharai and Ukhia upazila up to 5.96% at Cox's Bazar Sadar upazila (Banglapedia, 2015).



	Agriculture	Non-Agriculture Laborer	Industry	Commerce	Transport & Communication	Service	Construction	Religious Services	Rent and Remittance	Others
Mirsharai	38.93	3.61	0.57	13.26	2.93	18	1.19	0.34	8.84	12.33
Sonagazi	36.4	3.35	1.58	12.67	4.4	15.62	2.11	0.56	14.04	9.27
Cox's Bazar Sadar	49.84	7.92	1.04	17.39	2.56	1.19	0.27	5.96	1.84	11.99
Banshkhali	58.73	6.68	11.42	1.7	0.5	6.78	0.58	0.43	1.51	11.67
Ukhia	54.4	10.61	0.36	15.05	3.4	0.34	1.45	0.34	1.46	12.95

Fig. 3.1: Main Sources of Income at the Sample Areas
Source: Banglapedia, 2015

The average per capita income at coastal zone was Tk.55, 760 ((Banglapedia, 2015).The coastal zone of Chattogram receives comparatively higher GDP, where the agricultural labourers are the largest livelihood group (71% of the total coastal households) with the lowest income. Despite being the major income source for the coastal people, this sectors receives very low wage, climate change induced hazards (Abedin, 2013). The non-agricultural groups are engaged in fishing and fisheries farming (Ahsan, 2013).

3.13.3 Land Use Pattern and Land Cover Transformation

The major land use types of the east coast are the shrimp and fish farms, salt fields, agricultural lands, ship breaking yards, industries, tourist spots and residential areas. Nishat et al. (2002) stated that, the land use types in the study area are- the agricultural plots, mixed evergreen and deciduous forest, and mixed thickets and forests.

Roy, Binata (2016) measured the spatio- temporal pattern of land use cover change from 2002 to 2014 in Chattogram district. The study revealed that, the land use categorized as 'Urban area' and 'Barren land' was increasing at an alarming rate, while 'Forestland' and 'Water body' was decreasing gradually. Development of unplanned urban settlements, unethical and illegal encroachment of water bodies, wetlands, vegetated and cultivable lands due to accelerating rate of urbanization, rural to urban migration and other socio-economic and political crisis were the key factors of land use change.

All these natural and anthropogenic features have been gradually turning the opportunities of the east coast into vulnerabilities owing to unscrupulous anthropogenic activities at the east coast. The vulnerabilities of each sample areas have been discussed below.

3.14 Opportunities and Vulnerabilities at the Study Area

The above mentioned physical and social processes functioning at the east coast offers diverse development opportunities. However, the opportunities get hindered by various vulnerabilities owing to natural and anthropogenic causes. In the Working paper 005 of WARPO (Abu et al., 2003) mentioned the coastal zone of Bangladesh as 'an area in which the vulnerabilities and opportunities require special management approaches'.

From the literatures and field survey, the study attempted to identify the opportunities as well as the vulnerabilities functioning as the obstacles in the development processes of the east coast.

3.14.1 Opportunities at the Study Area

The east coast possess diverse geo-environmental resources like the world's longest uninterrupted sea beach, wide open estuaries, wide and shallow continental shelf, huge amount of sediment load carried downstream from the upstream of the rivers, mud plains, sandy beaches, sand dunes, densely vegetated hilly ranges, mineral resources, rich terrestrial and coastal & marine ecosystem biodiversity (Nishat et al.,2002).

From the socio-economic perspectives, the east coast serves as the major hub of business, industries and flourishing eco-tourism potentialities. The recent development of the 'Blue economy' (FAO,2019), the socio-economic activities such as the artisanal and industrial fishing, marine fish and fisheries cultivation, development of coastal and marine aquaculture, expansion of eco-tourism and trade, exploitation of renewable energy like oil, gas, and mineral; development of eco-friendly ship-building and recycling industries, construction of highways, bridges and railways, human resource development and many other related sectors development initiatives might be considered as the key opportunities to alleviate poverty and achieve socio-economic sustainability in the study area.

All these opportunities instigated to explore the ways to ensure full functional implementation of the existing ICZMP (1999), associated with the SDGs for the east coast. Accordingly, the study attempted to measure the state of selected geo-environmental indicators and to develop a 'Strategic Policy Framework' to incorporate them in the existing ICZMP (1999) to establish an area-specific and realistic sustainable development plan for the present study area.

The geomorphic and socio-economic opportunities prevailing in the sample areas have been discussed in the following sections to ensure coastal zone management at local level.

(i) Opportunities at the Feni River Estuary

The wide, shallow estuary of the Feni River once was the main breeding ground of hilsa fish. After the construction of the Muhuri Closure Dam (MCD), the high tide induced saline water intrusion has been restricted which turned the area into an agricultural hub. The estuary area now provides the local communities land for vegetable and fruit farming, and fish cultivation resulting into enhanced socio-economic condition of the local communities. The indigenous farming and fishing practices were changed to commercial farming and fishing practices.

(ii) Opportunities at the Jalkadar River Estuary

The Jalkadar River, flowing through the Banshkhali upazila is the main source of water for the local communities. Further, the river functions as the main drainage system which drains off the saline water intrusion during high tides into the coastal part of the upazila.

In socio-economic perspectives, the Sharker bazar situated along the Banshkhali upazila protection dam is main the fish landing station and the retail fish market. The fishermen from the bay and the fish mongers from all over the country meet at this bazar for trading. The other side of the estuary along Chhanua is the center of salt farming.

(iii) Opportunities at the Bakkhali River Estuary

Situated at the Cox's Bazar upazila, the river estuary is one of the busiest water ways to connect with the offshore islands like Kutubdia, Sandwip, and Moheshkhali. The

No.6 fishery ghat, the Nuniarchara fishery ghat and the Nuniarchara industrial area comprising of salt and ice factories, dried fish and frozen fish processing factories have enhanced the socio-economic significance of the area. Recent development of the ‘Fishermen Rehabilitation’ housing project at the Khurushkul union, construction of the Khurushkul Bridge connecting the main land at Badar Mokam with the housing project has turned the sample area into a flourishing socio-economic center (Present Study,2018).

(iv) Opportunities at the ECAs of Teknaf peninsula

The sample areas like Himchari, Sonarpara and Inani beach along the Marine drive of the Teknaf peninsula is the main center of shrimp hatcheries and shrimp processing factories, tourism and agriculture . Hence, the GoB has taken huge initiatives to protect the erosion prone coastline and has declared the area as the most ecologically vulnerable portion of the coast termed as the ‘Ecologically Critical Area (ECA)’ . Recent construction of the Marine drive has multiplied the socio-economic potentialities of the area.

Despite the presence of these opportunities, vulnerabilities like below has been deteriorating the geo-environmental state of the east coast.

3.14.2 Vulnerabilities in the Study Area

The coastal vulnerabilities are distinct from other parts of the country and the level of vulnerabilities varies in respect of socio-economic and political hindrances. The aforementioned vulnerabilities manifest the poverty at the study area as these factors function as hindrances which limit the choices of livelihood in all aspects. Literatures (Istiakh et al., 2019; Sarwar & Islam, 2013; Islam et al., 2020; Shamsuddoha & Chowdury, 2007; Islam & Mohiuddin, 2004) stated the eastern coastal zone as a very dynamic coast where natural vulnerabilities prevail as a consequence of the geomorphic activities like shoreline erosion and accretion, landslides, strong diurnal tidal wave and wind, climate change induced (CCI) cyclones and storm surges, sea level rise (SLR) and increased saline water intrusion. The unscrupulous anthropogenic activities like accelerated amount of toxic pollutants disposed into the water and soil from industrial and municipal waste disposal, logging, over and unplanned exploitation of natural resources enhance the vulnerabilities at the study area.

The following sections depict the vulnerabilities prevailing at the sample areas of the present study to reveal the vulnerabilities at local level.

(i) Vulnerabilities at the Feni River Estuary

Massive sediment accretion process at local scales due to construction of the Muhuri Closure dam (MCD), decreasing tidal activity, silt deposition by tides from the bay, land slide from barren hill slopes due to over exploitation of timber trees, and embankments around the vegetable, fruit and fish projects, increasing occurrences of cyclones and storm surges amplifying high strong waves, sea level rise (SLR) generated increased saline water intrusion into the fresh water zone, increasing pollution from huge municipal garbage dumping, accelerated heavy metal concentration and fluctuation of non metal nutrients in soil and water due to discharge of toxic industrial and other kinds of toxic effluents, along with the consequent biodiversity loss are the major vulnerabilities at the sample area.

(ii) Vulnerabilities at the Jalkadar River Estuary

Saline water intrusion due to SLR and high tides, strong wave action at the river banks, erosion proneness of the earthen bank protection dams, narrowing down of river width and depth due to garbage disposal, higher level of heavy metal concentration owing to discharge of industrial and other types of effluents, biodiversity loss and/ or change are the major vulnerabilities of the sample area.

(iii) Vulnerabilities at the Bakkhali River Estuary

The high tidal and strong wave action leading to erosional activities at east bank, accretion on the west bank, increased salinity due to SLR, char accretion at the inner side of the Bakkhali River dam, weak wave actions at the downstream along the estuary, pollution and toxicity from the dumping and discharge of huge amount of municipal garbage and industrial waste, and the consequent biodiversity loss are the major vulnerabilities at the sample area.

(iv)Vulnerabilities at the ECAs of Teknaf peninsula

Strong tidal wave and wind actions, amplified cyclone generated water surge enhanced by the uninterrupted long, wide and shallow continental shelf, heavy metal concentration from industrial effluents, waste disposal from the shrimp hatcheries and tourist spots, changes in physio-chemical quality of the soil and water, and logging of trees along the sample area are the key vulnerabilities.

The consequences of all the above mentioned vulnerabilities are sudden land loss through shore line erosion, increased soil salinity, decreased agricultural soil quality, crop and livestock loss and/ or decline, decreased soil and water quality, loss and decrease of shrimp and other fish and fisheries resources, loss of lives and properties, getting into debts, and to a great extent, settlement displacements.

3.15 Conclusion

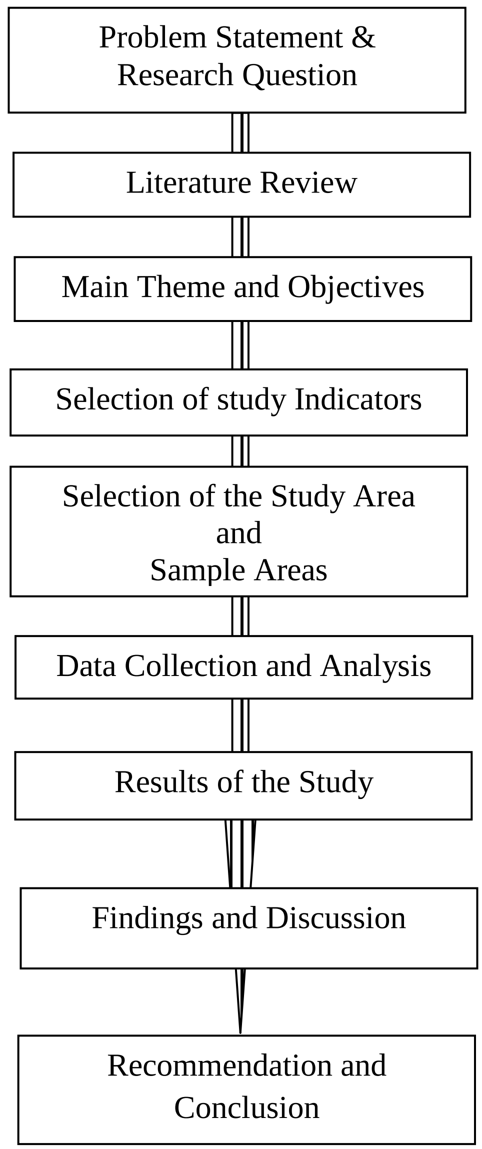
The opportunities and vulnerabilities prevailing at the east coast have not been given adequate attention to harness and exploit the maximum of the opportunities, ways to mitigate the vulnerabilities, as well as to implement the existing ICZMP (1999) and other future plans and policies in a fully-functional manner.

Accordingly, the study endeavored to analyze the state of the selected geo-environmental indicators, the cause & effect relationship between the indicators and the anthropogenic activities by formulating a 'PSR' model. Finally, the study attempted to develop a 'Strategic Policy Framework' to incorporate the indicators into the existing ICZMP and future management approaches for the east coast.

4.1 Methodological Framework of the Present Study

After thorough literature review of the selected geo-environmental indicators, and the previous coastal zone development initiatives of the GoB, a ‘Methodological Framework’ of the present study was formulated like below:

Fig.4.1: Methodological Framework of the Present Study



4.1.1 Selection of the Study Area and Sample Areas

The east coast of Bangladesh was selected as the study area after a reconnaissance survey, literature survey and analysis of the satellite images. The diverse physiographic features like longest uninterrupted coastline of the world, wide shallow continental shells, presence of vast as well as geo-environmentally significant estuaries, brackish water and soil, prominent geomorphic processes, and rich biodiversity has turned the east coast as a dynamic zone of natural and anthropogenic interactions. The east coast of Bangladesh has become the potential zone of socio-economic development, especially after the emergence of ‘Blue Economy’ as a potential tool of human development in the country. Despite all these opportunities, the adverse impacts of rapid urbanization, over and under use of natural resources, partial functionality of the previous development plans have been hindering the coastal management in a sustainable way. The unscrupulous anthropogenic activities upon the geo-environmental processes, as well as the consequent environmental deterioration, and changes in biodiversity of the east coast enthused to select the eastern coastal zone as the study area.

Study Area

The east coast of Bangladesh included within the Chattogram Coastal Plain (CCP), and the narrow coastal strip of Teknaf peninsula, extending from the Feni River up to the Badar Mokam was selected as the study area (Chowdhury, 2015) (Map 4.1). The coast runs parallel to the young (Tertiary) folded hill range, characterized by continuous sand dunes and sandy beaches, stretching through the longest unbroken beach of the world, the Cox`s Bazar (Chowdhury, 2016). The central place of different socio-economic activities such as industries, business and tourism; the entire coastal zone is the habitat of rich aquatic and terrestrial ecosystems. Bio-ecologically the area has been designated as the zone 8a (Nishat, et al., 2002) and the affluent biodiversity and diversified geo-environmental features of the study area exert a significant influence not only upon Bangladesh, but also in broader perspective, to its neighboring countries.

Sample Areas

In the present study, the east coast of Bangladesh was observed as a zone of ample natural and socio-economic opportunities. Nevertheless, the literatures and reconnaissance survey of the present study revealed the anthropogenic activity induced deterioration of the geo-environmental state as the vulnerabilities ensuing hindrances in the development of the east coast. Accordingly, the study realized the need to incorporate the selected geo-environmental indicators into the existing ICZMP (1999), as well as into the future plans and policies to develop the east coast in a sustainable way. The study observed that, unscrupulous anthropogenic interventions were increasingly deteriorating the geo-environmental state of the sample areas. The consequences were the rapid changes in the geomorphic features, deterioration of environmental state, and decline and/ or change in biodiversity in the terrestrial and the coastal and marine ecosystems of each sample area.

Hence, the present study selected four most geo-environmentally vulnerable areas of the east coast as the sample areas of the present study after a reconnaissance survey, literature survey and analysis of the satellite imageries of the east coast for the last twenty five (1990-2015) years (Map 4.2).

The sample areas were selected basing upon the factors like- (i) the areas of major land erosion and accretion, (ii) the areas of severe pollution, (iii) the areas experiencing significant biodiversity change, and (iv) the areas with ecologically criticalities.

The sample areas along the Marine drive, Teknaf coast –the Himchari and Sonarpara shrimp hatchery areas, and Inani beach tourist spot along Marine drive express way were categorized within the ecologically critical areas (BECA, 1995).

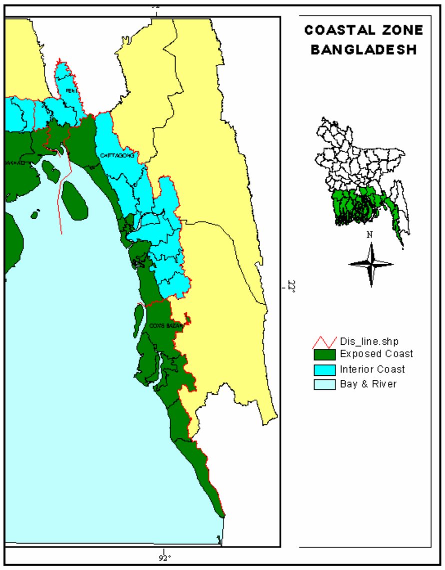
The absolute location of the present study sample areas has been shown below (Tables 4.1 to 4.5). These are:

1) The Feni River Estuary, Mirsharai Upazila, Chattogram

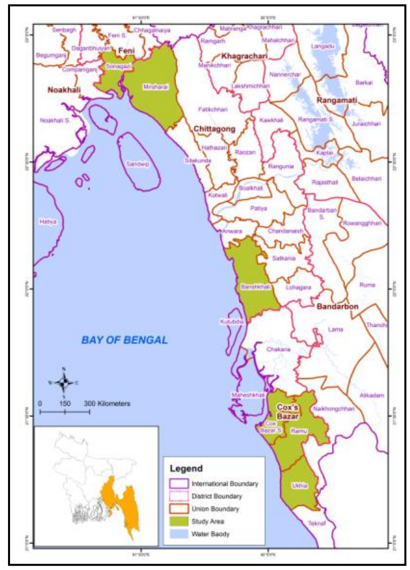
2) The Jalkadar River Estuary, Banshkhali Upazila, Chattogram

3) The Bakkhali River and Channel Estuary, Cox's Bazar Sadar, Cox's Bazar Upazila, Chattogram

4) The Marine Drive, Teknaf, Ukhia and Cox's Bazar Upazila, Chattogram



Map 4.1: The Present Study Area
Source: PDO-ICZMP, WARPO, 2002



Map 4.2: The Sample Areas
Source: Study, 2018

Table 4.1: Absolute Location of Feni River Sample Areas, Mirsharai

Sample Area ID	Sample Area Name	Latitude	Longitude
Sample 01	Abuler Char	22° 16′20″ North	91° 25′ 42 ″ East
Sample 02	Ichakhali Char	22° 35′09″ North	91° 26′ 02″ East
Sample 03	North Mukter Char	22° 50′ 11″ North	91° 27′ 12″ East
Sample 04	South Mukter Char	22° 49′ 28″ North	91° 26′ 28″ East
Sample 05	Muhuri Dam, East Side	22° 50′ 11″ North	91° 27′ 26″ East

Table 4.2: Absolute Location of Jalkadar River Sample Areas, Banshkhali

Sample ID	Sample Area	Latitude	Longitude
Sample 01	Coastal Protection Dam, Sharker Bazar	21° 57′ 33″ North	91° 56′ 12″ East
Sample 02	Coastal Protection Dam, Gondamara	21° 56′ 32″ North	91° 53′43″ East
Sample 03	Parabon, Protection Dam, Banshkhali	21° 56′ 29″ North	91° 53′ 30″ East
Sample 04	Coastal Protection Dam, Katkhali Bazar	21° 56′ 36″ North	91° 54′ 10″ East
Sample 05	Mojaher Para, Ward no.09, Chhanua	21° 56′ 15″ North	91° 55′ 26″ East

Table 4.3: Absolute Location of Bakkhali River Sample Areas , Cox's Bazar

Sample ID	Sample Area	Latitude	Longitude
Sample 01	No.6 Fishery Ghat, Bakkhali River	21° 27′ 32 ″ North	91° 58′ 12.7″ East
Sample 02	Nuniarchara Fishery ghat, Bakkhali River	21° 28′ 30.2 ″ North	91° 58′ 31.9″ East
Sample 03	Khurushkul Project Area, Bakkhali River	21° 30′ 34 ″ North	91° 02′ 35 ″ East
Sample 04	Nuniarchara Industrial area, Bakkhali River	21° 27′ 02 ″ North	91° 58′ 13″ East

Source: Present Study, 2018

Table 4.4: Absolute Location of Bakkhali Channel Sample Areas, Cox's Bazar

Sample ID	Sample Area	Latitude	Longitude
Sample 01	Char Para, Bakkhali Channel	21º 27′ 39.8 ″ North	91º 57′ 17.7 ″ East
Sample 02	Kutubdia Para, Bakkhali Channel	21º 27′ 51.5 ″ North	91º 57′ 25.3″ East
Sample 03	Char Para, Bakkhali Channel mouth	21° 27′ 46″ North	91º 57′ 28.3 ″ East
Sample 04	Kutubdia Para, Bakkhali Channel mouth	21º 28′ 08.5 ″ North	91º 57′ 23.1 ″ East

Table 4.5: Absolute Location of Marine Drive Sample Areas, Cox's Bazar

Sample ID	Sample Area	Latitude	Longitude
Sample 01	Inani Beach, Ukhia, Marine Drive, Cox's Bazar	21º 14′ 5.3 ″ North	92º02 ′ 50.5 ″ East
Sample 02	Sonarpara, Ukhia, Marine Drive, Cox's Bazar	21º 16′ 37.6 ″ North	92º 2′ 56.2 ″ East
Sample 03	Himchari, Ukhia, Marine Drive, Cox's Bazar	21º 20′58.3 ″ North	91º 01′ 36.8 ″ East

Source: Present Study, 2018

4.1.2 Extent of (length and width) of the Present Study Area

The extent, the length and width of the study area of the present study sample areas is shown in Table 4.6. Three sample areas were chosen at the river estuaries to investigate the geo-environmental condition in the brackish water and estuarine soil. Added to these sample areas, the Ecologically Critical Area (ECA) zone of the Marine Drive has been selected as the sample area.

Table 4.6: Extent (length and width) of the Present Study Area

Study Area	Length	Width	Extent (Area)
Marin Drive	25.9 km	4.8 km	125.67 sq.km
Bakkhali River and Channel Estuary	6.09 km	3.7 km	22.74 sq.km
Feni River Estuary	13.1 km	107.8 km	412.18 sq.km
Jalkadar River Estuary	12.8 km	1.5 km	18.36 sq. km

Source: Study, 2018

4.1.3 Geo-Environmental Indicators for the Present Study

The Canadian Government started to develop the environmental indicator concept in the late 1980s, as an attempt to simplify the large quantities of new environmental data. In 1987, the Dutch government; followed by the G-7 power in 1989, took initiatives to develop environmental indicators, but all these attempts were ensued. In 1992, the United Nations Conference on Environment and Development, known as the Earth Summit (held at Rio de Janeiro) emphasized the need for sustainable development as well as the necessity of precautionary measures for environmental protection. The conference called to develop indicators for sustainable development (Agenda 21). A set of environmental indicators, intermingled with the geomorphic and biodiversity indicators of the east coast were selected to conduct the research. These were:

4.1.3(i) Geomorphic Indicator

- Net Shoreline Movement (NSM) or Net Shoreline Change

4.1.3 (ii) Environmental Indicators

- The concentration of five heavy metals in the soil and water,
- The concentration of two non-metals (nutrient) in soil and water, and
- The quality of four physio-chemical parameters of soil and water.

4.1.3 (iii) Biodiversity Indicators

- The concentration of five heavy metals in mollusk shells,
- The $CaCO_3$ content in mollusk shells, and
- The Vegetation Coverage of study area.

4.1.4 Key Environmental Indicators for P-S-R Model

The study adopted three key environmental indicators developed by the OECD (2008). These indicators were used in the 'Pressure-State-Response' model formed for the present study (Table 8.14) where the model attempted to illustrate the 'Cause and Effect' relationship between the study indicators, as well as to depict the approach of responses by the stakeholders regarding their management.

1) The 'State' indicators were used to measure the quality or 'State' of the environment. For example, amount of lead concentration in water.

2) The 'Pressure' indicators were used to measure the environmental stresses created by the pressure indicators, as well as to show the reasons of environmental problems, i.e., the depletion of water quality due to release of pollutants, conversion of natural ecosystem for other uses.

3) The 'Response' indicators were used to measure the management efforts taken at national and local level to mitigate, conserve and protect the state of environment.

4.1.5 Research Approach

The research approach of the present study was an intermingled one. Both Qualitative and Quantitative research approach were followed during the research work.

a) Qualitative Research approach-

- Field Observations and Field Survey, and
- Key Informant Interview (KII) of different stakeholders was conducted.

b) Quantitative Research approach-

The data and samples collected for identifying the state of the geo-environmental indicators of the study were measured and analyzed by the following methods.

i) Modified Normalized Difference Water Index (MNDWI) method was applied upon six 'Temporal Landsat Images' of the study area for twenty five years (1990-2015) to detect the 'Land-Water Boundary' along the sample areas.

ii) Digital Shoreline Analysis System (DSAS) was carried out to calculate shoreline rate-of-change statistics, using the historic shoreline positions for the last twenty five years (1990-2015). Transects were generated perpendicular to the reference baseline along the sample areas. The distance between the baseline and each shoreline intersection point on DSAS transect were used to calculate the shoreline change.

iii) Normalized Difference Vegetation Index (NDVI) method was applied upon the sample areas for two different years (1990 and 2015) to reveal the amount of vegetation coverage along the sample areas.

iv) The Atomic Absorption Spectroscopy (AAS) method was used to find out heavy metal concentration, non-metal content, the physio-chemical quality of the collected water, soil and mollusk shell samples. The $CaCO_3$ concentration of the collected mollusk shell samples was measured.

4.1.7 Data Sources

The soil, water and mollusk shell samples were collected from the source points and non-source points during the month of March in two consecutive years 2016, 2017, while the Management plans and policies proposed and executed by the concerned authorities was investigated in March, 2018.

(a) Primary Source Data (Field Survey, March, 2016, 2017and 2018):

Five sample areas of the Feni River, Mirsharai Upazila, five sample areas of the Jalkadar River, Banshkhali Upazila, ten sample areas at the Bakkhali River and channel, Cox's Bazar Sadar upazila and three sample areas of Marine drive, Ukhia, Teknaf upazila, Chattogram were selected as the sample areas. The field surveys were carried out from 20th -25th March, 2016, 24th - 26th March, 2017 and 16-20th March, 2018 consecutively. The water, soil and mollusk shell samples were collected from the point sources of pollution along sample areas. The collected samples were sorted, dried, grinded, to digest and analyze with the Atomic absorption spectroscopy (AAS) method at the Centre for Advanced Research in Sciences (CARS), laboratories of Department of Geography and Environment and Department of Soil and Environment, Dhaka University.

Questionnaire, FGD, KIIs, and Case Studies

A mixed method of Questionnaire, FGD and KII (Appendix A) and Case Studies (Appendix B) was used to conduct survey with the local communities, the CPP officials and volunteers, Scientists of Bangladesh Fisheries Research Institute, Chief Executive Engineer of Bangladesh Water Development Board (BWDB), Chottogram; Divisional Forest Officer, Chottogram and Cox's Bazar, Chairman and CPP Union Leader of Baharchhara Union, Banshkhali Upazila, Journalist/CPP Union Leader of Sharal Union, Banshkhali Upazila and the Chief of Operation of Prime Minister's Rehabilitation Project, Cox's Bazar, throughout the three consecutive years of 2016, 2017 and 2018. The secondary data were collected to know about the status, causes and consequences of geo-environmental deterioration at the study area.

b) Secondary Data Sources

- Six Temporal Landsat Images (1990-2015) were collected and recreated with Arc/GIS software to form Net Shoreline Movement (NSM) maps with Modified Normalized Difference Water Index (MNDWI) method;
- Transects were generated upon the extracted shorelines of the NSM maps to calculate the distance with the Digital Shoreline Analysis System (DSAS);
- The Vegetation Index, as well as, Vegetation Coverage maps was created with Normalized Difference Vegetation Index (NDVI) method;
- The statistical data were collected from published materials like-books, journals and reports of concerned authorities and organizations; and

The attributed data were analyzed and presented with Maps, Tables, and in different graphic forms.

4.1.8 Method of Soil, Water and Mollusk Sample Collection

The soil, water and mollusk shell samples were collected from both point sources and non-point sources of pollution by 'Point Sampling' method. The sources of pollutants and toxic wastes are the industries, fish markets, fish and fisheries processing factories and ice factories, tourist spots and municipality garbage of the sample areas.

4.1.9 Method of Sample Analysis

The concentration of the heavy metals like-Iron (Fe), Zinc (Zn), Lead (Pb),Copper (Cu) and Cadmium (Cd) in the collected sample soil, water and mollusk shells were digested by Nitric-hydrochloric Acid Digestion method and then were measured with the Atomic Absorption Spectroscopy (AAS) technique. Moreover, the presence of two nutrients like-the Sulphur and Phosphorous in the soil and water samples were digested and measured. The collected samples were analyzed at three laboratories of the University of Dhaka (D.U.), such as- the Centre for Advanced Research in Science (CARS), department of Geography and Environment, and the department of Soil, Water and Environment.

(a) Heavy Metal Analysis by AAS Method

AAS is a spectroanalytical procedure for determining the concentration of a particular element (the analyte) in a sample to be analyzed. Analyte is a substance whose chemical constituents are being identified and measured. In the present study, total 21 samples (11 soil samples and 10 water samples) were collected from the source points of pollution along the Bakkhali River and Teknaf peninsula, Cox's Bazar. Added to these, 10 samples (5 soil samples and 5 water samples) from the Feni river, and another 10 samples (5 soil samples and 5 water samples) from the Jalkadar river were collected during the field surveys conducted in March 2016 and 2017 consecutively. The soil samples were collected from a depth of six to eight inches deep. The surface water samples and the mollusk shells were collected from the same sample areas. These were digested in Nitric-hydrochloric Acid Digestion method and then filtered into clear bottles. The digested samples were submitted to measure the concentration level of the analytes like-Iron, Zinc, Copper, Lead, and Cadmium at CARS, D.U. The samples were analyzed by Flame AAS. The wavelengths of the heavy metals were -228.8 nm for Cadmium, 324.8 nm for Copper, 248.3 nm for Iron, 283.3 nm for Lead and 213.9 nm for Zinc. Specific hollow cathode lamp was used to analyze the samples. The Flame AAS method was followed to conduct the Metal Content Analysis. The instrument has minimum detection limit of 0.01 mg/L for Cd, 0.03 mg/L for Cu, 0.04 mg/L for Fe, 0.20 mg/L for Pb and 0.01 mg/L for Zn in the flame method. Samples were aspirated through nebulizer and the absorbance was measured with a blank as reference. Calibration curve was obtained using standard samples (containing 0.2, 0.4, 0.6, 0.8 and 1.0 mg/L for Cd, 0.2, 0.4, 0.6, 0.8 and 1.0 mg/L for Cu, 0.5, 1.0, 2.0, 3.0, 4.0, 5.0 and 10.0 mg for Fe, 0.2, 0.5, 1.0, 2.0 and 3.0 mg/L for Pb and 0.2, 0.4, 0.6, 0.8, 1.0 and 2.0 mg/L for Zn). The correlation coefficient was found for Cd 0.999, for Cu 0.999, for Fe 0.998, for Pb 0.998 and for Zn 0.999. The sample had to be diluted many folds to keep the results in the analytical range. The values given below are the results of the soil samples.

(b)The content of the Phosphorous and Sulphur was measured by HNO3 digestion method (combination of Nitric-Perchloric acids).

(c) Three physio-chemical parameters, such as the pH, EC, and Temperature of soil and four physio-chemical parameters, such as the pH, EC, TDS and Temperature of water was measured with the pH Meter, calibrated by pH 7.0 buffer solution (distilled water) to analyze the environmental quality of the study area. The samples were measured and analyzed in the Environmental Laboratories of the Department of Geography and Environment; the Department of Soil, Water and Environment; and Centre for Advanced Research in Sciences (CARS), University of Dhaka.

(d)Mollusk Shell Calcium Carbonate ($CaCO_3$) Content Detection Method

The mollusk shell samples were analyzed to measure the $CaCO_3$ content at CARS, D.U. The samples has been digested and made 100 ml in volume. The Calcium (wavelength 422.7 nm) specific hollow cathode lamp, with minimum detection limit of 0.06 mg/L for Ca in the flame method was used to analyze the samples. The samples were aspirated through nebulizer and the absorbance was measured using standard samples 1.0, 2.0, 3.0, 4.0 and 5.0 mg/L for $CaCO_3$. The correlation coefficient was found for $CaCO_3$ was 0.999. The samples had to be diluted many folds to keep the results in the analytical range.

4.1.10 Satellite Imagery Analysis and Presentation Techniques

(a) Six Radiomterically Corrected Temporal Landsat Images were recreated and analyzed with Arc/GIS and ERDAS Imagine Software. These maps were used to measure the Vegetation coverage by the NDVI method and the net shoreline movement pattern by the DSAS and MNWDI methods. The detailed features of the six Radiomterically Corrected Temporal Landsat Images for the present study have been shown in Table 4.7.

(b)The Normalized Difference Vegetation Index (NDVI) Method

The vegetation coverage of the four sample areas were revealed by the Normalized Difference Vegetation Index (NDVI) method. The NDVI process creates a single-band dataset that mainly represents greenery (Weier, et al., 2000). The negative values represent clouds, water, and snow, and values near zero represent rock and bare soil.

The equation of NDVI is - (NIR - R) / (NIR + R); where, NDVI stand for Normalized Difference Vegetation Index; R and NIR denote the spectral reflectance measurements acquired in the Red (Visible) and Near Infrared regions respectively. The NDVI quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). For instance, the healthy vegetation (chlorophyll) reflects more near-infrared (NIR) and green light compared to other wavelengths. They take on values between 0.0 and 1.0 and the scale of NDVI ranges from -1.0 and +1.0.

Table 4.7: Six Radiomterically Corrected Temporal Landsat Images

SPACECRAFT ID	SENSOR ID	DATE OF ACQUISITION	CLOUD COVER	UTM ZONE AND MAP PROJECTION	CELL SIZE (M)	NUMBER OF BANDS	WRS PATH	WRS ROW
LANDSAT-5	TM	1990-03-05	2%	WGS84 - UTM 46	30	7	136	44
LANDSAT-5	TM	1995-03-19	1%	WGS84 - UTM 46	30	7	136	44
LANDSAT-5	TM	2000-02-29	18 %	WGS84 - UTM 46	30	7	136	44
LANDSAT-5	TM	2005-03-14	67%	WGS84 - UTM 46	30	7	136	44
LANDSAT-7	ETM	2010-03-20	0%	WGS84 - UTM 46	30	8	136	44
LANDSAT-7	ETM	2015-03-18	5%	WGS84 - UTM 46	30	8	136	44

Source: Present Study, 2018

(c)Methods of Measuring Net Shoreline Movement (NSM)

The Net Shoreline Movement (NSM) along the coastal zone of the study areas was measured into five steps using five different methods. Firstly, the Digital Shoreline Analysis System (DSAS) was applied upon the sample area shorelines, which provides the user a 'Shoreline rate-of-change' statistics from multiple historic shoreline positions. In the present research, a systematic assessment of the rate of the shoreline change at the study area over a period of 25 years (from 1990 to 2015) were carried out by applying the

DSAS software. Digitized maps were created from the six radiomterically corrected Temporal Landsat Images, with pixel resolution of 30 meters on the ground (Table 4.2).

Secondly, to operate the DSAS system, each satellite image was corrected to clear the atmospheric obstacles, to minimize the spectral, as well as radiometric obscurants, the atmospheric components, like-water vapor, dust particles, and clouds, which interrupt the reflection of spectral information. Therefore, an improved Dark Object Subtraction (DOS) method, formulated by Chavez (1988) was applied on the Top of Atmosphere (TOA) reflectance images to obtain the final atmospherically corrected surface reflectance images. Thirdly, the Shore Line Extraction and Accuracy Assessment was conducted for a comparative assessment of shoreline movement for the east coast of Bangladesh. Hence, six Radiomterically Corrected Temporal Landsat images were acquired for five different years (1990 to 2015) from the Earth Explorer database of the USGS (Table 5.1). At fourth stage, the Modified Normalized Difference Water Index (MNDWI) Method (McFeeters, 1996 and Xu, 2006); and the manual digitizing at fixed zoom-in level by Single Operator (Dewan, et al. 2017) were applied to extract the Land-Water boundary from the satellite images. All of these indices specifically identify the wetland from the satellite image. In general, the water indices use green and infrared spectral bands of different ranges to identify Land and Water areas, which produce up to 96.9% accuracy (Frazier and Page, 2000).The equation applied for MNDWI is:

MNDWI (TM, ETM+) = (gr - mir) / (gr + mir), *where,* ***TM*** *= Landsat Thematic Mapper,* ***ETM****=Enhanced Thematic Mapper (multispectral scanning radiometer),* ***gr =*** *green, and* ***mirs =*** *mid infrared.*

These are the atmospherically corrected Surface reflectance of green and mid infrared. This equation of MNDWI method was used on the atmospherically corrected images using Erdas Imagine 2014 software to identify Land-Water boundaries.

At fifth stage, the raster images were opened in ArcGIS v.10.3 and water boundaries were manually extracted from different modified spectral images.

At sixth stage, precise analysis of shoreline shifting was carried out by a comparative analysis of a manually created Base Line (which also can be a user defined line or a buffer generated one), with the historical shorelines (Chand and Acharya, 2010).

Finally, user-defined Base lines were created along the shorelines, from which the vertical Transects, intersecting all shorelines were casted at 500 meters distance from each other. The widely used statistical method for Shoreline Change Analysis (Dolan, et al. 1991) was applied to calculate the Net Shoreline Movement (NSM) at this stage. The NSM was calculated to estimate the distance between the oldest and youngest shorelines for each Transect. In the present study, accretion was presented in positive numerals, while the negative numerals were used to mention erosion for the DSAS calculation.

5.1 Introduction

The Chattogram Coastal plain has been constantly going through shoreline accretion and erosion processes at different rates creating a wide range of geomorphic features, such as piedmont plains, sand dunes and sandy beaches. The movement of waves tides and winds; deposition of weathered or eroded sands carried down by rivers; and decayed corals and shell fishes are the major natural causes of coastline accretion. On the other hand, strong tidal currents, abrasion and / or corrosion by wind and water, massive deforestation, landfall of tropical cyclones and increased soil salinity are the natural causes of coastline erosion. As an integral part of the present study objective, this chapter attempts to portray the net shoreline movement (NSM) of the sample areas for twenty five years starting from 1990 up to 2015.

The present study attempted to measure the NSM along the sample area shorelines to gather accurate spatio-temporal information regarding the trend and rate of accretion and erosion hitherto. Nevertheless, to compare with the earlier studies on NSM at the east coast of Bangladesh, the present study conducted a comparative analysis of Six Temporal Landsat images of previous twenty five years (1990-2015).The shoreline of the three sample river estuaries of the Feni River, the Bakkhali River, and the Jalkadar River, as well as of the Teknaf peninsula, Marine Drive were analyzed to reveal the pattern of NSM. The sample areas showed evidence of both erosion and accretion during the field study of the present research. Though the NSM of the present study sample areas portray the shoreline change pattern during previous twenty five years (1990-2015), the study has not intended for predicting future shoreline positions or rates of change.

5.2 Results of the Study

The EPR method, developed by the U.S. Geological Survey (USGS, 2015) has been used to calculate the NSM of the sample areas for a study period of twenty five years (1990-2015), segregated into five years interval (Fig.5.1 to 5.20). Total 123 orthogonal transects were generated at an interval of 50 meters in relation to a user-defined Baseline. Each transect intersected at a point on the shoreline establishing a measuring point. The EPR was calculated by dividing the distance of shoreline movement by the time elapsed between the two shorelines. The shoreline change rate was expressed in meters per year, where the positive values indicate accretion and the negative values indicate erosion along a transect (USGS, 2015).

5.2.1 NSM of the Feni River Estuary :1990-2015

The Feni River is a meandering and dynamic water body which has been constantly reshaping its shoreline driven by the forces like tidal flow, different volume and pattern of siltation, as well as changes in vegetation coverage along its both shores. The NSM of the river estuary was examined in the present research (Table 5.1 and Fig.5.1 to 5.5) for twenty five years (1990-2015) at an interval of five years.

Table 5.1: The NSM of the Feni River Estuary

Time span (Years)	Accretion (%)	Total Transects	Erosion (%)	Total Transects
1990 – 1995	12	03	88	22
1995 – 2000	48	12	52	13
2000 – 2005	28	07	72	18
2005 – 2010	76	19	24	06
2010 – 2015	64	17	36	08

Source: Present study, 2018

The transact drawn upon the study area at five years interval illustrate that, the deposition rate increased gradually throughout the years. The End Point Rate (EPR) graphs (Table 5.1 and Fig.5.1- Fig.5.5) derived from the NSM of the shorelines illustrates that, accretion rate was only 12 percent in 1990-1995 time periods near the estuary mouth, which increased four folds during 1995-2000 (48 percent), followed by a drastic fall in the time span of 2000-2005 (28 percent) . However, the accretion rate escalated more than three times during the years 2005-2010 (76 percent) and declined to 64 percent in the time span of 2010-2015 (Table 5.1 and Fig.5.5).

On the other hand, the EPR graph of 1990-1995 depicted the scenario of major erosional activities (88 percent) along the southern and mid section of the estuary (Table 5.1 and Fig.5.1), while exceptions were observed at two transects (ID 01 and ID 02) at the estuary mouth, and at the transect ID 18 at the northern section of the study area, which is located near the Muhuri Closure dam (MCD). The present study filed survey and the ArcView attributed data of the satellite imageries showed the evidences of ‘ox-bow lake’ formation in the area flanked by the transect ID 22 to transect ID 26 (Map 5.1). In the 1995-2000 periodic cluster the erosion rate decreased in 52 percent (Table 5.1 and Fig. 5.2), showing the middle section of the study area as the most erosion prone zone. The rate of erosion gradually increased during 2000-2005 time period (72 percent) which indicated maximum erosion at the middle section of the study area (Table 5.1 ,Fig.5.3 and Map.5.1). The mid section compromising the transects (ID 04, 05, 07-18, 20, 21, 23-25) illustrated the erosion dominancy (72 percent) at the study area during 2000-2005 (Fig. 5.3). However, during the years 2005-2010 reverse situation were observed at the lower section and the mid section, while the erosion rate decreased to only 24 percent (Table 5.1 and Fig. 5.4). However, in the time spans of 2010-2015 the rate erosion increased to 36 percent which dominated the southern section of the study area (Fig.5.5).

Fig. 5.1: Net Shoreline Movement of the Feni River (1990-1995)

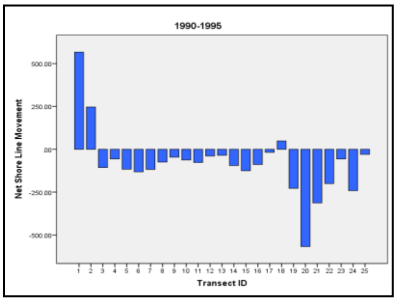


Fig. 5.2: Net Shoreline Movement of the Feni River (1995-2000)

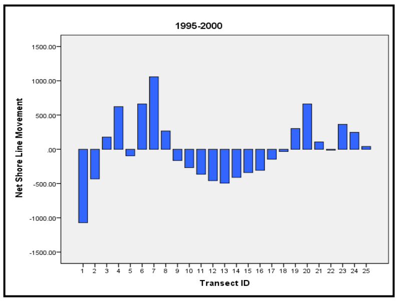


Fig. 5.3: Net Shoreline Movement of the Feni River (2000-2005)

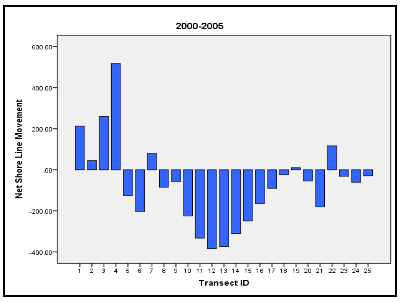
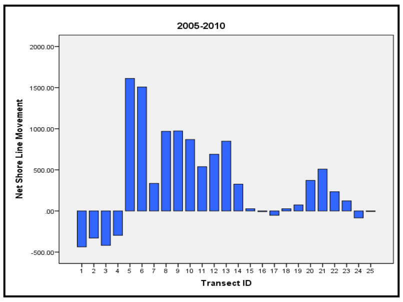


Fig. 5.4: Net Shoreline Movement of the Feni River (2005-2010)



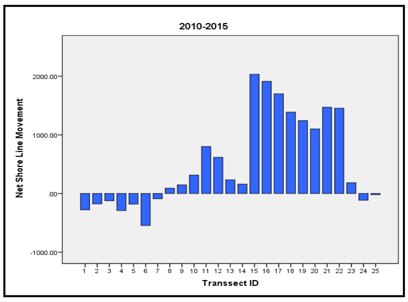


Fig. 5.5: Net Shoreline Movement of the Feni River (2010-2015)

Source: Present study, 2018

During this time transects 01 to 04 showed erosional activities, while transects 05 to 15 showed accretion activities. In the time span 2010-2015, the lower and mid section showed almost similar NSM, with an exception at the upper section, where depositional activities doubled than that of the previous time span (Fig.5.5).

5.2.2 NSM of the Jalkadar River Estuary :1990-2015

Total 25 transects were drawn on both sides the Jalkadar River estuary (Map 5.2).

The EPR graphs (Fig. 5.6 to 5.10) show the NSM from 1990 to 2015. In the years 1990-1995, erosion was 2.4 percent more than accretion (Table 5.2 and Fig.5.6).

Table 5.2: NSM at the Jalkadar River Estuary: 1990-2015

Time span (Years)	Accretion (%)	Total Transects	Erosion (%)	Total Transects
1990 – 1995	48.8	21	51.2	22
1995 – 2000	62.9	27	37.1	16
2000 – 2005	48.9	21	51.1	22
2005 – 2010	53.5	23	46.5	20
2010 – 2015	76.8	33	23.2	10

Source: Present study, 2018

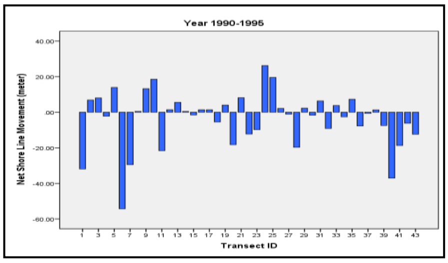


Fig. 5.6: Net Shoreline Movement of the Jalkadar River (1990-1995)

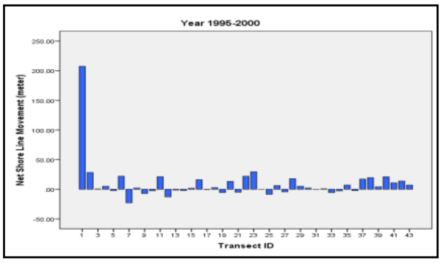


Fig. 5.7: Net Shoreline Movement of the Jalkadar River (1995-2000)

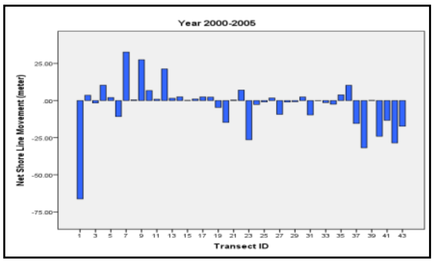


Fig. 5.8 Net Shoreline Movement of the Jalkadar River (2000-2005)

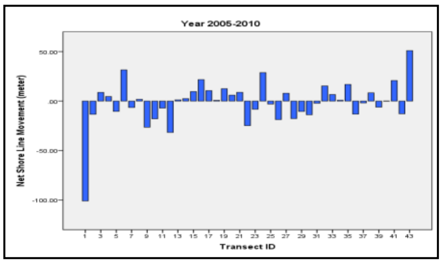


Fig. 5.9: Net Shoreline Movement of the Jalkadar River (2005-2010)

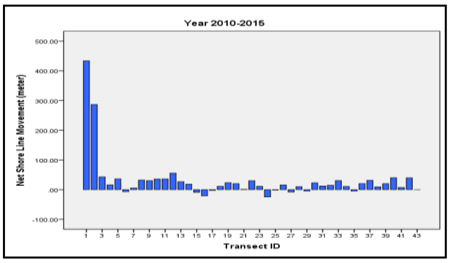


Fig. 5.10: Net Shoreline Movement of the Jalkadar River (2010-2015)

Source: Present study, 2018

Almost alternative trend of accretion and erosion was observed through the estuary during this time. Only exceptions was seen at transect 06, where erosion was at maximum (-55 meters) level, followed by the transect 01 and 10 (-31 meters) (Fig.5.6). However, converse situation was seen in case of accretion. Transect 24 reduced to 30 meters, followed by transect 10 and 25, reaching a length of 20 to 21 meters consecutively. Other transects illustrated a lesser length in case of accretion. In time span 1995-2000, the Jalkadar River experienced more accretion than erosion.

However, in periodic cluster of 1995-2000, the transect 01 depicted a peculiar length of 200 meter accretion, while all other accretion lengths ranged from 25 meters to 27 meters in average (Fig.5.7). However, during the time span 2000-2005, accretion and erosion seems to be almost equal varying from 48.9 percent to 51.1percent consecutively (Fig.5.8).

In 2005-2010 time spans, almost similar situation was observed like that of 2000-2005. In this year the accretion (53.5percentage) was 07 percent more than that of the erosion (46.5 percent) (Fig.5.9). The NSM of the years 2010-2015, accretion (46.8 percent) dominated the estuary area, while an insignificant percent of erosion (10 percent) was observed during this time (Fig.5.10). The overall situation illustrates a stable and balanced net shoreline movement, while the situation differed during the years 1995-2000 and the years 2010-2015.

5.2.3 NSM of the Bakkhali River Estuary: 1990-2015

Total 22 transects were drawn on the east side along the study area of the Bakkhali River estuary (Map 5.3). The EPR graphs (Fig. 5.11 to Fig. 5.15) depict the NSM scenario at Bakkhali River estuary for the last twenty five years (1990-2015). During the time span of 1990-1995, only erosion (100 percent) was observed along the Bakkhali River, with no sign of accretion along the 51 transects (Fig.5.11). The reverse situation was seen during the years 1995-2000, while erosion actively (32 percent) was changed by the accretion activities (68 percent) almost into half (Fig.5.12). Gradual changes into the NSM of the Bakkhali River have been observed during the time span of 2000-2005 (Fig.5.13) (Table 5.3). During this time period a balance was observed between the accretion (56 percent) and erosional activities (44 percent). However, during 2005-2010 time spans, erosional activities (64.6percentage) took over the accretion activities (35.4percentage) (Fig.5.14). The erosional activities have been observed to dominate the estuary area in the years 2010-2015 (Fig.5.15).

Table 5.3: NSM at the Bakkhali River Estuary: 1990-2015

Time span (Years)	Accretion (%)	Total Transects	Erosion (%)	Total Transects
1990 – 1995	41.2	21	58.8	30
1995 – 2000	84.3	43	15.7	08
2000 – 2005	21.6	11	78.4	40
2005 – 2010	29.4	15	70.6	36
2010 – 2015	3.9	02	96.1	49

Source: Present study, 2018

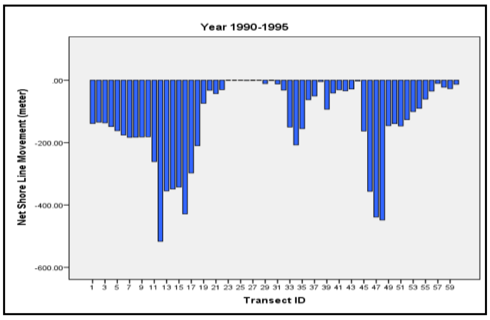


Fig. 5.11: Net Shoreline Movement of the Bakkhali River Estuary (1990-1995)

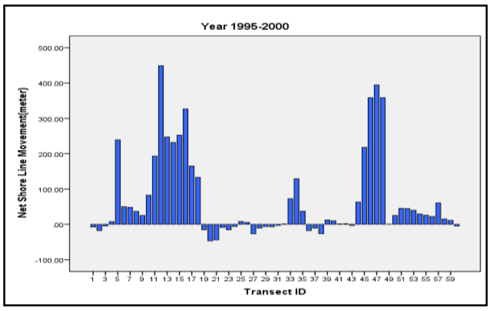


Fig. 5.12: Net Shoreline Movement of the Bakkhali River Estuary (1995-2000)

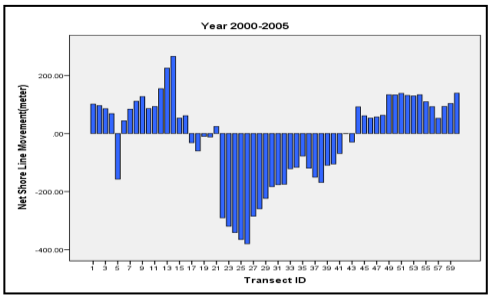


Fig. 5.13: Net Shoreline Movement of the Bakkhali River Estuary (200-2005)

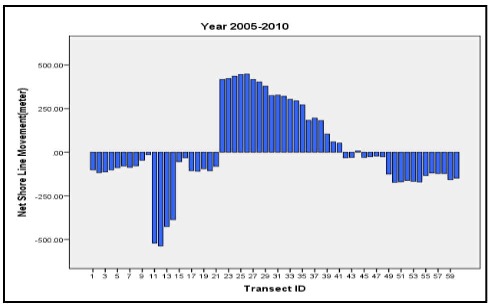


Fig. 5.14: Net Shoreline Movement of the Bakkhali River Estuary (2005-2010)

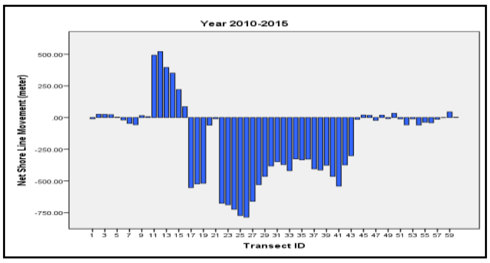


Fig. 5.15: Net Shoreline Movement of the Bakkhali River Estuary (2010-2015)

Source: Present study, 2018

At this time period, only 28.6 percent area was accreted, while about 2.5 times higher percentage of area was under erosional activities. The overall condition of NSM along the Bakkhali River study area illustrated trend of major erosion at the initial stage of the study time, balanced with accretion activities gradually at the middle time spans, to accelerate again during the end of the study time duration.

5.2.4 NSM of the Marine Drive, Teknaf Coast: 1990-2015

The Teknaf coast comprises an uninterrupted coastline with sandy beach and sand dunes, extending up to the foot of the hill ranges (Map 5.4). The transect 08 illustrates the maximum length of erosion measuring 707.35 meters across the line, while the Transect line 16 portrays the lowest length of accretion, measuring only 17.15 meters.

Table 5.4: NSM at the Teknaf, Marine Drive: 1990-2015

Time span (Years)	Accretion (%)	Total Transects	Erosion (%)	Total Transects
1990 – 1995	12	03	88	22
1995 – 2000	48	12	52	13
2000 – 2005	28	07	72	18
2005 – 2010	76	19	24	06
2010 – 2015	64	17	36	08

Source: Present study, 2018

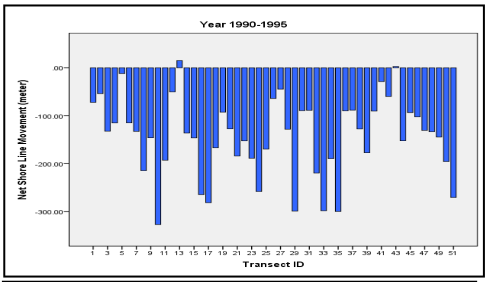


Fig. 5.16: Net Shoreline Movement of Marine Drive (1990-1995)

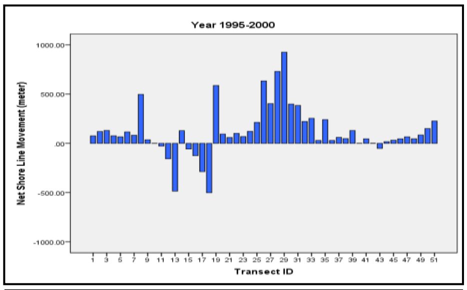


Fig. 5.17: Net Shoreline Movement of Marine Drive (1995-2000)

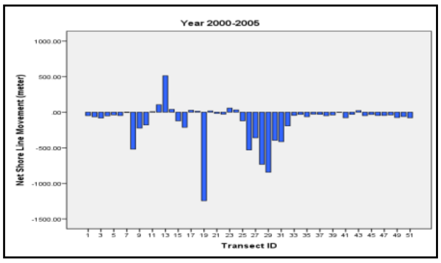


Fig. 5.18: Net Shoreline Movement of Marine Drive (2000-2005)

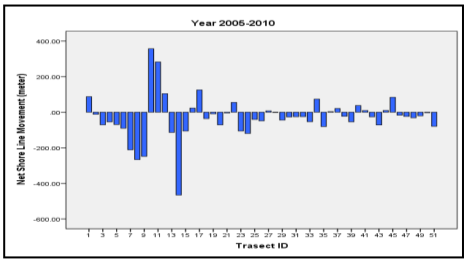


Fig. 5.19: Net Shoreline Movement of Marine Drive (2005-2010)

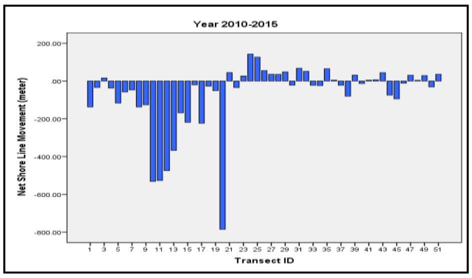


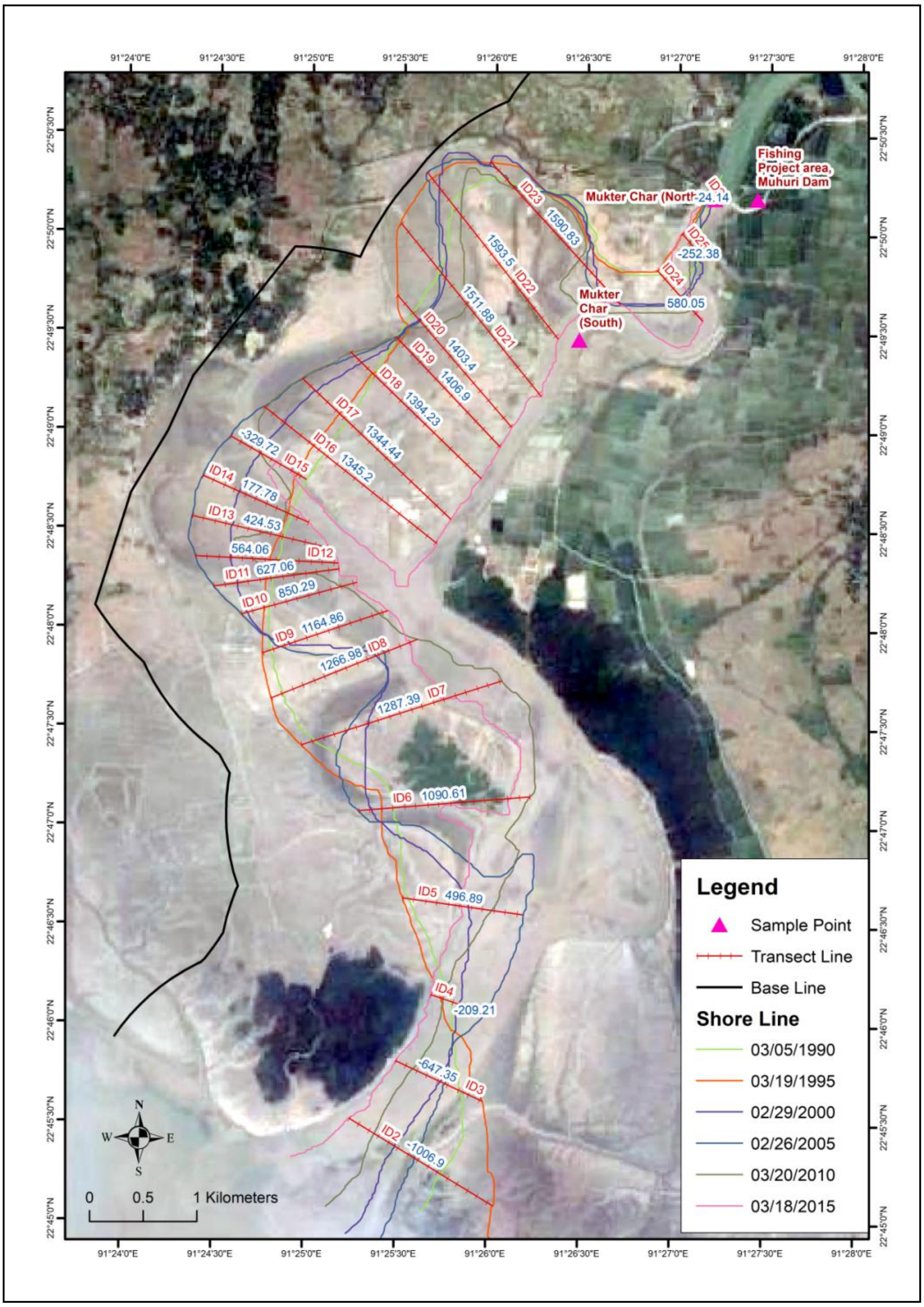
Fig. 5.20: Net Shoreline Movement of Marine Drive (2010-2015)

Source: Present study, 2018

The coastline between the Himchari and Sonarpara, which includes 17 Transect lines (from ID 6 to ID 21) was declared as the Ecologically Sensitive area by the DoE in 1995 (Banglapedia,2012). This area is highly vulnerable to wave erosion. At present, erosion process was restrained by laying huge geo-sand bags and cemented tetra pods (Table 5.4).

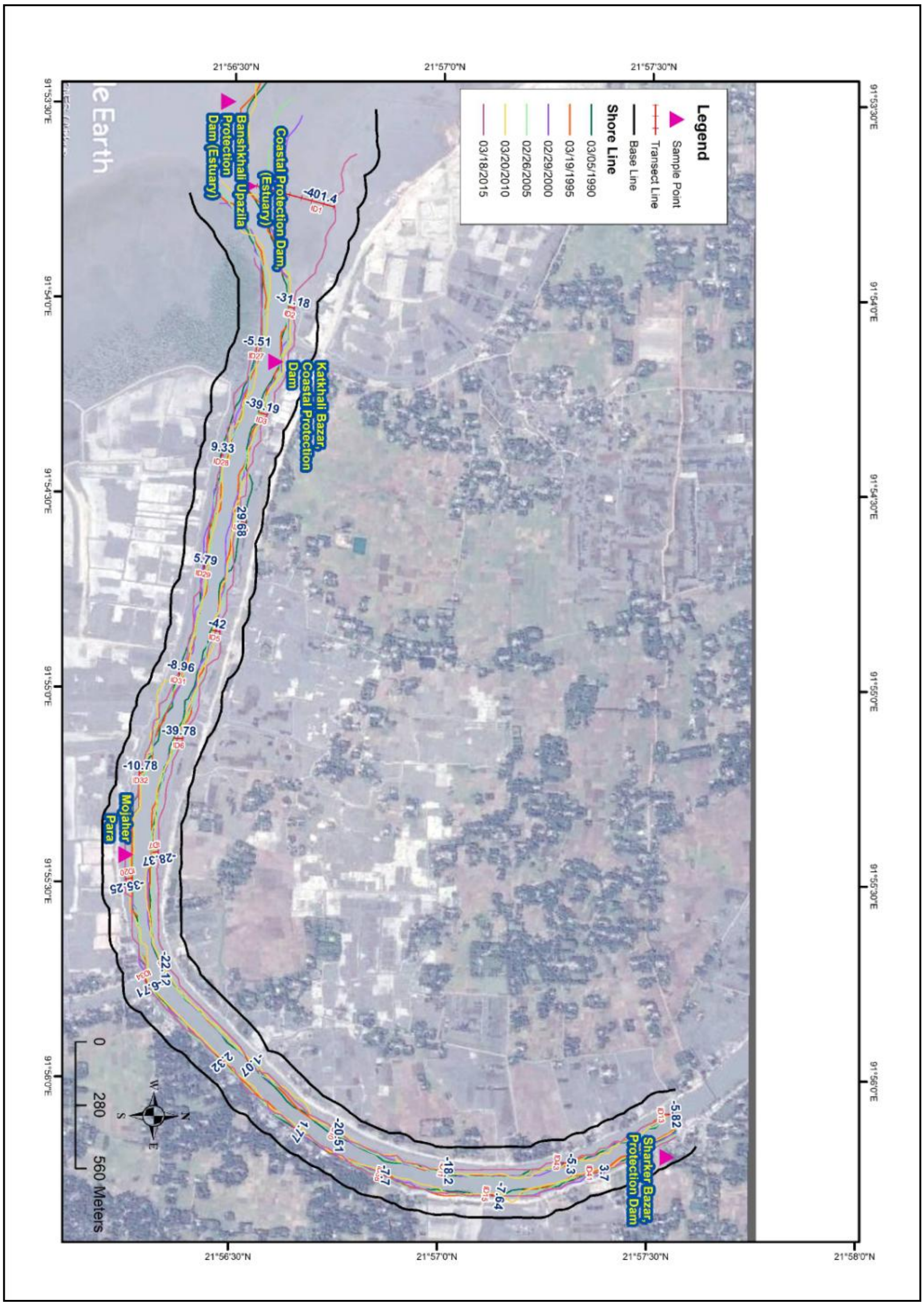
The Marine drive study area has experienced major erosion (96.1 percent), with a very insignificant percentage of accretion (3.9 percent) in the time period of 19990-1995. Almost reverse situation was observed during the time span of 1995-2000, while accretion dominated the area (84.3 percent) and erosion was seen to be only 15.7percentage. The NSM of the study area during the years 2000-2005, entirely opposite situation was observed. At this duration, erosion dominated (80.4 percent) the accretion (19.6 percent) activities.

During the time pan of 2005-2010, erosional activities sustained in the area (70.65 meters), while the accretion activities slightly increased (15 percent) than that of the previous time duration. The time span of 2010-2015 illustrates a moderately balanced situation, where erosion (58.8 percent) dominates the accretion (41.2 percent) by 17.6 percent. The NSM of the marine drive study area illustrates erosional pattern, with only exception during 1995-2000.



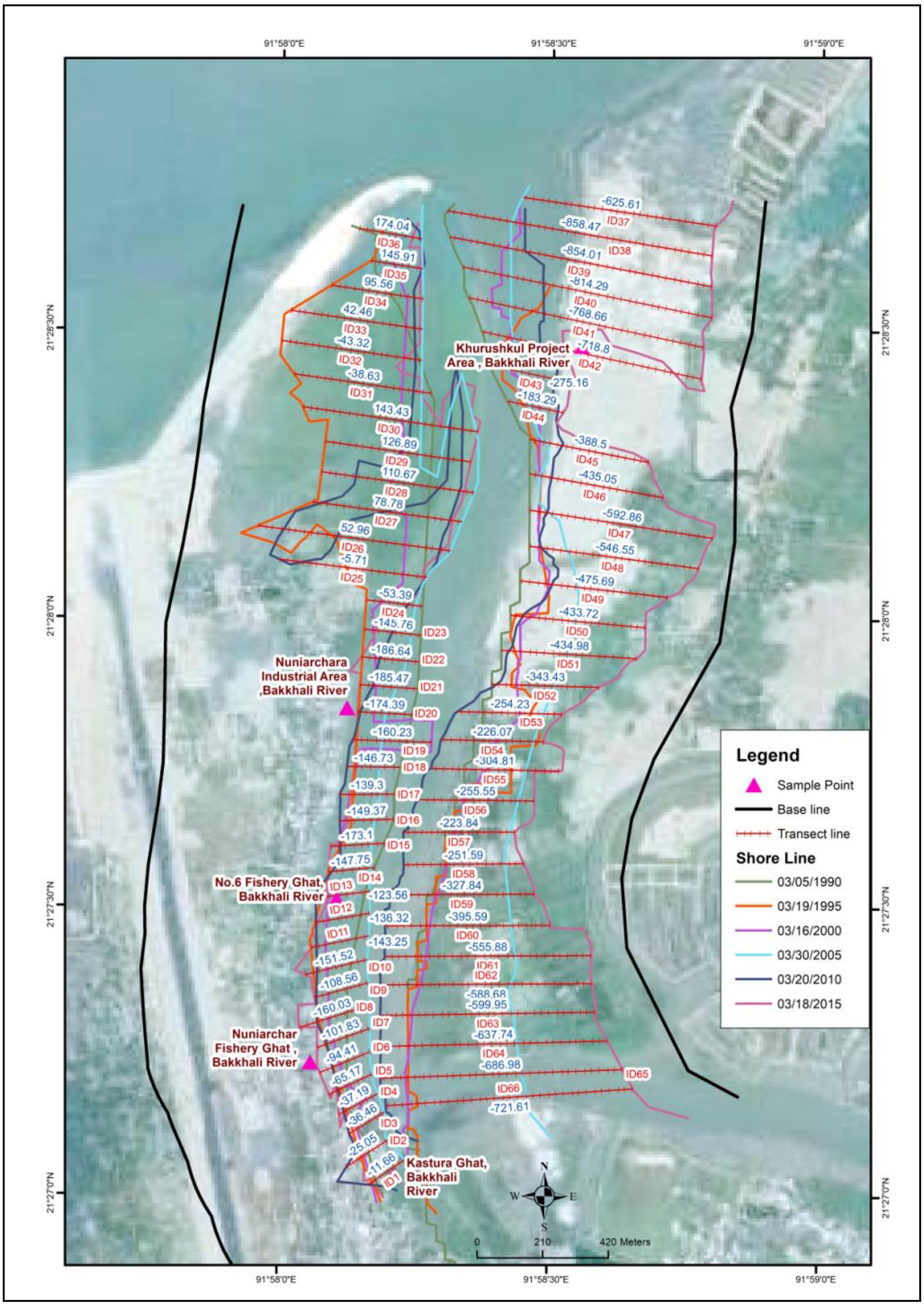
Map 5.1: Net Shoreline Movement at the Feni River Estuary: 1990-2015

Source: Digital Shoreline Analysis System (DSAS), ArcGIS®, Present Study, 2017



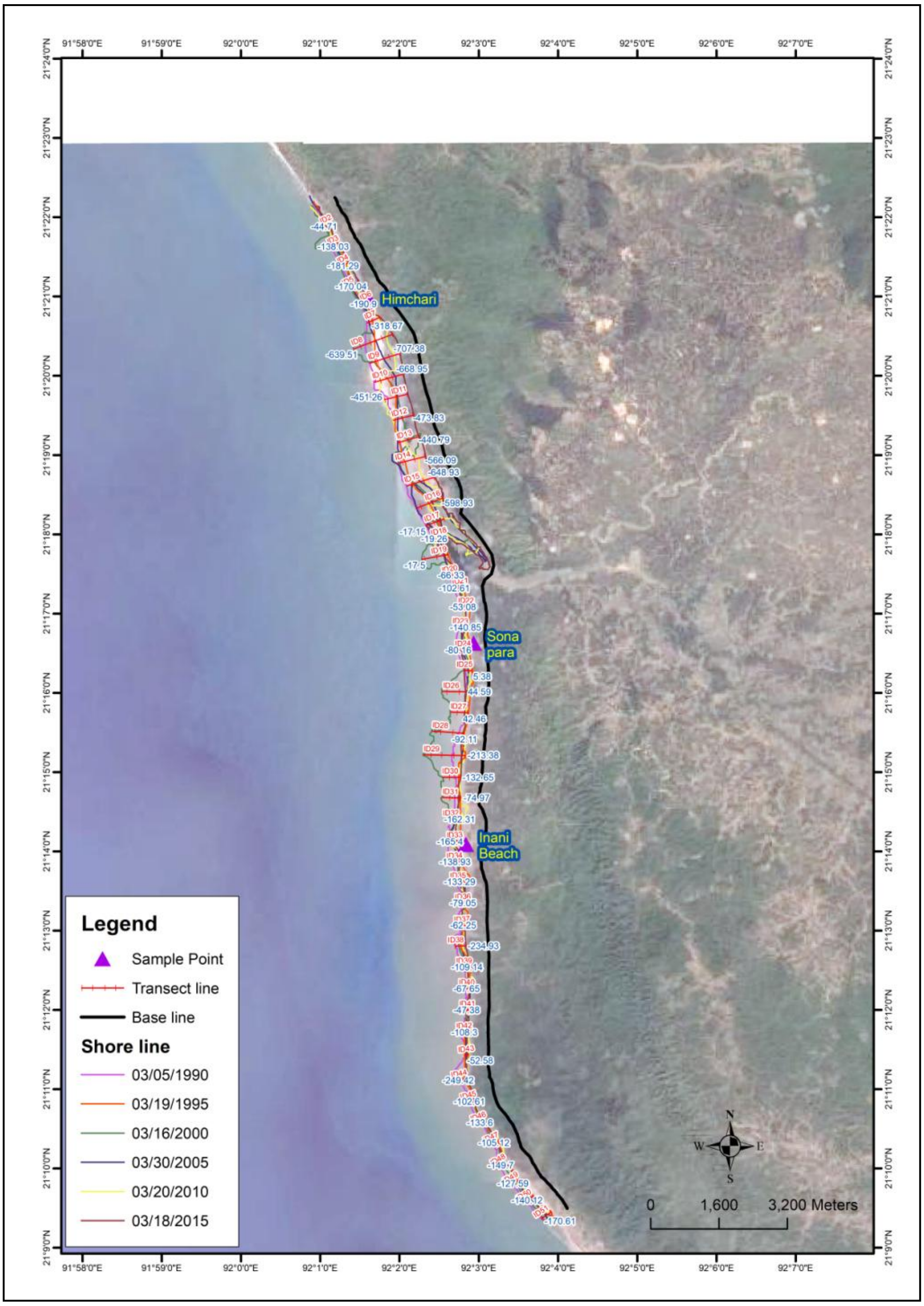
Map 5.2: Net Shoreline Movement at the Jalkadar River Estuary: 1990-2015

Source: Digital Shoreline Analysis System (DSAS), ArcGIS®, Present Study, 2017



Map 5.3: Net Shoreline Movement at the Bakkhali River Estuary: 1990-2015

Source: Digital Shoreline Analysis System (DSAS), ArcGIS®, Present Study, 2017



Map 5.4: Net Shoreline Movement at the Marine Drive: 1990-2015

Source: Digital Shoreline Analysis System (DSAS), ArcGIS®, Present Study, 2017

5.3 Conclusion

The east coast of Bangladesh is moderately dynamic, which is mainly erosion prone with a comparatively lesser accretion process along Sonarpara coast, Teknaf peninsula. The present study illustrates the NSM for a 25 years (1990-2015), at five years interval, with total 122 Transects drawn upon six radiomterically corrected Temporal Landsat Images, at pixel resolution of 30 meters on the ground. The investigation of the Transects show that, the Feni River estuary is the most dynamic one among the four sample areas of the present study. On the other hand, from the present research field survey, erosion was seen to be dominant along the west bank of the Bakkhali River estuary due to the strong tidal flows along the banks, as a subsequence of the sea bound fishing trawlers and speed boats continuously commuting in the Cox’s Bazar-Moheshkhali route. These water vehicles create strong waves along the estuary area, which is a major reason of erosion at Bakkhali River. Reverse situation is seen on the east bank of the river, where submerged chars are found. The NSM in the study area is, to some extent, controlled by the human induced environmental alteration at the east coast. For instance, the fluctuation of heavy metal and non-metal or nutrient concentration along with changes in pH, temperature, EC, and TDS in the soil and water of the study area; intensity of extreme weather events like cyclones and storm surges are the major driving factors of shoreline change in the study area. The history of cyclones and storm surges of the study area depicts that, the saline bay water swells up to 10-15 feet and rushes into the rivers and coastal areas, breaking the embankments to incur irreparable loss /damage of assets, lives and farm lands.

The literatures about the existing ICZMP (1999), especially those regarding the coastal embankments, coastal afforestation, coastal and marine resources conservation, as well as the issues related with ensuring local community resilience prove that, the geomorphic stability of the study area is one of the vital issues of sustainable development. Hence, the present study selected one of the most significant features of coastal and marine ecosystem, the NSM as an indicator to be incorporated into the existing ICZMP (1999) and future management framework for the east coast.

6.1: Introduction

The chapter discusses the results of the environmental quality of the sample soil and water of the east coast of Bangladesh. Firstly, the field survey was conducted along the three sample areas of the Marine Drive, Teknaf peninsula along with the Bakkhali River and channel estuary in March, 2016. The other two sample areas, such as, the Feni River and the Jalkadar River (locally known as Jalkadar khal) was surveyed in March, 2017. The collected soil and water samples have been examined to find out the concentration level of heavy metals, non-metals /nutrients and physio-chemical parameters. The soil samples were collected in ‘Composite Soil Sampling’ method and the water samples were collected in ‘Point Sampling’ method during the hot dry days of March in two consecutive years 2016 and 2017, as in this season, the toxicity of the soil and water can be detected more accurately. The sample processing (Illustration 6.1-6.11) and measurements were conducted at the laboratories of the Department of Geography and Environment, the Department of Soil, Water and Environment, and CARS, D.U., to assess the environmental quality of the study area.

6.2 Environmental Quality of Soil and Water of the Feni River Estuary, Mirsharai, Chottogram

Soil and water samples were collected from five source points of pollution from the Feni River estuary like- Abuler char, North and South Mukter Char, Ichakhali char and east side of Muhuri dam (Map 6.1). The source points of pollution were mainly anthropogenic like- fish markets, boat construction and repairing factories, shrimp hatcheries, fish processing factories, salt farms, industrial wastes and municipal garbage. The samples were collected during the dry weather (pre-monsoon), 24^{th}-26^{th} March, 2017.

6.2.1 Heavy Metal Concentration in Soil of the Feni River Estuary

The heavy metal concentration of the soil, collected by ‘Composite Soil Sampling’ method from five sample areas along Feni River estuary was measured to evaluate the environmental condition of the river. Among the five heavy meats measured for the present study, the hierarchy of average concentration of the heavy metals was: Fe> Pb > Cu > Zn >Cd. The results have been discussed in Table 6.1.

The Cd Concentration

The Cd concentration in the soil ranged from 0.01 mg/g to 0.03 mg/g in sample soil of the Feni River (Table 6.1). This showed a quite insignificant concentration of Cd in the soil.

Table 6.1: Heavy Metal Concentration in the Soil at Feni River Estuary, 2018

Sample ID	Cd-content	World Standard of Cd	Cu-content	World Standard of Cu	Fe-content	World Standard of Fe	Pb-content	World Standard of Pb	Zn-content	World Standard of Zn
Soil Sample	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g
Sample 01 (Abuler Char)	0.02	0.11	0.57	0.9	5.87	3.4	0.56	0.03	0.18	5.0
Sample 02 (Ichakhali Char)	0.03	0.11	0.72	0.9	5.43	3.4	0.61	0.03	0.18	5.0
Sample 03 (North Mukter Char)	0.01	0.11	0.65	0.9	5.54	3.4	0.55	0.03	0.17	5.0
Sample 04 (South Mukter Char)	0.02	0.11	0.64	0.9	5.53	3.4	0.57	0.03	0.18	5.0
Sample 05 (East Side Muhuri Dam)	0.02	0.11	0.52	0.9	4.7	3.4	0.52	0.03	0.14	5.0
Average	0.02		0.62		5.41		0.56		0.17	

Source: i) Present Study, 2018; ii) Rashid, et al., 2014

The Cu Concentration

The concentration of Cu ranges from 0.52 mg/g to 0.72 mg/g with an average (n=05) value of 0.62 mg/g. The highest concentration (0.65 mg/g) was at Ichakhali char (S 02), an abandoned char covered with sea-grass beds and small mangrove plants. The second highest concentration of the Cu was found in the soil of north Mukter char (S 03).

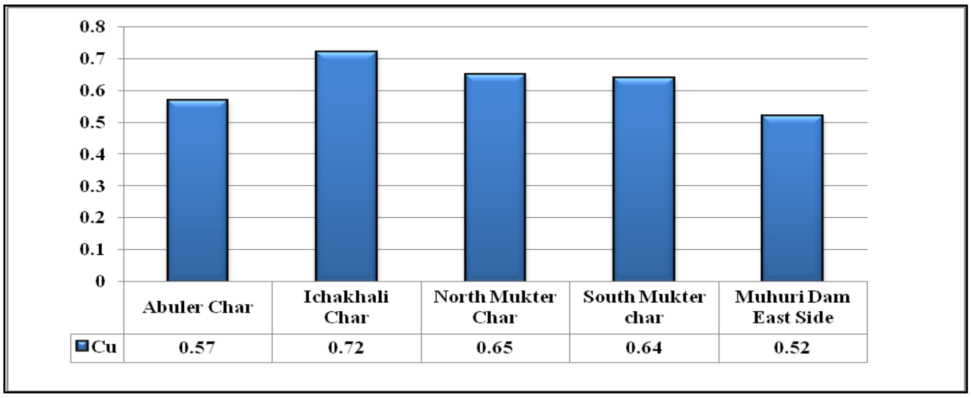
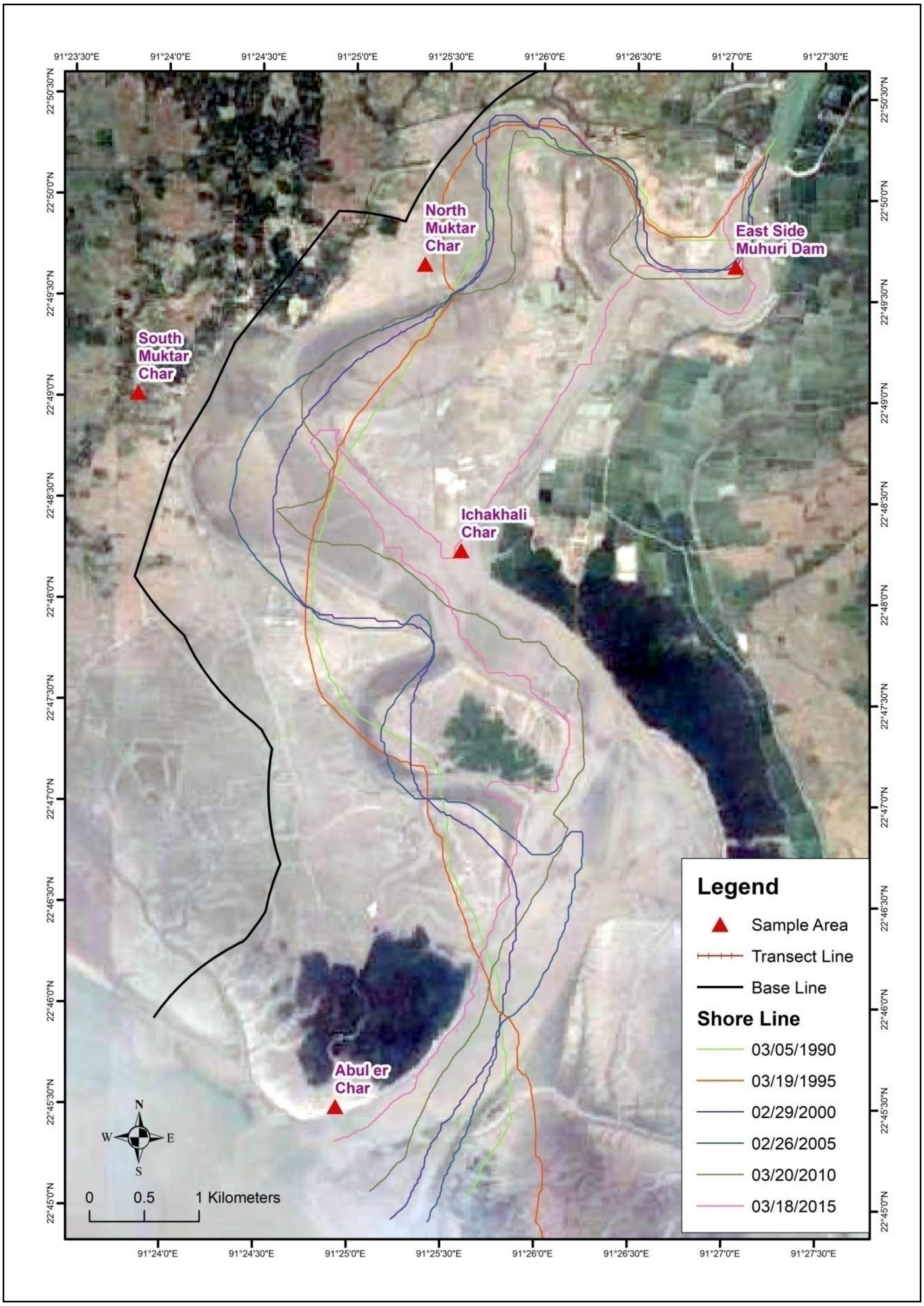


Fig. 6.1: Cu Concentration in Soil

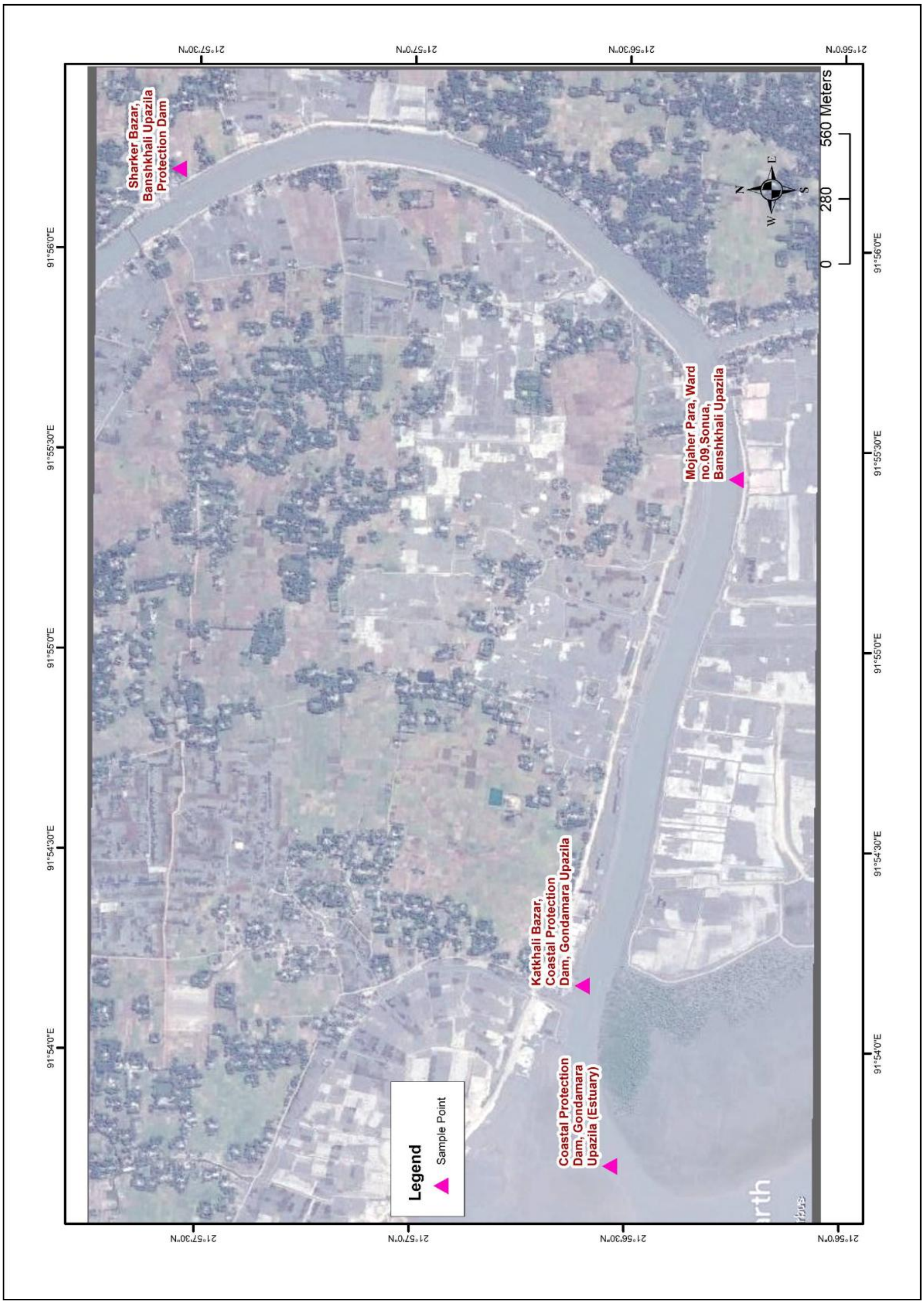
Source: Present Study, 2018

The lowest content of Cu (0.52 mg/g) was found at east bank of Muhuri dam, at the fishing and vegetable/ fruit farming area. It was noticeable that, the concentration of Cu was twofold more than that of the world standard average (0.30 mg/g) in almost every Sample area (Table 6.1, Fig. 6.1).



Map 6.1: Sample areas of Feni River Estuary, Mirsharai, Chottogram, 2018

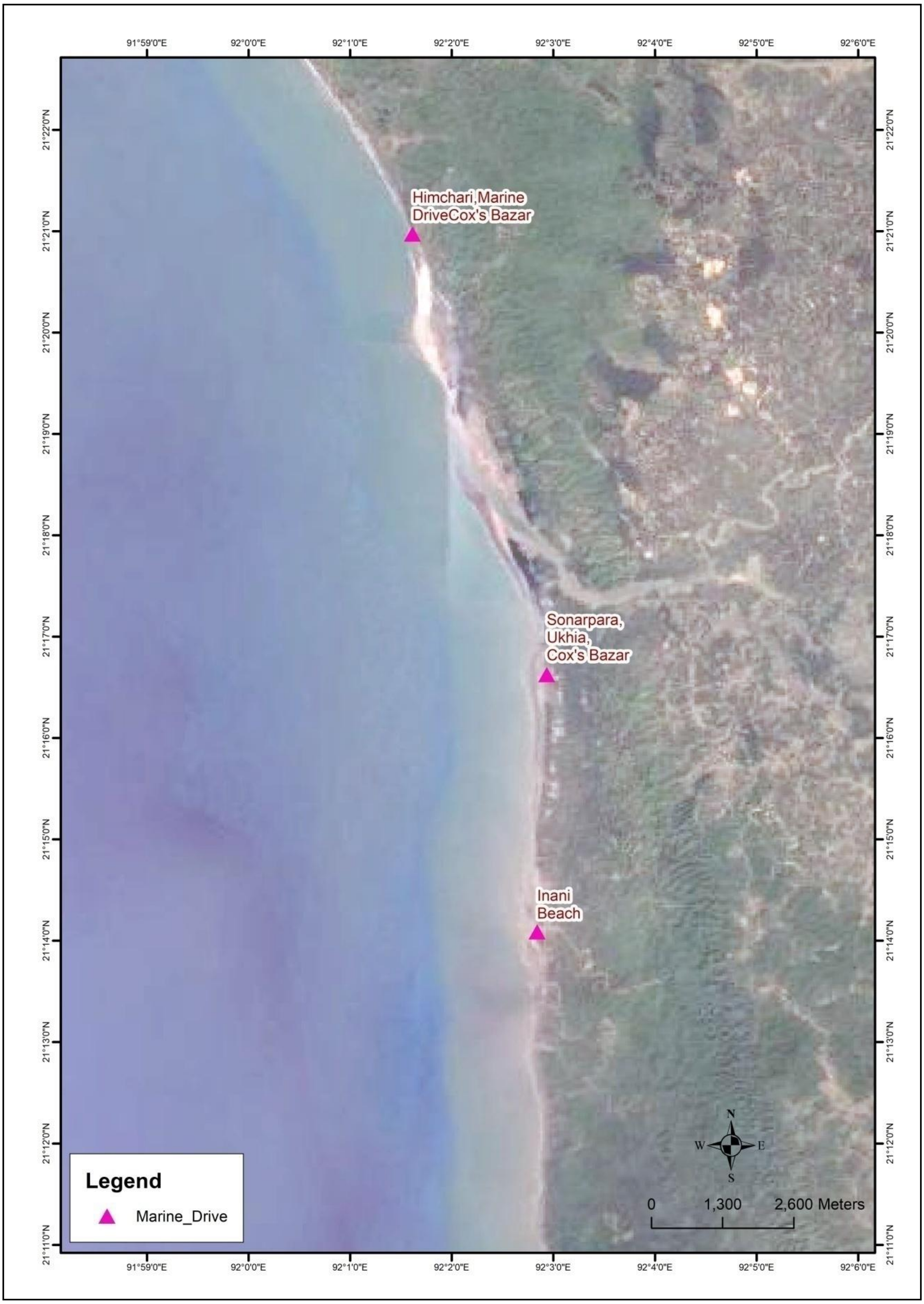
Source: Present Study, 2018



Map 6.2: Sample areas of Jalkadar River Estuary, Banshkhali, Chottogram, 2018

Source: Present Study, 2018

Map 6.3: Sample areas of Bakkhali River Estuary, Cox's Bazar, 2018
Source: Present Study, 2018



Map 6.4: Sample areas of Marine Drive, Teknaf, Cox's Bazar, 2018

Source: Present Study, March, 2018

Fe Concentration in Soil

The concentrations of Fe in soil ranges from 4.70 mg/g to 5.87 mg/g, with an average (n=05) concentration of 5.41 mg/g. Among 05 source points, S 01 shows highest concentration of Fe (5.87 mg/g), which was 2.5 mg/g more than the world average (3.4 mg/g). The second highest Fe concentration (5.54 mg/g) was found at north Mukter Char (S 03) inhabited by the local Fisher communities.

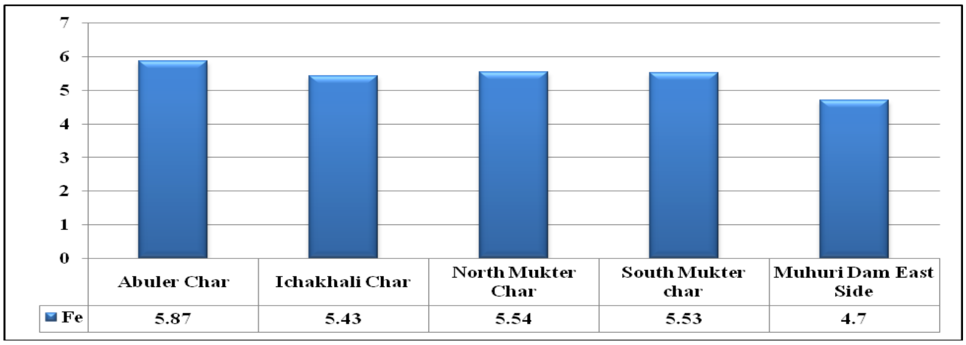


Fig. 6.2: Fe Concentration in Soil
Source: Present Study, 2018

All sample areas at Feni River estuary have higher concentration of **Fe** than the world average (3.4 mg/g), with the lowest concentration (4.7 mg/g) at S 05 (Table 6.1 and Figure 6.2).

Pb Concentration in Soil

The concentration of Pb varies from 0.52 mg/g to 0.61 mg/g with an average (n=05) value of 0.56 mg/g. The highest concentration (0.61mg/g) has been found at Ichakhali char (S 02), while the second highest concentration (0.57mg/g) has been found at west bank of Muhuri Dam (S 05). The lowest concentration of Pb has been found at south Mukter char (S 04) (Table 6.1, Fig. 6.3).The average concentration of Pb (0.56 mg/g) in the sample areas has already crossed the margin of world average (0.03 mg/g).

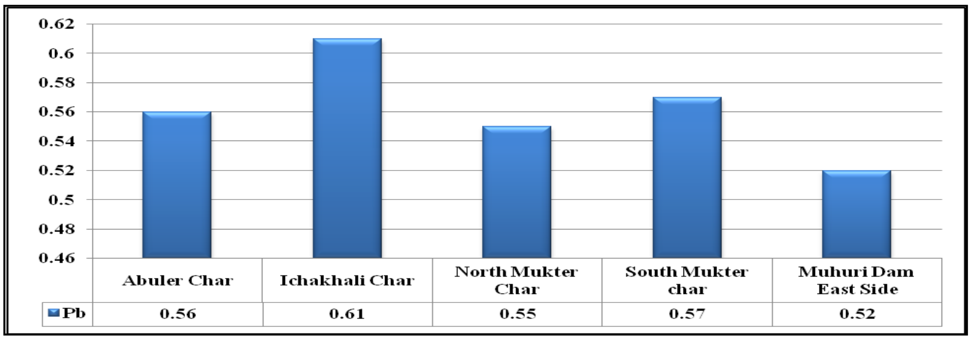


Fig.6.3: Pb Concentration in Soil
Source: Present Study, 2018

Zn Concentration in Soil

The concentration of Zn in soil varies from 0.14 mg/g to 1.18 mg/g with an average (n=05) of 0.17 mg/g in the study area (Table 6.1). The Zn shows the highest concentration (0.18 mg/g) at three sample areas like S 01, S 02 and S 05, while the lowest concentration (0.14 mg/g) has been found at S 05,at west bank of Muhuri Dam (Table 6.1, Figure 6.4). However, concentration of Zn was significantly lower in comparison to world average (5.0 mg/g).

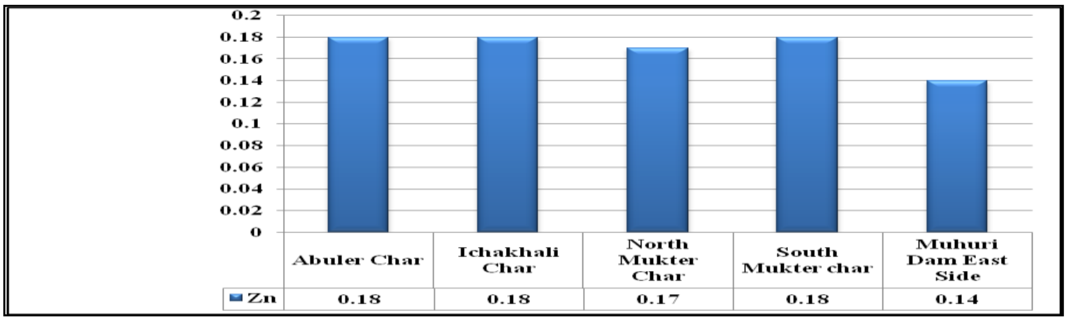


Fig. 6.4: Zn Concentration in Soil

Source: Present Study, 2018

The hierarchy of average heavy metal concentration in Feni River sample area soil was: Fe > Pb > Cu > Zn > Cd.

6.2.2 Heavy Metal Concentration in Water of the Feni River Estuary

The heavy metal concentration in water of the five sample areas along Feni River estuary was measured to evaluate the environmental status of the river. However, the hierarchy of average concentration of the heavy metals in water samples was: Fe> Pb> Zn>Cu>Cd. The findings has been discussed below:

Cd Concentration in Water

The Cd concentration ranges from 0.03 mg/L to 0.12 mg/L, with an average (n = 5) of 0.08 mg/L. The highest Cd concentration (0.12 mg/L) was at the source point of Abuler char (S 01).The second highest Cd content was at Ichakhali char and (S 02) and north Mukter char (S 03) along the Feni River estuary (Table 6.2, Fig. 6.5).

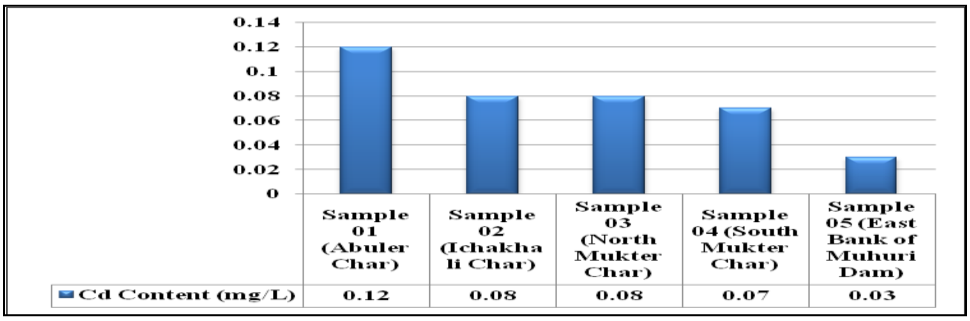


Figure 6.5: Cd Concentration in Water

Source: Present Study, 2018

Cu Concentration in Water

The concentration of Cu varies from 0.05 mg/L to 0.21 mg/L with an average (n =5) value of 0.12 mg/L. The highest concentration (0.21 mg/L) was at source point of North Mukter char (S 03) along the west bank of Feni River (Table 6.2, Figure 6.6).The second highest concentration of Cu (0.12 mg/L) was at the Abuler char and Ichakhali char (S 01 and S 02).

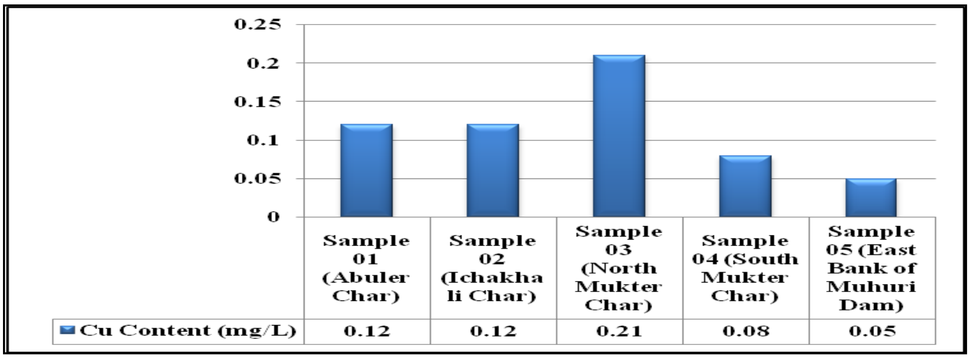


Figure 6.6: Cu Concentration in Water

Source: Present Study, 2018

These estuarine chars were rich in aquatic plants, sea-weeds, sea-grass, crabs, and mollusks. The lowest Cu content (0.03 mg/L) was found at source point of the rural settlement areas east to the Muhuri Dam (S 05).

Table 6.2: Heavy Metal Concentration in Water of the Feni River Estuary

Sample ID	Cd-content	World Standard of Cd	Cu-content	World Standard of Cu	Fe-content	World Standard of Fe	Pb-content	World Standard of Pb	Zn-content	World Standard of Zn
Water Sample	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Sample 01 (Abuler Char)	0.12	0.11	0.12	0.9	1.58	3.4	0.41	0.03	0.15	5.0
Sample 02 (Ichakhali char)	0.08	0.11	0.12	0.9	1.48	3.4	0.40	0.03	0.19	5.0
Sample 03 (North Mukter Char)	0.08	0.11	0.21	0.9	2.01	3.4	0.50	0.03	0.36	5.0
Sample 04 (South Mukter Char)	0.07	0.11	0.08	0.9	1.53	3.4	0.25	0.03	0.18	5.0
Sample 05 (East of Muhuri Dam)	0.03	0.11	0.05	0.9	1.14	3.4	0.23	0.03	0.15	5.0
Average=	0.08		0.12		1.54		0.36		0.21	

Source: i) Present Study, 2018; ii) Rashid, et al., 2014 (World Average of Heavy Metals)

Fe Concentration

The concentration of Fe varied from 1.14 mg/L to 2.01 mg/L in estuary water, while the average (n=5) concentration was 1.54 mg/L. The highest concentration of Fe (2.01 mg/L) was at the source point of North Mukter Char (S 03), a barren char land covered with sea grass. The second highest concentration (1.58mg/L) was at the

Abuler Char (S 01), lying at the mouth of the Feni River. The third highest Fe content was in the Ichakhali char (1.48 mg/L). Both the chars, inundated by high tide, were barren lands seasonally dwelled by the fishermen bound for the sea for fishing (Table 6.2, Figure 6.7).

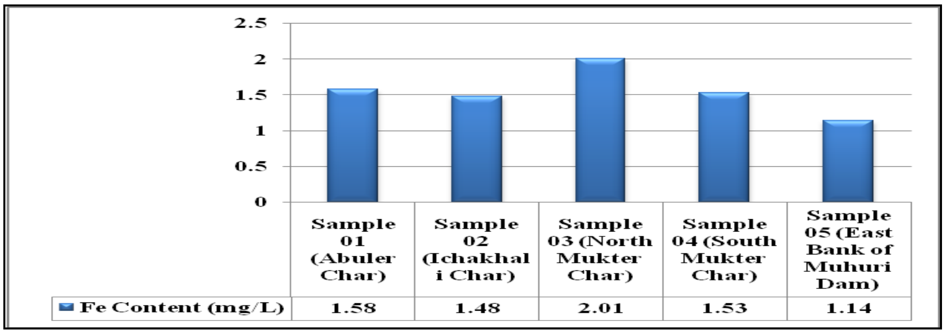


Figure 6.7: Concentration of Fe in Water

Source: Present Study, 2018

Pb Concentration in Water

The concentration of Pb varies from 0.23mg/L to 0.50 mg/L, with an average (n =5) of 0.36 mg/L (Table 6.2, Figure 6.8,). The highest concentration was found at the source points of north Mukter char (S 03), the east side of the Muhuri Dam. The second highest Pb content (0.41 mg/L) was at the Abuler char (S 01) followed by the Pb concentration of 0.40 mg/L at the Ichakhali char (S 02). The lowest Pb content (0.23 mg/L) and the average one (0.36 mg/L) in the Feni River estuary shows higher concentration than that of the world standard average (0.03 mg/L).

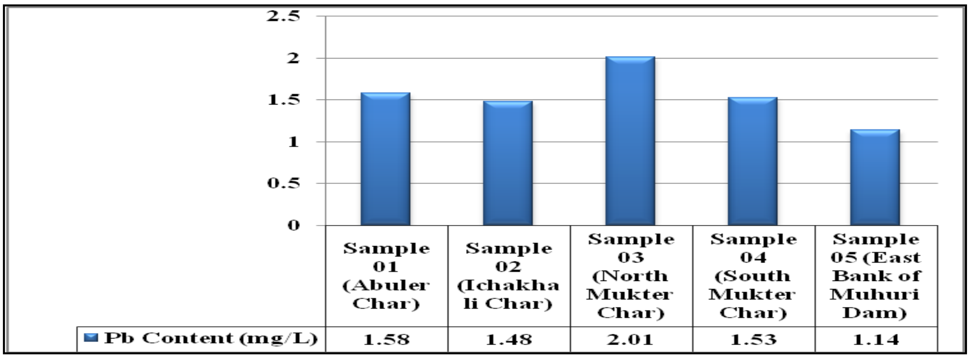


Figure 6.8: Concentration of Pb in Water

Source: Present Study, 2018

Zn Concentration in Water

The concentration of Zn varies from 0.15 mg/L to 0.36 mg/L, with an average (n=5) of 0.21 mg /L in the study area. Zn shows the lowest concentration at two source points such as- the S 01 (Abuler char) and S 05 (west bank of Muhuri dam) at Fish and Plantation Project area (Table 6.2, Figure 6.9). The highest Zn content (0.36 mg/L) was found at North Mukter Char (S 03), where the fishermen stays temporarily to harvest fish from the river and the bay. However, the water sample collected from the S 02 (Ichakhali char) has the second highest concentration of Zn (0.19 mg/L).

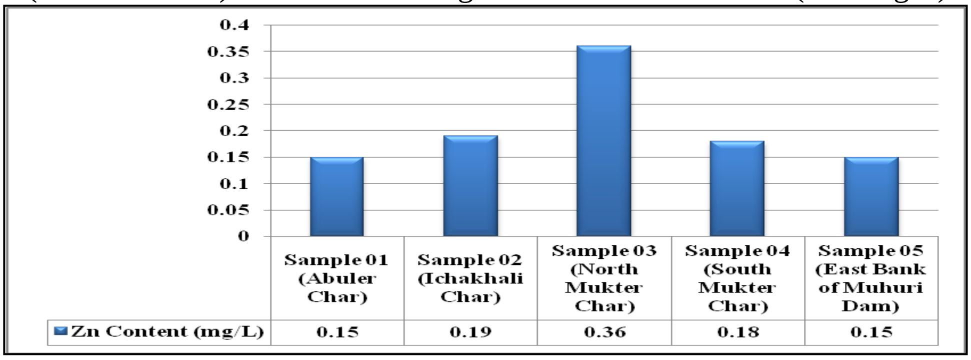


Figure 6.9: Concentration of Zn in Water

Source: Present Study, 2018

The summary of the heavy metal concentration in water of the Feni River sample areas show that, Fe has the highest average concentration (1.54 mg/L), which was about half of the amount of world average (3.4 mg/L). The second average concentration was of Pb (0.36 mg/L), which was more than 12 times higher than that of the world average (0.03mg/L). The average Zn concentration (0.21mg/L) was very insignificant in comparison to the world average of 5.0 mg/L. Conversely, the average Cd content was close to the world average, where only exception was found with that of the S 01 (0.12mg/L), slightly higher than the world average (0.11 mg/L). The average Cu content was about 0.12 mg/L and was 0.78 mg/L lesser than the world average (0.9 mg/L). The hierarchy of average heavy metal concentration in Feni River sample area water was: Fe > Pb > Zn> Cu > Cd.

6.2.3 Non-Metals (Nutrients) in Soil and Water of the Feni River Estuary

The amount of Phosphorous and Sulphur in soil and water samples of the Feni River estuary was only 01 ppt.

6.2.4 Physio-Chemical Quality of Soil of the Feni River

The physio-chemical quality of soil samples were measured with the HI 9813-5 and 9813-6 Portable machine at the department of Geography and Environment, University of Dhaka. The three parameters taken to measure the physio-chemical quality were - i) Potential of Hydrogen (pH), ii) Electric Conductivity (EC), and iii) Temperature.

i) Potential of Hydrogen (pH) of Soil

The standard value of pH for soil was 6.5-7.5, while pH value 6.6-7.3 was considered as Neutral (U.S. Soil Survey Division, 2011). The pH value of the sample areas of the Feni River varies from 6.4 to 8.3 (Table 6.3). Total two sample areas, such as, S 02 (pH 7.8) and S 03 (pH 7.7) contain Slightly Alkaline soil, while another two sample areas, like S 01(pH 8.1) and S 05 (pH 8.3) have Moderately 'Alkaline soil'. The S 04 (pH 6.4) has slightly 'Acidic soil'. Nevertheless, the average pH value was 6.02, which was within the 'Slightly Alkaline' soil class range in the pH scale (Table 6.3, Fig.6.10).

Table 6.3: Physio-Chemical Quality of Soil of the Feni River Estuary

Sample areas	pH	EC (mS/Cm)	Temperature (°C)
Sample 01 (East Side of Muhuri Dam)	8.1	0.08	27.6
Sample 02 (Ichakhali Char)	7.8	1.30	25.9
Sample 03 (North Mukter Char)	7.7	0.90	26.4
Sample 04 (South Mukter Char)	6.4	2.33	25.0
Sample 05 (West Side of Muhuri Dam)	8.3	0.34	27.6
Average	7.7	0.99	26.5

Source: Present Study, 2018 (* mS/Cm= mili Siemens/Centimeter)

ii) Electrical Conductivity (EC) of Soil

The average EC in soil of the Feni River estuary was 7.32 mS/Cm, ranging from 0.08-2.33 mS/Cm, with an average of 0.99 mS/C. The highest EC (2.33 mS/Cm) was found at S 04, South Mukter char (Fig. 6.11). However, the lowest EC was found at Abuler char (S 01).

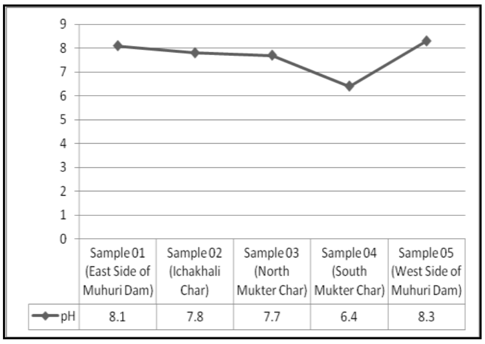


Fig.6.10: Potential of Hydrogen (pH) in Soil

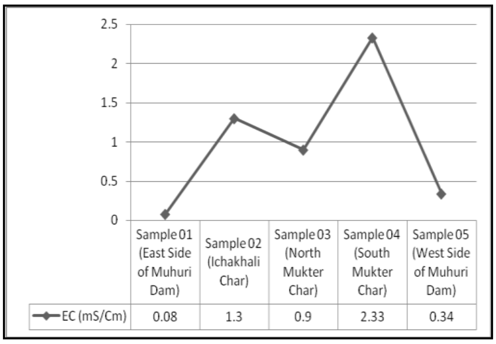


Fig. 6.11: Electric Conductivity (EC) of Soil

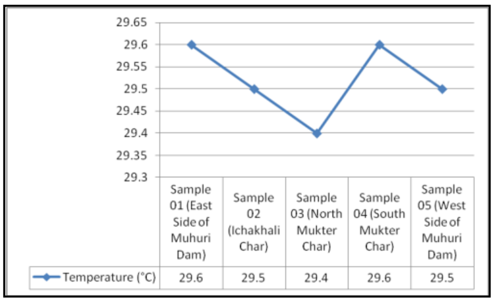


Fig. 6.12: Temperature of Soil

Source: Present Study, 2018

iii) Temperature of Soil

The range of the surface temperature of the sample area soil fluctuates between 25.3°C - 27.6°C (Table 6.3, Fig.6.12).

6.2.5 Physio-Chemical Quality of Water Samples of the Feni River

The physio-chemical quality of the water samples was measured with the HI 9813-5 and 9813-6 Portable machine at the department of Geography and Environment, University of Dhaka. The four parameters taken to measure the physio-chemical quality were: i) Potential of Hydrogen (pH), ii) Electric Conductivity (EC), iii) Total Dissolved Solids (TDS), and iv) Temperature

Table 6.4: Physio-Chemical Quality of Water

Sample Areas	pH	EC (mS/Cm)	Temperature (°C)	TDS
Sample 01 (East Side of Muhuri Dam)	6.8	8.48	29.1	1
Sample 02 (Ichakhali Char)	6.0	7.82	29.4	1
Sample 03 (North Mukter Char)	6.1	8.17	29.6	1
Sample 04 (South Mukter Char)	5.7	5.66	29.3	1
Sample 05 (West Side of Muhuri Dam)	5.4	6.78	29.5	1
Average	6.0	7.38	29.4	

Source: Present Study, 2018 * mS/Cm= mili Siemens/Centimeter

i) Potential of Hydrogen (pH) of Water

The Potential of Hydrogen (pH) of water samples of the Feni River estuary ranges from 5.4 to 6.8 in pH Scale, with an average value of 6.0 (Table 6.4,Fig.6.13). The standard range of pH value for the brackish sea water was of 7.5 to 8.4 (EPA, 2015). The water with pH 7.0 was neutral. The average as well as the individual pH values of each water samples of Feni River was within the standard range for brackish water fish resource. However, the pH level of the S 01 was 6.8, which was slightly lower than the neutral water pH value.

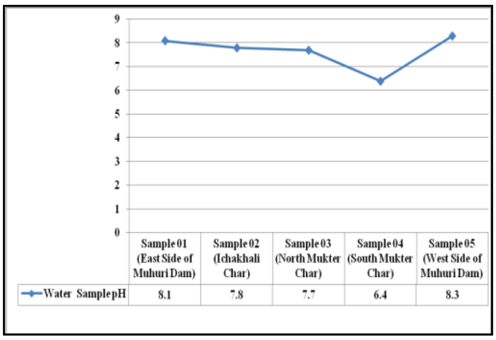


Fig. 6.13: Potential of Hydrogen (pH) in Water

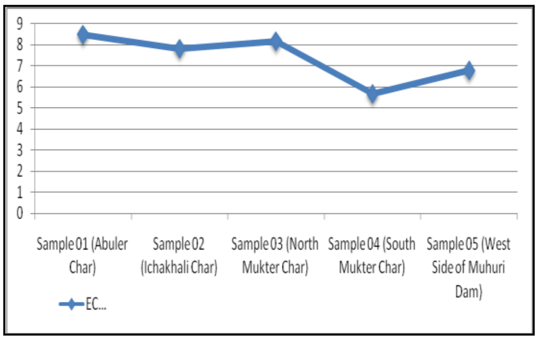


Fig. 6.14: Electric Conductivity (EC) of Water

Source: Present Study, 2018

ii) Electrical Conductivity (EC) in Water

According to the present study, the amount of EC varies from 5.66 mS/Cm to 8.48 mS/Cm in water samples, with an average of 7.38 mS /Cm. (Table 6.4, Fig.6.13).

iv) Temperature of Water

The average surface temperature of water of the sample areas were 23.1°C in average, showing an increasing trend (1°C) in temperature (22°C, Banglapedia, 2015). On the other hand, the range of temperature of the sample area water was between 22.4 °C to 23.6 °C (Table 6.4, Fig.6.15).

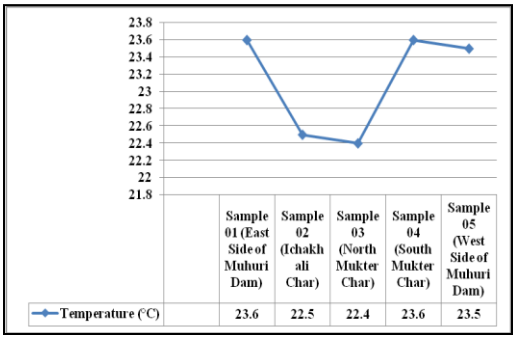


Fig. 6.15: Temperature of Water

Source: Present Study, 2018

ii) TDS in Water Samples

The average amount of Total Dissolved Solids (TDS) in the water samples of the study area was 01mg/L.

6.3 Environmental Quality of Soil and Water of the Jalkadar River Estuary, Mirsharai, Chottogram

The soil and water samples from five source points of the Jalkadar River estuary (Map 6.2) like-the Sharker Bazar, Gondamara Estuary, National Parabon, Katkhali Bazar, and Mojaher Para was collected and measured. Five heavy metals, such as Cadmium (Cd), Copper (Cu), Iron (Fe), Lead (Pb), and Zinc (Zn) and the content of two non-metals, such as the Phosphorous and Sulphur were measured. Moreover, the physio-chemical quality of three environmental indicators, such as the pH, EC, and Temperature of soil and four environmental indicators, such as the pH, EC, TDS and Temperature of water was assessed. The samples have been collected from the source points of pollution during the field survey (24th -26th March, 2017). The pre-monsoon dry weather was selected as the sample collection time, since this time was suitable for collecting the polluted soil directly from the source points.

6.3.1 Heavy Metal Concentration in Soil of Jalkadar River Estuary

The soil samples were collected by 'Composite Sampling' method from five source points of pollution of the Jalkadar River estuary (Table 6.5). The hierarchy of average heavy metal concentration in soil samples was: **Fe>Pb>Cu>Zn>Cd**

Table 6.5: Heavy Metal Concentration in Soil at Jalkadar River Estuary

Sample ID	Cd-content	World Standard of Cd	Cu-content	World Standard of Cu	Fe-content	World Standard of Fe	Pb-content	World Standard of Pb	Zn-content	World Standard of Zn
Soil Sample	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g
Sample 01 (Sharker Bazar)	0.03	0.11	0.71	0.9	5.57	3.4	0.52	0.03	0.20	5.0
Sample 02 (Gondamara Estuary)	BDL	0.11	0.53	0.9	3.36	3.4	0.40	0.03	0.30	5.0
Sample 03 (National Parabon)	0.02	0.11	0.62	0.9	5.43	3.4	0.53	0.03	0.20	5.0
Sample 04 (Katkhali Bazar)	BDL	0.11	0.57	0.9	5.29	3.4	0.48	0.03	0.21	5.0
Sample 05 (Mojaher Para)	0.01	0.11	0.68	0.9	6.00	3.4	0.65	0.03	0.22	5.0
Average=	0.02	0.11	0.62	0.9	5.33	3.4	0.52	0.03	0.23	5.0

Source: i) Present Study, 2018; iii) Rashid, et al., 2014 (World Average of Heavy Metals)

Cd Concentration in Soil

The Cd concentration ranges from 0.01 -0.03 mg/g in soil samples of the Jalkadar river with an average (n=5) concentration of 0.02 mg/g. The Cd concentration was BDL in S 02 and S 04 (Table 6.5, Fig.6.16).

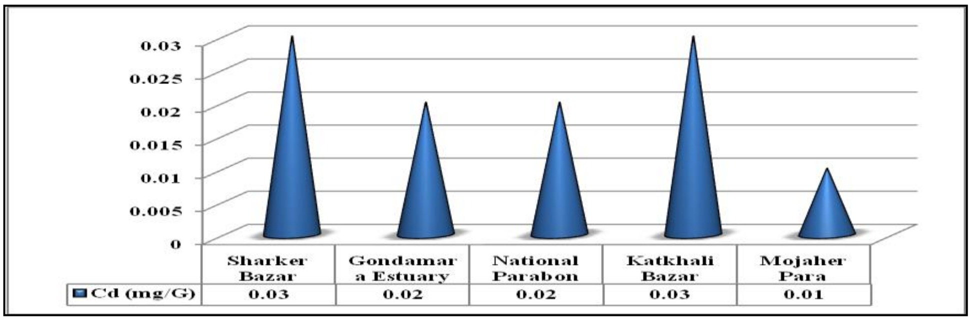


Fig. 6.16: Concentration of Cd in Soil

Source: Present Study, 2018

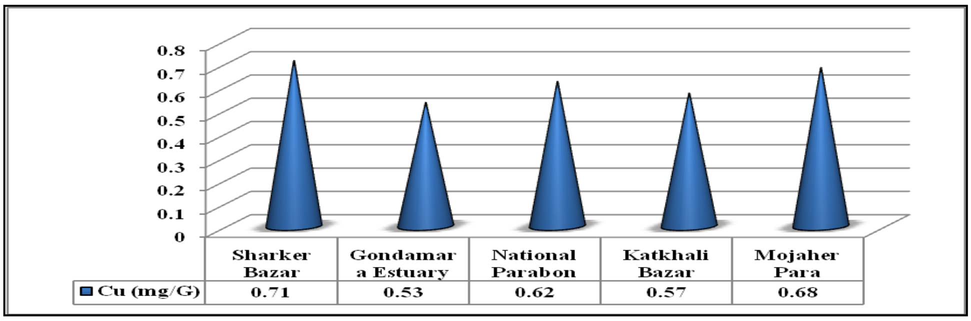


Fig. 6.17: Concentration of Cu in Soil

Source: Present Study, 2018

Cu Concentration in Soil

The concentration of Cu ranges from 0.53 to 0.71 mg/g with an average (n =05) value of 0.62 mg/g. The highest concentration was found at S 01, Sharker Bazar. The second highest concentration of Cu (0.68 mg/g) was found in soil of Mojaherpara (Sample 05), near the mouth of the estuary. The least Cu concentration was at S 02, Gondamara Estuary (Table 6.5, Fig.6.17).

Fe Concentration in Soil

The Fe concentration in soil ranges from 4.36 mg/g to 6.0 mg/g, while the average (n=05) concentration was 5.33 mg/g. Each sample area has higher concentration of Fe than that of the world standard average (6.4 mg/g). The highest concentration of Fe (6.0 mg/g) was at the source point of Mojaherpara (Sample 05), while the lowest concentration was found at Gondamara bank of the estuary (S 02). The second highest Fe concentration (5.57mg/g) was found at Sharker Bazar (S 01) (Table 6.5, Fig.6.18).

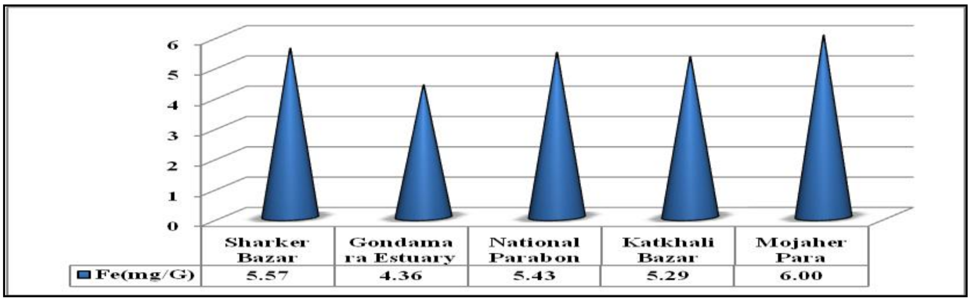


Figure 6.18: Concentration of Fe in Soil
Source: Present Study, 2018

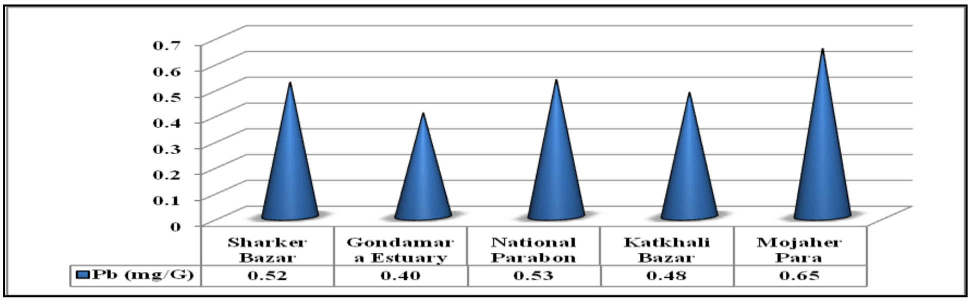


Fig.6.19: Concentration of Pb in Soil
Source: Present Study, 2018

Pb Concentration in Soil

The concentration of Pb varies from 0.40 to 0.65 mg/g, with an average (n=05) value of 0.52 mg/g (Table 6.5, Fig.6.19). The highest concentration (0.65 mg/g) was found at source points of Mojaherpara (Sample 05), while the second highest concentration (0.53 mg/g) was found at National Parabon (Sample 03).The lowest concentration was found at Gondamara bank of the estuary (S 02).The alarming fact was that, the average concentration of Pb in the sample areas was 17 times higher than that of the world average (0.03 mg/g).

Zn Concentration in Soil

The concentration of Zn in soil varies from 0.20 to 30 mg/g with an average (n=05) of 0.23mg/g in the study area (Table 6.5). Zn shows the highest concentration (0.30 mg/g) at the source point of Gondamara bank of the estuary (S 02), while the second highest concentration (0.22 mg/g) was found at S 05, Mojaherpara (Table 6.5, Figure 6.20). However, the concentration of Zn was significantly low in comparison to that of the world standard average (5.0 mg/g).

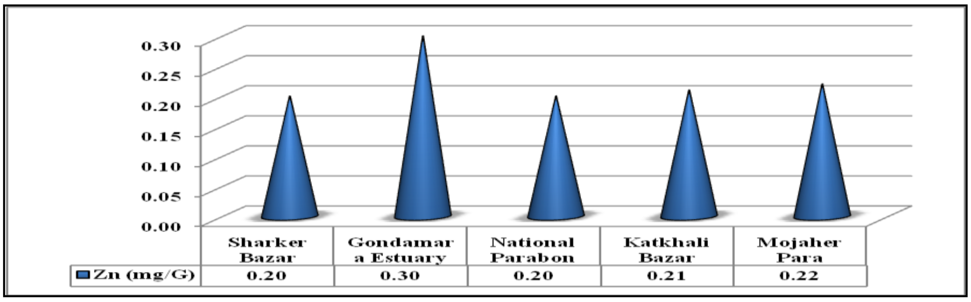


Fig.6.20: Concentration of Zn in Soil

Source: Present Study, 2018

6.3.2 Heavy Metal Concentration in Water of Jalkadar River Estuary

The concentration of heavy metals Cd, Cu, Fe, Pb and Zn in water of five source points, such as Sharker Bazar fish market and Ice factory, Katkhali Bazar boat repairing factory, National Parabon, and salt farms at Gondamara union were measured (Table 6.6). The table 6.6 show that, the hierarchy of average heavy metal concentration in sample water of the Jalkadar River was : Fe> Pb> Zn > Cu > Cd

Table 6.6: Heavy Metal Concentration in Water of Jalkadar River Estuary

Sample ID	Cd-content	World Standard of Cd	Cu-content	World Standard of Cu	Fe-content	World Standard of Fe	Pb-content	World Standard of Pb	Zn-content	World Standard of Zn
Water Sample	mg/L	Mg /L	Mg /L	mg/L	mg/L	mg/L	mg/L	Mg /L	Mg /L	Mg /L
Sample 01 (Sharker Bazar)	0.07	0.11	0.10	0.9	1.67	3.4	0.36	0.03	0.25	5.0
Sample 02 (Gondamara Estuary)	0.03	0.11	0.23	0.9	1.52	3.4	0.65	0.03	0.34	5.0
Sample 03 (National Parabon)	0.11	0.11	0.26	0.9	2.50	3.4	0.68	0.03	0.32	5.0
Sample 04 (Katkhali Bazar)	0.12	0.11	0.19	0.9	1.66	3.4	0.63	0.03	0.53	5.0
Sample 05 (Mojaher Para)	0.12	0.11	0.21	0.9	1.84	3.4	0.56	0.03	0.32	5.0
Average=	0.09		0.20		1.84		0.58		0.36	

Source: Present Study, 2018; ii) Rashid, et al., 2014

Cd Concentration in Water

The **Cd** concentration ranges from 0.03 mg/L to 0.12 mg/L, with an average (n = 5) of 0.09 mg/L (Fig.6.21). The highest Cd concentration (0.12 mg/L) has been found at two source points Katkhali bazar and Mojaherpara (S 04 and S 05). The second highest Cd content has been found in S 03 along the National Parabon and sea-grass bed of the Coastal Protection Dam.

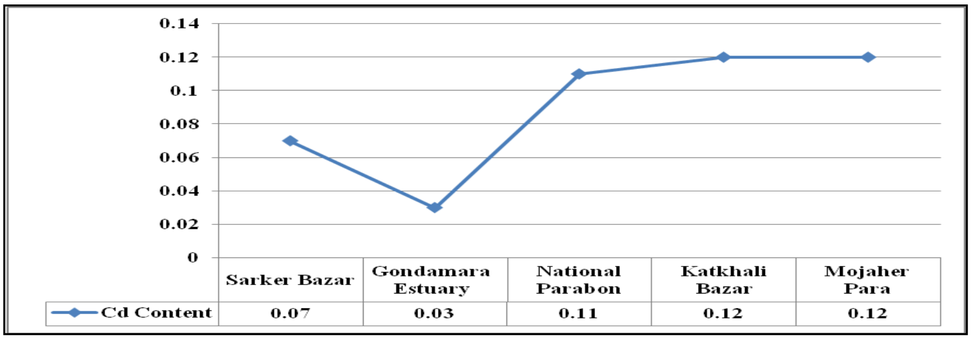


Fig. 6.21: Concentration of Cd in Water
Source: Present Study, 2018

Cu Concentration in Water

The concentration of Cu varies from 0.10 mg/L to 0.26 mg/L with an average (n=5) value of 0.20 mg/L. The highest concentration (0.26 mg/L) has been found at source point of the National Parabon (S 03) along the east bank of Jalkadar River (Figure 6.22, Table 17).

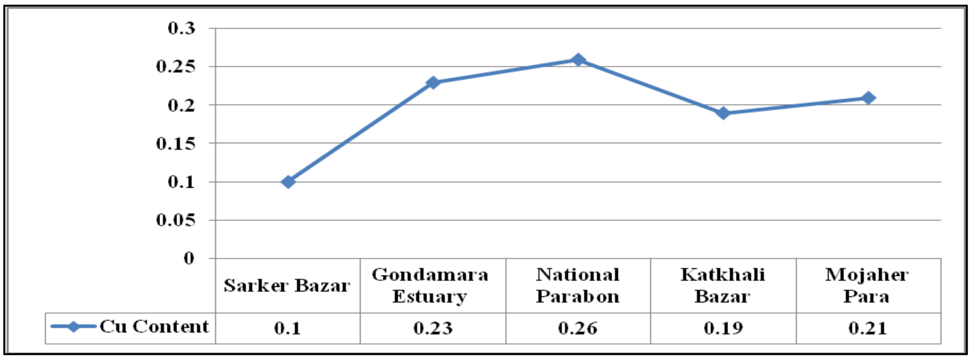


Fig.6.22: Concentration of Cu in Water
Source: Present Study, 2018

The second highest concentration of Cu (0.23 mg/L) was found at the Coastal Protection Dam, Gondamara estuary (S 02). The lowest Cu content (0.10 mg/L) was found at source point of the Sharker Bazar area (S 01).

Fe Concentration in Water

The concentration of Fe varied from 1.52 mg/L to 2.50 mg/L, while the average (n=5) concentration was found to be 1.84 mg/L (Fig.6.23). The highest concentration of Fe (2.50 mg/L) was at the National Parabon (S 04), near the estuary of Gondamara union. The second highest concentration (1.84 mg/L) was at S 05 (Mojaherpara, ward no.9) at Chhanua union. The third highest Fe content (1.67 mg/L) was found in water at Sharker Bazar, Banshkhali dam area.

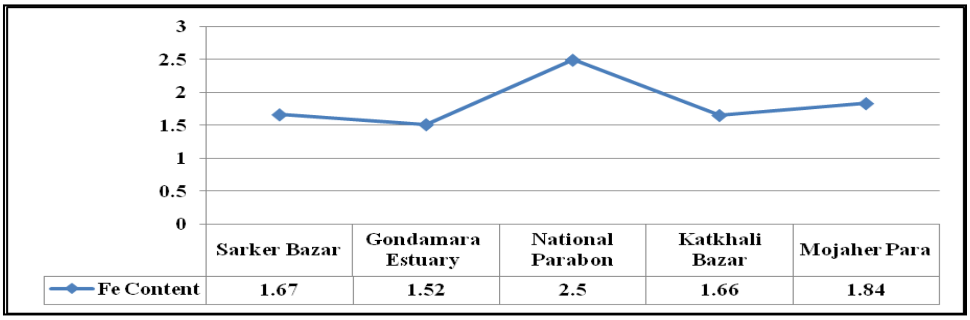


Fig. 6.23: Concentration of Fe in Water
Source: Present Study, 2018

Pb Concentration in Water

The concentration of Pb varies from 0.36mg/L to 0.68 mg/L, with an average (n =5) of 0.58 mg/L (Table 6.6, Figure 6.24). The highest concentration was found at National Parabon (S 03). The second highest Pb content (0.65 mg/L) was found at Gandamara coastal protection dam (S 02), followed by Pb 0.63 mg/L at Katkhali Bazar, Gandamara (S 04). Moreover, the lowest (0.36 mg/L) and the average (0.58 mg/L) Pb content in the Jalkadar River estuary was consecutively 0.33 mg/L and 0.55 mg/L higher than that of the world average (0.03 mg/L). Alarmingly, even the average Pb concentration of the sample areas was 19.3 times higher than the world average.

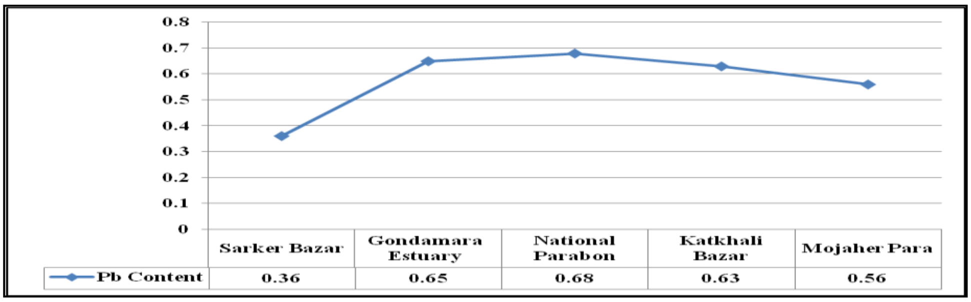


Fig.6.24: Concentration of Pb in Water

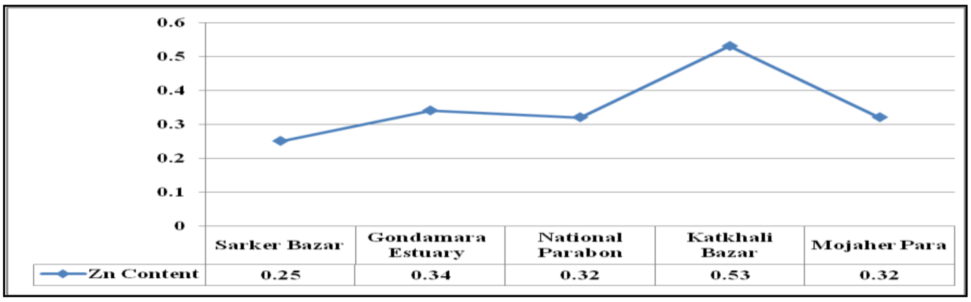


Fig.6.25: Concentration of Zn in Water
Source: Present Study, 2018

Zn Concentration in Water

The concentration of Zn varies from 0.25 mg/L to 0.53 mg/L, with an average (n=5) of 0.36 mg /L in the study area. The lowest concentration was at source points of S 01 (Sharker Bazar, Banshkhali) (Table 6.6, Fig.6.25). The highest Zn content (0.53 mg/L) was at S 04, at Katkhali Bazar, Coastal Protection Dam, and Gondamara Upazila. The source point of Gandamara estuary (S 02) has the second highest concentration of Zn (0.34 mg/L).

The summary of heavy metal concentration in water of the Jalkadar River sample areas showed that, the average concentration of all the heavy metals except Pb was lower than that of the world average. The average Pb concentration (0.58 mg/L) found in water of the sample areas was almost 0.55 mg/L more than the world average (0.03mg/L). On the other hand, the average content of Cu (0.20 mg/L) was around 4.5times lesser than the world average. The world average of Zn (5.0 mg/L)was 13.9mg/L more than that of the average Zn content (0.36 mg/L) measured for the present study. The hierarchy of average concentration of heavy metals in water of the Jalkadar River sample areas was found as follows: Fe > Pb > Zn> Cu > Cd.

6.3.3 Amount of Non-Metals (Nutrients) in Soil and Water of the Jalkadar River

The two non-metals, Phosphorous and Sulphur were measured in the present study, as these two function as the nutrients for the aquatic environment. The amount of these two non-metals in the Jalkadar River water was 0 PPT.

6.3.4 Physio-Chemical Quality of Soil of the Jalkadar River Estuary

The physio-chemical quality of soil and water samples from five source points of the sample areas of the Jalkadar River estuary was measured with the HI 9813-5 and 9813-6 Portable machine at the department of Geography and Environment, University of Dhaka. Total three parameters of soil samples like (i) Potential of Hydrogen (pH), (ii) Electric Conductivity (EC) and (iii) Temperature was measured.

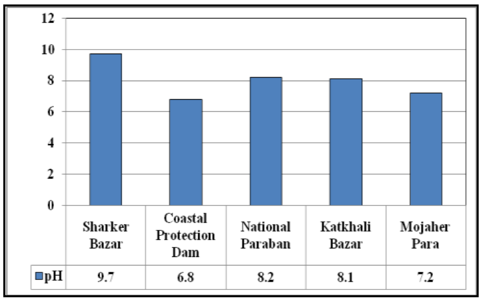
i) Potential of Hydrogen (pH) of Soil

The standard range of pH value for soil was 6.5-7.5, while the pH value of 6.6–7.3 was considered as Neutral (U.S. Soil Survey Division, 2011).The pH value of the sample areas of the Jalkadar River varied from 6.8 to 9.7 (Table 6.7).The present study shows that, water at Sharker Bazar (S 01) has pH level 9.7, which was alarmingly high and was categorized as ‘Very Strongly Alkaline’.

Table 6.7: Physio-Chemical Quality of Soil of the Jalkadar River Estuary

Soil Sample areas	pH	EC (mS/Cm)	Temperature (°C)
Sample 01 (Sharker Bazar, Banshkhali)	9.7	0.85	26.7
Sample 02 (Coastal Protection Dam, Gondamara Upazila)	6.8	1.32	26.8
Sample 03 (National Para ban, Banshkhali Upazila)	8.2	1.43	24.9
Sample 04 (Katkhali Bazar Dam, Gondamara Upazila)	8.1	1.92	23.8
Sample 05 (Mojaher Para, Chhanua, Banshkhali Upazila)	7.2	2.79	27.3
Average	8.0	1.70	25.9

Source: Present Study, Field Survey, 2018 * mS/Centimeter= mili Siemens/Cm



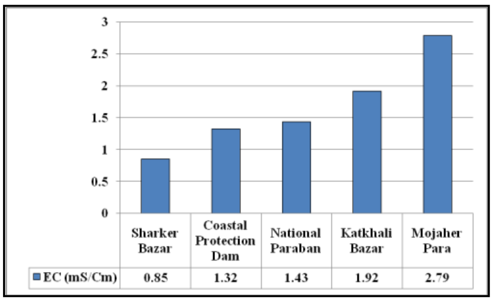


Fig.6.26: Potential of Hydrogen (pH) **Fig. 6.27: Electric Conductivity (EC)**

Source: Present Study, 2018

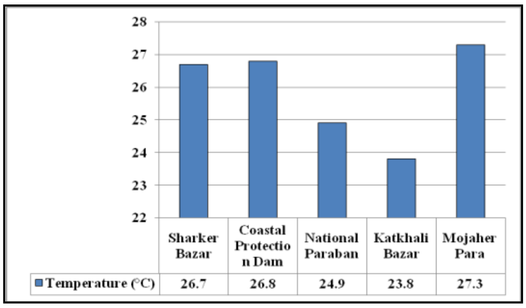


Fig. 6.28: Temperature

Source: Present Study, 2018

The other two sample areas, such as National Parabon and Katkhali Bazar (S 03 and S 04) contained 'Moderately Alkaline soil' (pH 8.2 and 8.1), while the soil pH of other two sample areas like the Coastal Protection dam, Gondamara (pH 6.8) and Mojaherpara (pH 7.2) (S 02 and S 05) were 'Neutral'.

Nevertheless, the average level of pH (pH 8.0) crossed the Neutral range of 'Soil pH scale' to be categorized as 'Moderately Alkaline' (Table 6.7, Fig.6.25).

ii) Electrical Conductivity (EC) in Soil

The average electric conductivity in soil samples of the Jalkadar River sample areas was 1.70 mS/Cm, ranging from 0.85-2.79 mS/Cm (Table 6.7, Fig.27). The highest EC (2.79 mS/Cm) was found at S 05, Mojaherpara, Gondamara and the lowest EC was found at Sharker Bazar (S 01).

iii) Temperature in Soil

The temperature of soil in the sample areas ranged between 23.8° C-26.8° C during the survey (pre-monsoon period).The average temperature of soil samples was 25.9° C (Table 6.7, Fig.6.28).

6.3.5 Physio-Chemical Quality of Water Samples in the Jalkadar River Estuary

The physio-chemical quality of the surface water samples of the Jalkadar River estuary was measured with the HI 9813-5 and 9813-6 Portable machine at the department of Geography and Environment, University of Dhaka. The four parameters taken to measure the physio-chemical quality of the water were: i) Potential of Hydrogen (pH), (ii) Electric Conductivity (EC), (iii) Total Dissolved Solids (TDS), and (iv) Temperature.

Table 6.8: Physio-Chemical Quality of Water of the Jalkadar River Estuary

Water Sample	pH	EC (mS/Cm)	Temp. (°C)	TDS
Sample 01 (Sharker Bazar, Banshkhali)	6.3	8.00	26.7	1
Sample 02 (Coastal Protection Dam, Gondamara)	7.2	8.99	27.7	1
Sample 03 (National Para ban, Banshkhali)	7.4	8.97	27.6	1
Sample 04 (Katkhali Bazar, Gondamara Upazila)	7.2	9.01	28.6	1
Sample 05 (Mojaher Para, Chhanua, Banshkhali)	6.3	8.13	28.5	1
Average	6.9	7.18	27.8	1

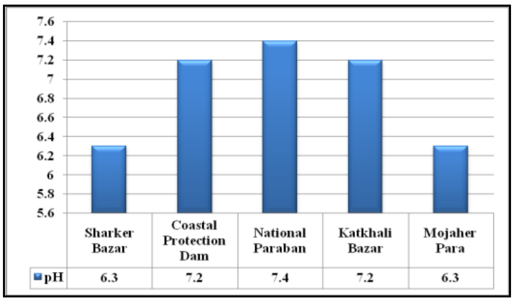
Source: Present Study, 2018 * mS/Cm= mili Siemens/Centimeter

i) Potential of Hydrogen (pH)

The Potential of Hydrogen (pH) of water samples ranged from 6.3 to 7.4, with an average pH value of 6.9. The standard range of pH value for the brackish water was of 6.5-8.5 (EPA, 2006). The S 01 and S 05 contains pH 6.3, and was categorized as Acidic. On the other hand, water of the S 02 (pH 7.2), S 03 (pH 7.4) and S 04 (pH 7.4) was categorized as Alkaline (Table 6.8, Fig.6.29).

ii) Electrical Conductivity (EC) of Water

During the study period, the average EC in water samples was 8.32 mS/Cm. The EC varied from 7.2-8.9 mS/Cm in water samples (Table 6.8, Fig.6.30).



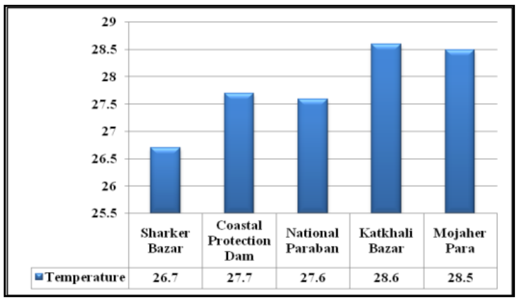


Fig. 6.29: Potential of Hydrogen (pH) **Fig.6.30: Electric Conductivity (EC)**

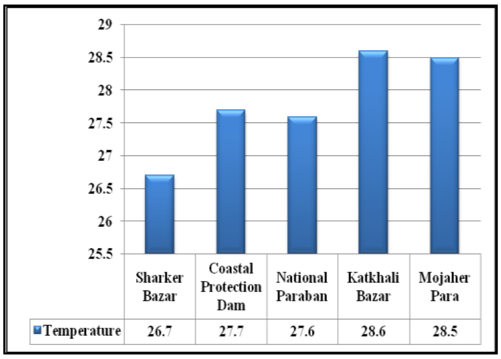


Fig.6.31: Temperature

Source: Present Study, 2018

iv) Temperature of Water

The average surface temperature of sample water was 27.8°C and the surface water temperature at the sample areas ranged from 26.7 °C to 28.6°C (Table 6.8, Fig.6.31).

ii) TDS in Water

The average amount of Total Dissolved Solids (TDS) in water samples of the study area was 01 mg/L.

6.4: Environmental Quality of Soil and Water of the Bakkhali River and Channel Estuary

The soil and water samples from the source points of Bakkhali River like No. 6 Fishery Ghat, Nuniarchara Fishery Ghat, Khurushkul Project area, and Nuniarchara Industrial area; and from source points of Bakkhali channel estuary like Char Para, Kutubdia Para, Char Para channel mouth, and Kutubdia Para channel mouth (Map 6.3 and Map 6.4) was measured . The concentration of five heavy metals, two non-metals and three physio-chemical parameters of soil, such as the pH, EC, and Temperature and four parameters such as the pH, EC, Temperature and TDS were measured to assess the environmental quality of the river and channel estuary. The samples were collected from 21st-23rd March, 2016.

6.4.1 Heavy Metal Concentration in Soil of the Bakkhali River and Channel Estuary

The soil samples were collected by 'Composite Soil Sampling' method from total 08 sample areas along the Bakkhali River and channel estuary. The concentration of five heavy metals was measured to assess the environmental quality of the river and channel estuary soil (Table 6.9). Table 6.9 shows the hierarchy of average heavy metal concentration in soil was: Fe> Pb> Zn >Cd> Cu.

Table 6.9: Heavy Metal Concentration in Soil of the Bakkhali River and Channel Estuary, Cox's Bazar

Sample ID	Cd-content	World Standard of Cd	Cu-content	World Standard of Cu	Fe-content	World Standard of Fe	Pb-content	World Standard of Pb	Zn-content	World Standard of Zn
Soil Sample	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g
Sample 01 (No.6 Fishery Ghat, Bakkhali River)	0.01	0.11	0.17	0.9	3.39	3.4	0.37	0.03	1.01	5.0
Sample 02 (Nuniarchara Fishery Ghat)	0.01	0.11	0.14	0.9	3.70	3.4	0.36	0.03	1.07	5.0
Sample 03 (Khurushkul, Bakkhali River)	BDL	0.11	0.31	0.9	2.48	3.4	0.37	0.03	0.78	5.0
Sample 04 (Nuniarchara I/A, Bakkhali River)	BDL	0.11	0.32	0.9	6.00	3.4	0.32	0.03	0.83	5.0
Sample 05 (Char Para, Bakkhali Channel)	BDL	0.11	0.13	0.9	3.72	3.4	0.29	0.03	0.74	5.0
Sample 06 (Kutubdia Para, Bakkhali Channel)	BDL	0.11	0.30	0.9	3.68	3.4	0.35	0.03	0.91	5.0
Sample 07 (Char Para, Bakkhali Channel mouth)	0.01	0.11	0.16	0.9	4.31	3.4	0.34	0.03	0.88	5.0
Sample 08 (Kutubdia Para, Bakkhali Channel)	BDL	0.11	0.18	0.9	3.20	3.4	0.25	0.03	0.94	5.0
Average=	0.01		0.20		3.56		0.33		0.90	

Source: i) Present Study, 2018 ii) CARS, D.U.

Cd Concentration in Soil

The Cd concentration was 0.01 mg/g in three sample areas: (i) No.6 Fishery ghat, (ii) Nuniarchara fishery ghat (S 01 and S 02), and (iii) Char Para, Bakkhali channel mouth (S 07) with an average (n=8) concentration of 0.01mg/g.

The concentration of the Cd was below detection level (BDL) at other sources points of Bakkhali River and channel. However, the average concentration of Cd (0.01mg/g) was quite lower than the world average of 0.11 mg/g (Table 6.10).

Table 6.10: Concentration of Cadmium in Soil

Soil Sample	Cd-content (mg/g)
Sample 01 (No.6 Fishery Ghat, Bakkhali River)	0.01
Sample 02 (Nuniarchra Fishery Ghat, Bakkhali River)	0.01
Sample 03 (Khurushkul Project Area, Bakkhali River)	*BDL
Sample 04 (Nuniarchara I/A, Bakkhali River)	*BDL
Sample 05 (Char Para, Bakkhali Channel)	*BDL
Sample 06 (Kutubdia, Bakkhali Channel)	*BDL
Sample 07 (Char Para, Bakkhali Channel mouth)	0.01
Sample 08 (Kutubdia Para, Bakkhali Channel mouth)	*BDL

Source: Present Study, 2016 *BDL=Below Detection Level

Cu Concentration in Soil

The concentration of Cu ranged from 0.13 mg/g to 0.32 mg/g with an average (n =08) value of 0.21 mg/g. The highest concentration was found at the source point of the No.06 fishery ghat at Bakkhali River estuary (S 01).

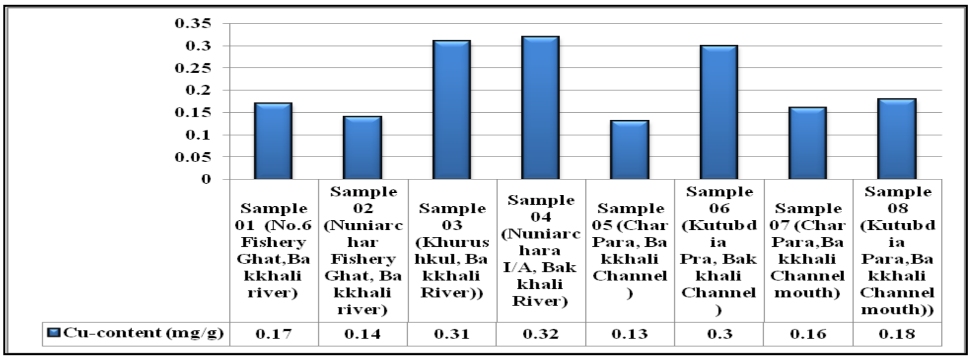


Fig.6.32: Concentration of Cu in Soil

Source: Present Study, 2018

The second highest concentration of the Cu was found in soil at Khurushkul, Bakkhali River (S 03). A narrow channel, stretched along the Bakkhali channel west bank constantly drain the household waste materials and toxic effluents from the Uttar Kutubdia Para village (S 06).This sample area had the third highest content of Cu (0.3 mg/g). Noticeable was that, the concentration of Cu was quite lower than that of the world average in all sample areas.

Fe Concentration in Soil

The concentrations of Fe in soil ranged from 2.48 mg/g to 4.31mg/g, while the average (n=8) concentration of Fe is found to be 3.6 mg/g. Among eight source points, five source points (S 02, S 04, S 06, S 05, 06, and S 07) showed higher concentration of Fe than that of the world average (3.4 mg/g). The rest three source points (S 01, S 03, and S 08) showed lower concentration of Fe than that of the world average (Table 6.9, Figure 6.31). The highest concentration of Fe (6.31 mg/g) was found at the sandy beach of Char Para, Bakkhali channel mouth (S 07). The second highest concentration of Fe (6.0 mg/g) was found at the source point of Nuniarchar industrial area, at the Bakkhali River west bank (S 04). The third highest Fe concentration (mg/g) was 3.72 mg/g was found at Char Para dried fish processing area (S 05). The other two sample areas with higher Fe content are the Nuniarchara fishery ghat area (S 02) at Bakkhali River and the Kutubdia Para village (S 06) at Bakkhali channel.

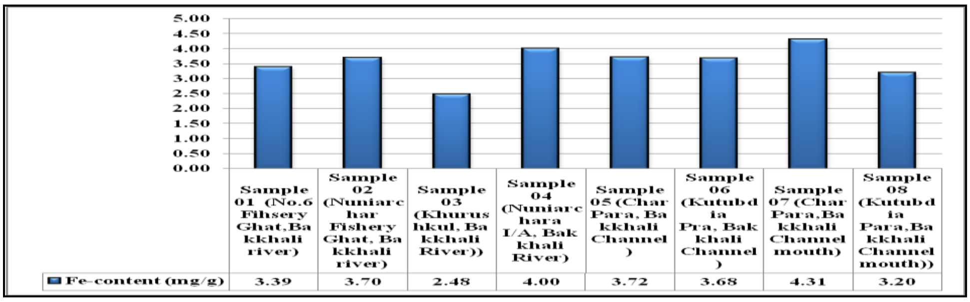


Fig.6.33: Concentration of Fe in Soil

Source: Present Study, 2018

Pb Concentration in Soil

The concentration of Pb varied from 0.25 mg/g to 0.37 mg/g with an average (n=8) value of 0.33 mg/g. The highest concentration (0.37 mg/g) was found at two source points of Bakkhali River (S 01 and S 03), while the second highest concentration (0.36 mg/g) was found at Nuniarchara fishery ghat, Bakkhali River (S 02). The lowest concentration of Pb (0.25 mg/L) was found at Kutubdia Para, Bakkhali channel mouth (S 08).

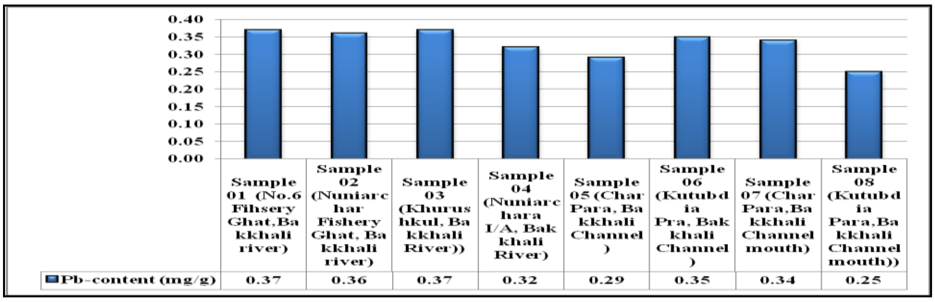


Fig.6.34: Concentration of Pb in Soil

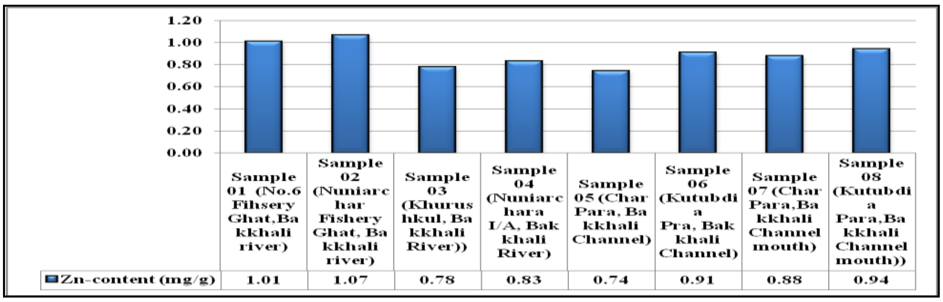


Fig.6.35: Concentration of Zn in Soil

Source: Present Study, 2018

Zn Concentration in Soil

The concentration of Zn in the soil varied from 0.78 mg/g to 1.07 mg/g with an average (n=8) of 0.9 mg/g in the study area (Table 6.9, Figure 6.34). Zn showed the highest concentration (1.07 mg/g) at source point of Nuniarchar fishery ghat (S 02), while the second highest concentration (1.01 mg/g) was found at No.6 fishery ghat area (S 01). The concentration of Zn in each sample area was significantly lower in comparison to that of the world average (5.0 mg/g).

The summary of the heavy metal concentration in soil of the Bakkhali River and channel sample areas showed that, in eight source points the Fe concentration varied from 2.48 mg/g to 4.31 mg/g. The highest Fe content (4.31 mg/g) at S 07 (Char Para) was noticeably higher than the world average (3.4 mg/g).Conversely, the highest concentration of heavy metals, such as the Cu (0.32 mg/g) at Nuniarchara industrial area (S 04) and Zn (1.07mg/g) at Nuniarchara fishery ghat (S 02) did not cross the world average concentration and the least content of the Cd (0.01 mg/g) was found at No. 6 and Nuniarchara fishery ghat (S 01and S 02) and at Char Para River mouth (S 07). On the other hand, the concentration of Pb was the highest (0.37 mg/g) at No.6 fishery ghat and Khurushkul project area (S 01 and S 03); followed closely by Pb concentration at Nuniarchara fishery ghat at S 02 (0.36 mg/g) and at Kutubdia Para (S 06; 0.35 mg/g). It should be noticed that, even the average concentration of Pb (0.33 mg/g) in the sample areas of the present study was 10 times more than that of the world standard (0.03 mg/g). According to the average concentration of the heavy metals in soil of the sample areas, the hierarchy was found as: Fe > Zn> Pb> Cu>Cd.

6.4.2 Heavy Metal Concentration in Water of the Bakkhali River and Channel Estuary

The concentration of five heavy metals such as Cd, Cu, Fe, Pb, and Zn of seven source points in water of the Bakkhali River and channel estuary were measured to determine the environmental quality of the river and channel water (Table 6.13). Table 6.11 shows that, the hierarchy of average heavy metal concentration in water of the Bakkhali River and channel water was: Fe >Pb> Zn >Cd> Cu.

Table 6.11: Heavy Metal Concentration in Bakkhali River and Channel Estuary Water

Sample ID	Cd-content	World Standard of Cd	Cu-content	World Standard of Cu	Fe-content	World Standard of Fe	Pb-content	World Standard of Pb	Zn-content	World Standard of Zn
Water Sample	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Sample 01 (No.6 Fishery ghat)	0.24	0.11	0.39	0.9	0.71	4.4	1.21	0.03	0.16	5.0
Sample 02 (Nuniarchar Fishery ghat)	0.08	0.11	0.14	0.9	1.80	3.4	0.73	0.03	0.13	5.0
Sample 03 (Khurushkul)	0.24	0.11	0.37	0.9	1.78	3.4	1.43	0.03	0.22	5.0
Sample 04 (Nuniarchar I/A)	0.20	0.11	0.28	0.9	0.82	3.4	2.09	0.03	0.21	5.0
Sample 05 (Char Para, Bakkhali Channel)	0.21	0.11	0.33	0.9	1.00	3.4	1.08	0.03	0.16	5.0
Sample 06 (Kutubdia Para, Bakkhali Channel)	0.16	0.11	0.30	0.9	2.22	3.4	0.96	0.03	0.15	5.0
Sample 07 (Char Para, Channel mouth)	0.01	0.11	*BDL	0.9	1.03	3.4	*BDL	0.03	0.05	5.0
Average=	0.16		0.3		1.3		1.25		0.17	

Source: i) Present Study, March 2018; ii) Rashid, et al., 2014 *BDL=Below Detection Level

Cd Concentration in Water

The Cd concentration ranges from 0.01 mg/L to 0.24 mg/L, with an average (n=7) of 0.16 mg/L. The highest Cd concentration (0.24 mg/L) was at No.6 fishery ghat area (S 01) and Khurushkul Project area (S 03), the second highest Cd content (0.21 mg/L) was at Char Para (S 05) (Table 6.11, Fig.6.36).

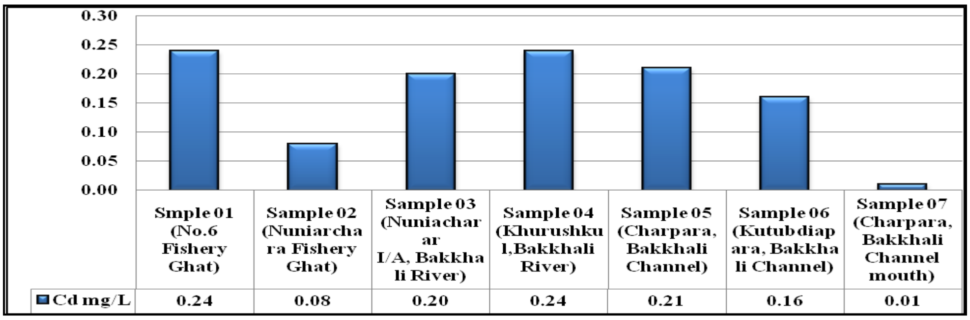


Fig. 6.36: Concentration of Cd in Water

Source: Present Study, 2018

Cu Concentration in Water

The concentration of Cu varies from 0.14mg/L to 0.39 mg/L with an average (n =7) of 0.3 mg/L. The highest concentration (0.39 mg/L) has been found at source point of No.6 fishery ghat area (S 01) (Table 6.13, Figure 6.37).The second highest content of Cu (0.37 mg/L) has been found at Khurushkul Project area (S 03).

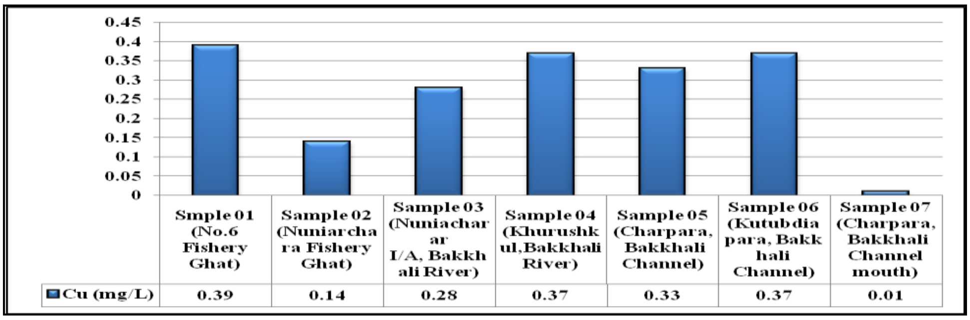


Fig.6.37: Concentration of Cu in Water
Source: Present Study, 2018

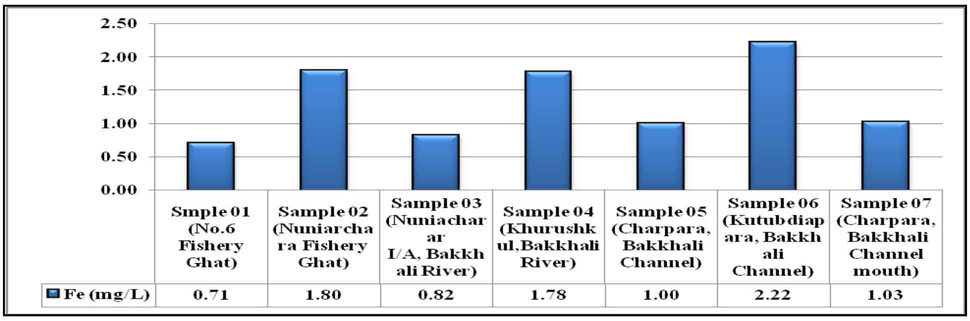


Fig. 6.38: Concentration of Fe in Water
Source: Present Study, 2018

Fe Concentration in Water

The Fe concentration varies from 0.71 mg/L to 2.22 mg/L in the Bakkhali River and channel estuary, while the average (n=7) concentration was found to be 1.30 mg/L (Table 6.11, Fig. 6.38). The highest concentration of Fe (2.22 mg/L) was found at source point of Kutubdia Para (S 06), followed by the second highest concentration (1.80 mg/g) at Nuniarchar Fishery ghat (S 02) area. The Khurushkul project area has the highest Fe content (1.78 mg/L).

Pb Concentration in Water

The concentration of Pb varies from 0.73mg/L to 2.09 mg/L, with an average (n=7) of 1.26 mg/L. The highest concentration was found at the Nuniarchra industrial area (S 04) of Bakkhali River (Table 6.11, Figure 6.39). However, during high tide the river along with the adjacent low lying areas inundates under 5 to 6 feet brackish bay water which wash away the effluents from the area. The second highest Pb content (1.43

mg/L) was found at Khurushkul project area (S 03), followed by the Pb content of 1.21 mg/L at No.6 Fishery ghat (S 01).

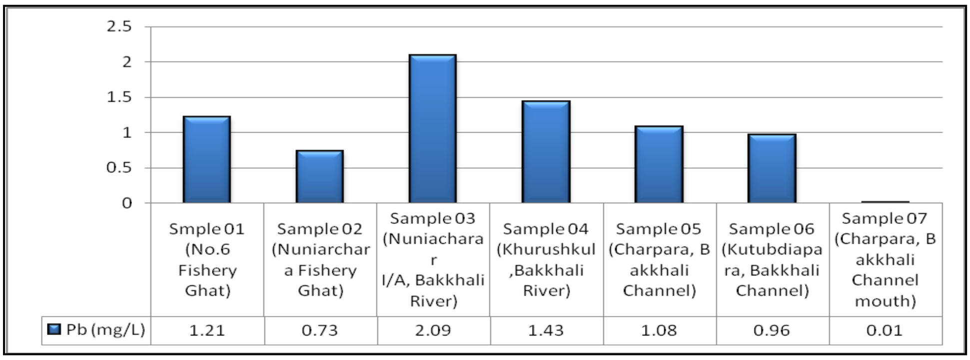


Fig.6.39: Concentration of Pb

Source: Present Study, 2018

Zn Concentration in the Water

The concentration of Zn varies from 0.05mg/L to 0.22 mg/L, with an average (n=7) of 0.17 mg/L in the study area. Zn shows the highest concentration at Khurushkul project area (S 03). The second highest Zn content (0.21 mg/L) was found at Nuniarchara industrial area, where the toxic water continuously drain into the river water (Table 6.11, Fig.6.40). However, the water sample collected from the Char Para at the Bakkhali channel mouth (S 07) has the lowest concentration of Zn (0.05 mg/L).

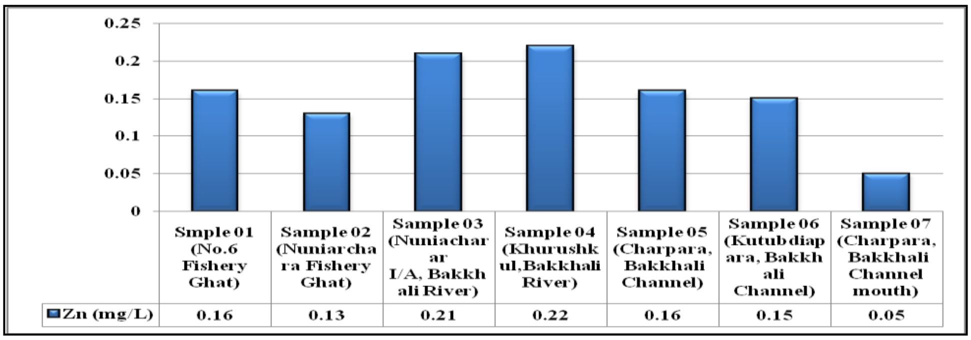


Fig. 6.40: Concentration of Zn in Water

Source: Present Study, 2018

The summary of heavy metal concentration in water of the Bakkhali River and Channel sample areas show that, out of seven sample areas, five sample areas (S 01, S 03, S 04, S 05, S 06) has higher Cd concentration than the world standard average. The highest Cd concentration in the S 01 and S 03 was 0.24 mg/L, which was around 0.13 mg/L more than the world average (0.11 mg/L).The average Cd content (0.16 mg/L) of the present study sample areas was about 0.05 mg/L more than the world average. The average Pb concentration (1.25 mg/L) in water of the sample areas was almost 41 times higher than of the world average (0.03mg/L). On the other hand, in the sample areas, the average concentration of Cu (0.33 mg/L) was 0.57 mg/L, Fe

(1.30 mg/L) was 2.37 mg/L and Zn (0.17 mg/L) was 4.83 mg/L lesser than that of the world average. According to the average concentration, the hierarchy of heavy metals in the water of the sample areas was as follows: Fe > Pb > Cu> Cd > Zn.

6.4.3 Amount of Non-Metals (Nutrients) in Soil and Water of the Bakkhali River and Channel Estuary

Two most important non-metals: (i) Phosphorus and ii) Sulphur, which also function as the nutrients in estuarine environment was measured to detect the environmental condition of the Bakkhali River and channel estuary.

Amount of Phosphorus and Sulphur in Soil

Totally six soil samples (S 01,S 03, S 05,S 06, S 07, S 08) have Phosphorous content within 01 PPM. The rest two samples (S 02 and S 04) of soil have 02 PPM phosphorous content. On the other hand, the Sulphur was below detection level (BDL) in the soil of the sample areas.

Amount of Phosphorus and Sulphur in Water

The amount of Phosphorous and Sulphur in water samples were below 03 PPT.

6.4.4 Physio-Chemical Quality of Soil Samples of the Bakkhali River and Channel Estuary

The physio-chemical quality of the soil samples were measured with the HI 9813-5 and 9813-6 Portable machine at the Environmental laboratory of the department of Geography and Environment, University of Dhaka. The three parameters taken to measure the physio-chemical quality of the soil samples were: i) Potential of Hydrogen (pH), ii) Electric Conductivity (EC), and iii) Temparature

Table 6.12: Physio-Chemical Quality of the Soil

Sample areas	pH	EC (mS/Cm)	Temperature (°C)
Sample 01 (No.6 Fishery Ghat, Bakkhali River)	8.4	2.31	24.3
Sample 02 (Nuniarchara Fishery Ghat)	8.2	6.42	23.5
Sample 03 (Khurushkul Project area)	8.3	6.00	23.2
Sample 04 (Nuniarchara I/A, Bakkhali River)	7.4	6.37	24.2
Sample 05 (Char Para, Bakkhali Channel)	7.3	3.98	22.5
Sample 06 (Kutubdia, Bakkhali Channel)	6.9	4.26	22.6
Sample 07 (Char Para, Bakkhali Channel)	6.9	5.80	23.1
Sample 08 (Kutubdia Para, Bakkhali Channel)	5.1	5.35	22.1
Average	7.2	4.6	23.2

Source: Present Study, 2018 *** mS/Cm= mili Siemens/Centimeter**

i) The Potential of Hydrogen (pH) of Soil

The world standard range of pH value in soil for brackish water aquaculture was 6.5 - 7.5 (Soil Survey, U.S. 2011), while the pH value of the present study sample areas vary from pH 5.1 to 8.4. The soil at the Kutubdia Para River mouth (S 08; pH 5.1) and Nuniarchara industrial area (S 04; pH 7.4) was 'Slightly Alkaline'.

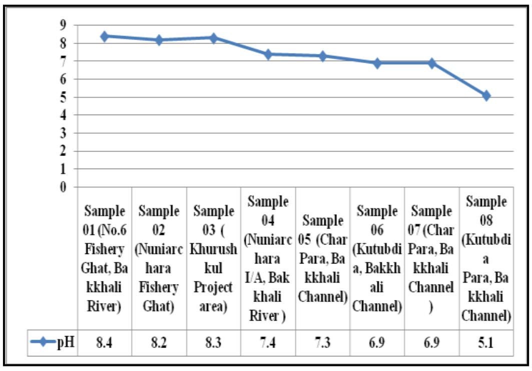


Fig.6.41: The Potential of Hydrogen (pH) of Soil

Source: Present Study, 2018

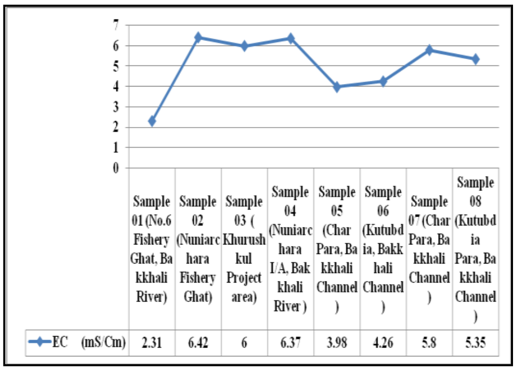


Fig. 6.42: Electrical Conductivity (EC) of Soil

Source: Present Study, 2018

The soil of the sample areas, such as the Char Para, Kutubdia Para and Char Para river mouth (S 05, S 06,S 07) was categorized as 'Neutral soil' (pH 6.9-7.3).The soil of other three Sample areas, such as No.6 fishery ghat, Nuniarchara fishery ghat, and Khurushkul project area (S 01, S 02,S 03) was 'Moderately Alkaline' (pH 8.2-8.4). Nevertheless, the average pH value was 7.2 (n=8), which was at the last edge of 'Neutral Soil' range in the pH scale (Table 6.12, Fig.6.41).

ii) Electrical Conductivity (EC) of Soil

The average EC in soil samples of the study area was 4.6 mS/Cm, ranging from 2.3-6.4 mS/Cm (Table 6.12, Fig.6.42).The highest EC (6.4 mS/Cm) has been found at Nuniarchara Fishery ghat and Nuniarchara industrial area along Bakkhali River (S 02 and S 04); followed by the second highest EC at Khurushkul project area along Bakkhali River bank (6.0 mS/Cm). The lowest EC has been found at No.6 Fishery ghat area (S 01).

iii) Temperature in the Soil

The range of soil temperature at the sample areas has been found to be between 22.1°C -24.3°C during the survey (23.4°C in average), showing an increasing pattern in comparison to the average temperature of 22°C, prevailing at the east and south coast of Bangladesh (Banglapedia, 2015) (Table 6.12, Fig.6.43).

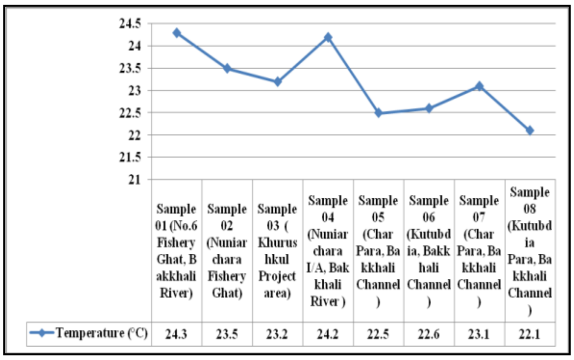


Fig. 6.43: The Temperature of the Soil
Source: Present Study, 2018

6.4.5 Physio-Chemical Quality of Water of the Bakkhali River and Channel Estuary

The physio-chemical qualities of the seven surface water samples were measured with the HI 9813-5 and 9813-6 Portable machine at the department of Geography and Environment, University of Dhaka. The four parameters taken to measure the physio-chemical quality were: i) Potential of Hydrogen (pH), ii) Electric Conductivity (EC), iii) Total Dissolved Solids (TDS), and iv) Temparature (°C)

Table 6.13: Physio-Chemical Quality of Water

Water Samples	pH	EC (mS/Cm)	TDS (PPM*)	Temperature (°C)
Sample 01 (No.6 Fishery Ghat, Bakkhali River)	8.3	8.63	1	31.5
Sample 02 (Nuniarchara Fishery Ghat, Bakkhali River)	7.8	8.64	1	31.7
Sample 03 (Khurushkul project area, Bakkhali River)	8.1	8.65	1	31.6
Sample 04 (Nuniarchara I/A, Bakkhali River)	8.4	8.65	1	31.5
Sample 05 (Char Para, Bakkhali Channel)	8.6	8.65	1	32.1
Sample 06 (Kutubdia, Bakkhali Channel)	7.5	8.75	1	31.9
Sample 07 (Char Para, Bakkhali Channel mouth)	7.6	8.73	1	31.8
Average	8.04	8.67	1	31.7

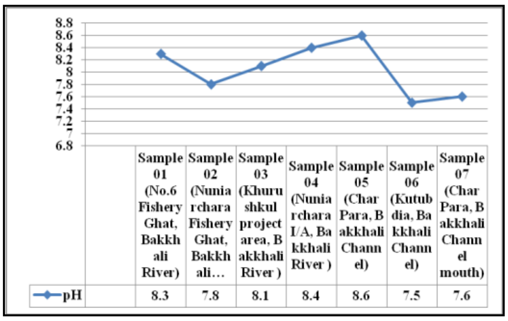
Source: Present Study, 2018 * PPM: Parts Per Million

i) The Potential of Hydrogen (pH) of Water

The Potential of Hydrogen (pH) of water samples in the study area ranges from 7.5 to 8.6, with an averge value of 8.04 (Table 6.15, Fig. 6.44). The standard range of pH value for the brackish sea water was of 6.5 to 8.5 (EPA,2005). The water of the source point at Char Para (S 05) contains the highest concentration (pH 8.6), which categorize the water as 'Alkaline'. The Kutubdia Para (S 06) has the lowest pH concentration. All the sample areas in the Bakkhali River and channel estuary contain higher pH value, which means the water in this sample area was 'Alkaline' (Table 6.13, Fig.6.44).

ii) Status of Electrical Conductivity (EC) of the Water

The average EC in water samples of the study area was 5.06 mS/Cm, while the amount of EC varies from 8.63-8.75 mS/centimeter (Table 6.13, Fig.6.45).



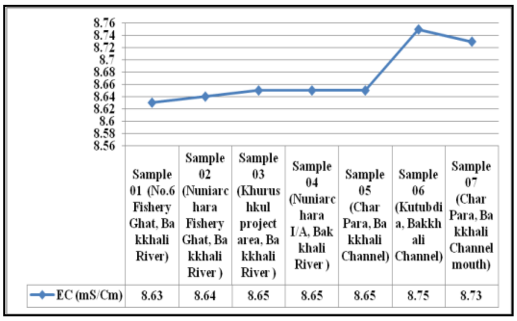


Fig. 6.44: Potential of Hydrogen (pH) **Fig. 6.45: Electric Conductivity (EC)**

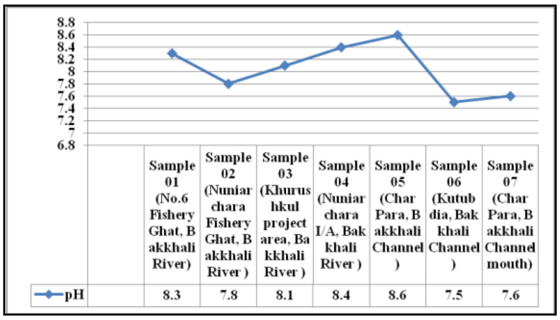


Fig.6.46: Temperature

Source: Present Study, 2018

iv) Temperature in Water Samples

The average surface temperature of water of the sample areas was found to be 31.7°C in average, while the usual surface temperature of the Bay of Bengal ranged from 22°C to 31° C (Table 6.15). On the other hand, the temperature of the sample soil was between 31.5 °C to 32.1°C (Table 6.13, Fig.6.46).

v) TDS in Water Samples

The average as well as the individual amount of Total Dissolved Solids (TDS) in water samples of the study area was 01 mg/L (Table 6.13).

6.5 Environmental Quality of Soil and Water of the Marine Drive Study Area

The soil and water of three source points along the coast of Marine Drive, like the Sonarpara Shrimp hatchery area, the Himchari Shrimp hatchery area and the Inani Beach Tourist Spot area was measured to determine the environmental qualities of soil and water of the area (Map 6.4). Total five heavy metals, such as Cadmium (Cd), Copper (Cu), Iron (Fe), Lead (Pb), and Zinc (Zn); two non-metals/ nutrients, such as the Phosphorous and Sulphur, three physio-chemical parameters of soil, such as the pH, EC, and Temperature and four parameters of water, such as, pH, EC, TDS and Temperature; were measured to analyze the environmental condition of the sample areas**.** The samples were analyzed in the Environmental laboratories of the department of Geography and Environment, department of Soil, Water and Environment, and CARS, D.U. The samples were collected during the dry weather (pre-monsoon), from 16th -20th March, 2016.

6.5.1 Heavy Metal Concentration in Soil of the Marine Drive, Cox's Bazar

The concentration of five heavy metals, such as Cd, Cu, Fe, Pb, and Zn of three source points of the Marine Drive has been shown in Table 6.14.The hierarchy of average heavy metal concentration in soil samples was: Fe> Zn >Pb> Cu> Cd.

Cd Concentration in the Soil

The Cd concentration of the soil samples along the three source points of Marine Drive was 0.01 mg/g (Table 6.14).

Table 6.14: Heavy Metal Concentration in Soil of the Marine Drive, Teknaf Peninsula, 2016

Sample ID	Cd-content	World Standard of Cd	Cu-content	World Standard of Cu	Fe-content	World Standard of Fe	Pb-content	World Standard of Pb	Zn content	World Standard of Zn
Soil Sample	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g
Sample 01 Inani Beach, Marine Drive	0.01	0.11	0.13	0.9	2.58	3.4	0.24	0.03	0.77	5.0
Sample 02 Sonarpara, Marine Drive	0.01	0.11	0.15	0.9	2.09	3.4	0.26	0.03	0.71	5.0
Sample 03 Himchari, Marine Drive	0.01	0.11	0.08	0.9	4.94	3.4	BDL	0.03	0.86	5.0
Average	0.01		0.12		3.20		0.25		0.78	

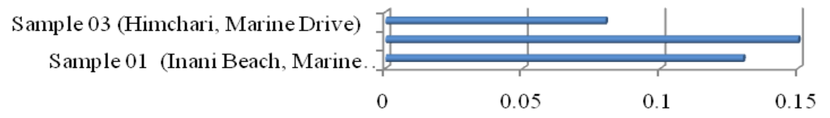
Source: i) Present Study, 2018; ii) Rashid, et al., 2014 (World Standard of Heavy Metals) *BDL=Below Detection Level

Cu Concentration in Soil

The concentration of Cu ranged from 0.08 mg/g to 0.15 mg/g, while the average (n=3) was 0.12 mg/g (Table 6.14, Fig. 6.47) in the study area. The soil sample, collected from a drain pouring toxic waste water directly to the soil and water from several hatcheries had the highest content of Cu (S 02). The Cu content of the sample areas were quite lower than the world average (0.9 mg/g).

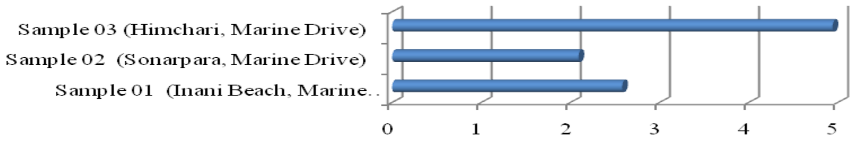
Fe Concentration in Soil

The Fe concentration ranges from 2.09 mg/g to 4.94 mg/g, while the average (n=3) was 4.20 mg/g (Table 6.14, Fig. 6.48). The highest content of Fe was at Himchari Shrimp hatchery area (S 03), which was 1.54 mg/g more than the world average (3.4 mg/g).



	Sample 01 (Inani Beach, Marine Drive)	Sample 02 (Sonarpara, Marine Drive)	Sample 03 (Himchari, Marine Drive)
Cu-content mg/g	0.13	0.15	0.08

Fig. 6.47: Concentration of Cu in Soil
Source: Present Study, 2018

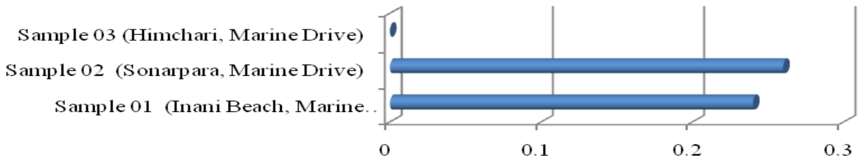


	Sample 01 (Inani Beach, Marine Drive)	Sample 02 (Sonarpara, Marine Drive)	Sample 03 (Himchari, Marine Drive)
Fe-content mg/g	2.58	2.09	4.94

Fig. 6.48: Concentration of Fe in Soil
Source: Present Study, 2018

Pb Concentration in Soil

The **Pb** concentration of S 01 and S 02 was 0.24 mg/g and 0.26 mg/g, while the average (n=2) was 0.25 mg/g (Table 6.14, Fig. 6.49). The Pb concentration of S 03 was below detection level (BDL). However, the average concentration of Pb in the soil of sample areas was 10 times higher than the world standard average concentration (0.03 mg/g).



	Sample 01 (Inani Beach, Marine Drive)	Sample 02 (Sonarpara, Marine Drive)	Sample 03 (Himchari, Marine Drive)
Pb-content mg/g	0.24	0.26	0

Fig. 6.49: Concentration of Pb in Soil
Source: Present Study, 2018

Zn Concentration in Soil

The **Zn** concentration ranges from 0.71 mg/g to 0.86 mg/g, while the average (n=3) was 0.78 mg/g (Table 6.14, Fig. 6.50). The highest content of Zn was at Himchari Shrimp hatchery area (S 03).The concentration of Zn in the soil of the sample areas was quite lower than the world average concentration (5.0 mg/g).

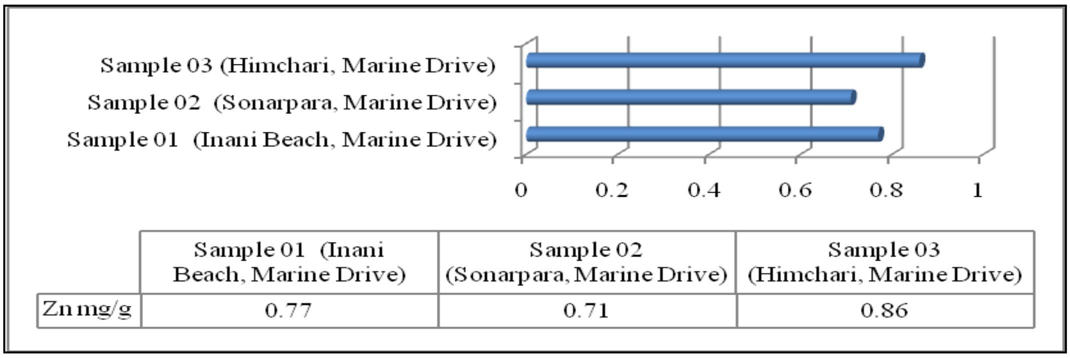


Fig. 6.50: Concentration of Zn in Soil

Source: Present Study, 2018

6.5.2 Amount of Non-Metals (Nutrients) in Soil and Water of the Marine Drive Sample areas

The two most important non-metals (i) Phosphorus and ii) Sulphur, which as well function as the nutrients in estuarine environment was measured to detect the environmental condition of the sandy beach ecosystem along the Teknaf coastline.

Amount of Phosphorus and Sulphur in Soil

Two soil samples (S 01 and S 03) had Phosphorous content within 01 PPM, while S 02 had 02 PPM phosphorous. The Sulphur content was below detection level (BDL) in soil of the sample areas.

6.5.3 Physio-Chemical Quality of Soil at Marine Drive Study Area

The physio-chemical quality of three sample areas was measured with the HI 9813-5 and 9813-6 Portable machine at the department of Geography and Environment, University of Dhaka. The parameters taken to measure the physio-chemical quality were: i) Potential of Hydrogen (pH), ii) Electric Conductivity (EC), iii) Temparature

Table 6.15: Physio-Chemical Quality of Soil at Marine Drive Sample areas

Soil Sample	pH	EC (mS/Centimeter)	Temperature (°C)
Sample area 01 (Inani Beach, Marine Drive)	5.8	6.37	26.5
Sample area 02 (Sonarpara, Marine Drive)	7.6	2.04	26.5
Sample area 03 (Himchari, Marine Drive)	7.6	1.22	26.4
Average	7.0	3.21	26.5

Source: Present Study, 2018

(i) Potential of Hydrogen (pH) of Soil

The pH level of the three source points of the Marine Drive varies from 5.8 to 7.6. This shows that, the soil of both S 02 and S 03 were ‘Slightly Alkaline’ type. The soil quality at Inani beach tourist spot area (S 01), as well as, the average soil condition of the sample areas was ‘Moderately Acidic’ in nature (Table 6.15, Fig.6.51).

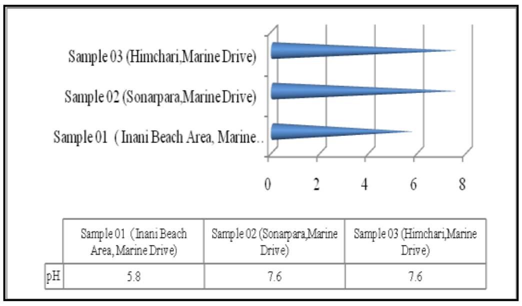


Fig. 6.51: Potential of Hydrogen (pH)

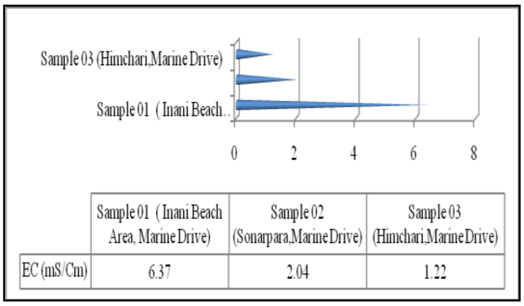


Fig. 6.52: Electrical Conductivity

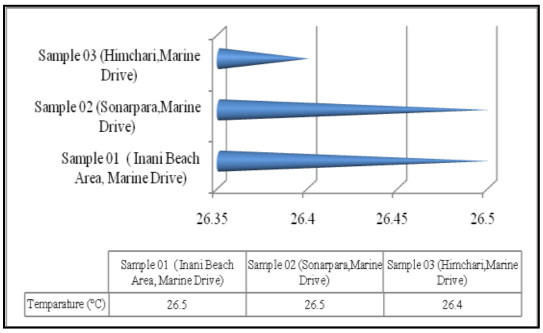


Fig. 6.53: Temperatures

Source: Present Study, 2018

(ii)Electrical Conductivity of Soil

The EC of the soil ranged from 1.22 mS/Cm to 6.37 mS/Cm in the sample areas, with an average EC of 4.21 mS/Cm (Table 6.15, Fig.6.52).

(iii)The Temperature of Soil

The temperature of the sample area varied from 26.4 to 26.5 °C, and the average temperature was 26.5°C (Table 6.15, Fig.6.53).

6.5.4 Heavy Metal Concentration in Water of the Marine Drive Study, Teknaf Coast

The concentration of five heavy metals, such as Cd, Cu, Fe, Pb, and Zn of three source points of the Marine Drive were measured to determine the environmental quality of water. The hierarchy of average concentration of heavy metal in sample water was: Fe> Pb> Cu> Cd> Zn.

Table 6.16: Heavy Metal Concentration in Water of Teknaf Coast

Sample ID	**Cd-content**	**World Standard of Cd**	**Cu-content**	**World Standard of Cu**	**Fe-content**	**World Standard of Fe**	**Pb-content**	**World Standard of Pb**	**Zn content**	**World Standard of Zn**
Water Sample	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Sample 01 (Inani Beach, Marine Drive)	0.20	0.11	0.37	0.9	3.43	3.4	1.1	0.03	0.29	5.0
Sample 02 (Sonarpara, Marine Drive)	0.23	0.11	0.34	0.9	2.48	3.4	BDL	0.03	0.26	5.0
Sample 03 (Himchari, Marine Drive)	0.36	0.11	0.48	0.9	1.55	3.4	1.46	0.03	0.1	5.0
Average	0.27		0.40		2.49		0.90		0.22	

Source: i) Present Study, 2018; ii) Rashid, et al., 2014 (World Average of Heavy Metals)

Cd Concentration in Water

The Cd concentration of water samples along three source points of Marine Drive ranged between 0.20-0.36 mg/L (Table 6.16, Fig.6.54). The highest Cd content (0.36 mg/L) was found at Himchari shrimp hatchery area (S 03), while the average was 0.27 mg/L. The sample area water contained two times more Cd than world average (0.11 mg/L).

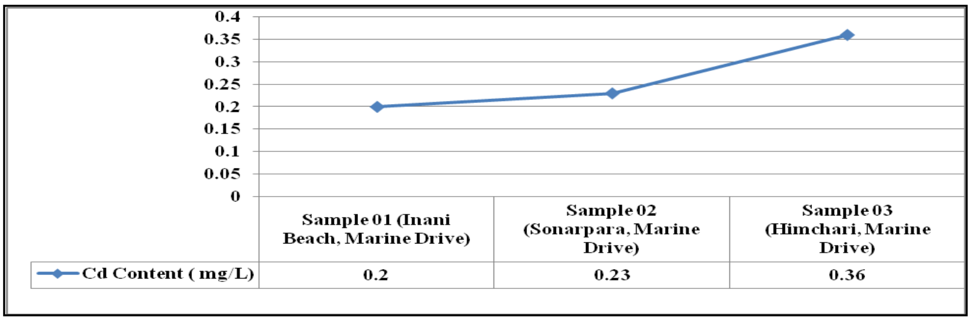


Fig. 6.54: Cd Concentration in Water

Source: Present Study, 2018

Cu Concentration in Water

The concentration of Cu ranged from 0.34 to 0.48 mg/L, while the average (n=3) was 0.4 mg/L (Table 6.16, Fig.6.55) in the study area. The water samples collected from the source points of toxic waste water from several hatcheries and fish processing factories had the highest content of Cu (S 02). However, the average Cu content of the sample areas was nearly half of the world average (0.9 mg/L).

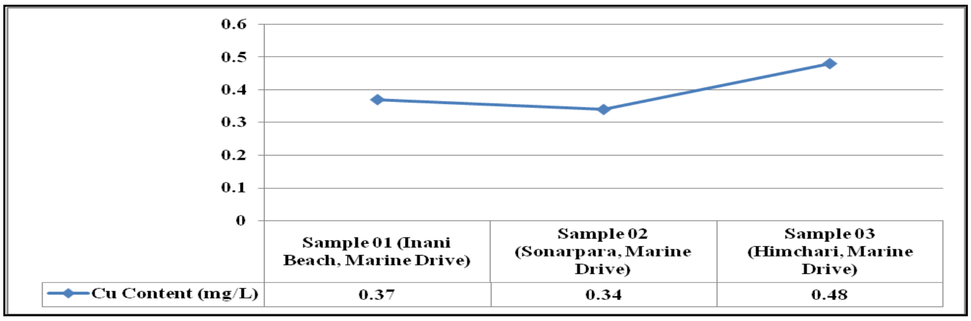


Fig. 6.55: Concentration of Cu in Water

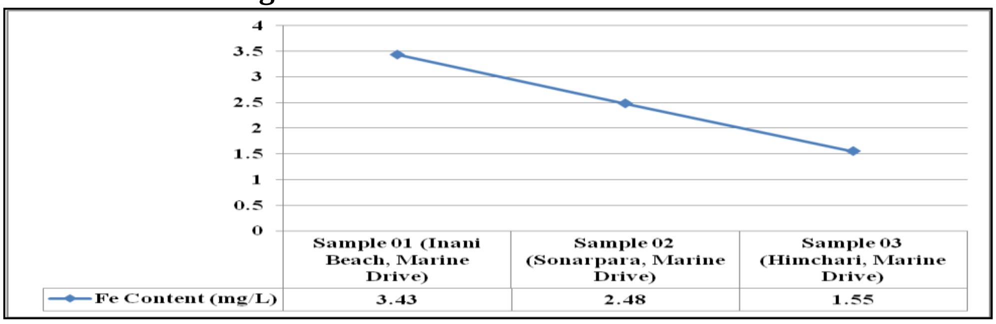


Fig.6.56: Fe Concentration in Water

Source: Present Study, 2018

The Fe concentration ranged from 1.55 to 3.43 mg/L, and the average (n=3) was 2.49 mg/L (Table 6.16, Fig. 6.56). The highest content of Fe was at Inani beach tourist spot area (S 03), which slightly crossed the level of world average (3.4 mg/L).

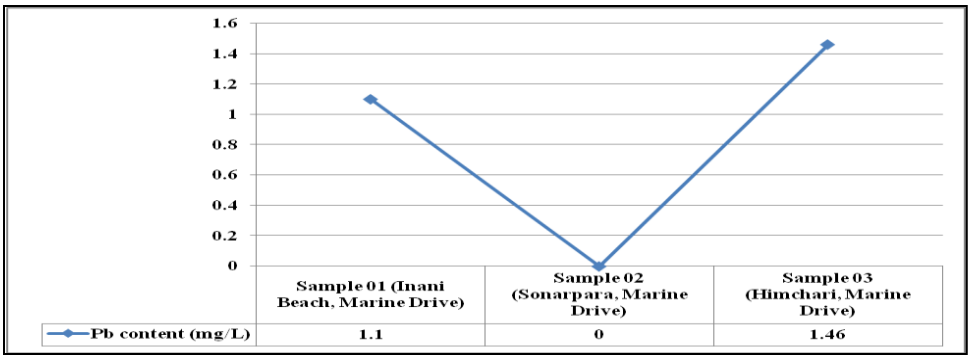


Fig.6.57: Pb Concentration in Water

Pb Concentration in Water

The Pb concentration of S 01 and S 03 were 0.1 mg/L and 1.46 mg/L consecutively, while the average (n=2) was 0.9 mg/L (Table 6.16, Fig. 6.57). The Pb concentration of Sonarpara shrimp hatchery area (S 02) was below detection level (BDL). However, the average Pb concentration in the water of sample areas was 30 times higher than the world average concentration (0.03 mg/L).

Zn Concentration in Water

The Zn concentration ranges from 0.1 to 0.29 mg/L, while the average (n=3) was 0.22 mg/L (Table 6.16, Fig. 6.58). The highest content of Zn was at Inani beach tourist spot area (S 01).The concentration of Zn in the soil of the sample areas was quite lower than the world standard average concentration (5.0 mg/g).

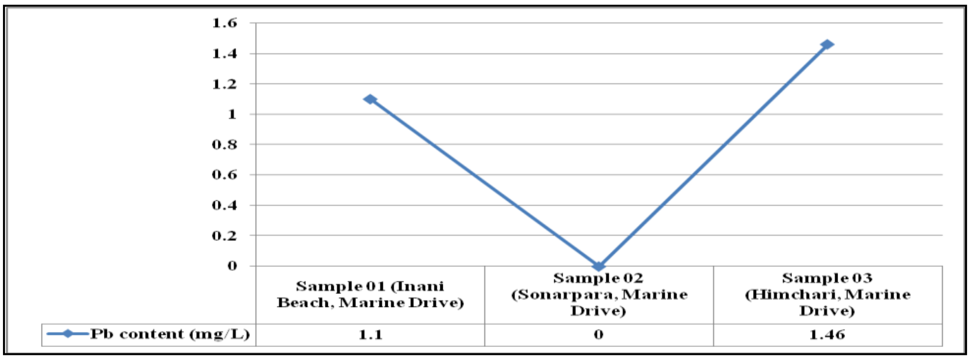


Fig.6.58: Zn Concentration in Water

Source: Present Study, 2018

6.5.5 Amount of Non-Metals (Nutrients) in Water of the Study Area

The amount of both Phosphorous and Sulphur in the water samples were below 03 PPT.

6.5.6 Physio-Chemical Quality of Water of the Study Area

The four parameters taken to measure the physio-chemical quality were (i) Potential of Hydrogen (pH), (ii) Electric Conductivity (EC), (iii) Temparature

Table 6.17: Physio-Chemical Quality of Water at Marine Drive Sample Areas

Water Sample	pH	EC (mS/Cm)	Temperature (°C)
Sample area 01 (Inani Beach, Marine Drive)	7.7	8.48	31.6
Sample area 02 (Sonarpara, Marine Drive)	8.5	8.17	31.8
Sample area 03 (Himchari, Marine Drive)	8.4	0.22	31.9
Average	8.2	5.6	31.8

Source: Present Study, 2018

(i) Potential of Hydrogen (pH) in Water

The pH content of the water samples ranged from 7.7 to 8.5, with an average (n=3) of pH 8.2. This proves that, water of each sample area crossed the Neutral water boundary and was of alkaline type (Table 6.17, Fig.6.59).

ii) Electric Conductivity (EC) in Water

Electric conductivity (EC) of water at Marine drive sample areas was between 0.2 to 8.5 ms/Cm, while the average (n=3) was 5.6 mS/Cm (Table 6.17, Fig.6.60).

iii) Temparature of Water

The temperature of water at the sample areas ranged from 31.6 to 31.9 °C (Table 6.17, Fig.6.61).

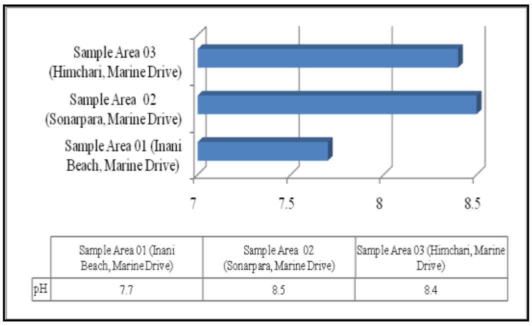


Fig. 6.59: pH in Water

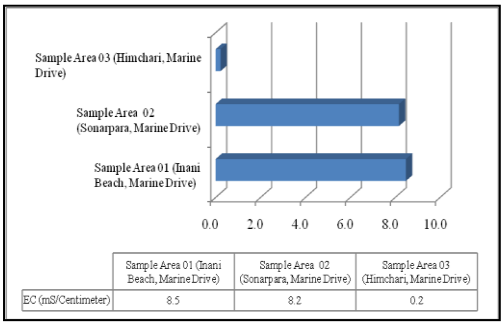


Fig. 6.60: EC in Water

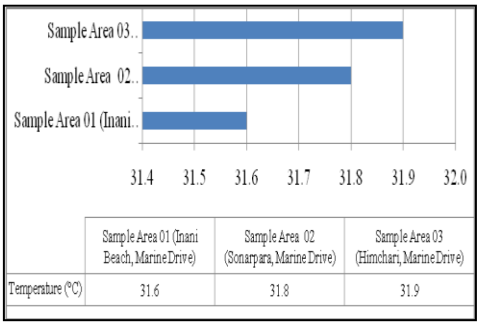


Fig. 6.61: Temperature of Water

Source: Present Study, 2018

The summary of the water samples of the study area showed that, the average Cd concentration in water was 0.27 mg/L, while the average Pb content (0.9 mg/L) was almost 30 times higher than the world average (0.03 mg/L). The average Fe concentration was 2.49 mg/L, which was about 0.91 mg/L below the world average. Fe concentration was 2.49 mg/L. However, the average Cu (0.40 mg/L) and Zn (0.22 mg/L concentration was quite lower than their world average (0.9 mg/L and 5.0 mg/L accordingly). The non-metal or nutrient concentration in the water of the sample areas was below 03 PPT for Phosphorous as well as Sulphur content.

In view of the physio-chemical quality of the sample area water, it was revealed that, the average pH content of the water was 8.2, which was considered as 'Alkaline' in nature. The average electrical conductivity of the water samples was 5.6 mS/Cm and the temperature was 32.1°C in average.

Illustration 6.1: Collected Soil Samples

Illustration 6.2: Digestion of Water Samples

Illustration 6.4: Filtering the Digested Soil Samples

Illustration 6.5: Digested Water Samples Stored in bottles

Illustration 6.1 to 6.5: Sample Processing Methods

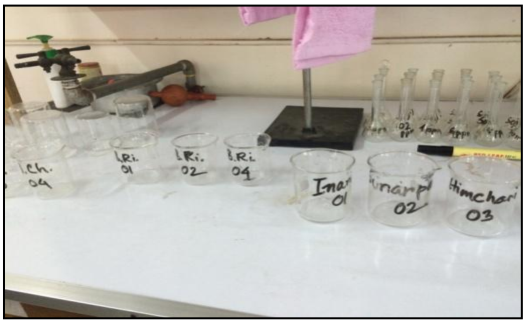


Illustration 6.6: Preparing to measure the Physio-Chemical Parameters of Soil and Water Samples

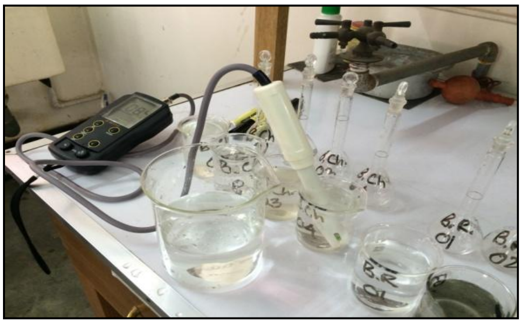


Illustration 6.7: Measuring the Physio-Chemical Parameters of the Samples with Ph Meter

Illustration 6.8: Cleaning the collected Mollusk Shell Samples

Illustration 6.9: Grinding the Collected Mollusk Shells

Illustration 6.10: Powdered Mollusk Shell Samples

Illustration 6.11: Preparing the Grinded Mollusk Shell Samples for digestion

Illustration 6.6 to 6.11: Sample Processing Methods

6.6 Conclusion

The study of the environmental condition of the four sample areas, the Feni River, Jalkadar River, Bakkhali River and channel, and the Marine Drive reveals that, both in soil and water, the concentration of Pb was the highest, consecutively being 10 to 18 times and 12 to 42 times higher than the world average. This was actually frightening for the entire eastern coastal zone ecosystem. The Fe concentration has followed by the Pb concentration in soil samples, being 1.5 to 1.6 times higher than the world average. However, the Cd content crossed the world standard limit at the source points of the Bakkhali River and channel estuary water. Nevertheless, the Cu and Zn concentration was quite below the world standard average. This high concentration of Pb, Cu and Fe in the study area soil was creating an adverse effect on estuarine environment of our country. In case of the physio-chemical quality of the study area, the pH content was observed to be alarmingly high in average for both soil and water samples. The adverse response of estuarine flora and fauna to the changes in pH, EC, TDS and temperature discloses the consequences of anthropogenic impacts on estuarine floral and faunal species. The electrical conductivity and temperature of the soil was lower than that of the water. However, the amount of TDS in water was found to be 01 PPM. The literatures as well as the present research prove the deteriorating situation of the present study area. The toxic condition of the environmental features like the heavy metal concentration in the soil, water and mollusk shells; the deteriorating physio-chemical quality of the soil and water along the sample area estuaries and coastline; the declining calcium content in the mollusk shells turning them to fragility indicating the bio-diversity loss in the rich coastal and marine ecosystem has inspired the selection of these criteria as the indicators to measure the state of the environmental condition of the present study area.

7.1 Introduction

Bangladesh, a land of diverse ecosystems, has been significantly rich in terrestrial, avifaunal and aquatic resources due to its unique geo-physical location, climatic condition, and great seasonal variability. The diverse ecosystems of Bangladesh has been broadly clustered as- (a)Terrestrial ecosystem, (b) Inland Water ecosystem, and (c) Coastal and Marine ecosystem. The Terrestrial ecosystem comprises three distinct categories, such as (i) the Forest ecosystem, (ii) the Agro ecosystem, and (iii) the Homestead ecosystem. In the present research, the vegetation coverage status of the four sample areas was discussed as a component of the Terrestrial ecosystem. The Estuarine ecosystem (area 6,102 km^2), enriched with diverse flora and fauna, with brackish water and mangrove swamp areas (Byomkesh, et al., 2008) was discussed as a significant component of the Coastal and Marine ecosystem.

7.2 Bio-ecological Zone of the Study Area

Bio-ecological zoning in Bangladesh was conducted by IUCN, Bangladesh while producing an atlas on Bio-ecological zones of Bangladesh in 2002 (Nishat et al., 2002). Bio-geographically, Bangladesh has been included within the Oriental Region, lying between the transition of the Indo-Himalayan and Indo-Chinese sub regions (Nishat, et al., 2002). The country has been within the transitional zone for the flora and fauna of the Indian subcontinent and Southeast Asia, and has been part of the Indo-Burma biodiversity hotspot (Turley et al., 2016).

The Present Study area has been categorized as the 'Bio-Ecological Zone 8a' (Nishat, et al., 2002), which consists- i) the Coastal Plain, and iii) the Sandy Beach/Sand Dunes (Map 7.1). Nevertheless, Bangladesh has been one of the most significant bio-ecological regions of the world, in terms of migratory species, stepping stones, staging ground and flyways of wildlife movement. The country has been situated at the intersection of two major international shorebird migration flyways, for instance, along the western edge of the East Asian-Australian flyway and eastern edge of the Central Asian Indian flyway.

7.3 Bio-Diversity Status of the Study Area

Bangladesh, due to its unique geographic location, climatic condition and large seasonal variability, holds a great range of different flora and fauna. The ecosystems of

Bangladesh have been broadly clustered as (a) Terrestrial, (b) Inland Water, and (c) Coastal and Marine. The present study focuses upon the bio-diversity of the two ecosystems, dominating the east coast of Bangladesh, namely, (i) the Terrestrial and (ii) the Coastal and Marine ecosystem. The status of the vegetation coverage of the study area was discussed in the following section as a component of Terrestrial ecosystem Illustration.

7.3.1 The Floral Bio-Diversity of the Study Area

The floral biodiversity refers to the diversity of naturally occurring indigenous or native plants at a specific region during a particular era. The floral bio-diversity of the study area mainly consists of the mangrove plants, algae or sea weeds, grasslands, and reed lands. Conversely, the Vegetation coverage refers to the assemblage of plant species and the ground cover they provide.

In the present research, the forest ecosystem within the terrestrial diversity of Bangladesh was studied from the secondary data sources, such as, institutional survey and satellite image interpretation.

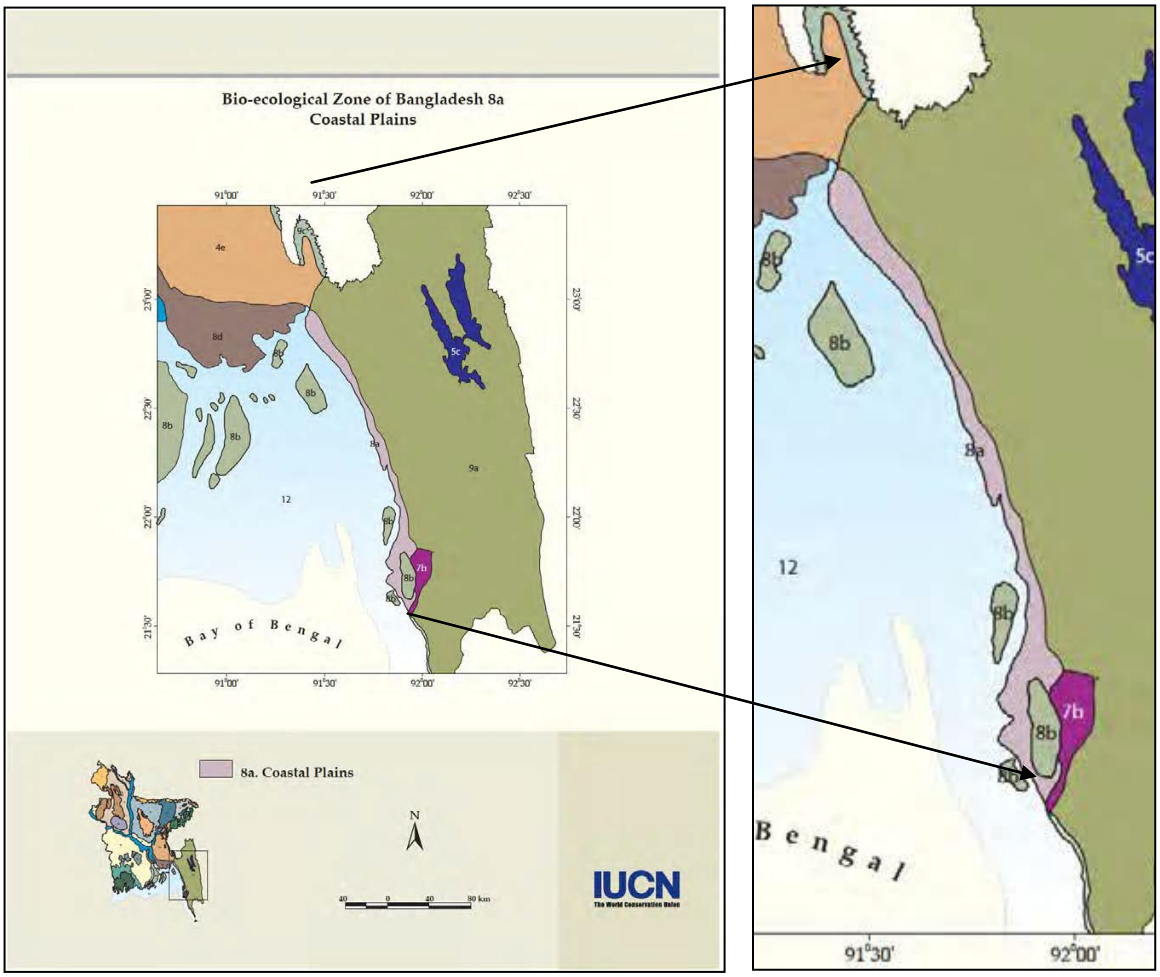
The Vegetation coverage of the four sample areas was shown in maps for two different years, the 1990 and 2015, respectively and a Vegetation Index was prepared by deriving the vegetation coverage area with the NDVI Scale (Fig. 7.1).

(i)The Vegetation Coverage of the Sample Areas

In the present research, the vegetation coverage of the four sample areas, namely, the Feni River, the Jalkadar River, the Bakkhali River and the Marine Drive Study area, for two different years of two decades, like, the 1990 and the 2015, was revealed by the Normalized Difference Vegetation Index (NDVI) method for the East coast of Bangladesh. The NDVI process creates a single-band dataset that mainly represents greenery (Weier, et al., 2000). The negative values represent clouds, water, and snow, and values near zero represent rock and bare soil.

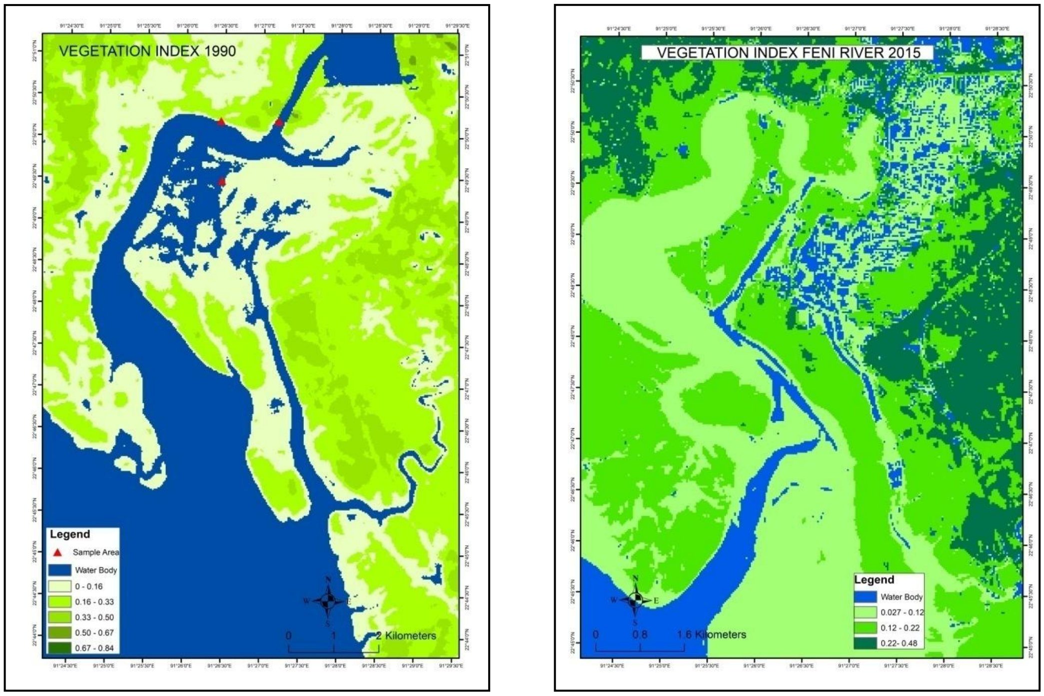
The equation of **NDVI**: **NDVI = (NIR - R) / (NIR + R);** where, **NDVI** stand for **Normalized Difference Vegetation Index** **R** & **NIR** stand for the spectral reflectance measurements acquired in the **Red (visible);** and **Near Infrared** regions, respectively.

The NDVI quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). For instance, the healthy vegetation (chlorophyll) reflects more near-infrared (NIR) and green light compared to other wavelengths. They take on values between 0.0 and 1.0 and the **NDVI** itself varies between **-1.0 and +1.0**.

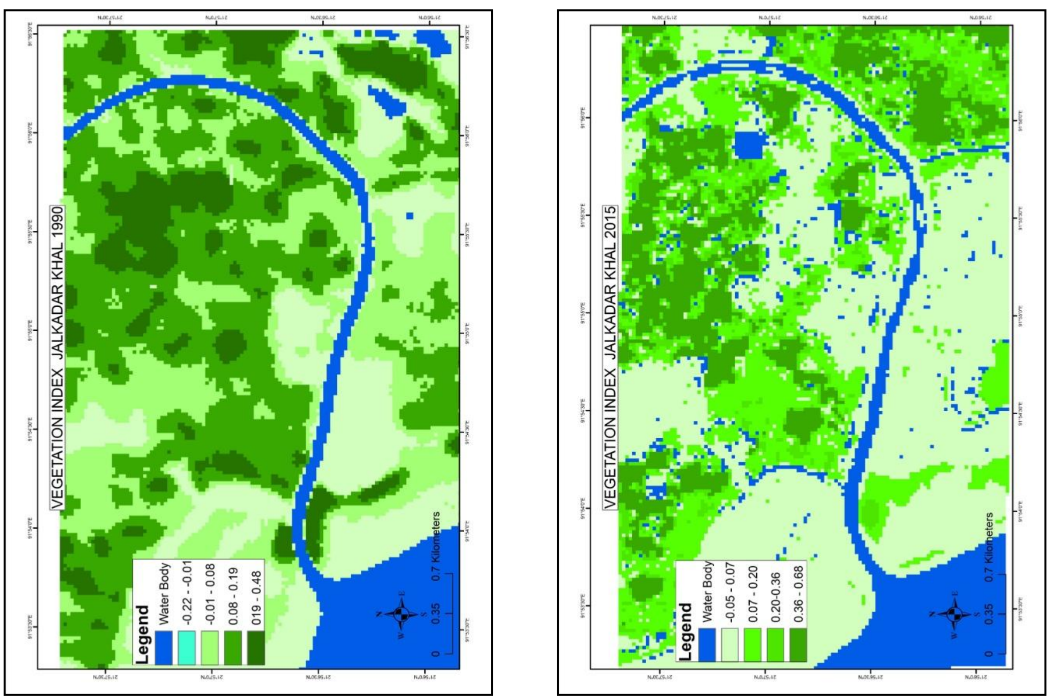


Map 7.1: Bio-Ecological Zone (8A) Chittagong Coastal Plain (Present Study Area), Chottogram East Coast

Source: Bio-Ecological Zones of Bangladesh, Nishat, et al., 2002

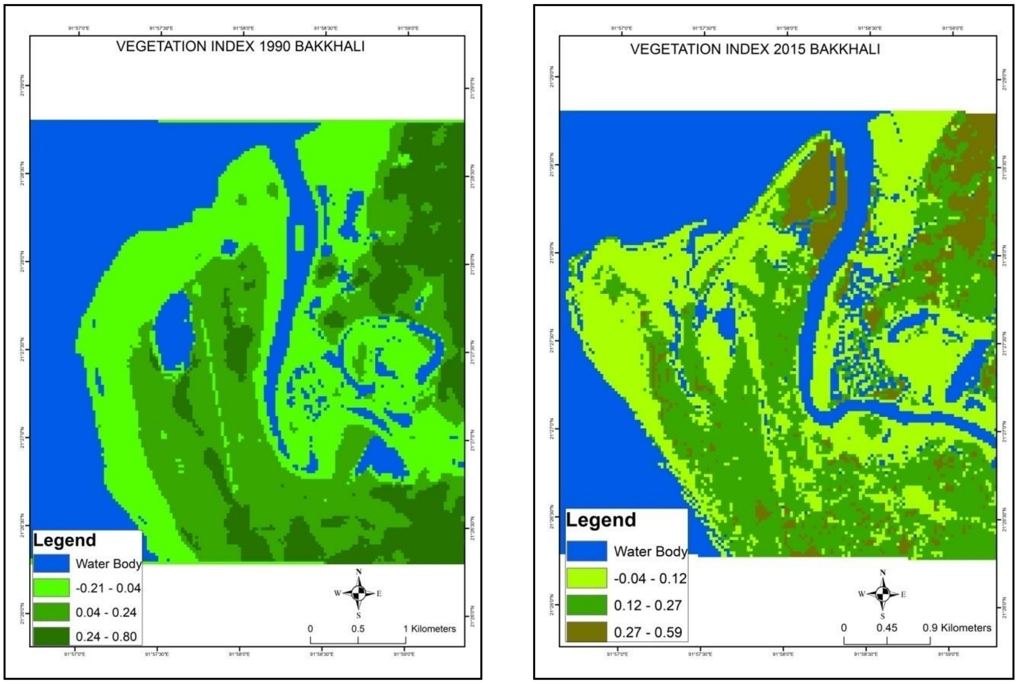


Map 7.2: Vegetation Coverage of Feni River Estuary, 1990 and 2015

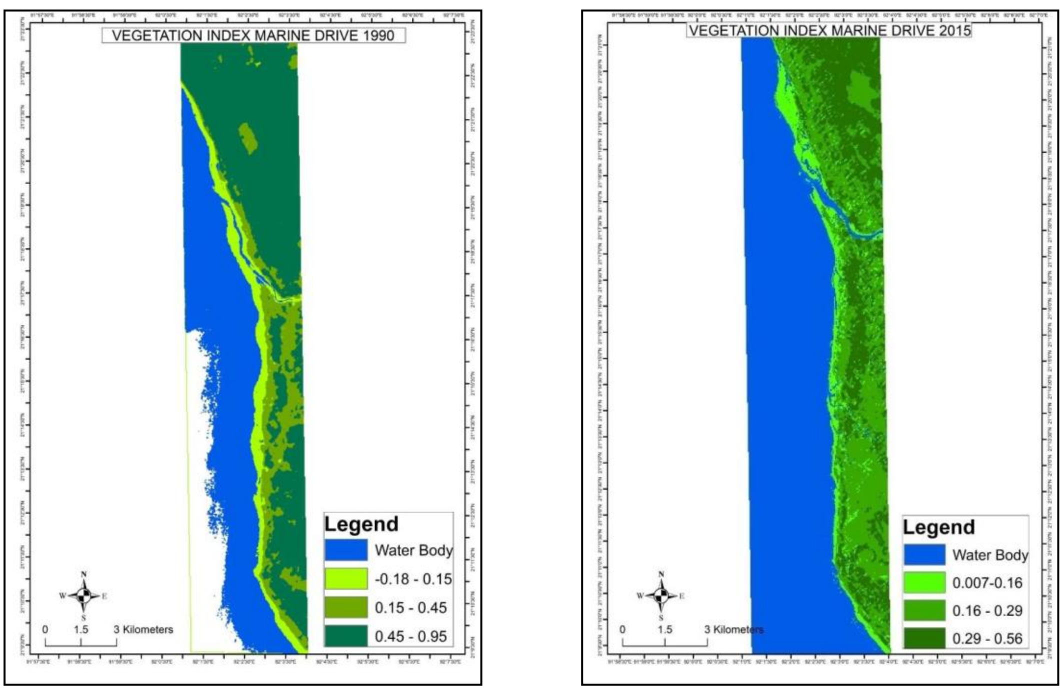


Map 7.3: Vegetation Coverage of Jalkadar River Estuary, 1990 and 2015

Source: Present Study, 2018



Map 7.4: Vegetation Coverage of Bakkhali River Estuary, 1990 and 2015



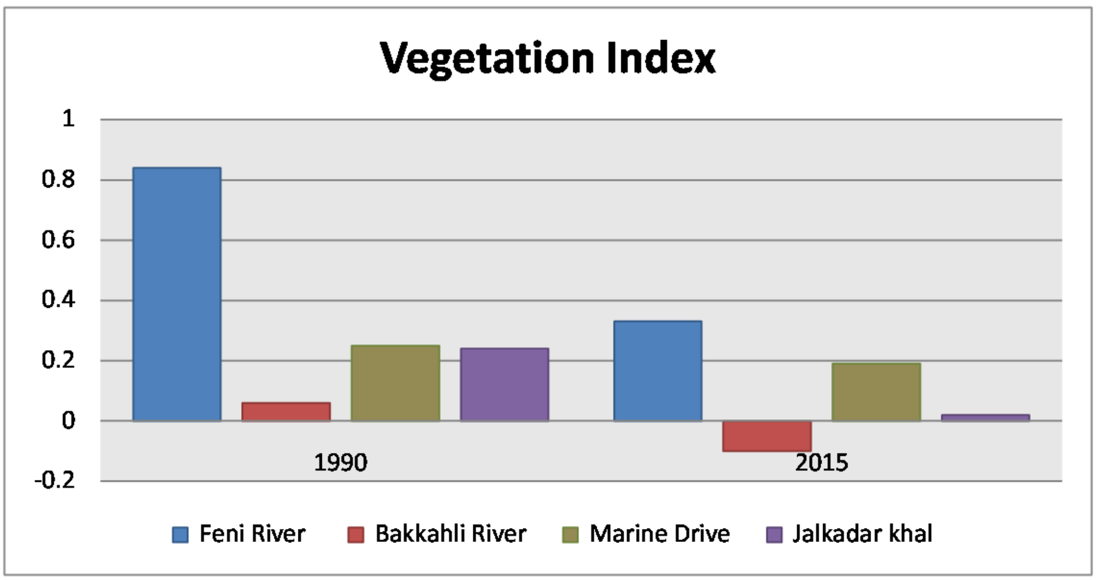
Map 7.5: Vegetation Coverage of Nhila-Teknaf Plain, Cox's Bazar: 1990 and 2015

Source: Present Study, 2018

(ii) The Vegetation Index of the Four Sample Areas: 1990 & 2015

A vegetation index has been an indicator that describes the greenness, the relative density and health of vegetation, for each pixel in a satellite image. The Normalized Difference Vegetation Index (NDVI) was used in the present research to calculate the NDVI of the four sample areas to illustrate the graphical picture of the vegetation coverage in the years of 1990 and 2015 (Fig.7.1). For NDVI, at a given pixel, a number that ranges from minus one (-1) to plus one (+1) has been used to indicate the greenness of the plants. Thus, a value close to zero stands for no green leaves or no vegetation, while, a value close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves (Weier,et.al.,2000).

Fig.7.1: The Vegetation Index of the Four Sample Areas of the Study Area:1990 & 2015



Source: Present Study, 2018

In figure 7.1, the comparative statistics of the Feni River vegetation coverage depict that, the amount of vegetation coverage reduced from +7.1 (1990) to +3.75 (2015) in Index scale. The vegetation index value for the Jalkadar River reduced from + 0.21 (1990) to + 0.01 (2015), while that of the Bakkhali River declined from +0.02 (1990) to -0.03(2015). However, the value at the Marine Drive coastal zone reduced from + 0.21 (1990) to + 0.02(2015). Hence, from the vegetation index of the present study, the extensive decline in vegetation coverage in the study area has been evidently perceptible.

7.3.2 The Faunal Bio-Diversity of the Study Area

The status of the mollusks, chelonians, crabs and sea weeds of the study area have been discussed in the following section as a component of the Coastal and Marine ecosystem. Mollusks are the single largest marine animal group, containing 301 species, and making up almost one-fourth of all known species in Bangladesh (DoE, 2015).

The Chattogram coastal plain of Bangladesh possesses low, flat and fertile coastal plains. Ample rainfall and fertile flood plains with rich vegetation, the rivers, streams, swamps and artificial lakes and water reservoirs offer good habitats for the land and marine water mollusks.

In the present study, the calcified mollusk shells have been studied as these have been the pollution concentrating organ of the mollusks. Moreover, the biomineralization process of the shells allows these to accurately record of the environmental changes due to pollution.

Nevertheless, the calcified mollusk shells have been suitable samples to track past contamination events, as these have the ability to concentrate large amount of pollutants. Specifically, the mollusk shells can absorb large amount of heavy metals and can be preserved for a long time (Mascaro, et al., 2015).

(i) Heavy Metal Concentration in the Mollusk Shells

The heavy metal concentration of the mollusk shells collected from source points of the Feni River, Jalkadar River, Bakkhali River and channel, and Teknaf Coast (Fig.7.1 & Fig.7.2) was measured to determine the concentration level of five heavy metals, such as, Cadmium, Copper, Lead, Zinc and Iron. The mollusk shell samples collected from the sample areas were (i) the hard Clam / quahog (Mercenaria mercenaria), the Bivalve Clam (Margaritifera auricularia) and the Trumpet Snails (Melanoides tuberculata) (Table 7.1, Fig.7.2).

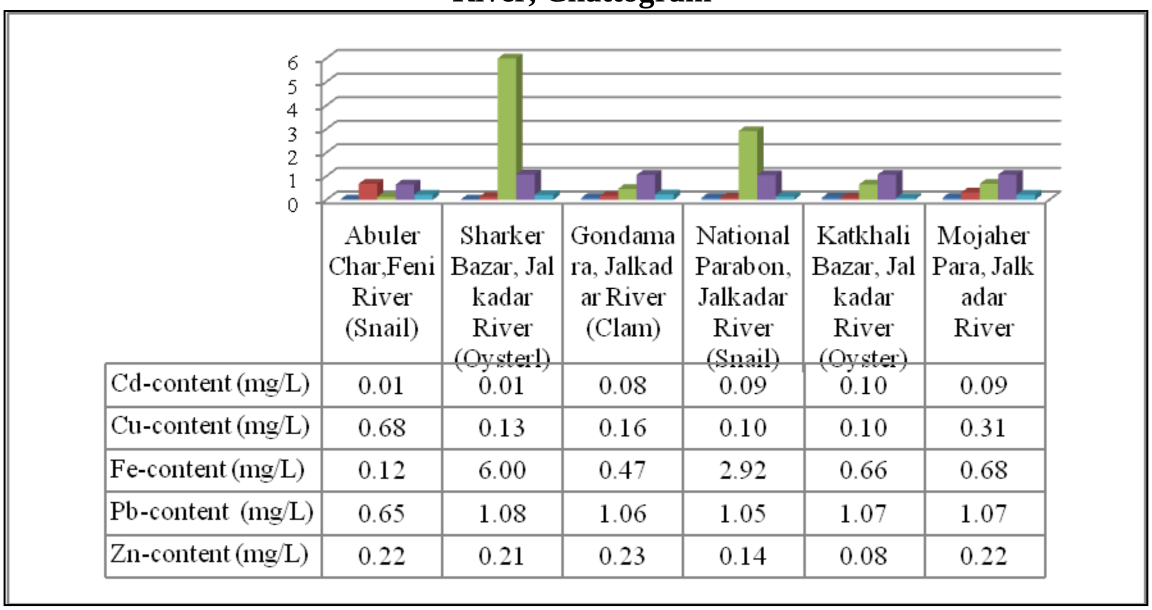
However, the oysters were mainly found in plenty near estuarine river mouths where waters was brackish and less than 10 meters deep. The heavy metal content of the sample shells of the mollusks has been illustrated in Table 7.1and Fig.7.2. The hierarchy of average concentration of metals in sample mollusk shells was: Fe> Pb> Cu> Zn >Cd

Table 7.1: Heavy Metal Concentration in the Mollusk shells at the Feni River & Jalkadar River, Chattogram

Mollusk Shell Samples * (* According to the availability of the mollusks)	Cd-content (mg/L)	Cu-content (mg/L)	Fe-content (mg/L)	Pb-content (mg/L)	Zn-content (mg/L)
Abuler Char, Feni River (Snail)	0.01	0.68	0.12	0.65	0.22
Sharker Bazar, Jalkadar River (Oyster)	0.01	0.13	6.00	1.08	0.21
Gondamara Union, Jalkadar River Clam)	0.08	0.16	0.47	1.06	0.23
National Parabon, Jalkadar River (Snail)	0.09	0.10	2.92	1.05	0.14
Katkhali Bazar, Jalkadar River (Oyster)	0.10	0.10	0.66	1.07	0.08
Mojaher Para, Jalkadar River (Snail)	0.09	0.31	0.68	1.07	0.22
Average	0.06	0.25	1.81	1.00	0.18

Source: i) Samples Collected from Field Survey for Present Study, March 2016; ii) Samples analyzed at CARS, DU, 2016

Fig 7.2: Heavy Metal Concentration in Mollusk shells at Feni River & Jalkadar River, Chattogram



Source: i) Present Study, 2018; ii) Samples analyzed at CARS,DU, 2016, * Availability of the mollusk shells

The **Cd** content of the shells in S 05 (0.07 mg/L) was the highest and that of the S 04 (0.04 mg/L) was the lowest with an average of 0.05 mg/L (n=5).The **Cu** concentration in the sample areas had a very close value ranging from 0.05 mg/L to 0.08 mg/L. However, the Fe concentration depicts the highest average of all the heavy metals in the sample areas (0.64 mg/L) and the second highest value has been found with the average of **Pb** (0.41 mg/L).The **Zn** content shows lower value of 0.02 mg/L-0.08 mg/L with an exception at S 05 (0.24 mg/L).

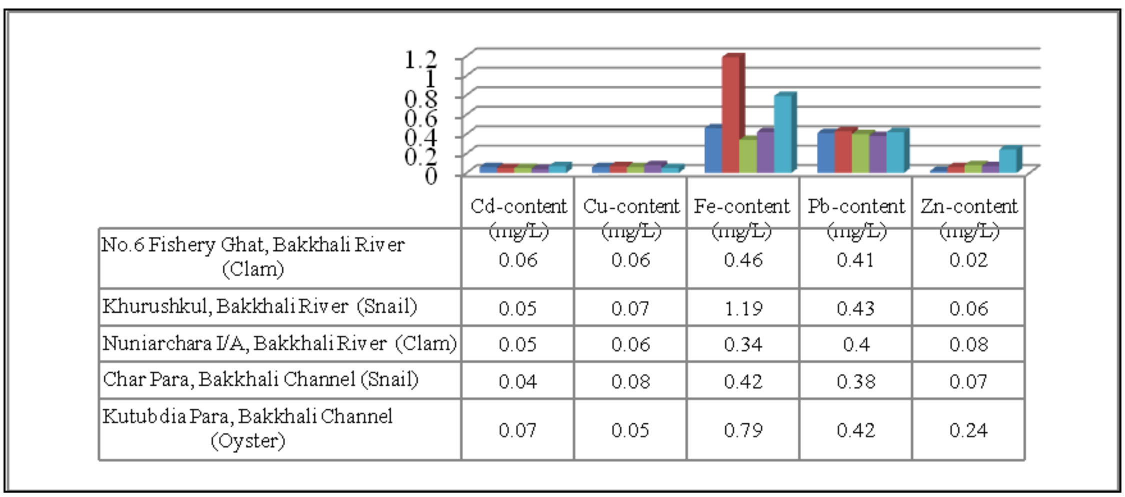
Table 7.2: Heavy Metal Concentration in Mollusk shells at the Bakkhali River & Channel Estuary, Cox's Bazar

Mollusk Shell Samples*	Cd-content (mg/L)	Cu-content (mg/L)	Fe-content (mg/L)	Pb-content (mg/L)	Zn-content (mg/L)
No.6 Fishery Ghat, Bakkhali River (Clam)	0.06	0.06	0.46	0.41	0.02
Khurushkul Project Area, Bakkhali River (Snail)	0.05	0.07	1.19	0.43	0.06
Nuniarchara I/A, Bakkhali River (Clam)	0.05	0.06	0.34	0.40	0.08
Inani Beach (Snail)	0.04	0.08	0.42	0.38	0.07
Kutubdia Para, Bakkhali Channel (Oyster)	0.07	0.05	0.79	0.42	0.24
Average	0.05	0.06	0.64	0.41	0.09

Source: i) Samples Collected from Field Survey for Present Study, March 2016; ii) Samples analyzed at CARS, DU, 2016,

* According to the availability of the mollusks

Fig. 7.3: Heavy Metal Concentration in Mollusk shells at the Bakkhali River and Channel Estuary, Cox's Bazar



Source: i) Samples Collected from Field Survey for Present Study, March 2016; ii) Samples analyzed at CARS, DU, 2016,

* According to the availability of the mollusks

An earlier study observed that, the average concentration of Cd, Fe, Pb and Cu were relatively higher than the standard concentration in sea water of east coast of Bangladesh. The study also cited that, a direct relationship between the content of heavy metal in seawater and in the biological samples. The study found that, the mollusk shells in St.

Martin's Island has been getting damaged due to the toxicity caused by heavy metals, such as, Zn, Pb, Cu, Fe, and Mg in their shells, which eventually may reduce the growth of mollusks in the Coastal and Marine ecosystem (Rashid, et al., 2015).

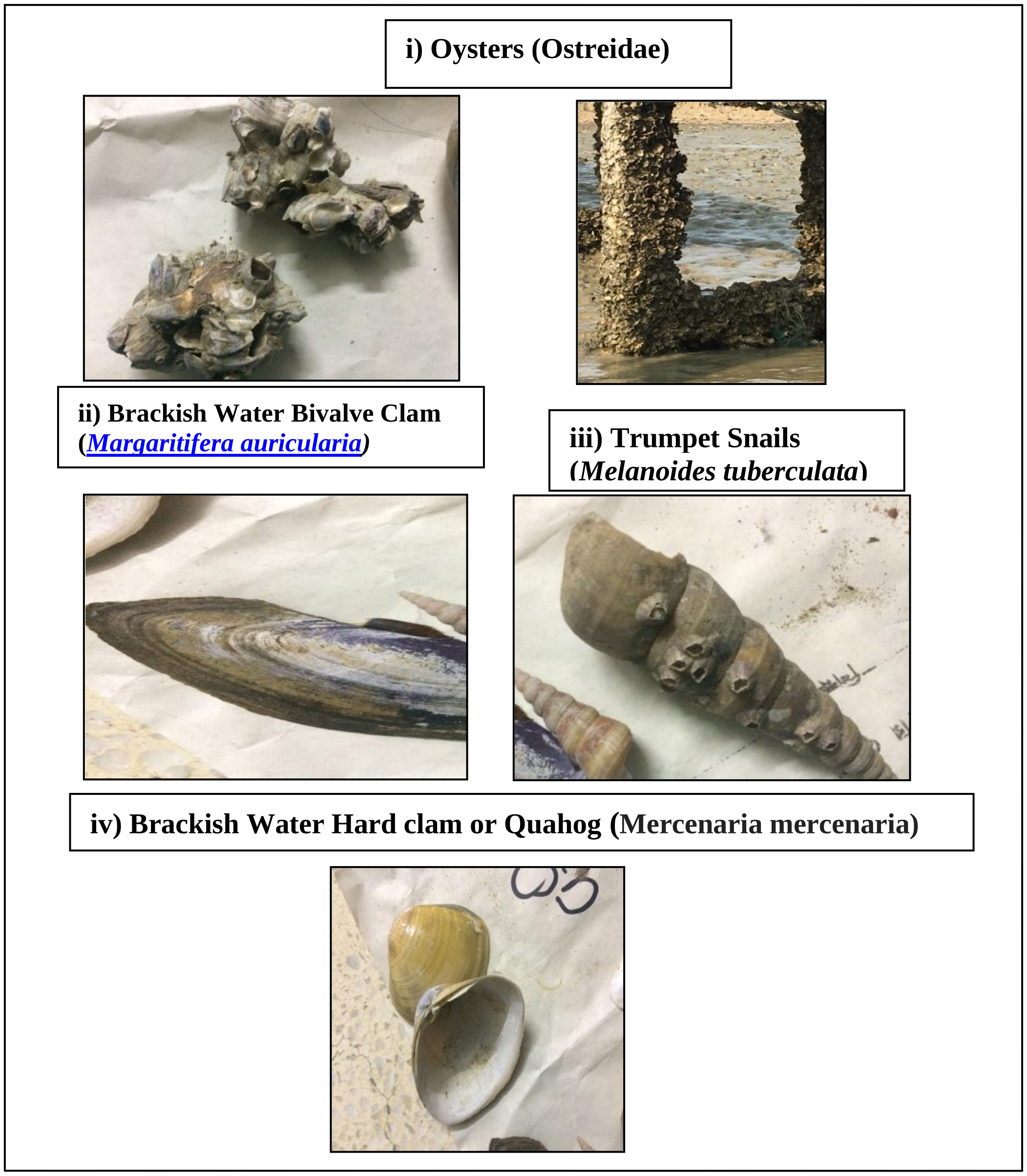


Fig.7.4: Mollusk Shells of the Bakkhali River and Channel Estuary, Cox's Bazar

Source: Present Study, Field Survey, Bakkhali River, Channel & Marine Drive, 2018

Calcium Carbonate ($CaCO_3$) Content in the Mollusk Shells of the Study Area

The shells have been the exoskeletons of mollusks, used for protection, and to avoid dehydration. The shells, unlike typical animal structures have been not made up of cells. The mantle or the skin of mollusks secretes liquid shell materials, which gradually harden on contact with water or air. Moreover, the shells participate in the biological activities of a mollusk, such as, to determine the distribution and survival of the adult snails).

The previous studies (Rashid, et al., 2015 and Soido et al., 2009) mentioned that, the mollusk shells have three distinct layers and most of the shell structure has been composed of Calcium (95% - 97%), with only a small quantity of protein (±2%), along with the organic materials and other trace materials like, manganese, iron, aluminum, sulfate and magnesium (±1%). The CA content of the mollusk shell samples collected from the sample areas was illustrated in Table 7.3.

Table 7.3: $CaCO_3$ Content (mg/L) in Mollusk Shells of the Feni River, Jalkadar River, Bakkhali River and Inani Beach

Sample ID	$CaCO_3$ Content (mg/L)	$CaCO_3$ Content (Percentage)
Abuler Char, Feni River	1.99	94.5
Sharker Bazar, Jalkadar River	2.02	91.1
Gondamara, Jalkadar River	1.79	89.5
National Parabon, Jalkadar River	1.78	89.1
Katkhali Bazar, Jalkadar River	1.49	74.5
No.6 Fishery Ghat, Bakkhali River	0.88	44.5
Nuniarchara Fishery Ghat, Bakkhali River	0.85	42.5
Khurushkul, Bakkhali River	1.03	51.5
Nuniarchara I/A, Bakkhali River	1.98	74.0
Char Para, Bakkhali Channel	0.99	49.5

Source: i) Present Study, 2018; ii) CARS, DU, 2017; * According to the availability of the mollusks

The percentage of the highest $CaCO_3$ content (94.5 %) was measured in the mollusk shells collected from the Abuler Char sample area in the Feni River, followed by the $CaCO_3$ content (91.1 %) in the samples of Sharker Bazar in Jalkadar River. The percentage of the other three sample mollusk shells collected from the Jalkadar River shows a gradual decrease in $CaCO_3$ content (74 5 to 89 %). Nevertheless, the samples from the Bakkhali River and channel shows drastic decrease in the $CaCO_3$ content (42.5% to 74%). The lower (42.5 % to 44.5 %) $CaCO_3$ content was measured in the two fishery ghat sample areas, highly polluted as well as contaminated by toxic wastes from the industries (Fig.7.5).

Rashid et al., 2015, mentioned that, the average $CaCO_3$ content of the sea shells and oysters at St. Martin's Island was 80%, where the normal shells has been composed of 95% - 97% of calcium carbonate. Conversely, the $CaCO_3$ content in the Present study sample mollusk shells ranged from 0.85 mg/L (42.5%) to 2.02 mg/L (91%), showing a decline in the $CaCO_3$ content (Table 7.3, Fig. 7.5). The decreasing percentage of the $CaCO_3$ content in the sample mollusk species, such as, the trumpet snails, bivalve hard clams, fresh water clams and the oysters was observed in the reduced shell thickness and breaking strength (Fig.7.4).

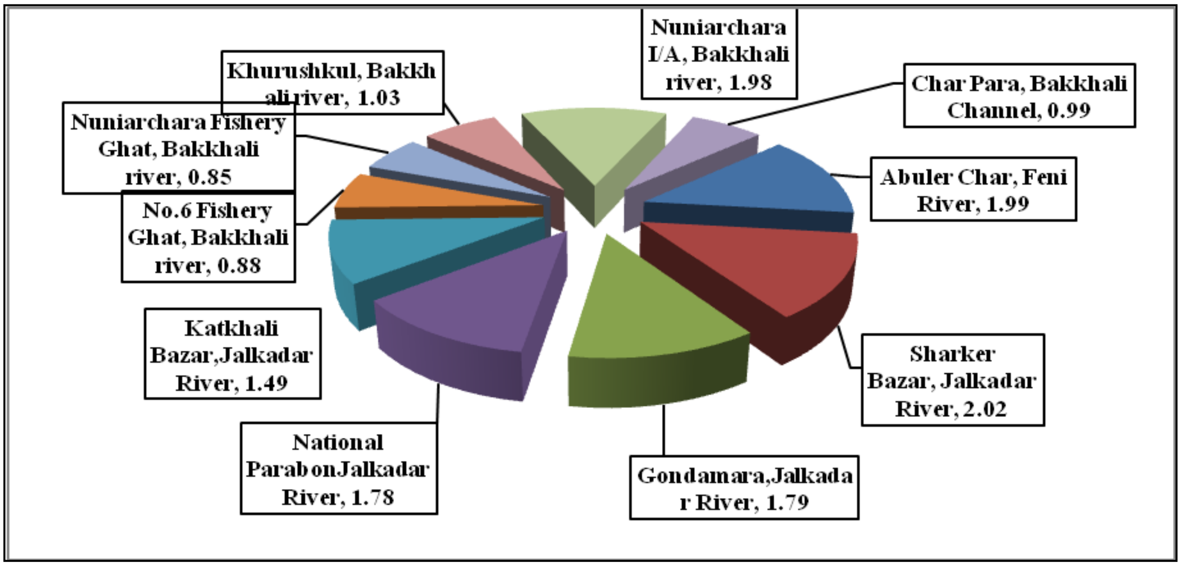


Fig.7.5: $CaCO_3$ Content (mg/L) in Mollusk Shells of the Study Area

Source: i) Present Study, March, 2017 * According to the availability of the mollusks

(iii) Bio-Diversity of Fisheries Resources in the Study Area

During the KII survey with the scientists at the Bangladesh Fisheries Research Institute (BFRI), Cox's Bazar regarding the faunal diversity, it was revealed that, the east coast of Bangladesh has been an important breeding ground of four species of Chelonians (marine turtles and tortoise), associated with high diversity and moderate density of marine mollusks, crabs, and sea weeds. The main fisheries resources of the study area have been discussed below.

Chelonians (Turtles and Tortoises)

The Chittagong region has been the home of many land dwelling (Tortoise) and sea dwelling (Turtles) chelonians. However, the coastal and marine waters of East coast support five species of sea dwelling marine turtles (DOE, 2015) mentioned in the Table 7.1.

Table 7.4: Coastal and Marine Water Turtles in East coast

Common name of the Turtles	Biological Name of the species
1. Olive Ridely Turtle	*Lapidochelys olivacea*
2. Green Turtle	*Chelonia mydas*
3. Hawksbill Turtle	*Eretmochelys imbricate*
4. Leather back Turtle	*Dermochelys coriacea*
5. Loggerhead Turtle	*Caretta caretta*
6. Sunderban River terrapin	*Batagur baska*

Source: Fifth National Report on Biological Diversity, DOE, 2015

Crabs

In the changing environment of the coastal area, crab has emerged as a potential exportable commodity in the country. Farmers has been transferring from shrimp to crab farming as it has been less susceptible to disease, resistant to adverse environmental conditions and has a good market price. In the coastal districts of Bangladesh, the mud crab has been one of the most popular crab species because of its size, meat quality, high price and export potential. The Mud crab (*Scylla* spp.) fishing and culture represent a valuable income component as these crabs have been the second earning commodity in country's shellfish products export line-up. In 1981, crab export in Bangladesh ranked third among the fisheries export earnings (Islam,S., 2015). These crabs have been found in their natural habitats, like, the mangrove areas, tidal River estuaries, and the shrimp culture ponds. The crab farming at the estuaries of the study area has been: the Bakkhali River, Cox's Bazar; Jalkadar River, Banshkhali; and the Feni River, Mirsharai, Chittagong. The other natural habitats has been the Rivers of Barisal, Bhola, Patuakhali, Bagerhat, Khulna, Satkhira swamps of the Sundarban Reserve Forest (SRF) and traditional shrimp ghers .Nevertheless, due to the decreased natural Mud crab population consequence by the increased exploitation in recent years, mud crab farming has been becoming increasingly popular. However, the mud crab aquaculture technique has been until now less developed in Bangladesh, though crab farming in coastal region was increasing. The farmers have been still dependent on wild seeds and follow traditional fattening process, due to lack of enough scientific knowledge of seed collection.

Sea Weeds

Seaweeds have been marine algae, which has been generally classified as a primitive type of plants, lacking true roots, stems and leaves. Seaweeds have been very important part of the marine ecosystem (Ahmed,2010). The sample areas of the present study has been the most potential ground for seaweed cultivation, because of the availability of favourable climatic conditions, adequate aquatic resources for seaweed cultivation, as well as cheap and abundant labour. Seaweeds in the study area once physically dominated the whole benthic environment and provide not only the primary food sources but also habitats for a whole range of other marine organisms.

7.3 Major Threats to Biodiversity in the Study Area

Biodiversity loss in the study area has been the consequence of several geo-environmental, socio-economic, as well as, institutional factors. Following has been the key reasons behind the rapid biodiversity loss in the study area.

i) Climate Change and Sea Level Change induced hazards and disasters
ii) Household and Industrial garbage adding pollution in soil and water
iii) Plantation of many exotic and non-native plant species has become invasive over local flora and fauna
iv) Lack of public awareness and knowledge about biodiversity loss
v) Loss of natural habitat due to unplanned Land use change, agricultural expansion, and shifting cultivation
vi) Illegal and detrimental land encroachment into the river banks by the local stakeholders
vii) Commercial shrimp cultivation in coastal areas
viii) Over exploitation of floral and faunal species for consuming and trading

However, the study revealed the need to integrate among different sectoral activities to surmount the limitations, to ensure fully-functional implementation of the existing plans and policy frameworks, and to build linkages between the government and local stakeholders for the biodiversity conservation in the study area.

7.4 Significance of Biodiversity Conservation in Bangladesh

The implication of biodiversity conservation in Bangladesh has been an absolute prerequisite, if observed from different contexts like below:

i) Environmental Context: The physical environment has been a complex assortment of many factors like, the climate, weather, and the physio-chemical characteristics of the terrestrial, aquatic and atmospheric spheres of an area. The physical environmental diversity occurs at different stages, starting from the small community level up to the national level in broad context. Nevertheless, deterioration in any of these levels exerts adverse impact upon the others in a chain-reaction approach. For instance, the climate change of a region has great influence upon the biodiversity of that area.

ii) Geomorphic Context: The characteristics of different geomorphic units vary to a large extent. For instance, the estuarine wetlands differ from the inland wetlands in its physio-chemical as well as geomorphic structures. The changes in the geomorphic characteristics of an area transform as well as modify the floral and faunal biodiversity of that area through a process of adaptation. The sea level rise and changes in sea current cause coastal erosion at an amplified level, and eventually causes depletion in biodiversity of that area.

iii) Anthropogenic Context: The anthropogenic activities bring great changes in all of the domains of the earth, such as, the terrestrial, aquatic, atmospheric and the biological spheres. The adverse effects of unplanned and unwise exploitation of the natural resources at the coastal area of Bangladesh have caused the depletion and deterioration of the flora and fauna resources of the coastal area. For instance, the effluents from the industries and factories, along with the household garbage cause coastal erosion, almost 91% of the perennial streams in the eastern region of the country have dried up or filled up with garbage and solid wastes from industries.

According to the Bangladesh Environment Conservation Act (BECA), 1995 (Islam,M., 2015), the Cox's Bazar district contains three focal ‘Ecologically Critical Areas (ECAs)’ such as (i) the long, narrow and forested coastal zone of Teknaf Peninsula (10,465 ha in area), (ii) the St Martin's Island (590 ha), a sedimentary continental island located a 10 km south of Teknaf Peninsula, and (iii) the Sonadia Island (4,924 ha), only 3 km away from Cox’s Bazar through Moheshkhali channel, Teknaf Peninsula. The Teknaf Peninsula, one of the longest sandy beach ecosystems (80 km) in the world, has been the transitional ground for the fauna of the Indo-Himalayan and Indo-Malayan ecological sub-regions. The peninsula provides breeding areas for four globally threatened species of marine turtles and, lying along international bird migration flyways, serves as a significant bird area, with over 81 species recorded. Finally, its inshore water hosts globally threatened marine mammals.

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7.5 Conclusion

The socio-economic as well as geo-environmental situation of the study area has been predominantly dependent upon the floral and faunal bio-diversity, along with other geomorphic and environmental factors. The anthropogenic interventions, such as, increasing population, development of scores of unplanned structures, expansion of alternative types agriculture, rapid industrialization, mixing of pollutants and toxic effluents from various sources have been affecting adversely upon the geo-environmental condition and biological diversity of the study area, leaving many species extinct and several others endangered.

This chapter illustrated the pattern of biodiversity change as well as the consequences of bio-diversity degradation upon the entire geo-environmental condition of the study area have been observed. Nevertheless, a huge potentiality waits to be explored into the biodiversity-based sustainable development in the east coast of Bangladesh. Hence, an integrated sustainable management planning to protect the over-exploitation of the biological resources has been needed to be taken for the study area.

8.1: Introduction

The coastline of Bangladesh is bordered by more than 580 km long coastline, stretched along the south and south-east of Bangladesh. The literature review and reconnaissance survey revealed that, despite the emergence of the east coast as a flourishing zone of socio-economic development, the east coast of the country has been least explored in the context of finding out the ‘Cause and Effect’ relationship between anthropogenic activities and the geo-environmental state. Hence, the present study selected the east coast as the study area to investigate the geo-environmental state of the zone. Further, the worst affected source points of pollution along the east coast, such as the Feni River, the Bakkhali River, and the Jalkadar River estuaries, along with the source points of pollution located along the Marine drive, Teknaf coast were selected as the sample areas.
The significant geo-environmental features of the east coast were selected as the study indicators.

The geo-environmental characteristics of the study area offer a great deal of socio-economic development opportunities for the east coast and in broader perspective for the entire country. Regardless the opportunities, the east coast has been experiencing increased rate of anthropogenic activity induced geo-environmental deteriorations. The present study observed that, unawareness and lack of proper knowledge of local and national stakeholders regarding coastal geo-environment has been exerting detrimental effects upon the geo-environment and in broader perspective, upon the terrestrial and coastal and marine ecosystems of the east coast. Hence, the central research questions of the study was to identify the ‘Cause and Effect’ relationship between anthropogenic activities and geo-environmental state, and to structure a ‘Strategic Policy Framework’ through which the incorporation of the study indicators into the ICZMP and future coastal development plans can be attempted.

Accordingly, the study attempted to structure a ‘Pressure-State-Response’ (PSR) model (Fig. 8.15) to illustrate the causes of geo-environmental deterioration and their effects upon the ecosystems. Further, the study attempted to incorporate the study indicators into the existing ICZMP and other future development plans and policies. The findings derived from the results of the present study have been discussed in this chapter.

8.2 The Geo-environmental State, Causes and Consequences of Deterioration at the East Coast

The findings of the study have been discussed from three perspectives, such as (i) the shoreline change pattern, (ii) the environmental and (iii) biodiversity state of the east coast. The anthropogenic causes of deterioration of selected geo-environmental indicators upon the biodiversity, leading to ecological criticality have been discussed as well.

Firstly, the most significant geomorphic process, the shoreline change pattern along the east coast for the study period of 25 years (1990-2015) has been discussed. Though the geomorphic, hydrologic, and climatic processes function as the main driving force of shoreline movement; the study attempted to identify the anthropogenic activities functioning behind the shoreline movement. The present study found the unscrupulous discharge of industrial effluents, dumping of huge municipal garbage at the coastal zone, excessive logging of trees, changeability of selected water and soil parameters, intensive and unplanned land use as the causes of shoreline movement at the east coast. The literatures also mentioned the anthropogenic interventions as the driving forces of NSM besides the natural driving forces, such as the geomorphic and climatic processes (Dewan et al., 2016, Hossain, S., 2015, Van, et al., 2008, Matin and Baig, 2006, Stroeve, 1993 and Sarwar and Woodroffe, 1991).

Secondly, the environmental state of the study area has been discussed with a view to depict an overall scenario of the geo-environment of the east coast. According to the United State Environmental Protection Agency (EPA) Cd, Cr, Cu, Hg, Ni, Pb, and Zn are the eight most common pollutant heavy metals (Resource Conservation and Recovery Act, 1976). Among these, the present study selected five heavy metals, such as the Cd, Cu, Pb, Zn and Fe to measure their level of concentration in soil and water. The measurement of selected heavy metals, non-metals, and physio-chemical parameters was conducted to investigate the adverse impacts of their fluctuation upon the coastal soil and water, ensuing biodiversity change and / or loss and ecological criticality. The adverse affects of these environmental parameters upon the soil and water quality of the study area has been discussed in the following sections. Ali, et al. (2016) claimed that, the main sources of heavy metal pollution in soil were the urban traffics, and agrochemical products used in the agricultural land. Mominul et al. (2018) mentioned that, municipal wastes from rapidly growing urbanized areas, industrial effluents, chemical fertilizers for agricultural land and vegetable farms in sewage-irrigated areas are highly contaminated with Cd, Pb, and Chromium (Cr). Raknuzzaman et al. (2016) claimed that, the shrimp hatchery areas at Cox's Bazar contains the highest levels of Zn, Cu and Pb due to huge discharge of different salts and chemicals from hatcheries to the beach soil.

The study also measured the concentration of two non-metals, such as the phosphorous and the sulphur in soil and water of the east coast. The sulphur and phosphorous are the main nutrients for plants and animals. These two nutrients play a significant role in cell development and are vital for life and growth. Insufficient phosphorous might lead to decreased crop yield (Douglas and Durst, 2002). The concentration of these two nutrients was from 0 ppt to 03 ppt at the sample areas. The study investigated the quality of soil and water of the sample area through measuring several physio-chemical parameters, such as the pH, EC and Temperature of soil and pH, EC, Temperature, and TDS of water to find out the consequences of fluctuation of these parameters upon the geo-environment of the study area. Mertens et al. (2013) claimed that, excess presence of pH in soil change the Slightly Alkaline soil into Moderately Alkaline; and decrease of per unit of pH increases the Zn fivefold in soil. The USDA (2014) mentioned that, soil EC is an indicator of salinity of soil, which indicates the nutrient availability and loss, soil texture, and available water capacity. Hence the crop yields and activity of soil micro-organisms, such as emission of greenhouse gases are regulated by the EC (USDA, 2014). Hailng et al. (2018) stated that, soil temperature plays a vital role in the physical, hydrological, and biological processes. The soil temperature regulates the transformation and uptakes of nutrients by plant roots and agricultural crops (Haishui et al., 2018). The significant difference between the soil temperatures in the sample areas accentuated the findings of Hailng et al. (2018) who mentioned that, the soil might show high spatio-temporal variability. Further, lower pH consequences in increased solubility, as well as toxicity of the heavy metals like cadmium, lead, and copper. Nevertheless, the high pH in water (above 10.0) can damage the gills and skin of aquatic organisms (Fondriest, 2013). The study found that, human induced pollution and toxicity in all physical biomes of the earth affect the pH in water leading to significant changes in the biodiversity (Fondriest, 2014). Again, lower pH content consequences in increased solubility and toxicity of the heavy metals like cadmium, lead, and copper. For every 1°C increase in temperature, EC can increase up to 2 to 4 percent (Fondriest, 2014), while changes in the EC content in water creates imbalance in the entire ecosystem causing biodiversity change and/ or loss.

The third indicator, the biodiversity of the study area declined owing to the unscrupulous discharge of industrial effluents, dumping of huge municipal garbage at the coastal zone, excessive logging of trees, changeability of selected water and soil parameters, intensive and unplanned land use. The vegetation coverage of the study area was selected as the floral biodiversity indicator. The vegetation functions as the 'producers' in the food chain of the terrestrial ecosystem. Hence, the study attempted to analyze the state of vegetation coverage of the study area to reveal the floral biodiversity of the terrestrial ecosystem.

On the other hand, mollusk shells were selected as the faunal biodiversity indicator to identify the faunal biodiversity state of the study area. The mollusks are the 'first level consumer' in the food chain of the coastal and marine ecosystem. Moreover, the mollusks shells are broadly used to trace the history of heavy metal concentration (Mascaro, et al., 2015). The above-mentioned sections described the general pattern of the geo-environmental indictors of the study area. The following sections discuss the geo-environmental state of the study indictors in each sample area.

8.2.1 Geo-environmental State of the Feni River Estuary

The findings derived from the analysis of the results has been discussed from three different perspectives, such as the net shoreline movement, environmental quality of soil and water, and biodiversity of the terrestrial and coastal and marine ecosystems of sample areas has been discussed below.

The Net Shoreline Movement (NSM) of the Feni River Estuary

The Feni River is a very dynamic river characterized by distinct geomorphic, environmental and biological diversity. However, the geo-environmental opportunities were getting hindered by multivariate anthropogenic interventions. Hence, the study attempted to investigate into the state of the selected geo-environmental indictors, as well as the causes and effects of their deterioration at the Feni River estuary sample area.

The selected geomorphic indicator of the study was the process of shoreline movement or change expressed as the 'Net Shoreline Movement' (NSM). The NSM of the Feni River estuary was discussed herewith to reveal the chronological NSM of the sample area shorelines. Though the Feni River NSM is the consequence of several geomorphic processes; anthropogenic causes such as construction of the Muhuri Closure Dam (MCD) in 1986 (TA 8154) for the Muhuri Irrigation Project (MIP), and the consequent Muhuri accreted area (MAA) in the reservoir side of the MCD, land filling due to huge garbage and waste disposal from surrounding settlements, industries and factories, fishing trawlers and passenger boats anchored at the shores, discharge of toxic effluents from fishing farms, vegetable and fruit farms, unethical and unplanned land acquisition, excessive logging of indigenous trees, loosening of soil bonding due to changes in soil quality, heavy metal contamination in coastal soil and water were observed as the major causes of rapid shoreline movement along the study area. The Feni River estuary experienced major NSM during the selected study time (1990-2015). The transects drawn upon the study areas showed that, the lowest length of accretion was 424.53 meters (ID 13) and the highest length of accretion was 1593.5 meters (ID 22), while the length of erosion ranged from -24.4 meters (ID 26) to -1006.9 meters (ID 02) during the study period (Map 5.1). For the convenience of the discussion, as well as to depict the significant NSM ensued geomorphic features along the entire study area was divided into three major sections namely, (i) the Northern section (comprising the Transects 18-26), (ii) the Middle section (comprising the Transects 10-17), and (iii) the Southern section (comprising the Transects 02-09) (Table 8.1 and Map 5.1).

Table 8.1: NSM Induced Geomorphic Features of the Feni River Estuary

Sections of Study Area (Transect Lines)	**ID Location of Shoreline Change**		**Geomorphic Features**
	Accretion	**Erosion**	
Southern Section (South Ichakhali union, Mirsharai) (ID 02- ID 09)	ID 05, ID 06, ID 07, ID 08, ID 09 (05 Transects)	ID 02, ID 03, ID 04 (03 Transects)	Accretion dominated area Char land formation
Middle Section (South Ichakhali union, Mirsharai Upazila) (ID 10- ID 17)	ID 10, ID 11, ID 12, ID 13, ID 14, ID 16, ID 17 (07 Transect lines)	ID 15 (01 Transect Line)	Accretion prone area Erosion only at Transect ID 15
Northern Section (ID 18- ID 26) (North Sonagazi union, Feni Upazila)	ID 18, ID 19, ID 20, ID 21, ID 22, ID 23, ID 24 (07 Transect lines)	ID 25, ID 26 (02 Transect Line)	Accretion prone area Ox-bow lake formation in progress along transects ID 23 to ID 26

Source: Present Study, 2018 *NSM=Net Shoreline Movement

*Total 25 Transects (ID 01 Transect is out of the study area as the transects are auto generated by DSAS)

The EPR graphs of the Feni River estuary (Fig.5.1-Fig.5.5) illustrated that, the accretion rate increased gradually throughout the years. For instance, the lowest accretion rate was only 12 percent (1990-1995) while the highest accretion rate was in the time spans of 2005-2010 (76 percent). However, the total length of accretion at the Feni River sample area was 31492.26 meter (average 1259.69 meter), while the total length of erosion was -13860.19 meter (average -554.40 meter). Thus, the 'Net Gain' in terms accretion at the sample area was 705.28 meter (Present Study, 2018). The EPR graph of 1990-1995 periodic cluster depicted an ox-bow like formation between the transect ID 23 to ID 26 at the northern section of the sample area. However, the estuary mouth area was erosion prone. The distinct geomorphic features of the Feni River estuary indicate that, the entire area has become accretion dominated, with shallow river bed and newly formed char lands, like North and South Mukter char, Abuler char (Map 5.1). However, erosion activities were observed at the estuary mouth (ID 01, 02, and 03), ID 15, and ID 25 and ID 26 at the middle and northern section consecutively (Fig.5.1- Fig.5.5 and Map 5.1).

The reckless extraction of timber trees from the hill slopes, cutting of hill sides and consequent heavy landslides from the hills were revealed as a major cause of rapid siltation at the estuary (Banglapedia, 2015). Sarwar et al. (2013) mentioned that, on the promontory between the estuary of the Feni River and that of the other rivers, the most rapid rates of accretion was calculated to exceed 600 m/yr. The present study accentuated the fact that, the Feni River estuary is currently accretion dominated, which was mainly erosion prone in the years 1990 -2005 (Fig. 5.1 to Fig. 5.5). Eysink, 1983 (mentioned in Akter, 2016) declared that, major source of sediment at the Feni estuary was the huge amount of silt carried by the seawater. The study found that, the siltation towards the regulator site below the MCD gradually reduced and average sediment concentration during high water flow condition was about 400 mg/l. However, the study mentioned that, at the outfall of the estuary higher value of sedimentation was observed (Eysink,1983). Matin and Baig (2006) stated that, the obstruction of normal water flow in a tidal channel due to water control structures for a long time ensues into heavy siltation at that channel. Matin and Baig (2006) mentioned that, after the construction of the MCD upon the Feni River estuary for the MIP, a rapid siltation occurred which enhanced the height of the area about 4m in the first year followed by 0.6m in the second year. (Banglapedia, 2015) mentioned about the accretion of around 300 ha. of land to form the Muhuri Accreted Area (MAA) at the Feni River reservoir side.

Environmental Condition of the Feni River Estuary Soil and Water

The environmental condition the Feni River estuary was determined by measuring the concentration of five major heavy metals, two non-metals, and four physio-chemical parameters of soil and water. The point sources of pollution of soil and at the Feni River sample area were the untreated toxic effluents from the Ice and Fish processing factories, boat making and repairing factories, shrimp hatcheries, fish cultivation ponds, vegetable farms, along with the household garbage.

The Heavy Metal Concentration

Among the five heavy meats measured for the present study, the hierarchy of average concentration of the heavy metals was: Fe> Pb > Cu > Zn >Cd. The average concentration of Cd in soil samples of the Feni River estuary was quite low (0.02 mg/g), while average Cu concentration was 0.28 mg/g lesser than the world average (0.9 mg/g). On the other hand, the average concentration of Cd (0.08mg/L), Cu (0.12 mg/L), Fe (1.54mg/L) and Zn (0.21mg/L) in water samples of the Feni River were quite lower than that of the world average. Nevertheless, the average (0.36 mg/L), even the lowest concentration of Pb (0.23 mg/L) in the sample area water was alarmingly higher than the world average (0.03 mg/L). However, the hierarchy of average concentration of the heavy metals in water samples was: Fe> Pb> Zn>Cu>Cd.

Shahid et al. (2016) claimed that, Cd might cause serious deleterious effects both in plants and mammalian consumers. The main source of Cd in soil is the emissions from industries. According the researchers, Cd has high phytoaccumulation mobility from soil to plant and hence, might enter the food chain. Eisler (1985) and Neff (2002) narrated that, bioavailability of Cd in sea water, only 5 to 10 times higher than the natural concentration is considered as toxic for plants and animals; causing decreased growth, depressed respiration, and shortened life-span. Ansari et al. (2015) mentioned that, the anthropogenic sources, such as airborne dust during copper metallurgy are a major source of Cu, Pb and Cd.

Apori, et al. (2018) stated that, Cu is an essential heavy metal for plant growth available in soil. Wide and continuous use of fertilizers in agricultural sector causes Cu contamination. According to Market Research.com (2016) a wide variety of copper made products, such as copper foil, bars and rods, sheets and plates, tubes and pipes, wire, and many other products are produced in Bangladesh. The soils naturally contain 2 to 100 ppm (average 30 ppm) of Cu which is essential for plant growth. On the other hand, excessive Cu concentration might cause toxicity leading to decrease in plant growth and seed germination. The average of concentration of Fe in soil was 2.01 mg/g and Pb was 0.53 mg/g, which were higher than the world average (Table 6.1). The noticeable point was that, even being barren chars the Pb content in soil of Abuler char (0.56 mg/g) and Ichakhali char (0.61mg/g) was remarkably higher in comparison to world average (0.03 mg/g). The presence of average Zinc (0.17mg/g) in the soil was significantly lower than that of the world average (5.0 mg/g).

The center for Agriculture, Food and the Environment (2019) mentioned the Pb as an extremely stable heavy metal which is a dangerous neurotoxin to human and other animals. The centre also mentioned that, densely populated and industrial areas where weathering, chipping, scraping, sanding, and sand-blasting of lead-based painted materials is carried out are the major sources of high Pb concentration. Nevertheless, though the report mentioned that, presence of 15 to 40 ppm of lead in one kg of soil is considered as natural, pollution might increase the level to several thousand ppm. The average concentration of Fe (5.41 mg/g) of the sample area soil exceeded the world standard average (3.4 mg/g). The higher concentration of Fe in the soil is harmful for the local biodiversity, such as the mangroves, sea weeds, mollusks, crabs and other floral and faunal species. The U.S. EPA (2003) claimed that, Fe is an essential plant micronutrient occurring naturally. The green plants take up Fe for energy transformation processes, and phytoplankton growth. Nevertheless, deficiency of Fe in plants lessens the chlorophyll of the leaves, which disrupt the marine food chain by obstructing the photosynthesis of phytoplankton, the base of marine food chain. The point to ponder that, besides the natural occurrence, the Fe is widely used worldwide for commercial, industrial, and household products. The corroded Fe products eventually mix into the coastal water. However, Fe itself is not toxic, but this heavy metal interacts with other toxic metals (U.S. EPA, 2003).

However, consequences of such high concentration of Cd, Pb and Fe in both soil and water of the sample area indicated the disposal of untreated toxic wastes from the point sources of pollution, such as the ice factories, boat repairing factories, water vehicles, and household garbage into the river (Illustration 8.20 and 8.21).

Increasing socio-economic activities and small industrial establishments along both banks of the river accelerated the amount of toxic effluent discharge in the area. The overall concentration of Pb is found to be higher than the world average both for soil and water, followed by the Fe. The sources of Pb and Fe contamination, such as, the different toxic effluents coming from industries, and factories have to be stopped by treating the toxic effluents at the source points. This can be done by creating separate industrial zone, where all types of toxic waste treatment plant will be established, operated and monitored regularly. Apori, et al. (2018) stated that, the soil remediation consists of actions such as removal, control, containment, or reduction of contaminants in soil to a safe level for biological entities. The paper mentioned that, the remediation of copper contaminated soil can be done by the phytoremediation process as this method is economical and eco-friendly. Though the heavy metals naturally exist in quite small amount in water, fluctuation in the concentration of these metals exerts detrimental effects upon the Coastal and Marine ecosystem.

The Non-Metals in Soil and Water

The Phosphorous (P) functions as vital nutrient for living organisms. Though main natural source of phosphorous in water is soil erosion, the anthropogenic sources are municipal wastes, drainage from agricultural land, excreta from livestock, and diffused urban drainage (Lee et al., 1978; mentioned in Kroiss et al., 2011). Both deficiency and/or excess of P in soil might lead to decreased crop yield (Douglas and Durst, 2002), decreased plant growth and eventually death (Provin and Pitt,n.d.). On the other hand, excess P in water increases the growth of algae and other undesirable plants ensuing into eutrophication in water bodies, decreased number of fish and desirable plants (USGS, n.d.). However, deficiency of P in water causes distortion of plant morphology (Atkinson and Davison, 1973).

The amount of P in soil and water samples of the Feni River estuary was measured as 01 ppt. Such low concentration of P might be a reason of faunal biodiversity loss in the area (Fig.7.1).

The other non-metal nutrient measured for the present study was the Sulphur (S) in the soil and water of the Feni River sample area. S is one of the major nutrients for the living beings. Mostly originated from the natural source like S containing minerals in parent materials, this nutrient enters the biological systems through microbial activities in soil, from plants and animal residues, and from external sources (Prasad, 2016). Deficiency of S in soil hinder, as well as decline the growth, quality and amount of plant and crop yield (Prasad,2016), while excess S in soil decrease the pH in soil and lead to low pH induced problems (Agronomi Library,n.d.). Norici (2005) in a review report stated that, in heavily polluted areas, the concentration of S might decrease and result into S deficiency problems.

Though the natural sources of S in coastal and marine ecosystem are runoff, fallout, underwater geothermal vents, the anthropogenic sources are burning of large quantity of fossil fuels and release of huge amount of hydrogen sulfide gas into the atmosphere ensuing acid rain, which mixes into the aquatic ecosystems. The high concentration of S deteriorates the biodiversity state by lowering pH (Stefels, 2007).

In the present study, the amount of S in soil and water samples of the Feni River estuary was measured as 01 ppt. Such low concentration of S might be a reason of faunal biodiversity loss in the area (Fig.7.1), as well as declined condition of mollusk shells (Fig.7.3) at the sample area due to lowered pH and consequent acidification of estuarine water (Gazeau,2013).

Physio-Chemical Quality in Soil and Water

The selected physio-chemical parameters of the sample soil were: (i) Potential of Hydrogen (pH), (ii) Electric Conductivity (EC), and (iii) Temperature. On the other hand, the physio-chemical parameters for water were: (i) Potential of Hydrogen (pH), (ii) Electric Conductivity (EC), (iii) Temperature, and (iv) Total Dissolved Solids (TDS).

The pH value of sample area soil ranged from 6.4 to 8.3 with an average of 7.7 (Table 6.3, Fig.6.10).Conversely, the pH value in sample area water ranged from 5.4 to 6.8 with an average of 6.0 in pH scale (Table 6.4,Table 8.2, Fig.6.13). These depict that, the pH in soil slightly exceeded the Neutral range of 6.6-7.3 (U.S. Soil Survey Division, 2011), while the pH in water was samples of the Feni River was within the standard range for brackish water fish resource. However, the pH level of the S 01 was 6.8, which was slightly lower than the neutral water pH value.

Table 8.2: Physio-Chemical Quality in Soil in the Feni River Estuary

Sample areas	pH Soil	pH Water	EC (mS/Cm) Soil	EC (mS/Cm) Water	Temperature (°C) Soil	Temperature (°C) Water
Sample 01 (East Side of Muhuri Dam)	8.1	6.8	0.08	8.48	27.6	23.6
Sample 02 (Ichakhali Char)	7.8	6.0	1.30	7.82	25.9	22.5
Sample 03 (North Mukter Char)	7.7	6.1	0.90	8.17	26.4	22.4
Sample 04 (South Mukter Char)	6.4	5.7	2.33	5.66	25.0	23.6
Sample 05 (West Side of Muhuri Dam)	8.3	5.4	0.34	6.78	27.6	23.5
Average	7.7	6.0	7.32	7.38	26.5	23.1

Source: Present Study, 2018

According to Fondriest (2014), the anthropogenic pollution and toxicity bring changes in pH level in soil and water, leading to changes in solubility and toxicity of heavy metals like Cd, Pb, and Cu. Again the fluctuation of temperature affects the EC. For instance, for every 1°C increase in temperature, EC can increase up to 2 to 4 percent (Fondriest, 2014). The soil and water temperature in the Feni River sample area showed an increase from the standard average (soil 29.6 °C and water 23.1 °C), which might cause changes in the EC of the sample area soil and water. Again, changes in EC content in soil and water creates imbalance in the ecosystems causing biodiversity change and/ or loss. Chowdhury (2015b) mentioned the average temperature of the surface water of the Bay of Bengal was 28.0° C, with an annual variation between 25°C to 30°C. Khan et al. (2010) stated that, the sea surface temperature (SST) near Cox's Bazar rose about 0.8° C in summer season (May) and 0.4° C in winter (November) over a time period of 14 years (1985-1998). The increased temperature of water in the study area is related to the constant disposal of toxic wastes, garbage disposal and movement of water vehicles.

The average EC of soil was 7.32 mS/Cm in laboratory environment measured by pH meter, while Haque,M (2018) measured the EC (4.15 dS/m or 4.15mS/m) of soil at a depth of 4.1-6 cm depth of south coastal region. Again, average EC of sample area water was 7.38 mS/Cm, which was quite below the standard EC in sea water (>45 mS/Cm) (Rhoades et al., 1992). Though the EC level in sample water was quite low, the accelerating rate of toxic waste disposal and heavy metal concentration might change the EC content in water to create imbalance in the aquatic ecosystem.

Biodiversity Change

(i) Faunal Biodiversity: Heavy Metal and $CaCO_3$ Concentration in Mollusk Shells

The biodiversity of the Feni River sample area declined significantly, after the construction of 'Muhuri Closure Dam'. The natural estuarine flora and fauna declined both in terms of species, as well as in quantity at a great scale. The average heavy metal concentration in the mollusk shells collected from the Abuler char (S 01), showed that the highest concentration was of Cu (0.68 mg/L), followed by Pb (0.65 mg/L), while the $CaCO_3$ content was 1.99 mg/L (Table 7.1, Fig. 7.2). High concentration of the heavy metals indicated the causes of fragility of the mollusk shells in the sample area. Further, once known as the rich breeding ground of Hilsa fish (BFRI, 2018), the Feni River estuary has been experiencing reduced population of the egg hatching Hilsa. At present, the entire estuary has been practicing fish cultivation of species like, Tilapia, Shrimp, Rui, Koi, Magur, and Coral in the fish cultivation projects along the estuary (BFRI, 2018).

(ii) Floral Biodiversity: Vegetation Coverage

The natural vegetation, specifically, mangrove plants (locally known as Parabon) were observed on both side of the Feni estuary during the study. Nonetheless, numerous farms of vegetables and fruits, and paddy fields were observed along the MAA areas. The 'Vegetation Index' showed that, in 2015, the vegetation coverage reduced almost into half (+3.75) in comparison to that of the 1990 (+7.1) along the sample area (Fig.7.1, Map 7.2).

Nevertheless, at present the Feni River estuary is an affluent farm area, with a rapidly changing shoreline. Moreover, the socio-economic activities of the sample area have been adding toxic effluents into the estuarine water, soil and biological entities due to the untreated disposal of wastes. However, the higher concentration of Fe and Pb in the area proves that, the entire ecosystem has been adversely affected by anthropogenic activities.

8.2.2 Geo-environmental State of the Jalkadar River Estuary

The anthropogenic activities, such as disposal of municipal garbage, discharge of toxic effluents from fish processing factories, ice factories, and fishing trawlers and passenger boats, unethical land acquisition, unplanned land use, excessive logging of indigenous trees, soil dredging for construction, loosening of soil bonding due to changes in soil composition, as well as soil quality, heavy metal contamination in coastal soil and water, and weakly structured coastal protection dams and embankments were the major anthropogenic causes of rapid changes or movements of the coastline along the sample areas (Illustrations 8.1-8.10).

The Net Shoreline Movement (NSM)

Among 25 transects drawn upon both banks of the Jalkadar River, only six transects (Table 8.3) was accretion prone, ranging from 1.77 meter to 29.68 meter (Map 5.2). Conversely, the rest 19 transects was erosion prone, ranging from -1.07 meters to - 401.4 meters at transect 01 (Map 5.2). The Jalkadar River is protected by the coastal protection dams on both sides. To reveal the NSM of the Jalkadar River, the entire study area was divided into three major sections, namely the (i) Western section (Transect 01- 08), (ii) the Middle section (Transect ID 09- ID 16), and (iii) the Eastern section (transect ID17-ID 25) (Map 5.2).

Table 8.3: NSM Induced Geomorphic Features of the Jalkadar River Estuary: 1990-2015

Sections of Area (Transect ID)	Status of Shoreline Change		Geomorphic Features
	Accretion	Erosion	
Western Section (Shekherkhil Union) (ID 01- ID 08)	ID 04 (One Transect)	ID 01, ID 02, ID 03, ID 05, ID 06, ID 07, ID 08 (07 transects)	Erosion prone earthen dam
Middle Section (Chhanua Union) (ID 09- ID 16)	ID 14 (One Transect)	ID 09, ID 10, ID 11, ID 12, ID 13, ID 15, ID 16 (07 transects)	Curved pattern due to wave cut erosion, the coastal protection dam is high, but partially eroded
Eastern Section (Gondamara Union) (ID 17- ID 25)	ID 17, ID 18, ID 23, ID 24 (Four transects)	ID 19, ID 20, ID 21, ID 22, ID 25 (Five transects)	The bank of the river is erosion prone, the coastal protection dam is low and damaged

Source: Present Study, 2018 *NSM=Net Shoreline Movement *Totally 25 Transects

The NSM of these sections of the study area were presented with EPR graphs (Fig.5.6 to Fig.5.10). The NSM of the Jalkadar River illustrated accretion process in only 06 transects, of which 04 transects were observed at the eastern section of the study area (Gondamara Union), with only one transect in middle section (Chhanua Union) and 01 in Eastern section (Shekherkhil Union) of the estuary. The assumed reason of accretion on this transects is natural process. However, anthropogenic causes of accretion such as, garbage dumping was observed during present study along the dam of the Gondamara union (Illustration 8.4). Conversely, totally 19 transect depicted erosional activities along the estuary (Fig.5.6 to Fig.5.10). The areas at seven transects in western section (Shekherkhil union), another seven transects in middle section (Chhanua union), and five transects in eastern section (Gondamara union) were erosion prone (Map 5.2). The present study revealed that, flash flood from the hill forests at the east of the Banshkhali upazila causes excessive water flow in the river during heavy monsoon rainfall (Chairman, Banshkhali Union, 2016),which has accelerated shoreline erosion along the Banshkhali union protection dam (Illustration 8.16).

However, opposite situation was observed in the NSM along the Jalkadar River estuary during the same time extent. The NSM of the estuarine area of the river showed a slight change as a consequence of the protection dams on both sides (Fig. 5.6 to Fig.5.10). However, the earthen dams on both sides are quite vulnerable to high tide and storm surges. The east bank of the river is protected by the Banshkhali upazila protection dam, while the west bank of the river is protected by the coastal bank along the Gondamara union (Map 5.1). The length of the highest accretion was 29.7 meters (ID 04) and the lowest was 2.32 meters (ID 35) along the Western and Middle section. On the other hand, the length of the highest erosion was -401.4 meters (ID 01) and the lowest was -1.07 meters (ID 09) along the Western and Middle section. Hence, the net loss was 27.40 meters (Present Study, 2018). Nevertheless, EPR graph of 1990-2010 showed that, the NSM of the river was moderately balanced varying between average ratios of 20:23, while there was an increase in accretion activities during 2010-2015 (33 percent) along the Western section of the Jalkadar River estuary. Consequently the erosion process was observed to decrease to 23.2 percent throughout the sample area (Table 5.2).

Environmental Condition of Jalkadar River Estuary

The Jalkadar River is the main source of water, fish and fisheries and farming to the Gondamara and Chhanua unions in Banshkhali Upazila, Chattogram. The source points of pollution of the Jalkadar River were the Sharker Bazar fish retail market, ice factories, and boat construction and repairing factories of the upazila, from where effluents are drained constantly to the river through open drains constructed across the road from the ice factories and fish market (Illustration 8.22).

The average concentration of Fe (5.33 mg/g) in soil was almost 1.93 mg/g more than the world average (3.4 mg/g) and in all source points, the concentration of Fe exceeded the world average (ranged from 3.36 mg/g to 6.0 mg/g), except the S 02, which was slightly below the world average (3.36 mg/g). However, the average concentration of Cd (0.02 mg/g) in sample soil was quite below the world average (0.11 mg/g) and that of the Cu (0.62 mg/g) and Zn (0.23 mg/g) was quite lower from the world standard averages (0.9 mg/g and 5.0 mg/g consecutively). The hierarchy of average heavy metal concentration in soil samples was: Fe>Pb>Cu>Zn>Cd.

The heavy metal concentration in the water of the Jalkadar River sample area showed that, the average Pb concentration (0.58 mg/L) found in the water of the sample areas was almost 0.55 mg/L more than the world average (0.03mg/L). The boat repairing factories, salt farming fields, fish market, and around twenty ice factories at Sharker Bazar, Shekherkhil are the main sources of pollution (Illustrations 8.12 to 8.13). The hierarchy of average heavy metal concentration in water samples was: Fe> Pb> Zn > Cu > Cd.

Literatures (Ansari et al.,2015, Mominul et al.,2018, and Raknuzzaman et al.,2014) as well stated about the anthropogenic sources and the adverse consequence of high concentration of Pb in soil and water.

The Non-Metals in Soil and Water

The concentration of both P and S in the soil and water of the Jalkadar River was below detection level. It seemed alarming as both P and S function as vital nutrients for the floral and faunal living beings. The fluctuation of physio-chemical parameters might have caused P and S deficiency in the soil and water of the Jalkadar River sample area.

Physio-Chemical Quality of the Jalkadar River

The Table 8.4 illustrated the comparative scenario of the physio-chemical quality of soil and water at Jalkadar River sample area. The average pH (8.0) in soil of the sample area exceeded the Neutral (6.6 -7.3) range of pH (U.S. Soil Survey Division, 2011), indicating high contamination of soil. Mertens et al. (2013) claimed that, excess presence of pH in soil change the Slightly Alkaline soil into Moderately Alkaline; and decrease of per unit of pH increases the Zn fivefold in soil. On the other hand, the average pH (6.9) in water samples was within the Neutral (6.6 -7.3) range (USDA, 1998). The study found that, human induced pollution and toxicity in all physical biomes of the earth affect the pH in water leading to significant changes in the biodiversity (Fondriest, 2014). Again, lower pH content consequences in increased solubility and toxicity of the heavy metals like cadmium, lead, and copper. Though the pH in water was still within the Neutral range, the constant discharge of pollutants and garbage might ensue into exceeding limit of the pH in water in a near future. The high pH in water (above 10.0) can damage the gills and skin of aquatic organisms (Fondriest, 2013).

Though the average EC (1.7 mS/Cm) in soil sample was within normal range, the average EC in water samples was quite high (8.7 mS /Cm). Fondriest (2014) mentioned that, for every 1°C increase in temperature, EC can increase up to 2- 4 percent, while changes in the EC content in water creates imbalance in the entire ecosystem causing biodiversity change and/ or loss. The USDA (2014) mentioned that, soil EC is an indicator of salinity of soil, which indicates the nutrient availability and loss, soil texture, and available water capacity. Hence the crop yields and activity of soil micro-organisms, such as emission of greenhouse gases are regulated by the EC (USDA, 2014).

The surface soil temperature of the soil samples varied between 24.9° C to 27.3° C, showing a slight increase than the mean annual surface temperature of 28° C (Banglapedia, 2015), while average temperature was 29.6° C. Hailng et al. (2018) stated that, soil temperature plays a vital role in the physical, hydrological, and biological processes, as it regulates the transformation and uptakes of nutrients by plant roots and agricultural crops (Haishui et al., 2019).

Table 8.4: Physio-chemical Quality of Soil and Water at Jalkadar River Estuary

	pH in Soil	pH in Water	EC (mS /Cm) of Soil	EC (mS/Cm) of Water	Temp. (°C) of Soil	Temp. (°C) of Water
Sample 01 (Sharker Bazar, Banshkhali)	9.7	6.3	0.85	8.0	26.7	26.7
Sample 02 (Coastal Protection Dam, Gondamara)	6.8	7.2	1.32	8.9	26.8	27.7
Sample 03 (National Parabon, Banshkhali)	8.2	7.4	1.43	8.9	24.9	27.6
Sample 04 (Katkhali Bazar, Gondamara Upazila)	8.1	7.2	1.92	9.0	23.8	28.6
Sample 05 (Mojaher Para, Chhanua, Banshkhali)	7.2	6.3	2.79	8.1	27.3	28.5
Average	8.0	6.9	1.70	8.7	25.9	27.8

Source: Present Study, 2018

On the other hand, the Banglapedia (2015) mentioned average surface water temperature as 28° C, which ranged from 26° C to 29° C. Hence, the average temperature of water samples was within normal range (27.8° C).

Biodiversity Change

Faunal Biodiversity: Heavy Metal and $CaCO_3$ Concentration in Mollusk Shells

The Jalkadar River estuary, flowing between Gondamara and Shekherkhil Unions of the Banshkhali Upazila was once very rich in fish resources. The fishes like Hilsa, Rupchanda, and Coral are still now available in the area, though their population has decreased alarmingly. However, the increased pollution, illegal land grabbing at the upstream, and most importantly, the pirate attacks are the main reasons of occupation change in the estuary area (FGD, 2018). The cemented ghats in the entire estuarine area were observed to cover with oysters, locally known as 'Kachra' (Illustration 8.24). The mollusk shells were collected from five sample areas of the Jalkadar River to measure the concentration of heavy metals of the Jalkadar River estuary. Hence, the hierarchy of average concentration of metals in sample mollusk shells was: Fe> Pb> Cu> Zn >Cd . The $CaCO_3$ content of the Jalkadar River was measured from the mollusk shells from five source points, which ranged from 0.85 mg/L to 2.02 mg/L.

Floral Biodiversity: Vegetation Coverage

The shoreline along the Banshkhali Upazila had sparse vegetation, most of which were different types of mangrove trees. Conversely, the shoreline along the Gondamara union was mostly occupied by paddy fields, and salt farms. Nevertheless, the east mouth of the estuary had a national Parabon, seen to be covered with small plants during the survey in 2017. The vegetation coverage of the Jalkadar River reduced about 0.2 in indicator scale (Fig.7.1, Map 7.2). The coastal dam along the Gondamara union was covered with sea-grass and small mangrove plants.

The Jalkadar River has a great significance as the main waterway running through the Banshkhali and Gondamara upazilas. Besides serving as the only source of freshwater, the river is also the only source of fish and fisheries in the area. The present study revealed that, the Jalkadar River estuary should be protected from further pollution and illegal land grabbing. The boat making and repairing factories, the salt farms, the fish market, the proposed coal plant should be reconsidered to be designed in a more sustainable approach.

8.2.3 Geo-environmental State of the Bakkhali River Estuary

The Net Shoreline Movement (NSM)

Among the 22 transects, only six transects (ID 07, 11, 12, 13, 14, and 15) showed that, the area was under char accretion process ranging from 10.02 to 547.6 meters in length. On the other hand, the rest 16 transects went through erosional processes. The transect 05 depicted the highest length of erosion measuring 607.1 meters, while the transect 01 portrayed the lowest length of accretion, measuring only 07.4 meters (Map 5.3).

The entire study area of the Bakkhali River estuary experienced char accretion, which was quite distinct during the low tide (Table 8.5). Moreover, huge municipal garbage disposal was triggering the accretion process. In fact, the water body seen in the satellite imagery map of 2015 was filled up with municipal garbage, toxic effluents and garbage discharged from ice factories, fish cold storages and fish processing factories (Illustration 8.5). However, the diurnal high tide the river water inundates the adjacent areas of the bank under 5 to 6 feet water and washed away toxic waste materials.

Table 8.5: NSM Induced Geomorphic Features of the Bakkhali River Estuary, Cox's Bazar: 1990-2015

Sections of Study Area (Transect ID)	Status of Shoreline Change		Geomorphic Features
	Accretion	Erosion	
Southern Section (ID 01-22)	-------	Id 01 to ID 22 (22 transects)	Wave erosion along the river bank
Central Section (ID 23-44)	ID 26, ID 27, ID 28, ID 29, ID 30, ID 31, ID 34, ID 35, ID 36 (09 Transects)	ID 23, ID 24, ID 25, ID 32, ID 33, ID 37, ID 38, ID 39, ID 40, ID 41, ID 42, ID 43, ID 44 (13 transects)	Wave erosion along the river bank
Northern Section (ID 45-66)	--------	ID 45 to ID 66 (22 Transects)	Wave erosion along the river bank Newly accreted chars inundated by diurnal tidal waves

Source: Present Study, 2018

At the Bakkhali river estuary, the natural sediment load was comparatively higher, which increased drastically during monsoon. The heavy monsoon rains carried down huge amount of sediment and sand with the river flow in the downstream estuarine area. In fact, human interference, such as the Bakkhali Rubber Dam constructed in 1995, and reconstructed in 2005 (with 84 meters length and 3.5 meters width) at the upstream carried down a huge amount of silt (locally known as Charis; Hossain, 2015a) from the hilly regions at the source. This kind of heavy siltation enhanced the river bed to be loaded up rapidly. Hossain (2015b) stated about the natural sedimentation process. The researcher stated that, sediment load in Bakkhali estuary was comparatively higher, with a significant change in deposition rates. According to the study, huge amount of sediment and sand was carried down by huge river water to the river estuary in the monsoon period. The researcher also observed that, the rubber dam in the Bakkhali River caused siltation in the upstream of the Bakkhali River. Nevertheless, the human interference was stated as the obstacle for the normal flow velocity, as well as the natural transportation of sediment load through the estuary (Map 5.3). The EPR graphs (Fig.5.11 to Fig.5.15) illustrated a peculiar shoreline change pattern. During the time span of 1990-1995, the river estuary experienced 100 percent erosion activities, which reduced to 40 percent in the next five years 1995-2000, and gradually reduced to 17 percent during 2010-2015 time periods. However, the river estuary experienced 96.1 percent accretion after the construction of the rubber dam (Fig.5.3). Extensive accretion process was observed at the ‘Fishing Community Rehabilitation Project’ at Khurushkul union at the Bakkhali River estuary mouth during the present study field survey. The whole estuary was going under anthropogenic accretion activities (Illustration 8.6-8.9). Huge amount of soil were carried by the trawlers from the Meghna River and was deposited at the project area. On the other hand, the municipal garbage was seen to be dumped at the construction site of the Khurushkul Bridge at Bodor Mokam (Illustration 8.9).

Environmental Condition of the Bakkhali River Estuary

Heavy Metal Concentration

The soil and water samples were collected from the sample areas to measure the quality of the river water and soil.

Heavy Metal Concentration

The No.6 fishery ghat, the Nuniarchara fishery ghat, the ice factories, the shrimp and fish and fisheries processing factories at Nuniarchara industrial area, and the recently developed rehabilitation project were the main point sources of pollution. The entire estuary was filled with garbage of the fish markets and municipality, dried fish processing factories, fish and fisheries cold storage along with toxic effluents from ice mills and other small industries (Table 6.13, Fig.6.35). The hierarchy of average heavy metal concentration in soil was: Fe> Pb> Zn >Cd> Cu; and that of water was: Fe >Pb> Zn >Cd> Cu.

Though the average concentration of Cd in soil was quite below the world average (0.01 mg/g) (Table 6.9, Table 6.10), the Cd concentration in water exceeded the world average (0.16 mg/L) at the Bakkhali River and channel sample area (Table 6.9, Table 6.10, Fig.6.36). However, the anthropogenic sources of Cd such as, Cd-bearing materials and fossil fuels, fertilizers, and municipal waste water and sludge discharge residues from electroplating of motor parts, and batteries (Eisler,1985). The report also mentioned that, the aquatic flora and fauna with proximity to industrial and urbanized areas and point sources of Cd contained wastes cause decreased growth, depressed respiration, and shortened life-span of marine plants and animals in the study area (Eisler,1985). Hence, the increased untreated industrial waste disposal at the sample area might increase the Cd concentration in soil and water of the Bakkhali River and channel estuary ensuing into biodiversity loss in the sample area.

The soil and water samples collected from the source points of several shrimp hatcheries and fish processing factories had the average concentration of Cu (0.2 mg/g) in soil (Table 6.9, Fig.6.32), and in water 0.3 mg/L in water (Table 6.9, Fig.6.37).However, in both soil and water samples the Cd concentration was nearly half of the world average (0.9 mg/g or mg/l). According to Leal, et al.(2018) Cu is an essential heavy metal for some biological functions, but high concentration of Cu turns the heavy metals toxic and affects the metabolic process of marine organisms. The increasing anthropogenic interferences like dumping of industrial and domestic wastes, agricultural practices, and use of copper containing marine anti-fouling paints for the water vehicles is feared to raise the amount of Cu in the sample area water.

The average Fe concentration in soil and water of the Bakkhali River and channel sample area were 3.56 mg/g (Table 6.9, Fig. 6.33) and 1.3 mg/l (Table 6.11, Fig. 6.38) consecutively. The highest content of Fe in soil was at S 04 (6.0 mg/g), which was almost double in comparison to the world average (3.4 mg/g). The lowest Fe concentration in soil (2.48 mg/g) was found at S 03, which showed a deficiency of Fe. The high concentration of Fe in soil samples were owing to increasing socio-economic activities, such as ice factories, use of motorized fishing trawlers and speed boats, construction of 'Fishing Community Rehabilitation Project' and Khurushkul Bridge.

On the other hand, the highest concentration of Fe in water was found at S 06 (2.2 mg/l), with the lowest measured 0.71 mg/l at S 01 (Table 6.11, Fig.6.38). The average Fe concentration in soil of the Bakkhali River and channel sample area exceeded the limit of world average (3.4 mg/g), while the average Fe concentration in water was below the world average of 3.4 mg/L. Both deficiencies and/ or excess Fe concentration might disrupt photosynthesis of phytoplankton that forms the base of marine food base.

The average Pb concentration in soil of the sample area was 0.33 mg/g and in water 1.25 mg/l. Hence, the average Pb concentration in soil was about 11 times more than the world average (0.03 mg/g) and in water was 41.7 times more than the world average (0.03 mg/l).

The Pb is a non-essential heavy metal which is considered as a major industrial effluent added from the leaded petrol, fuel combustion, industrial process, and solid waste combustion. Moreover, the Pb might get into the water due to corrosion of leaded water pipelines, and leaded paints. The Pb is highly persistent and a small amount of Pb is highly poisonous for the aquatic organisms leading to disruption of the marine food chain (Sánchez, 2018).

The average Zn concentration in soil of the sample area was 0.9 mg/g, and in water was 0.17 mg/L, which were very insignificant in comparison to world average (5.0 mg/g). These results were also supported by Eisler (1993) and Bielmyer et al. (2012). Though Zink is an essential heavy metal for most aquatic organisms, increased anthropogenic interventions have been increasing the level of Zn which might be toxic to aquatic organisms. However, the accelerating rate of unscrupulous dumping of effluents from industries, tourist areas and households into the water along the study area might increase the Zn concentration in near future. The average heavy metal concentration in soil samples of the river depicted highest concentration of Fe (3.56 mg/g) followed by Zink (0.90 mg/g) and Pb (0.33 mg/g). According to the DoE, more than six tonnes of household garbage from the Cox's Bazar municipality was deposited at the ghat area daily (Dhaka Tribune, 2014), which turned the soil and water as filthy black, toxic and highly polluted. The toxic and polluted black water and the pollutants were observed to be flowing through the Kasturi ghat area to fall in the river water. Two dredgers were seen to excavate soil from the Kasturi ghat area to fill the Khurushkul bridge site, where the soil was highly contaminated with toxic effluents (Illustration 8.24 -8.27).

Non-Metals or Nutrients in Soil and Water of the Bakkhali River and Channel Estuary

The amount of Phosphorous and Sulphur in soil and water samples was below 03 PPT during study. Both Phosphorous (P) and Sulphur (S) are essential nutrients for all living things. Mainly mined from phosphate rocks, the P is the major source of commercial agricultural fertilizer (Cho, 2013). Nevertheless, the anthropogenic sources are municipal wastes, drainage from agricultural land, excreta from livestock, and diffused urban drainage (Lee et al., 1978; mentioned in Kroiss et al., 2011). Lower concentration of P in soil might lead to reduced crop yield (Douglas and Durst, 2002), decreased plant growth, death (Provin and Pitt,n.d.), and distortion of plant morphology (Atkinson and Davison, 1973). On the other hand, excess P in water increase algal growth ensuing into eutrophication in water bodies, decreased number of fish and desirable plants (USGS, n.d.). However, the amount of P in soil ranged from 01 ppm to 02 ppm and in water was 03 ppm at the Bakkhali River and channel estuary. On the other hand, the S was below 03 ppm in soil and below detection level (BDL) in water samples. The S is one of the major nutrients for the living beings. Mostly originated from the natural source like S containing minerals in parent materials, this nutrient enters into the food chain through microbial activities in soil, from plants and animal residues, and from external sources (Prasad, 2016). Deficiency of S in soil hinder growth, quality and amount of plant and crop yield (Prasad,2016), while excess S in soil decrease the pH in soil and lead to low pH induced problems (Agronomi Library,n.d.).

Physio-Chemical Quality of Soil and Water

The average pH (8.2) in sample soil was lesser than the pH in sample water (9.8) (Table 7.5). The amount of pH in both soil and water was alarmingly higher than the neutral level (7.5). The reason of such high availability of pH in soil and water is the constant discharge of effluents from the source points like the fishery ghat, fish processing factories, dried fish processing farms, ice factories, pollutants from the industrial area, and the Fishing Community Rehabilitation project.

Fondriest (2014) mentioned that, human induced pollution and toxicity in all physical biomes of the earth affect the pH in water leading to significant changes in the biodiversity. According to Fondriest (2013), high pH in water (above 10.0) can damage aquatic organisms.

Table 8.6: Physio-Chemical Quality of the Soil and Water at Bakkhali River and Channel Estuary

Sample areas	pH in Soil	pH in Water	EC (mS/Cm) in Soil	EC (mS/Cm) in Water	Temp. (°C) in Soil	Temp. (°C) in Water	TDS (PPM*) in Water
Sample 01 (No.6 Fishery Ghat)	8.4	8.3	2.31	8.63	24.3	31.5	1
Sample 02 (Nuniarchara Fishery Ghat)	8.2	7.8	6.42	8.64	23.5	31.7	1
Sample 03 (Khurushkul Project area)	8.3	8.1	6.11	8.65	23.2	31.6	1
Sample 04 (Nuniarchara I/A)	7.4	8.4	6.37	8.65	24.2	31.5	1
Sample 05 (Char Para, Bakkhali Channel)	7.3	8.6	3.98	8.65	22.5	32.1	1
Sample 06 (Kutubdia Para, Bakkhali Channel)	6.9	7.5	4.26	8.75	22.6	31.9	1
Sample 07 (Char Para, Bakkhali Channel mouth)	6.9	7.6	5.81	8.73	23.1	31.8	1
Sample 08 (Kutubdia Para, Bakkhali Channel mouth)	5.1	7.3	5.35	8.72	22.1	31.5	1
Average	8.2	9.8	5.07	8.67	23.2	31.7	1

Source: Present Study, 2018 (mS/Cm= mili Siemens/Centimeter; PPM: Parts Per Million)

The highest EC was found in the soil of S 02 (6.42 mS/Cm), while the highest EC in water was 8.75 mS/Cm at S 06.The average EC of soil (5.07 mS/Cm) and water (8.67 mS/Cm) crossed the limit of world average (Table 8.6).

The average temperature ranged between 23.2° C in soil and 31.7° C in water samples. Fondriest (2014) mentioned that, for every 1° C increase in temperature, EC can increase up to 2-4 percent, which consequences imbalance in the entire coastal and marine ecosystem leading to biodiversity change and/ or loss. Hence, the high amount of EC might be the consequence of increased temperature at the sample area (Table 8.6).

However, the average as well as the individual amount of Total Dissolved Solids (TDS) in water samples of the study area was 01 mg/L (Table 6.15).

Biodiversity Change

(i) Faunal Biodiversity: Heavy Metal and $CaCO_3$ Concentration in Mollusk Shells

Different types of mollusk shells were collected from the sample areas of the river and channel estuary (Fig 7.4). The average concentration of two heavy metals, such as, the Fe

(0.64 mg/L) and Pb (0.41 mg/L) was found to be much higher than the other three heavy metals. The $CaCO_3$ content in the mollusk shells was found to range between 0.88 mg/L to 1.98 mg/L (Table 7.3, Fig.7.2). Among the mollusks, the pearl producing mollusks were once available in plenty in the brackish water of the river, which due to anthropogenic interferences like heavy metal toxicity, soil and water pollution has decreased in types, as well as number (BFRI, 2018).

Other than the mollusks (Shell, Oyster, Mussels, and Clam), the Chelonians (Turtles and Tortoises) and the Mud crabs are also very important marine brackish water species of the river. The Chelonians are the scavengers of coastal and marine ecosystem, as well as are the agents of floral dispersion in different areas (BFRI,2018). According to BFRI (2018), among six marine species of Chelonians, five species are found in the coastal area. The Bakkhali River and its channel was once the main breeding ground of Leatherback turtle (BFRI, 2018).

(ii)Floral Biodiversity: Vegetation Coverage

The Vegetation Index illustrated that, the vegetation coverage of the Bakkhali River declined extensively from +0.02 (1990) to -0.03 (2015) in index scale, indicating a major loss of vegetation coverage along the estuary area during the study time (Fig. 7.1). The different forest ecosystems, such as the mangrove swamps, the sea weeds and sea-grass beds. However in March 2018 survey, about 90 percent of the mangrove trees and sea grass beds was observed to be destroyed on the west bank of the river and channel to develop, as well as extend the Cox's Bazar airport and the 'Fishing Community Rehabilitation' project at Khurushkul union for the landless fisherman in the estuary mouth of the river channel and estuary (Present Study,2018).

According to the BFRI (2018) the Bakkhali River estuary was highly rich in sea weed growth, which grew at the roots of the plants of Parabon of the tidal zone of the sample area. The BFRI attempted to cultivate the most abundant species of sea-weed known as the 'Hype', the yield was about 18 kg (BFRI, 2018). The sea-weeds and their byproducts are diverse and useful from both socio-economic and environmental perspectives (BFRI, 2018).The biodiversity of the Bakkhali River was once quite diversified. The unplanned and illegal anthropogenic interventions in the area was destroying the total ecosystem, causing the extinction of varied floral and faunal species, which act as the balancing factors at the estuarine environment.

Geo-environmental Condition of the Teknaf Coast, Marine Drive, Cox's Bazar

The Net Shoreline Movement of the Teknaf Coast, Marine Drive, Cox's Bazar

Total 50 transects were drawn upon the coastline of the study area of the Marine Drive, Cox's Bazar. Among 50 transects, only three transects (ID 25, 26 and 27) portrayed the process of sediment accumulation, ranging from 5.38 meter to 44.6 meter in length at the coastline of Sonarpara sample area. On the contrary, the rest 47 transects along the coastal zone from Sonarpara to Himchari showed a distinct sign of coastal wave erosion.

Table 8.7: NSM Induced Geomorphic Features along Teknaf Coast, Marine Drive: 1990-2015

Sections of Study Area (Transect ID)	Status of Shoreline Change		Geomorphic Features
	Accretion	Erosion	
Northern Section (Himchari National Park) (ID 01- ID 17)	NA	ID 01- ID 17, (17 Transects)	Erosion prone shoreline Maximum erosion in 2015 (ID 08 to ID 10)
Middle Section (Sonarpara, Ukhia) (ID 18- ID 34)	ID 25, ID 26, ID 27 (3 transects)	ID 18, ID 19, ID 20, ID 21, ID 22, ID 23, ID 24, ID 28, ID 29, ID 30, ID 31, ID 32, ID 33,& ID 34 (14 Transects)	Highly Erosion prone shoreline Maximum erosion in 2015 (ID 09-ID 20) Newly accreted sandy beaches due to protection (5.9m to 44.6m)
Eastern Section (Inani, Ukhia) (ID 35- ID 51)	NA	ID 35, ID36, ID 37, ID 38, ID 39, ID 40, ID 41, ID 42, ID 43, ID 44, ID 45, ID 46, ID 47, ID 48. ID 49, ID 50& ID 51 (17 Transects)	Erosion prone shoreline though more Stable

Source: Present Study, 2018 *NSM=Net Shoreline Movement *Totally 51 Transect

The EPR graphs (Fig.5.16 to Fig.5.20) of the sample area along Teknaf coast, Marine Drive depicted a highly erosion prone coast. The entire study area except only three transects (ID 25- ID 27), experienced erosion activities during the study time period of twenty five years (1990-2015). During the 1990-1995 time periods, the entire coast was erosion dominated (96.1percent). However, erosion process was comparatively insignificant than that of the previous time spans. However, the accretion process drastically increased up to 84.3 percent during the 1995-2000, which reversed to 10 percent in the years 2000-2005; and again increased up to 41.2 percent in 2010-2015 along the upper section of the study area. The main reason of this increased accretion process was due to the coastal embankment project of GoB. During the field survey long, huge geo-bags filled with sand and cemented Tetra pods were seen to be laid along the erosion prone areas of the Teknaf coast. Especially, the most erosion prone coastal area between the Himchari and Sonarpara was protected by double layer geo-sand bags. All the sample areas shorelines are protected by Dams and Embankments (Illustrations 8.1 to 8.4). Nevertheless, proper management is needed to protect the structures.

8.2.4 Environmental Condition of the Teknaf Coast, Marine Drive, Teknaf Coast

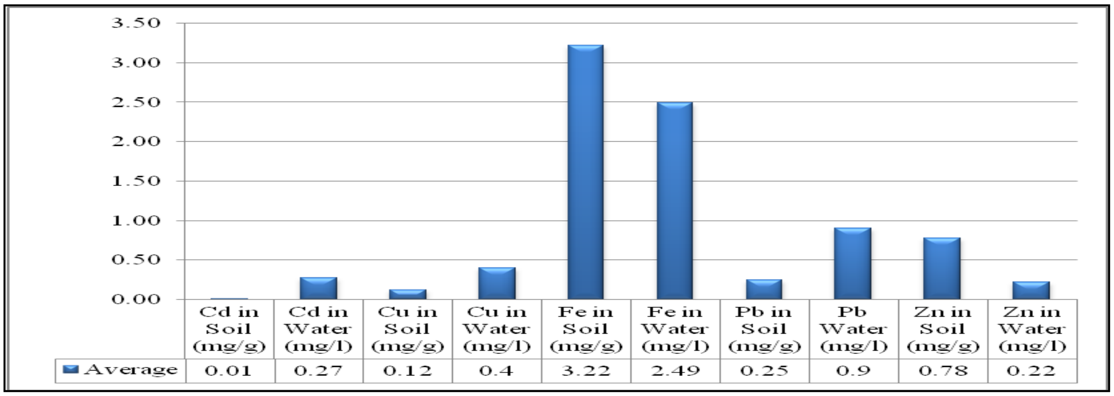
Heavy Metal Concentration

The soil and water samples were collected from three source points along Marine drive, Teknaf coast. The hierarchy of average heavy metal concentration in soil samples was: Fe> Zn >Pb> Cu> Cd; and that of water samples was: Fe> Pb> Cu> Cd> Zn.

From the data acquired, the average concentration of Cd in soil was 0.01 mg/g, followed by Cu (0.12 mg/g), Fe (3.20 mg/g), Pb (0.25 mg/g), Zn (0.78 mg/g) (Table 6.14, Fig.6.47-6.50). On the other hand, the average concentration of Cd in water was 0.27 mg/l, followed by Cu (0.40 mg/l), Fe (2.49 mg/l), Pb (0.9 mg/l), and Zn (0.22 mg/l) (Table 6.16, Fig. 6.54 -6.58). The Fe concentration in both soil and water was extremely higher than any other heavy metals in the study area (Table 6.14). The highest concentration of Fe was 4.94 mg/g in soil at S 03, 3.43 mg/l in water sample of S 01. Akter et al. (2019) studied heavy metal contamination in several dried fish of the Cox's Bazar region, where they mentioned that, being located at the top of the aquatic food chain, the fish are the major sources of heavy metal contamination, such as Cd, Pb, Fe, Cu, and Zn. Kabir and Eva (2014) mentioned that, heavy toxic metals like Na, Fe, Cr, Zn, Ni, and Pb are found in the soil of the shrimp farms (ghers). The researchers also mentioned that, the pH, salinity, EC of soil and water was found in a very fragile condition in the shrimp ghers. Mominul et al. (2018) reviewed literatures regarding current status of metal and metalloid pollution in Bangladesh. The paper mentioned that, municipal wastes from rapidly growing urbanized areas, industrial effluents, chemical fertilizers or agricultural land are the major causes of metal and metalloid pollution in Bangladesh. Kabir and Eva (2014) also mentioned that,the agricultural land and vegetables in sewage-irrigated areas are highly contaminated with Cd, Pb, and Chromium (Cr).

The average Cd concentration in sample soil was 0.01 mg/g and in water 0.27 mg/L (Fig. 8.7). Shahid et al. (2016) claimed that, Cd might cause serious deleterious effects both in plants and mammalian consumers. The main source of Cd in soil is the emissions from industries. According the researchers, Cd has high phytoaccumulation mobility from soil to plant and hence, might enter the food chain.

Fig.8.7: Average Heavy Metal Concentration in Soil and Water of the Marine drive, Teknaf Coast



Source: Present Study, 2018

The average concentration of Cd in water was 0.26 mg/g more in soil (Fig 8.7), which is alarming for the coastal and marine ecosystem of the sample area. However, the average concentration of Fe and Pb in soil and water was notably higher than the world averages (Fig 8.7). The excessive concentration of Fe and Pb is detrimental for the terrestrial and coastal and marine ecosystem of the Bakkhali River and channel estuary

The average Cu concentration in soil was 0.12 mg/g and in water was 0.40 mg/L (Fig.8.7). Apori, et al.(2018) mentioned that, the remediation of Cu contaminated soil can be done by the phytoremediation process as this method is economical and eco-friendly. The soils naturally contain 2 ppm to 100 ppm (average 30 ppm) of Cu which is essential for plant growth. On the other hand, excessive Cu concentration might cause toxicity leading to decrease in plant growth and seed germination.

The Zn concentration in soil at S 01 (0.78 mg/g), and in water at S 02 (0.22 mg/L), exceeded the world average (0.9 mg/g).

The study accentuates the findings of Raknuzzaman et al. (2014) who claimed that the shrimp hatchery areas at Cox's Bazar contains the highest levels of Zn, Cu and Pb due to huge discharge of different salts and chemicals from hatcheries to the beach soil.

Non-Metal Nutrients

The amount of Phosphorous in soil was between 01ppm to 02 ppm. The amount of P in water was 03 ppm. On the other hand, the amount of Sulphur in the soil samples was BDL and in water samples were below 03 PPT.

Physio-chemical Quality of Soil and Water

The physio-chemical parameters, such as the pH, EC and Temperature of the soil samples were measured. Table 8.8 shows that, the average pH in soil (7.0) was within the neutral range of pH scale. Conversely, the average pH of the water (8.2) was about 1.2 units higher than the neutral range of pH scale. Mertens et al. (2013) claimed that, excess presence of pH in soil change the Slightly Alkaline soil into Moderately Alkaline; and decrease of per unit of pH increases the Zn fivefold in soil.

Table 8.8: Physio-Chemical Quality of the Soil and Water at Marine Drive, Teknaf Coast

Soil Sample	pH in Soil	pH in Water	EC in Soil (mS/Cm)	EC in Water (mS/Cm)	Temp. (°C) in Soil	Temp. (°C) in Water
Sample area 01 (Inani Beach, Marine Drive)	5.8	7.7	6.37	8.48	26.5	31.6
Sample area 02 (Sonarpara, Marine Drive)	7.6	8.5	2.04	8.17	26.5	31.8
Sample area 03 (Himchari, Marine Drive)	7.6	8.4	1.22	0.22	26.4	31.9
Average	7.0	8.2	3.21	5.6	26.5	31.8

Source: Present study, 2018

The USDA (2014) mentioned that, soil EC is an indicator of nutrient availability and loss, soil texture, and available water capacity. Hence the crop yields and activity of soil micro-organisms, such as emission of greenhouse gases are regulated by the EC (USDA, 2014). The average soil EC in the sample area was 3.21mS/Cm in the study area. The average EC in soil was 3.21 mS/Cm, while the highest EC was two folds more than the average EC in soil (6.37 mS/Cm).

Further, the average temperature in soil was 26.5° C and in water was 31.8° C (Table 8.8). The significant difference between the soil temperatures in the sample areas accentuated the findings of Hailng et al. (2018) who mentioned that, the soil might show high spatio-temporal variability and soil temperature plays a vital role in the physical, hydrological, and biological processes. Haishui et al. (2019) mentioned that, the soil temperature regulates the transformation and uptakes of nutrients by plant roots and agricultural crops.

The average pH content of water samples was 8.2 in pH scale. This proves that, water of the sample area has exceeded the neutral pH level and is of ‘Alkaline’ type. The detrimental effects of low pH in water might cause declination and depletion of the corals at the S 03 (Inani beach), and reduced solubility of calcium carbonate causing inhibition of shells fish, such as snails and mollusks. Rashid et al. (2013) also mentioned that, the average pH at the east coast was 3.6 percent, and the study declared that, deterioration of mollusk shells was due to lower pH in water.

The average temperature of soil was 26.5° C and in water samples were 31.8° C in laboratory environment. Chowdhury (2015) mentioned the average temperature of the surface water of the Bay of Bengal is 28.0° C, with an annual variation between 25°C to 30°C (Banglapedia 2015). Khan et al. (2010) stated that, the sea surface temperature (SST) near Cox's Bazar rose about 0.8° C in summer season (May) and 0.4° C in winter (November) over a time period of 14 years (1985-1998). As mentioned earlier, for every 1°C increase in temperature, the EC might increase up to 2-4 percent (Fondriest, 2014). However, the increased temperature of water in the study area is related to the constant disposal of toxic wastes, garbage disposal and movement of water vehicles. The average EC of water samples was 5.6 mS/Cm, which was quite below the standard EC in sea water is >45 mS/Cm (Rhoades et al.1992). Though the EC level in sample water was quite low, the accelerating rate of toxic waste disposal and heavy metal concentration might change the EC content in water to create imbalance in the aquatic ecosystem.

The physio-chemical parameters like-the pH, temperature, and EC of soil and water samples are interrelated to each other. The study found that human induced pollution in the all physical biomes affect the pH in water leading to significant changes in the aquatic biodiversity. Fossil fuel consumption by automobiles, water vehicles, and industries; addition of several acidic compounds due to high level of CO_2 which decrease the pH level turning the water more ‘Acidic’. Further, point source pollution from agricultural runoff as well as waste water discharge containing detergents and soap based products from the numerous households, hotels, motels, and restaurants increases the acidity of water samples.

Illustration 8.1 & 8.2: Char lands formed at the MAA area of the MCD, Feni River, Mirsharai, 2017

Illustration 8.3: Shallow river depth at the estuary due to heavy siltation at the downstream of the MCD, Feni River, Mirsharai, 2017

Illustration 8.4: Land accretion due to garbage dumping at Jalkadar River estuary, Gondamara,Banshkhali, Chattogram, 2017

Illustration 8.5: Land accretion due to garbage dumping by local Influential persons at Bakkhali River Estuary, 2016.

Illustration 8.6: Land accretion due to sand filling by dredgers for Fishermen's Rehabilitation Project at Bakkhali River estuary mouth, 2016

Illustration 8.7: Land filling at Fisher men's Rehabilitation Project, Bakkhali River mouth
Illustration 8.8: Municipality garbage dumping process for land filling to construct the Khurushkul Bridge, Badar Mokam, Bakkhali River, 2018

Illustration 8.9: Kasturi ghat closed due to municipality garbage dumping for land filling to construct the Khurushkul Bridge, Bakkhali River, 2018

Illustration 8.10: Land accretion process by laying huge sand filled geo-bags to protect the erosion prone coastline, Teknaf coast ECA, Cox's Bazar, 2018

Illustrations 8.1-8.10: Shoreline Accretion due to Anthropogenic causes in study area, 2016-2018

Source: Present Study, 2018

Illustration 8.11: Shoreline erosion along the Feni River bank, Mirsharai, Chattogram, 2017

Illustration 8.12: Shoreline erosion along the Jalkadar river bank, Gondamara Union, Banshkhali, Chattogram, 2017

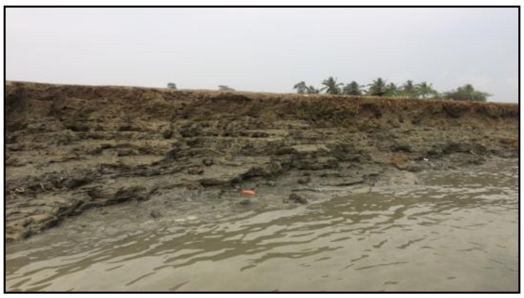


Illustration 8.13: Shoreline erosion along the Bakkhali River bank, Cox's Bazar, Chattogram, 2017

Illustration 8.14: Shoreline erosion protected with spurs at upstream of Bakkhali River Rubber dam, Cox's Bazar, 2017

Illustration 8.15: Massive shoreline erosion protected with cemented Tetra Pods and Geo-sand bags at Himchari, Marine Drive, Teknaf coast, 2016-2018

Illustration 8.16: Shoreline erosion along Jalkadar River, Banshkhali, Chattogram, 2018

Illustrations 8.11-8.16: Shoreline erosion owing to anthropogenic causes in the study area, 2016-2018

Source: Present Study, 2018

Illustration 8.17: Siltation inside the Spurs along the downstream of Bakkhali Rubber Dam, Badar Mokam, 2018

Illustration 8.18: Sand filling for Airport Extension Project, Cox's Bazar, 2016

Illustration 8.19: Bakkhali Rubber Dam, Badar Mokam, 2018

Illustrations 8.17-8.19: Anthropogenic Intervention causing shoreline movement at Bakkhali River Estuary

Source: Present Study, 2018

Illustration 8.20: The household garbage is the major source of pollution at Feni River estuary, 2016

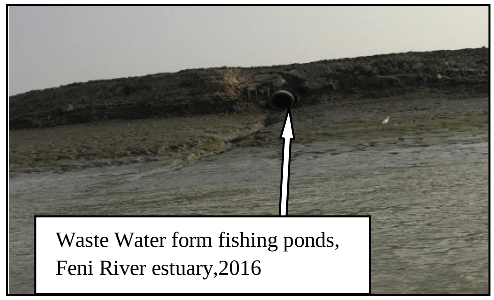


Illustration 8.21: The untreated waste water from the fishing ponds adds pollutants at the Feni River Estuary, 2016

Illustration 8.22: Untreated Effluents from Ice factories and Garbage disposed from Sharker Bazar into the Jalkadar river estuary, Banshkhali Upazila, 2017

Illustration 8.23: Disposal of untreated effluents from Boat Repairing Factories into the Jalkadar river estuary, Banshkhali Upazila, 2017

Illustration 8.20 -8.23: Sources of Pollution at the Sample Areas, 2016 to 2018

Source: Present Study, 2018




Illustration 8.24-8.27: Untreated Effluents and garbage being drained continuously from the No.6 Fishery Ghat, Bakkhali

Illustration 8.28: Untreated Effluents being drained continuously from the Nuniarchara Fishery Ghat, Bakkhali River, 2016 and 2018

Illustration 8.29: Untreated Effluents drained continuously from the Ice factories and the fishing trawlers of Nuniarchara Industrial area to the Bakkhali River and channel

Source: Field Survey, Present Study, 2016 and 2018

Illustration 8.24-8.29: Sources of Pollution at Bakkhali River Estuary, Cox's Bazar Municipality

Illustration 8.28: Toxic wastes drained through pipes to the coastal soil and water at Sonarpara, Marine Drive, Teknaf Coast, 2016 -2018

Illustration 8.29: Garbage thrown by tourists at Inani Beach, Marine Drive, Teknaf Coast, 2016 -2018

Illustration 8.28-8.29: Point Sources of Pollution at Teknaf Coast, Marine Drive, 2016 and 2018

Source: Field Survey, Present Study, 2016 and 2018

Biodiversity Change at Marine Drive, Teknaf Coast

(i) Faunal Biodiversity: Heavy Metal and $CaCO_3$ Concentration in Mollusk Shells

The three sample areas, the Himchari, the Sonarpara and the Inani Beach area at the Marine Drive are rich in diverse floral and faunal species. The Inani beach tourist area, one of the breeding grounds for Crabs, Chelonians, Sea weeds and Corals, was losing its biodiversity rapidly due to the unplanned tourism business activities. The beach area was occupied by small tourist shops, throwing their garbage directly on the beach, the coral boulders being picked up for collection by the tourists, hotels, motels and the boats plying in the Reju khal, which fall into bay near Inani tourist spot was enhancing the pollution deposit in the adjacent soil and water.

(ii) Floral Biodiversity: Vegetation Coverage

The vegetation coverage of the sample area has depleted at a great extent. The vegetation index scale value at the Marine Drive experience a huge decline from + 0.21 in 1990 to + 0.02 in 2015 (Fig.4.1, Map 4.4).

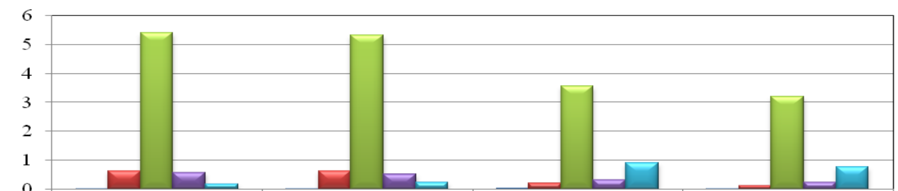
The Marine Drive, one of the most geo-strategically important high ways of the country runs through the long Teknaf coast, and is the habitat of diverse flora and fauna. However, this coastal zone is mostly erosion prone (Illustration 8.13). The study area between Himchari to Sonarpara was protected by laying geo-sand bags and tetra pods along the beach, after experiencing drastic shoreline erosion (Illustration 8.14). Nevertheless, toxic wastes from numerous shrimp hatcheries and various industries, hotels, motels and tourist spots like Inani beach was deteriorating the geo-environment as well as the biodiversity of the area.

The overall geo-environmental state of the study area depicted a deteriorating condition of the east coast. The anthropogenic activities were observed as the major sources of such decline. The socio-economically flourishing east coast has been going under huge development process, such as the establishment of industrial area at Nuniarchar along the west bank of the Bakkhali River, the huge fishery ghats, fishing trawler anchorage areas, and the recent expansion of Cox’s Bazar airport and the newly constructed Fishing Community Rehabilitation project at the estuary mouth. All these mass development activities have been enhancing the socio-economic value of the area, but on the contrary will cause drastic geo-environmental deterioration if not maintained and monitored strictly.

The shorelines of the sample areas experienced rapid movement both in terms of accretion and erosion during the study. Besides the natural reasons, the anthropogenic activities like land grabbing by garbage dumping, extraction of soil from the banks, excessive logging of tress from the hills and banks of the rivers, construction of coastal protection dams and closure dams for irrigation were observed as the major causes of shoreline movement.

The average heavy metal concentration in soil and water of the sample areas indicated (Fig.8.1 and Fig.8.2) notably higher concentration of Fe and Pb than that of the world average. However, the average concentration of Zn and Cu was within the limit of world average in most of the sample areas with some exceptions. However, the Cu concentration was quite low in each sample area soil and water.

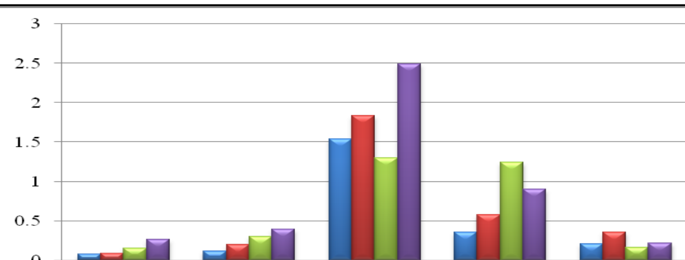
Fig.8.1: Average Heavy Metal Concentration in Soil Sample



	Feni River	Jalkadar River	Bakkhali River and Channel	Marine Drive,Teknaf
Cd	0.02	0.02	0.03	0.01
Cu	0.62	0.62	0.2	0.12
Fe	5.41	5.33	3.56	3.2
Pb	0.56	0.52	0.33	0.25
Zn	0.17	0.23	0.9	0.78

Source: Present Study, 2018

Fig.8.2: Average Heavy Metal Concentration in Water Samples



	Cd	Cu	Fe	Pb	Zn
Feni River	0.08	0.12	1.54	0.36	0.21
Jalkadar River	0.09	0.2	1.84	0.58	0.36
Bakkhali River and Channel	0.16	0.3	1.3	1.25	0.17
Marine Drive,Teknaf	0.27	0.4	2.49	0.9	0.22

Source: Present Study, 2018

In case of remediation of the existing high heavy metal contamination, Apori, et al. (2018) suggested about soil remediation, which consists of actions such as removal, control, containment, or reduction of contaminants in soil to a safe level for biological entities.

The biodiversity of the present study area was going through a rapid decline to over exploitation of the varied floral and faunal species. The shoreline change along the estuaries, vegetation coverage depletion, especially the mangrove forests to provide timber, and fire wood, burning of forests to clear land for settlement, as well as, being washed away due shoreline soil erosion are the main causes of biodiversity depletion.

Added to these, the untreated toxic wastes drained directly from the shrimp hatcheries, Fish and Fisheries cold storages, and ice factories to the coastal soil and water have severely damaged the entire biodiversity situation. The illegal method of shrimp and crab fry collection from the coastal water by the local people was killing other fish and fishery species. These above mentioned factors have been causing rapid biodiversity loss in the eastern coast by disrupting the food chains (Illustration 1.1 & 1.2) of the terrestrial and Marine and Coastal ecosystems along the study area. Being primary consumer in the food chain, the mollusks are widely used as the bio-indicators of metal contamination. Hence, in the present study, the concentration of the heavy metals and the Calcium ($CaCO3$) in the collected mollusk shell samples were measured to reveal the biodiversity deterioration in the study area.

8.5 The Correlation Coefficient Value for the Heavy Metal Concentration in the Sample Soil, Water and Mollusk Shells

The Correlation coefficient of heavy metal concentration in the sample soil and water, as well as soil and mollusk shell samples was calculated to find the strength of relationship between the variables. The correlation value ranged from -1.0 to 1.0. For instance, a correlation value with 1.0 show a 'Strong Positive Relationship', while a value with -1.0 shows a 'Weak Negative' relationship. The 'Strong Positive relationship' indicates that, the two variables move in one direction. For instance, increase of heavy metal concentration in sample soil increases the heavy metal concentration in water as well. Nevertheless, the correlation value between soil and water samples with 'Moderately Strong relationship' means that, the movement of two variables are not in the same direction. Further, the correlation value showing a 'Weak Negative relationship' means that, while one variable increases, the same indicator of the other variable decreases. The heavy metal concentration of the sample soil, water, and mollusk shells and the correlation of them have been illustrated below.

Correlation value for the Heavy Metal Concentration in the Feni River Sample Water, Soil and Mollusk Shells

The correlation value for the heavy metal concentration in the Feni River sample soil and water was 0.987, which meant there was a 'Strong Positive' relationship between the heavy metal concentration in soil and water samples (Fig.8.9).

Table 8.9: Correlation value for the Heavy Metal Concentration in the Feni River Sample Water, Soil and Mollusk Shells

Heavy Metals	Water	Soil	Mollusk
Cadmium	0.08	0.00	0.01
Copper	0.12	0.62	0.68
Iron	1.54	5.41	0.12
Lead	0.36	0.56	0.65
Zinc	0.21	0.17	0.22

Source: Present Study, 2018

However, further information regarding the data is as follows -

- Residual standard error: 0.1123 on 3 degrees of freedom (DF)
- Multiple R-squared: 0.9747, Adjusted R-squared: 0.9663
- F-statistic: 115.8 on 1 and 3 DF, p-value: 0.001717

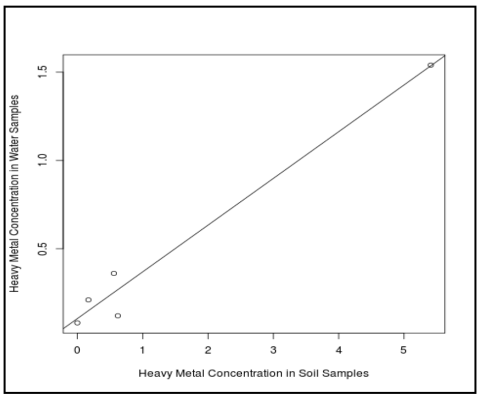


Fig. 8.7: Correlation value for heavy metal concentration in the Feni River sample soil and water

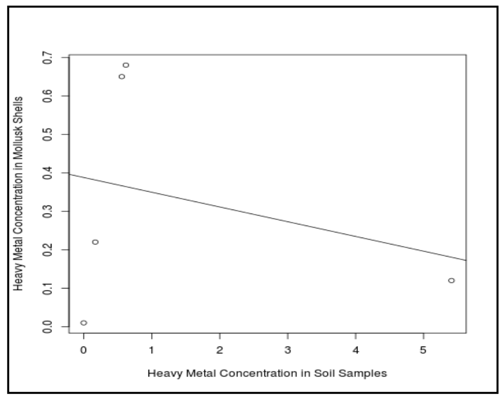


Fig. 8.8: Correlation value for heavy metal concentration in the Feni River sample soil and mollusk shells

Source: Present Study, 2018

On the other hand, the correlation value of heavy metal concentration in the Feni River sample soil and mollusk shells was -0.282646, which meant there was a ‘Weak Negative’ relationship between the heavy metal concentration in soil sample and heavy metals concentration in mollusk shells (Fig.8.8).

However, further information regarding the data is as follows -

- Residual standard error: 0.3429 on 3 degrees of freedom
- Multiple R-squared: 0.07989, Adjusted R-squared: -0.2268
- F-statistic: 0.2605 on 1 and 3 DF, p-value

The correlation value between the heavy metal concentration of sample soil and water of the Feni River was found to be 0.987, which illustrated a ‘Strong Positive’ relationship between the variables. This means the increase of heavy metal content in soil causes accelerated concentration of heavy metal in the water as well. Nevertheless, the correlation (-0.28) between of soil and mollusk shell of the Feni River sample areas showed a ‘Weak Negative relationship’, illustrating insignificant relation between the two variables. The mollusk shells were collected from the char lands near the estuary mouth, where the heavy metal concentration might have decreased due to the distance from the point source of pollution.

Correlation value for Heavy Metal Concentration in the Jalkadar River sample Water, Soil and Mollusk Shells

The correlation value between soil and water heavy metal concentration at Jalkadar River sample area was ‘Strongly Positive’, while that of the soil and mollusk shells was ‘Weak Negative’. This means that, heavy metal concentration in both soil and water increased simultaneously (Fig. 8.9). Converse situation was observed in case of soil and mollusk shells, where the fluctuation of heavy metal in soil had insignificant impact upon that of the mollusk shells (Fig.8.10).

Table 8.10: Correlation value for Heavy Metal Concentration in the Jalkadar River sample Water, Soil and Mollusk Shells

Source: Present Study, 2018

Heavy Metals	Water	Soil	Mollusk
Cadmium	0.09	0.02	0.074
Copper	0.20	0.62	0.160
Iron	1.84	5.33	2.146
Lead	0.58	0.52	1.066
Zinc	0.36	0.23	0.176

The correlation value for the heavy metal concentration in the Jalkadar River sample soil and water was 0.9732771, which meant there was a ‘Strong Positive ‘relationship between the heavy metal concentration in soil sample and heavy metals concentration in water (Fig.8.9).

However, further information regarding the data is as follows –

- Residual standard error: 0.1882 on 3 degrees of freedom
- Multiple R-squared: 0.9473, Adjusted R-squared: 0.9297
- F-statistic: 53.89 on 1 and 3 DF, p-value: 0.005223

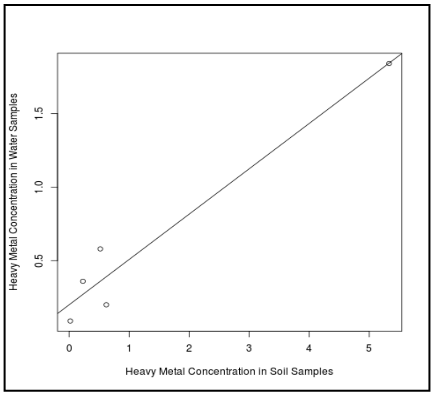


Fig 8.9: Correlation value for heavy metal concentration in the Jalkadar River sample soil and water

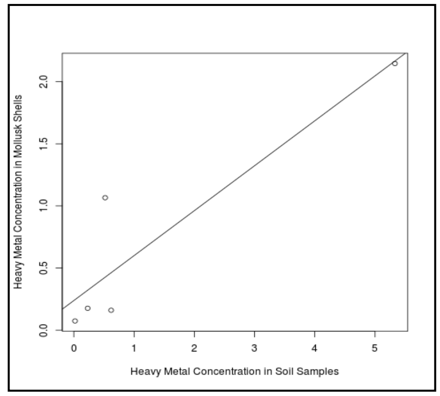


Fig. 8.10: Correlation value for heavy metal concentration in the Jalkadar River sample soil and mollusk shells

Source: Present Study, 2018

The correlation value for heavy metal concentration in the Jalkadar River sample soil and mollusk shells was 0.9091335, which meant there was a 'Strong Positive' relationship between the heavy metal concentration in soil sample and heavy metals concentration in mollusk shells (Fig.8.10).

However, further information regarding the data is as follows

- Residual standard error: 0.4288 on 3 degrees of freedom
- Multiple R-squared: 0.8265, Adjusted R-squared: 0.7687
- F-statistic: 14.29 on 1 and 3 DF, p-value: 0.03243

The correlation value between the heavy metal concentration of sample soil and water of the Jalkadar River was found to be 0.97, which illustrated a 'Strong Positive' relationship between the variables, indicating increased concentration of heavy metals in sample soil and water. The correlation (0.91) between soil and mollusk shell of the Jalkadar River sample area showed a 'Strong Positive relationship' between the variables, illustrating same trend of increased heavy metal concentration in both variables. The mollusk shells were collected from the point sources of pollution along the Shekherkhil Bazar, Gondamara union and Chhanua union, from where the heavy metals might have concentrated into the mollusk shells.

Correlation value for the Heavy Metal Concentration in the Bakkhali River and channel Sample Water, Soil and Mollusk Shells

The correlation value for the heavy metal concentration in the Bakkhali River sample soil and water was 0.6024107, which meant there was a 'Moderately Positive' relationship between the heavy metal concentration in soil sample and heavy metals concentration in water (Fig.8.11).

Table 8.11: Correlation value for the Heavy Metal Concentration in the Bakkhali River Sample Water, Soil and Mollusk Shells

Heavy Metals	Water	Soil	Mollusk
Cadmium	0.16	0.01	0.05
Copper	0.30	0.20	0.06
Iron	1.30	3.56	0.69
Lead	1.25	0.33	0.41
Zinc	0.17	0.90	0.10

Source: Present Study, 2018

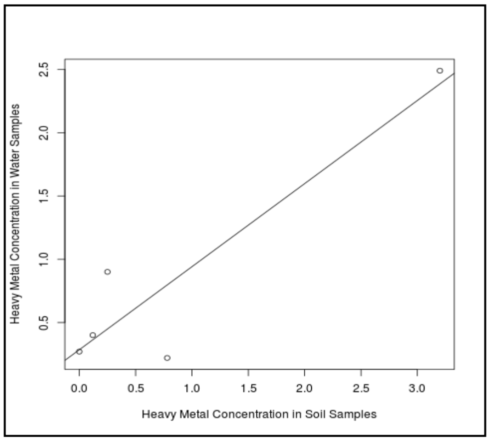


Fig. 8.11: Correlation value for the heavy metal concentration in the Bakkhali River sample soil and water

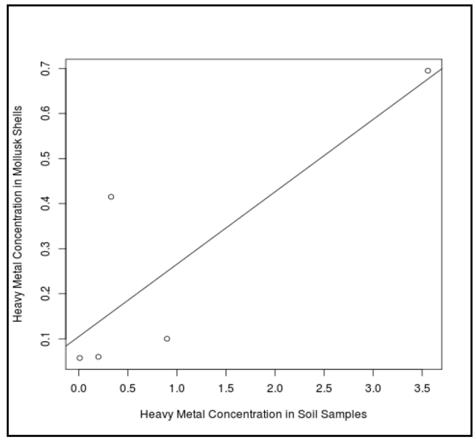


Fig. 8.12: Correlation value for the heavy metal concentration in Bakkhali River sample soil and mollusk shells

Source: Present Study, 2018

The correlation value for the heavy metal concentration in the Bakkhali River sample soil and mollusk shells was 0.8344267, which meant there was a 'Strong Positive' relationship between the heavy metal concentration in soil sample and heavy metals concentration in mollusk shells (Fig.8.12).

However, further information regarding the data is as follows -

- Residual standard error: 0.1799 on 3 degrees of freedom
- Multiple R-squared: 0.6963, Adjusted R-squared: 0.595
- F-statistic: 6.877 on 1 and 3 DF, p-value: 0.07884

The correlation value between the heavy metal concentration of sample soil and water of the Bakkhali River was 'Moderately Positive' (0.60) between the variables. This means the increase of heavy metal content in soil and water had a moderate influence upon each other. However, the correlation between of soil and mollusk shell of the Bakkhali River sample areas showed a 'Strong Positive relationship', illustrating a significant relation between the two variables. The mollusk shells were collected from the point sources of pollution along the Bakkhali River sample area. The heavy metals might have concentrated into the mollusk shells from the heavily polluted sample area. Different point sources of pollution, such as the dumping areas of municipality and fishery market garbage, toxic wastes from the Nuniarchara industrial area, Ice and Salt factories, the dried fish processing areas, and burned fuels from the fishing trawlers turned the soil and water into black and bad odor sludge.

Correlation value for Heavy Metal Concentration in the Teknaf Coast, Cox's Bazar sample Soil, Water & Mollusk shells

The correlation value for the heavy metal concentration at Teknaf Coast, Cox's Bazar sample soil and water was 0.9212763, which meant there was a 'Strong Positive' relationship between the heavy metal concentration in soil sample and heavy metals concentration in water (Fig.8.13).

Table 8.12: Correlation value for Heavy Metal Concentration in the Teknaf Coast, Cox's Bazar sample Soil, Water & Mollusk shells

Heavy Metals	Water	Soil	Mollusk
Cadmium	0.27	0.00	0.04
Copper	0.40	0.12	0.08
Iron	2.49	3.20	0.42
Lead	0.90	0.25	0.38
Zinc	0.22	0.78	0.07

Source: Present Study, 2018

However, further information regarding the data is as follows -

- Residual standard error: 0.4277 on 3 degrees of freedom
- Multiple R-squared: 0.8488, Adjusted R-squared: 0.7983
- F-statistic: 16.83 on 1 and 3 DF, p-value: 0.0262

The correlation value for the heavy metal concentration in the Teknaf Coast, Cox's Bazar sample soil and mollusk shells was 0.6473789, which meant there was a 'Moderate Positive' relationship between the heavy metal concentration in soil sample and heavy metals concentration in mollusk shells (Fig.8.14).

However, further information regarding the data is as follows -

- Residual standard error: 0.5403 on 3 degrees of freedom (DF)
- Multiple R-squared: 0.3629, Adjusted R-squared: 0.1505
- F-statistic: 1.709 on 1 and 3 DF, p-value: 0.2823

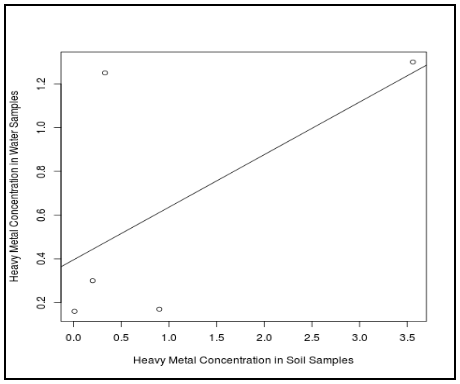


Fig. 8.13: Correlation value for heavy metal concentration at Teknaf Coast, Sample Soil and Water

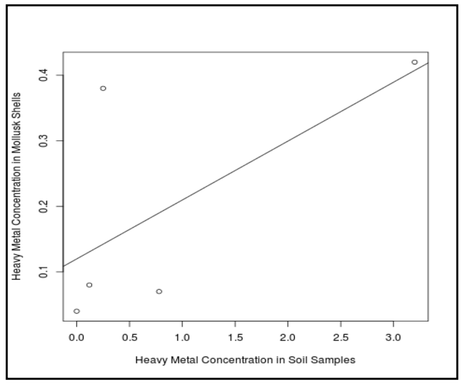


Fig. 8.14: Correlation value for heavy metal concentration at Teknaf Coast, Sample Soil and Mollusk Shells

Source: Present Study, 2018

The correlation value between the heavy metal concentration of sample soil and water of the Feni River was found to be 0.987, which illustrated a 'Strong Positive' relationship between the variables. This meant the increase of heavy metal content in soil caused accelerated concentration of heavy metal in the water as well. However, the correlation between of soil and mollusk shell of the Feni River sample areas showed a 'Weak Negative relationship', illustrating insignificant relation between the two variables. The mollusk shells were collected from the char lands near the estuary mouth, where the heavy metal concentration might have decreased due to the distance from the point source of pollution.

Table 8.13: Correlation value for Heavy Metal Concentration in the Sample area Soil, Water & Mollusk shells

Sample Areas	Correlation Values	
	Sample Soil and Water	Sample Soil and Mollusk shell
Feni River	0.98 (Strong Positive)	0.28 (Weak Negative)
Jalkadar River	0.97 (Strong Positive)	0.91 (Strong Positive)
Bakkhali River	0.60 (Moderately Positive)	0.83 (Strong Positive)
Teknaf Coast	0.92 (Strong Positive)	0.65 (Moderately Positive)

Source: Present Study, 2018

The correlation value between the heavy metal concentration of sample soil and water of the Marine Drive, Teknaf Coast was found to be 0.92, which illustrated a 'Strong Positive' relationship between the variables. This means heavy metal content in both soil and water accelerates together. Nevertheless, the correlation (-0.64) between of soil and mollusk shell of the Marine Drive, Teknaf Coast sample areas showed a ‘Moderately Positive relationship’, illustrating an insignificant relation between the two variables. The mollusk shells were found only at Inani tourist area, where the heavy metal concentration might have decreased due to the distance from the point source of pollution.

The correlation coefficient value of the soil and water of the study area show that, the heavy metal concentration had strong positive relationship in majority sample areas, with only one exception at Bakkhali River sample areas. However, the correlation coefficient value between the soil and mollusk shells in the study area started from weakly negative to moderately positive, with the dominance of strongly positive relationship. Thus the findings of the correlation of the heavy metal concentration in the soil, water, and mollusk shells indicate a strong interrelationship among the three indicators of the present study.

8.6 Pressure- State-Response (PSR) Model

After analyzing the deteriorating state of the geo-environmental indicators of the present study area, an attempt was taken to formulate a ‘Pressure-State-Response Model’ to feature the adverse impacts of the pressure indicators upon the state of the environment, which has to be alleviated by both public and private initiatives of plans and policies, known as the responses. Hence, the present study attempted to develop a simple ‘Pressure-State-Response (PSR)’ model (Table 8.14), following the concept of the ‘Driver-Pressure-State-Impact-Response’ (DPSIR) Framework, initially developed by the Organization for Economic Co-operation and Development (OECD, 1994). Later, the framework was adopted by the United Nations and European Environmental Agency to correlate the anthropogenic activities with the state of the environment (UN, 1997).

The PSR Indicators of the Present Study

In the present study, the PSR model was recommended as a tool for explaining the impacts of the anthropogenic activities (the Pressure indicators), upon the environmental condition (the State indicators). Further, the adaptation strategies (Response indicators) approach the Plans and Policy actions to resist as well as, develop sustainable methods for the natural resource utilization. This will generate the prospects to cease further geo-environmental degradation of the study area (Fig. 81). The present study ‘PSR Model’ illustrates the inter-relationship and inter-dependence of different pressure indicators and state indicators identified during the present study, while the response indicators are the surveyed plans and policies; the recommendations of the local stakeholders, working at the local areas, in a partial functional state due to various reasons.

Despite the recent flourishing socio-economic activities at the east coast of Bangladesh, research gaps were perceived in the sectors like-(i) recognizing the causes; (ii) planning the sustainable ways to mitigate and conserve; as well as, (iii) creating awareness and knowledge about the coastal geo-environment of the study area. Further, the literature reviews of the present study found a few research works regarding the integration of the environmental state and their degree of degradation along the coastal area in Bangladesh. Hence, the present research selected four major anthropogenic activities done by the local communities, as well as, the adjacent areas, as the 'Pressure' indicators. The Pressure indicators were measured to reveal the impacts of these upon the geo-environmental degradation in the study area. The present research focused upon five major effects of the anthropogenic activities such as (i) discharge of untreated or partially treated toxic industrial effluents; (ii) disposal of Municipality garbage at river estuary mouth; (iii) illegal encroachment of estuarine river banks; (iv) construction of river dams and coastal embankments; and (v) rapid deforestation. The findings of the present study revealed that, all the anthropogenic activities constantly generate pressure upon the natural coastal and marine ecosystem of the study area.

Again, the 'Pressure' indicators were observed to exert adverse impacts upon the geo-environment 'State' of the present study area. The 'State' indicators of the present research are the degrading (i) Geomorphic condition, (ii) Soil quality, (iii) Water quality, and (iv) Biodiversity. The present study findings illustrate the deterioration of the State indicators as an outcome of the effects of the Pressure indicators.

The 'Institutional Response' indicators of the present research were of two types. Firstly, the Integrated Coastal Zone Management Plan (ICZM, 1999 & 2002), developed by the Water Resource Planning Organization (WARPO), lead by the Ministry of Water Resources (MoWR) were reviewed thoroughly. The ICZM project delivered six key outputs, of which the three key outputs were the CZM (2005), CDS (2006), and PIP (2006); formed as the guidelines of coastal zone management of Bangladesh. Added to the ICZM plan, FGDs and KIIs were carried out with the head of the institutes, namely,

(i) Bangladesh Water Development Board (BWDB, Chattogram); (ii) Forest Division (Chattogram and Cox's Bazar); (iii) Bangladesh Fisheries Research Institute (BFRI, Cox's Bazar); and (v) Chairman and journalist of Banshkhali Union Parishad, Banshkhali, Chattogram.

On the other hand, FGDs and KIIs were performed with the 'Social Response' indicators like (i) the Red Crescent Officials and Volunteers (Chattogram and Cox's Bazar); and (ii) the Cyclone Preparedness Programme (CPP) Officials and Volunteers (Chattogram and Cox's Bazar).

The Functional Linkages among the PSR Indicators of the Present Study

The present study 'PSR Model' illustrates the linkages among the three types of indicators to assess their interrelationship by examining the types of pressure indicators prevailing at the study area; the consequences of these upon the geo-environmental condition; and by conducting a summative evaluation of the existing plans and policies implemented by the GoB through the local stakeholders to overcome the deteriorating geo-environmental condition. The following section is an attempt to discuss the linkages between the PSR indicators.

The first Pressure indicator 'Toxic Industrial Effluents' is one of the main causes of heavy metal or trace metal contamination into the soil, water, and biological entities of the present study. Other major causes are the marketplaces surrounding the Fishery Ghats, Dried fish processing farms, Shrimp hatcheries, Fish processing factories, Ice factories, Salt farms, Boat construction and Repairing factories, and many other small and medium factories at Nuniarchara Industrial area along the Bakkhali River. The constant discharge of chemical fertilizers from the vegetable farms and the fishing farms along the Feni River estuary adds contamination into the soil and water.

Nevertheless, obscurity remains in identifying the point sources of trace metal and pollutants in a downstream riverine country like Bangladesh, receiving huge industrial effluents from neighboring countries through around 230 trans-boundary rivers.

The second indicator, the 'Municipality Solid and Liquid Wastes' are the two main causes of pollution. A huge amount of solid garbage and waste water is constantly drained to the sample river estuaries and the Teknaf coastline from the Cox's Bazar Municipality, Fishery Ghats, namely, the No.6 Fishery Ghat, Nuniarchara Fishery Ghat, Kasturi Fishery ghat, Shekherkhil Fishery Ghat. Added to the above mentioned sources, huge amount of untreated toxic effluents and garbage was seen to be constantly discharged from the big fishing trawlers anchored near the sample area estuaries. The Feni River estuary has become contaminated with constant discharge of chemical fertilizers, and medicines used in the agricultural farms, and fish farms along the estuary banks. These wastes are not only responsible for pollution but increase the heavy metal concentration. Consequently, deterioration of the physio-chemical quality of the soil and water by accelerating the pH level, temperature, turbidity as well as EC in the sample areas was occurring. Moreover, the garbage and burnt lubricants; paints from the speed boats add Cadmium into the water. Added to these, the embankment cum road of the Jalkadar River along the Gondamara union was considered as point source of pollution. Waste water from the ice factories and huge amount of garbage from the fish market, situated upon the embankment constantly discharge polluted and toxic effluents directly into the river water. Further, the boat repairing factories add toxic pollutants in the soil and water of the estuary of the Jalkadar River (Illustrations 811 & 812).

The third Pressure index was the 'Illegal Encroachment' of estuarine river banks, especially along the Bakkhali and Jalkadar River (Illustration 86). The local people unethically deposit garbage at the river banks and surround the area with poles or pillars to claim the land ownership. Moreover, for construction of the 'Khurushkul Bridge' at Badar Mokam, a huge amount of municipal garbage is being dumped. These processes have several adverse effects such as (a) the river width has extremely narrowed down and the river estuary has almost filled up; while (b) the toxic effluents leaking from the dumped garbage was mixing into the soil and water to make them filthy and contaminated. The present study observed that, the Kastura Ghat has entirely clogged with garbage from the construction site of the Khurushkul Bridge at Badar Mokam. The remaining part of the waterway is filled up with black, filthy water with a huge amount of garbage flowing directly to the Bakkhali River. Nonetheless, the banks of the Jalkadar River estuary have also been filled up with dirty water and garbage. The present study observed that, households, markets, and small factories of the Banshkhali Upazila have been using the river as the waste disposal drain. All these above mentioned factors have been functioning as the reason of degraded soil and water quality, which was causing decline of biodiversity of the study area as well. However, the adverse effects of these ‘Pressure’ index upon the geomorphic condition has yet to be investigated.

The fourth Pressure indicator is the ‘Construction of River Dams and Coastal Embankments’. The dams are built at the downstream area of the sample river estuaries like -the Feni Closure Dam on the Feni River and the Bakkhali Rubber Dam on the Bakkhali River; and the coastal embankment along the highly erosion zone from Himchari to Inani, Teknaf Peninsula. The present study observed that, though the dams are beneficial for agricultural land irrigation; they are becoming detrimental for the local geo-environment in the long run. For instance, in rainy season excess water stored in the backside of the dams create strong wave current and erodes the banks of the Feni and Bakkhali River, and converse situation was noticed at the downstream areas of the dams. Both the Feni and Bakkhali River estuaries are being filled up with heavy silts as normal wave current has ceased along these sites (Illustrations 81-85 & 87). Huge amount of eroded sediments then deposit in the mouth of the estuaries and make the river bed shallower. Nevertheless, the embankments along the Jalkadar River and Inani coast have been serving as the protection from high erosion. However, the embankment along the Chhanua union of the Jalkadar River was noticed to be hugely damaged. On the other hand, the high road cum embankment along the Gondamara union is used as the main road of the union, with a bazaar, a fish market, and numerous ice factories on it. Moreover, the decreased level of salinity in the upstream area of the river dams (BWDB, Chattogram, 2018) results into alteration in the biodiversity. As a consequence of both excessive erosion as well as the faunal biodiversity depletion, the highly erosion zone of the Teknaf coast was declared as the ‘Ecologically Critical Area (ECA)’ by the GoB. Embankments have been constructed along the coast with built with huge geo-bags and cemented tetra pods to protect the land and faunal biodiversity of the area.

The fifth pressure indicator is the ‘Rapid Deforestation’ along the entire study area due to logging for timbers and firewood; as well as clearing the forest for shrimp cultivation, farming and settlements. The Vegetation Index (Fig.71, Page 148) in the present study illustrates that, major decline had taken place along the sample areas in a time span of 25 years (1990-2015). The vegetation coverage of the Feni River became almost three-fourth (+3.35) in 2015; while that of the Jalkadar River (+ 0.02) and Teknaf coast (+ 0.19) reduced almost into half. However, the cultivated vegetation along both banks of the Feni River was serving as an instrument for socio-economic advancement. Nevertheless, the worrying fact is that, the vegetation coverage along the Bakkhali River sample area has declined to an extreme level (-0.05) ensuing into negative values. The consequential effects are the deterioration of the soil and water qualities, as well as, biodiversity loss at a disquieting level.

The present research studied two types of ‘Response’ indictors such as (i) the institutional indicators, and (ii) the Social indicators. Firstly, literature review of the Integrated Coastal Zone Management (ICZM) for Bangladesh and two key reports of the Project, namely, the Coastal Management (CZM, 2005) and the Coastal Development Strategy (CDS, 2006) was conducted as the ‘Institutional response’ indicator. Further, the FGDs and KIIs were conducted with the institutional heads of the (ii) Bangladesh Water Development Board (BWDB, Chattogram), (iii) Forest Division (Chattogram and Cox’s Bazar), (iv) Bangladesh Fisheries Research Institute (BFRI), Cox’s Bazar, and (v) Banshkhali Union Parishad, Banshkhali, Chattogram.

All the institutional responses admitted the lack of integration among the stakeholders. Further, they indicated the weakness of the existing plans and policies. For instance, the Forest division in both Chattogram and Cox’s Bazar indicated about the negligence of the authority in protecting the forests. They mentioned the inadequacy of skilled work force for maintenance of even the protected forest areas. The reason of rapid decline in total vegetation coverage in the study area was mentioned as the weak monitoring, unethical attitudes of the local people and the need of proper conservation laws.

Secondly, the ‘Social Response’ indicators for the present study were the (i) Cyclone Preparedness Programme (CPP, since 1973), the sole government programme run by the Ministry of Disaster and Relief; working in collaboration with the (ii) Bangladesh Red Crescent Society (BDRCS since 1973). At present, the CPP is operating with 232 official staffs and 55,260 volunteers (18,420 female and 36,840 male) in the sector of cyclone preparedness along the east coast. Recently, the programme has started to work in the socio-economic sectors, such as coordinating the distribution of relief, rehabilitation as well as, establishment of water and sanitary system in the Rohingya Camp areas in Ukhia, Cox’s Bazar. Further, the Red Crescent is providing logistic supports to the CPP in the study area to confront all kinds of environmental and socio-economic disasters in the study area. Nonetheless, the CPP Officials opined about their inclusion into the management of environmental as well as socio-economic disasters at the coastal zone as they have developed a huge volunteer team with the local people, well trained in disaster management. From the FGDs done among the volunteers reveal that, they are willing to get engaged with sufficient training about the causes of climate induced disasters, environmental pollution, and biodiversity loss. The CPP volunteers of four Upazilas of Chattogram namely, the Shitakunda (Kumira Union), Banshkhali (Baharchara Union), and Moijjer Tek (Karnaphuli union) and Anowara Upazila Parishad expressed their deep interest in getting trainings on ‘Creating awareness’ and ‘Disaster management techniques’ with a mission to build a resilience community in their respective areas. This will certainly facilitate the coastal zone communities to exploit their natural resources in a sustainable approach.

The Coastal Development Strategy (CDS, 2005) reported that, both ICZMP plans (1999 and 2000) could not reach the level of full functionality owing to lack of strong linkages among local and national stakeholders, inappropriate implementation of policies, lack of close monitoring, and the non inclusiveness of local communities and stakeholders in the plan. Nevertheless, other non-government institutions were observed to be partially functional or working in segregated areas like sanitation, public health, and coastal forestation owing to the insufficient linkages between the stakeholders. However, owing to ineffectual monitoring of the existing Plans, Policies and Strategies for the coastal zone of Bangladesh the sustainable development initiatives, both in public and private sectors, has the least impact upon the geo-environmental condition of the study area.

Table 8.14: PSR Model for the Present Study

		State Indicators			
		Shoreline Movement	**Soil Quality**	**Water Quality**	**Bio-Diversity**
Pressure Indicator	**Toxic Industrial Effluents**	NA	i) Heavy metals contamination, ii) Deteriorating physio- chemical quality (Tables 6.1-6.17 Fig.6.1-6.61)	i) Heavy metal contamination, ii) Worse physio-chemical quality (Tables 6.1-6.17 & Fig.6.1-6.61)	i) Increased heavy metal concentration ii) Decreased pH causes ocean acidification- iii) Results into declined $CaCO_3$ content in mollusk shells causing iv) Declined population of mollusk shells due to fragility of the shells (Tables 7.1-7.3; Fig.7.1-7.5)
	Municipality Garbage	Accretion along river bank (Tables 5.1-5.7; Fig.5.1-5.20; Map 5.1-5.4)	i) Increased soil pollution, ii) Declined soil nutrients and fertility (Tables 6.1-6.17 & Fig.6.1-6.61)	i) Clogged Drainage, ii) Deteriorating water quality, iii) Black sludge water (Tables 6.1-6.17 & Fig.6.1-6.61)	i) Declined floral and faunal bio-diversity, and ii) Declined population and species diversity (Tables 7.1-7.3; Fig.7.1-7.5)
	Illegal Encroachment	i) Narrower river width, ii) Shallower depth (Tables 5.1-5.7; Fig.5.1-5.20; Map 5.1-5.4)	i) Huge deposit of pollutants, ii) Deteriorating physio-chemical quality (Tables 6.1-6.17 & Fig.6.1-6.61)	i) Clogged Drainage, ii) Deteriorating water quality, iii) Black sludge water (Tables 6.1-6.17 & Fig.6.1-6.61)	i) Declined floral and faunal bio-diversity, and ii) Declined population and species diversity (Tables 7.1-7.3; Fig.7.1-7.5)
	Construction of river Dams and Coastal Embankments	Heavy siltation in river down- stream area (Tables 5.1-5.7; Fig.5.1-5.20; Map 5.1-5.4)	i) Declined physio-chemical quality of soil (Tables 6.1-6.17 & Fig.6.1-6.61)	i) Decreased river upstream water flow (Source: BWDB, Chattogram, 2018) (Tables 6.1-6.17 & Fig.6.1-6.61)	i) Alteration in Bio-Diversity, ii) Increased cultivated species of flora and fauna (Tables 7.1-7.3; Fig.7.1-7.5)
	Rapid Deforestation	i) Shoreline Change, ii) Increased erosion (Tables 5.1-5.7; Fig.5.1-5.20; Maps 5.1-5.4)	Decrease in soil nutrients (Tables 6.1-6.17 & Fig.6.1-6.61)	Decreased water nutrients (Tables 6.1-6.17 & Fig.6.1-6.61)	Depletion of different Flora and Fauna types (Tables 7.1-7.3; Fig.7.1-7.5)

Response Indicators (National and Local Responses)
i) Integrated Coastal Zone Management (ICZMP), 2002 by Water Resource Planning Organization (WARPO) ii) Bangladesh Water Development Board (BWDB, Chattogram) iii) Forest Division, Chattogram and Cox's Bazar iv) Bangladesh Fisheries Research Institute (BFRI), Cox's Bazar
Social Institutions
i) Red Crescent (since 1972) ii) Cyclone Preparedness Programme (CPP, Since 1973) iii) Other NGOs

Source: Present Study, 2018

8.7 Incorporation of the Present Study Indicators into the Existing Sustainable Development Initiatives at National Level

The major national initiatives such as the plans, policies or strategies concerning sustainable development plan of the coastal zone of Bangladesh have been discussed in the earlier chapter (Chapter 2). The present study attempts to incorporate the three geo-environmental indicators of the present study, selected in accordance with the criteria of ICZM plan (1999), SDGs (2015-2030), Vision 2021, BOBLME (2008-2013), 7th FYP (2016-2020), Bangladesh Delta Plan (2100), as well as, other related initiatives of development by the GoB. The present research also studied the proposed Bangladesh Delta Plan (BDP), 2100 and the Ocean Decade Declaration in 2021 by UNESCO to find the relevance of the geo-environmental factors to be taken as their themes. The physiography, the climate change induced disasters, terrestrial and aquatic pollution, and the biodiversity status of the study area was found to be considered in these programs. Nevertheless, an endeavor was taken to show a relationship between the goals and indicators of the existing Plans and policies with that of the present study. The geo-environmental indicators of the present research have been selected according the goals of the existing ICZM plan (GoB, 1999). Further, the indicators represent the goals of the SDGs, as well as, the 7th FYP of Bangladesh. Further, the BDP, 2100, the UNESCO 'Ocean Decade, 2021', and the Bay of Bengal Literacy Program, 2019 as well emphasizes the 'Creation and Dissemination of Ocean and Coastal Literacy', which is one of the key theme of advocacy in the present study.

Added to the selection of the geo-environmental indicators for the present research, an attempt was taken to structure a 'Sustainable Development Framework' for the study area.

8.8 Strategic Framework for Sustainable Coastal Zone Management at East Coast of Bangladesh

This is distinctly perceptible from the present research that, the geo-environmental state of the eastern coast was rapidly deteriorating in every aspect like-the shoreline movement with a higher tendency of erosion; excessive water and soil pollution, as well as extensive damage of Terrestrial and Coastal and Marine ecosystems causing escalating biodiversity loss. Hence, the present study has attempted to construct a **'**Strategic Policy Framework'

(SPF) to incorporate the study indicators into the existing and future CZM and coastal development plans for the east coast. This framework intended to integrate the present study geo-environmental indicators into the existing policy frameworks to fill up the functional gaps, which have been hindering the full functionality of the existing plans and policies, specifically, the ICZMP of Bangladesh.

The proposed SPF of the present study advocates to incorporate the study indicators into four phases, such as (i) development of a ‘Mission’ with some specific (ii) ‘Visions’ through several selected (iii) ‘Objectives’, in a (iv) ‘Strategic Time-frame’ (Table 8.15).

The ‘Mission’ of the SPF was designed to incorporate the geo-environmental indicators of the study into the existing ICZMP, 1999 of Bangladesh.

The ‘Vision’ was determined to achieve the goal of the Mission into three consecutive phases. In the first phase, the causes and patterns of changes and /or depletion of different geomorphic features; the adverse effects of geomorphic changes upon the soil and water; and the impacts of these two geo-environmental indicators upon the changing and/ or degrading biodiversity state of the study area has to be studied.

In the second phase of the vision framework, ‘Functional Plans’ has to be developed for gradual ‘Paradigm Shift’ of livelihood and /or occupation of the coastal communities to build a resilient society. The policies regarding the awareness creation about CZM, and knowledge base development among the local communities about sustainable use of the natural resources has to be formulated. Emphasize has to be given upon regular training, workshops, seminars and demonstrations for the existing and new ‘Volunteers’, as well as the local stakeholders through the initiation of various free primary education and vocational training schemes among the local communities for alternative livelihood.

The Third Phase is the final phase to build, implement, and ensure after monitoring of the CZM plan strategies into the study area. Hence, regular training, workshops, seminars and demonstrations for the CPP and IFRCRC volunteers, as well as the local stakeholders was advocated in the framework. Introduction of various development schemes like- free primary education and vocational training among the local communities for alternative livelihood. Moreover, besides the existing CPP and FRCRC volunteers, devoted and enthusiastic pool of ‘Youth Volunteers’ for coastal zone disaster management and mitigation has to be created with the local student folk from each level of education. The inclusion of knowledge about environmental sustainability into the curriculum of the 'National Curriculum Textbook Board, (NCTB)' of Bangladesh, as well as conducting 'Training of the Teachers (TOT)' programmes about the climate change, geo-environment and sustainable development approach should be ensured. This will help to form a strong volunteer pool for coastal disaster management and mitigation by including the youth population of the country. In this phase, initiatives has to be taken to modify and imply the 'Waste Management' and 'Waste Treatment' plants for the Cox's Bazar Municipality, specifically for the study area.

The 'Objectives' of the 'Vision' was projected to be achieved in two 'Strategic Time-frames' like - (i) the initial Short-Term CZM plan for 5 to 10 years, which will be optimized through (ii) the Long-Term CZM plans comprising 10 to 15 years.

The Short-Term Coastal Zone Management plans was recommended to the- Creation and dissemination of comprehensive knowledge pool about Sustainable Development Goals (SDGs), Blue economy, Delta Plan, 2100, and Decade of Ocean Science (2021-2030). Besides generating knowledge, knowledge dissemination through non-formal methods, such as documentaries, dramas, demonstrations, and cultural programs at local level through the national media, as well as conducting regular training for the existing volunteers of local stakeholders about sustainability was advocated in the study.

The Long Term Coastal Zone Management plans at National Level (for 10 to 15 Years) was suggested to include creation of comprehensive and scientific knowledge base about Terrestrial and Coastal and Marine ecosystems of the Bay of Bengal, inclusion of the acquired knowledge into the national curriculum at all level, confirm the development and implementation of modern 'Waste Management Plant' as well as 'Waste Treatment System' at the Cox's Bazar Municipality, and development of well trained 'Volunteer Group' for coastal geo-environmental 'Disaster Management and Mitigation'.

Table 8.15: Proposed Strategic Policy Framework (SPF) for Coastal Zone Development and Management (CZM) Plan of the East Coast of Bangladesh

		Functions of the SPF Framework
Mission		**Incorporation of the present study geo-environmental indicators into the Existing and Future CZM & Development Plans of East Coast of Bangladesh**
Phases of achieving the Vision	**1st Phase**	1) Initiatives has to be taken to identify, as well as measure- (i) the causes and patterns of changes and/or depletion of different geomorphic features; (ii) adverse effects of geomorphic changes upon the environmental condition of the soil and water; and (iii) the role of these two geo-environmental indicators in changing and/ or degrading biodiversity state of the study area has to be studied. 2) Functional Plans has to be developed for gradual 'Paradigm Shift' of livelihood and /or occupation of the coastal communities to build a resilient society.
	2nd Phase	(i) Create awareness among the local stakeholders about CZM (ii) Create knowledge base among the local communities about sustainable use of the natural resources (iii) Conduct regular training, workshops, seminars and demonstrations for the existing and new volunteers as well as the local stakeholders. (iv) Initiate various schemes like free primary education and vocational training among the local communities for alternative livelihood
	3rd Phase	(i) Develop initiatives to modify and imply the 'Waste Management' and 'Waste Treatment Plant' for the Cox's Bazar Municipality, specifically the study area (ii) Include knowledge about sustainability in the educational national curriculum (iii) Develop strong volunteer pool for coastal disaster management and mitigation (iv) Creation of Youth Volunteer Teams (v) Conduct 'Training of the Teachers (TOT)' programmes about the climate change, and geo-environment and sustainable development approach
Objectives		(i) Protection of existing environment by sustainable use of natural resources (ii) Restoration of the natural biodiversity of the study area (iii) Stabilization of the Shoreline movement along study area (iv) Revision of existing Integrated Coastal Zone Management (ICZM) plan for the study area (iv) Propose Strategic Framework for incorporating the present study indicators into the existing Integrated Coastal Zone management plan for the east coast
Activities within the Strategic Time-Frame	**Five to Ten (5-10) years**	**(i) Short Term Management Plans at Local level (for 5 to 10 Years)** a) Creation and dissemination of comprehensive knowledge pool about Sustainable Development Goals (SDGs), Blue economy, Delta Plan,2100, and Decade of Ocean Science (2021-2030) b) Creation of non-formal method of knowledge dissemination, such as trainings, rallies, documentaries, dramas, demonstrations, and cultural programs at local level through the national media; and c) Conduct regular training for the existing volunteers of local stakeholders about sustainability.
	Ten to Fifteen (10-15) Years	**(ii) Long Term Management Plans at National Level (for 10-15 Years)** (a) Creation of comprehensive and scientific knowledge base about Coastal and Marine ecosystems of the Bay of Bengal (b) Inclusion of the acquired knowledge into the national curriculum at all level (c) Ensure the development and implementation of modern 'Waste Management Plant' as well as 'Waste Treatment System' at the Cox's Bazar Municipality (d) Develop well trained Volunteer Group for coastal geo-environmental Disaster Management and Mitigation.

Source: Present Study, 2018

Recognizing the research gap from the present study literature review, four specific objectives were selected for investigating the geo-environmental state of the study area through measuring the shoreline movement along the sample areas for two decades, and the environmental quality of the soil and water of the study area, as well as the degree of biodiversity change and /or loss due to the declined geo-environmental quality. After evaluating the geo-environmental criteria of the present study, a detailed study of the two key outputs of Integrated Coastal Zone Management Plan (ICZMP,1999 & 2000)-the 'Coastal Zone Management Policy (2005)' and 'Coastal Development Strategy (CDS,2006)' was done to evaluate the degree of success, as well as the 'Priority Investment Programs (PIP,2006)' of the ICZMP of Bangladesh. In accordance to the existing priorities given by the ICZMP, the recommendations of the local stakeholders, as well as findings of the present study, an attempt was taken to develop a 'Strategic Framework for Coastal Zone Management (CZM)' of the present study area, the east coast of Bangladesh. Further, the framework advocates several 'Short Term' and 'Long Term' plans at local and National level to be incorporated into the existing ICZM Plan.

Further investigations should be conducted about the advanced scientific methods like- 'Bioremediation' and 'Bioabsorption' to mitigate the environmental degradations in the study area, as well as, establishment and modification of advanced 'Waste Management System' and 'Waste Treatment Plants' has to be initiated at national level with functional linkages with the local stakeholders.

9.1 Conclusion

The study area, the east coast of Bangladesh is endowed with ample opportunities, such as the unique geomorphic features, brackish soil and water, accommodating habitat for affluent biodiversity. However, the east coast has been confronting with increasing geo-environmental vulnerabilities due to unscrupulous and ignorant anthropogenic interferences.

The literatures showed that, there was inadequate research regarding the ‘Cause & Effect’ relationship between the geo-environment and anthropogenic activities in the early literatures. Hence, the present study investigated into the ‘Cause and Effect’ relationship between the geo-environmental state and anthropogenic interferences at the east coast which has been presented with a PSR model in the study. To illustrate the ‘Cause and Effect’ relationship between the geo-environment and anthropogenic activities, the present study formulated a ‘Pressure-State-Response (PSR)’ model. In the model, the anthropogenic activities were expressed as ‘Pressure indicators’, which functioned as the driving forces of geo-environmental deterioration of the study area expressed as ‘State indicators’. Further, the national policy makers and national and local stakeholders of CZM of the east coast were expressed as the ‘Response indicators’.

The study observed that, the anthropogenic interferences function as the major forces in shaping the coastal geomorphology, as well as the terrestrial and coastal and marine ecosystems. Discharge of untreated toxic effluents from the source points of pollution along the east coast, such as the steel, iron, and chemical industries; ice and salt factories; dried fish processing farms, shrimp hatcheries, fish and fisheries farms, and fish processing industries; fishing trawlers and water vehicles; disposal of huge municipal garbage; mixed land use, and over exploitation of the natural resources has been ensuing geo-environmental vulnerabilities at the east coast.

Hence, to reveal the geo-environmental state of the east coast, the study measured the most prominent geomorphic process-the NSM of the study area; along with the most influencing environmental features, such as the concentration level of the five toxic heavy metals, two nutrients, and the physio-chemical parameters like the pH, EC, temperature, and TDS of soil and water of the east coast. Moreover, the key biological features, such as the vegetation coverage, along with the concentration of the heavy metals and $CaCO_3$ in the mollusk shells of the east coast was measured to analyze the geo-environmental state of the study area.

The study found that, rapid shoreline change or movement due to coastline erosion and accretion, deterioration of soil and water quality owing to heavy metal contamination and fluctuation of selected nutrients and physio-chemical parameters, and the consequent biodiversity change or loss were the main vulnerabilities prevailing at the study area. Nevertheless, the accelerated frequency and magnitude of CCI hazards, such as cyclone and storm surge, heavy rainfall induced hill slides; along with biodiversity change or loss has been worsening the geo-environmental state of the east coast.

Further, regarding the rate of success of the previous plans and policies, the study found that, unscrupulous anthropogenic activities, inadequate knowledge and unawareness of local stakeholders regarding the coastal geo-environment, weak linkages between the national policy makers and local stakeholders, and ineffectual implementation, monitoring and maintenance of the development plans and policies were the key reasons of partial functionality of the previous and existing coastal development plans in Bangladesh.

However, insufficient knowledge about the geomorphology, environment, and biodiversity of the east coast has ensued ignorance and unawareness at national and local level. These mentioned situations were observed as the limitations which has been constraining the incorporation of the study indicators into the CZM frameworks of Bangladesh.

Further, the study illustrated the ways to formulate a ‘Strategic Policy Framework’ (SPF) through which the geo-environmental indicators of the present study might be incorporated into the existing and future CZM and development plans and policies of the east coast to achieve a more sustainable coast.

9.2 Recommendations for Coastal Zone Management Plan for the East Coast

The present study attempted to suggest several scientific, as well as, socio-economic initiatives which might be incorporated for a fully functional CZM plan for the east coast of Bangladesh. These are as follows:

1) Re-excavation of the major river estuaries to ensure normal tidal water flow,
2) Construction of strong river bank and coastline protection dams to seize excessive erosion or accretion,
3) Reconstruction and maintenance of the previous river bank and coastline protection dams to protect the east coast from shoreline erosion,
4) Better maintenance of the Muhuri Closure dam, the Bakkhali River rubber dam, the Jalkadar River coastal protection dam, and the Teknaf coast protection dam has to be ensured to ascertain their full functionality,
5) Plantation of deep rooted indigenous trees, especially the mangrove trees upon the river

and coastline protection dams to reduce rate of soil erosion,

6) Ensuring reduced discharge of toxic industrial, agricultural and household effluents from point sources of pollution by establishment and maintenance of modern ‘Recycling Plants’ and ‘Waste Treatment Plants’,
7) Construction of secured landfill sites for toxic waste and municipal garbage disposal,
8) Innovation and introduction of eco-friendly bioremediation technology to decontaminate polluted sites,
9) Explore soil and water bioremediation process with indigenous flora and fauna to avoid foreign species inclusion which might cause imbalance in the terrestrial and aquatic ecosystems of the east coast
10) The habitats of fisheries resources of the east coast, such as the numerous species of sea -weeds, sea-grass, crabs, mollusks, pearl producing bi-valves, and chelonians has to protected to keep the balance in terrestrial and coastal and marine food chains,
11) The commercial production of the sea-weeds, mud crabs, chelonians, and pearl producing mollusks should be initiated at the east coast to reduce pressure upon the main foods,
12) Shrimp fry and mud crab producing farms should be established to lessen the amount of catch from the nature, as well as to avoid catch of undesirable fish and fisheries,
13) Production of alternative fish and fisheries resources by the local communities has to be inspired and initiated to ensure adequate supply for the local markets, as well as for foreign markets,
14) The CCI hazards has to be addressed by reconstructing stronger and higher river and coastline protection dams to obstruct the cyclone induced storm surges,
15) Development and inclusion of strong knowledge pool on coastal geo-environment in all level of National Education curriculum,
16) Creation of environmental awareness among local stakeholders and communities through diverse trainings, workshops, and demonstrations,
17) Establishment of strong linkages between national and local stakeholders for a vast information dissemination network,
18) Development of functional plans for ‘Paradigm Shift’ of livelihood of coastal communities to alleviate poverty, leading to establishment of resilient community,
19) Establishment of ‘Youth volunteer team’ for coastal disaster management and mitigation by involving the local youths to deal with the natural and socio-economic vulnerabilities of the east coast, and
20) The future development projects should be developed through the inclusion of indigenous

knowledge practiced by the local communities in managing the natural resource conservation.

All the above mentioned recommendations are expected to facilitate the local communities towards a paradigm shift from indigenous way of livelihoods to an all inclusive livelihood for the east coast.

9.3 Prospective Future Research

1) Integration of forthcoming CZM plans and policies with that of the existing ones,
2) The responses of existing ICZMP to the coastal geo-environmental issues of Bangladesh,
3) Probable impacts of natural hazards upon the fluctuation of heavy metals, nutrients, and physio-chemical parameter content in the coastal zone soil and water, and
4) Impacts of environmental deterioration upon the Terrestrial and Coastal and Marine ecosystem biodiversity of the coastal zone of Bangladesh.

Finally, incorporation of the present study indicators are expected to be contemplated as assistance for future CZM plans of Bangladesh.

Abedin,Md. Anwarul .(2013). Agriculture Adaptation in Coastal Zone of Bangladesh. (PDF) *Agriculture Adaptation in Coastal Zone of Bangladesh*. Springer https://www.researchgate.net/publication/316618530_Agriculture_Adaptation_in_Coastal_Zone_of_Bangladesh [accessed Sep 02 2020].

Abu, M. Kamal Uddin and Rob, Kaudstaal. (2003). *Delineation of the Coastal Zone*. Working Paper :WP005. Program Development office for Integrated Coastal Zone Management (PDO-ICZM). WARPO, GoB. www.iczmpbangladesh.org

Agronomic Library (n.d.). Sulfur Basics. Spectrum Analytic Inc. 1087 Jamison Rd NW, Washington Court House, OH 43160. ttps://spectrumanalytic.com/support/library/ ff/S_ Basics. html#:~:text=Apples-,Toxicity,pH%20of%20the%20soil%20decreases.

Ahmed ,Nesar and Tuperhudee, Wara.(2010). Seaweed Cultivation in Bangladesh: Problems and Potentials. *Kasetsart University Fisheries Research Bulletin*. No. 28.

Ahsan, Md. Emranul. (2013). *Coastal Zone of Bangladesh: Fisheries Resources and its Potentials*. 1st Edition, Lambert Academic Publishing, Editor: Irusu. ISBN: 978-3-659-48019-5. DOI: 10.13140/2.1.1253.7928

Akter, Suny, Fardous, Zeenath, Aktar,Jesmin , Rahman,Md. et al.(2020). Environmental contamination of heavy metals in some dried fish of coastal regions of Bangladesh. Bangladesh J. Zool. 47(2): 293-304, 2019 ISSN: 0304-9027 (print). Institute of Food and Radiation Biology, AERE, Bangladesh Atomic Energy Commission, Ganakbari, Savar, Dhaka-1349, Bangladesh.

Akter, J., Sarker, M.H., Popescu, I., and Roelvink, D. (2016). Evolution of the Bengal Delta and its prevailing processes. Journal of Coastal Research.32(5).1212–1226. Coconut Creek (Florida). ISSN 0749-0208.

Akonda, A. W. (1989). *Wetlands of Bangladesh*. In: Scott, D.A. (Ed.).A Directory of Asian Wetlands. IUCN: Gland, Switzerland and Cambridge, pp. 541-581

Alam, M., N. E. Huq, & Rashid, M. (1999). Morphology and Sediments of the Cox's Bazar Coastal Plain, South-East Bangladesh. *Journal of Coastal Research*, 15(4), 902-908. Retrieved September 5, 2020, DOI: 10.2307/4299010

Alam,M. Shamul.(2015). *Topography*. In Banglapedia: The National Encyclopedia of Bangladesh. Dhaka, Bangladesh: Banglapedia Trust, Asiatic Society of Bangladesh.

Alam,Md Khurshid.(2015).*Natural Hazards*. Banglapedia: The National Encyclopedia of Bangladesh (Online Ed.). Dhaka, Bangladesh: Banglapedia Trust, Asiatic Society of Bangladesh.

Ali, M.M., Ali, M.L., Islam, M.S.,and Rahman, M.Z.(2016). *Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh*. Environ. Nanotech. Moni. Mang.V. 5, Pp.27–35. https://doi.org/10.1016/j.enmm.2016.01.002

Ali, Syed Salamat. (2015). Social Forestry. Banglapedia: The National Encyclopedia of Bangladesh (Online Ed.). Dhaka, Bangladesh: Banglapedia Trust, Asiatic Society of Bangladesh.

Allison,M., Kepple,E.(2001).Modern sediment supply to the lower delta plain of the Ganges-Brahmaputra River in Bangladesh. *Geo-Marine Letters*.Vol.21.Pp.66–74. doi:10.1007/s003670100069

Amadore, L., Bolhofer, W.C., Cruz, R.V. et al. (1996). Climate change Vulnerability and Adaptation in Asia and the Pacific: Workshop summary. *Water Air Soil Pollution*. Vol. 92.Pp. 1–12. doi:10.1007/BF00175548

Ansari A.A., et al. (ed.). (2015). *Phytoremediation of Copper-Contaminated Soil*. In book: Phytoremediation: Management of Environmental Contaminants. Chapter: 12. Anna Karczewska, Andrzej Mocek, Piotr Goliński, Mirosław Mleczek. Springer International Publishing. doi: 10.1007/978-3-319-10969-5_12

Antonio J. Osuna-MascaróAntonio J. Osuna-MascaróTeresa Cruz BustosTeresa Cruz BustosBenjamin MarieBenjamin MarieShow. (2015).Heavy Metals in Mollusc Shells: A Quick Method for their Detection. Key Engineering Materials 672. DOI: 10.4028/www.scientific.net/KEM.672.340

Apori, E. O.S. Hanyabui,J. Asiamah . (2018).Remediation Technology for Copper Contaminated Soil: A Review. Asian Soil Research Journal. 1(3): 1-7, 2018; Article no.ASRJ.45322.doi: 10.9734/asrj/2018/4532

Asmawi, M. Zainora. (2012). The Future of Coastal Management Programme in Malaysia: Making the Coast Visible To Planners. *Planning Malaysia Journal*. Malaysian Institute of Planners. Vol.10. doi: dx.doi.org/10.21837/ pmjournal.v10.i3.104

Ashraful, et al. (2009). Monitoring and assessment of heavy metals levels in littoral sediments from the north eastern part of the Bay of Bengal coast, Bangladesh. *Journal of Industrial Pollution Control*. 25(2):105-111

Atkinson,D. and Davison,A.W.(1973). The Effect of Phosphorous Deficiency on Water Content and Resoponse to Drought. *New Phyto*.72, Pp.307-313. file:///D:/Phd.Literature%20Review/deficiency%20of%20phosphorous.pdf

Bangladesh Bureau of Statistics (BBS). (2001).Bangladesh Population Census 2001, Bangladesh Bureau of Statistics.

Bangladesh Fisheries Research Institute (BFRI). (2018). Marine Fisheries and Technology. Cox's Bazar, Bangladesh.

Bangladesh Water Development Board (BWDB). (2017).Coastal Embankment Improvement Project, Phase-1 (CEIP-1). Terms of Reference (Tor) for Consulting Services for Independent Panel of Expert (IPOE) for Design Expert in Embankment and Hydraulic Structures Package No.CEIP-1/D1/S19

Banglapedia. (2015). Upazilas of Bangladesh. In Banglapedia: The National Encyclopedia of Bangladesh. Dhaka, Bangladesh. Banglapedia Trust, Asiatic Society of Bangladesh.

Bangyu, Li. et al. (2014). Water Extraction in High Resolution Remote Sensing Image Based on Hierarchical Spectrum and Shape Features.IOP Conf. Ser. Earth Environ. Sci. Vol.17.012123. https://iopscience.iop.org/article/10.1088/1755-1315/17/1/012123/pdf

Baqui,M.A.(2015). *Geological Structure*. In: In Banglapedia: The National Encyclopedia of Bangladesh. Dhaka, Bangladesh. Banglapedia Trust, Asiatic Society of Bangladesh.

Bari,M.Fazlu.(2012).Dam. Banglapedia: The National Encyclopedia of Bangladesh (Online Ed.). Dhaka, Bangladesh. Banglapedia Trust, Asiatic Society of Bangladesh. *http://en.banglapedia.org/index.php?title=Dam*

Battelle Memorial Institute. (1998). *SOURCES OF LEAD IN SOIL: A LITERATURE REVIEW.* EPA 747-R-98-001a. Technical Programs Branch.Chemical Management Division. Office of Pollution Prevention and Toxics. Office of Prevention, Pesticides, and Toxic Substances. U.S. Environmental Protection Agency.Washington, DC 20460

Bhakta, J. & Kundu, Debajyoti & Dutta, Deblina & Anna Płaza, Grażyna. (2019*)*. Bioremediation in different domains of environment. In: *Green Technology for Bioremediation of Environmental Pollution.* Chapter 6, Nova Science Publishers, Inc., pp.1-16

Bhuiyan, et al. (2015). Maritime Boundary Confirmation of Bangladesh: Potentialities of Sea Resources and Challenges Ahead. *The Cost and Management*. Vol.43:5. ISSN 1817-5090

Bielmyer GK, Bullington JB, Decarlo CA, Chalk SJ, Smith K (2012): The effects of salinity on acute toxicity of zinc to two euryhaline species of fish, Fundulus heteroclitus and Kryptolebias marmoratus. *Integrative and comparative biology*, 52(6), 753–760 (available at: https://doi.org/10.1093/icb/ics045

Biswas, Ashok. (2011).Bangladesher Nodikosh. Bengal Publications Ltd. Bengal Center, Khilkhet, Dhaka. ISBN -978-984-91643-5-7

BOBLME Project. (2015).*The Bay of Bengal Large Marine Ecosystem*. Food and Agricultural Organization (FAO).Regional Office for Asia and the Pacific. http://www.boblme-bangladesh.org/bob_projects.php

BORI. (2015). Bangladesh Oceanographic Research Institute, Cox's Bazar, Ministry of Science and Technology, GoB. http://www.bori.gov. Bd/site/ page/ b3579768- 84bd-433e-9329-07cf02262f44/-

Brammer, Hugh. (2012). *The Physical Geography of Bangladesh*. Dhaka, Bangladesh. The University Press Limited. Dhaka

Brisman A. (2011) Stockholm Conference, 1972. In: Chatterjee D.K. (eds) Encyclopedia of Global Justice. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-9160-5_655

Brundtland, G. (1987). Report of the World Commission on the Environment and Development: Our Common Future. United Nations. United Nations General Assembly document A/42/427. https://sustainabledevelopment.un.org/ content/ documents /5987 our-common-future.pdf

Byomkesh, Talukder, Nakagoshi,Nobukazu, and Rashid, Md. Shahedur.(2008).State and management of wetlands in Bangladesh. Landscape and Ecological Engineering. 5(1):81-90. DOI: 10.1007/s11355-008-0052-5

Chao, Gloria. (1999). *The Emergence of Integrated Coastal and Ocean Management in Canada's Oceans Act - Challenges of Integrating Fragmented Resource Sectors in Georges Bank, Nova Scotia and Hecate Strait, British Columbia*.(Unpublished Thesis for Master of Laws). Dalhousie University. Halifax. Nova Scotia. Canada.

Cho, Renee. (2013). Phosphorus: Essential To Life—Are We Running Out?. Agriculture, Earth Sciences. State of the Planet. Earth Institute. Columbia University.

Chowdhury , M.Hasan. (2015). *Physiography*. In Banglapedia: The National Encyclopedia of Bangladesh. Dhaka, Bangladesh. Banglapedia Trust, Asiatic Society of Bangladesh. Last modified on 1 March 2015

Chowdhury , M.Hasan. (2016). *Geography of Bangladesh.* In Banglapedia: The National Encyclopedia of Bangladesh. Dhaka, Bangladesh. Banglapedia Trust, Asiatic Society of Bangladesh. Last modified on 13 March 2016

Chowdhury, S.Q. (2015a). *Chittagong Hill Tracts*. In Banglapedia: The National Encyclopedia of Bangladesh. Dhaka, Bangladesh. Banglapedia Trust, Asiatic Society of Bangladesh.

Chowdhury, S.Q. (2015b). *Bay of Bengal*. In Banglapedia: The National Encyclopedia of Bangladesh. Dhaka, Bangladesh. Banglapedia Trust, Asiatic Society of Bangladesh. ISBN 984-32-0576-6. OCLC 52727562.

Chowdhury, S.Q. (2015c). *Feni River*. In Banglapedia: The National Encyclopedia of Bangladesh. Dhaka, Bangladesh. Banglapedia Trust, Asiatic Society of Bangladesh.

Chowdhury, S.Q. (2015d). *Bakkhali River*. In Banglapedia: The National Encyclopedia of Bangladesh. Dhaka, Bangladesh. Banglapedia Trust, Asiatic Society of Bangladesh. ISBN 984-32-0576-6. OCLC 52727562.

Chowdhury, T. Hossain. (2015). *Ukhia Upazila*. In: Banglapedia: National Encyclopedia of Bangladesh (Second ed.). Asiatic Society of Bangladesh.

Chua Thia-Eng,et al.(1997). From Sectoral to Integrated Coastal Management: A Case in Xiamen, China. *Ocean and Coastal Zone Management.* Vol.37:2. Pp.233-251. doi.org/10.1016/ S0964-5691(00) 89025-0

Cicin-Sain,B., & Knecht, R. (1998). Integrated Coastal and Ocean Management: Concepts and Practices. In: Planas, F.J. Abelardo, et al. (2016). Validating Governance Performance Indicators for Integrated Coastal and Ocean Management in the Southeast Region of Cuba. Open Journal of Marine Science.Vol.6:1. https://www.scirp.org/(S (351jmbntvnsjt1aadkposzje)/ reference/ References Papers. aspx? Reference ID=1650941

Climate Change Cell (CCC). (2016). Assessment of Sea Level Rise on Bangladesh Coast through Trend Analysis. Department of Environment. Ministry of Environment and Forests, Bangladesh.

C Shi S., M. Hutchinson, L Yu, S Xu. (2001).Towards a sustainable coast: an integrated coastal zone management framework for Shanghai, People's Republic of China. Ocean & Coastal Management.Vol.44:5-6.P.411-427.doi.org/10.1016/S0964-5691 (01)00058-8

Cyclone Preparedness Program (CPP).(2018).Refresher's Training Manual for Skill Development of the CPP Volunteers. Ministry of Disaster Management and Relief, GoB

Dasgupta, S., et al. (2014). River Salinity and Climate Change: Evidence from Coastal Bangladesh. In: Policy Research Working Paper 6817, World Bank.

Data Leads, New Delhi. (2016). Bangladesh among Asian countries with less forest area: Laos, the most. In: *The Daily Star.* Thursday, January 2, 2016. https://www.thedailystar.net/environment/bangladesh-among-asian-countries-less-forest-area-1310851.(Last Modified: November 07, 2016)

Deb, Apurba Krishna. (2014). Coastal *Zone Management*. In Banglapedia: The National Encyclopedia of Bangladesh (Online Ed.). Dhaka, Bangladesh: Banglapedia Trust, Asiatic Society of Bangladesh. last modified on 5 May 2014. http://en.banglapedia.org/index.php?title=Coastal_Zone_Management

Department of Environment (DoE). (1995). *The Bangladesh Environment Conservation Act*. Act No. 1 of 1995. Ministry of Environment and Forests, Government of Bangladesh.

Department of Environment (DoE). (2006). *Bangladesh: National Programme of Action for Protection of the Coastal and Marine Environment from Land-Based Activities*. Ministry of Environment and Forests, Government of Bangladesh.

Department of Environment (DoE). (2010). *Fourth National Report: Biodiversity National Assessment and Programme of Action 2020*. Ministry of Environment and Forests. Government of Bangladesh.www.doe-bd.org

Department of Environment (DoE). (2015). *Biodiversity National Assessment: The Fifth National Report of Bangladesh to the Convention on Biological Diversity*. Government of Bangladesh.

Dewan,A., Corner,R., Saleem.A.,Rahman.M.M.,Haider,M.R., Rahman,M.M., Sarker, M.H.(2016).Assessing channel changes of the Ganges-Padma River system in Bangladesh using Landsat and hydrological data. Geomorphology. Vol.276, Pp.257-279. Elsevier.https://doi.org/10.1016/j.geomorph.2016.10.017

Dhaka Tribune. (7th August, 2014). *Pollution level of Bazar Bakkhali River reaches to all time high*. archive.dhakatribune.com/author/our-correspondent-cox%E2%80%99s-bazar

Douglas B. Beegle, and Philip T. Durst. (2002). Pennsylvania Nutrient Management Program. Managing Phosphorus for Crop Production. Pennstate Extention. https://extension.psu.edu/programs/nutrient-management/educational/soil-fertility/managing-phosphorus-for-crop-production

Earth Summit. (3 to 14 June, 1992). *AGENDA 21*. United Nations Conference on Environment & Development Rio de Janerio, Brazil. UN Department of Economics and Social Affairs. Division for Sustainable Development. *https://sustainable development. un.org /content/ documents/ Agenda21.pdf*

Edward R.C., Philip M.W.,Sara C.Y., Mary C. T., Natalie K. J.& Justin,R. (2007). Applying DPSIR to Sustainable Development, *International Journal of Sustainable Development & World Ecology*. doi.org /10.1080/ 1350450 0709 469753

Edward, R.Carr., Philip, M.Wingard., Sara C.Yorty., Thompson,Natalie Jensen.,& Justin, Roberson.(2007). Applying DPSIR to Sustainable Development. *International Journal of Sustainable Development & World Ecology.*Vol.14:6.Pp.543-555.Published online: 24 November 2009. doi.org/10.1080/13504500709469753

Ehlers, Peter. (2000).The Intergovernmental Oceanographic Commission: An International Organisation for the Promotion of Marine Research. *The International Journal of Marine and Coastal Law*. Vol.15: 4. doi.org/10.1163/157180800X00235

Eisler, Ronald. (1985).Cadmium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. *Biological Report 85 (1.2)*. Contaminant Hazard Reviews. Report No. 2. Patuxent Wildlife Research Center U.S. Fish and Wildlife Service Laurel, MD 20708 www. file:///C:/Users/User/Downloads/Documents/CHR_2_Cadmium_2.pdf

Environmental Management Framework (EMF). (2013). *Coastal Embankment Improvement Project, Phase-i project (CEIP-I)*. Bangladesh Water Development Board. Ministry of Water Resource, GoB. http://atelim.com/environmental-management-framework-emf-coastal-embankment-impr. html? part=8

Environmental Protection Agency (EPA). (2003). *Ecological Soil Screening Level for Iron*. Interim Final. OSWER Directive 9285.7-69. Office of Solid Waste and Emergency Response. 1200 Pennsylvania Avenue, N.W. Washington, DC 20460. https://rais.ornl.gov / documents/eco-ssl_iron.pdf

European Commission. (1997). *EU Policy on ICZM.* The Commission's demonstration programme on Integrated Coastal Zone Management 1996 - 1999. *https://ec.europa.eu/environment/iczm/demopgm.htm*

Eysink, W.D.(1983). Basic Considerations on the Morphology and Land Accretion Potentials in the Estuary of the Lower Meghna River. Dhaka. *Bangladesh: Land Reclamation Project*. Bangladesh Water Development Board, LRP Technical Report 15, 85p.

European Economic Area. (2013). Socio-ecological accounting: DPSWR, a modified DPSIR framework, and its application to marine ecosystem. *Ecological Economics,* Vol. 94, pp. 106-115. doi: 10.1016/j.ecolecon.2013.07.010.

Eysink, W. D.(1983). Basic considerations of the morphology and land accretion potentials in the Estuary of the lower Meghna River.LRP.TR-15.BWDB.

FAO. (2019). *The Bay of Bengal Large Marine Ecosystem Project*. Food & Agriculture Organization of the United Nations.

FAO. (2019). *Bangladesh Dialogue on Blue Economy: Bangladesh Blue Economy Dialogue on Fisheries and Mariculture*. Ministry of Fisheries and Livestock and the Food and Agriculture Organization of the United Nations.

FAO. (1998). Issues, Perspectives, Policy and Planning Processes for Integrated Coastal Area Management: PART A (in FAO Guidelines: Integrated Coastal Area Management and Agriculture, Forestry And Fisheries). Rome. www.fao.org/3/W8440e/W8440e02.htm

Food and Agriculture Organization of the United Nations (FAO). (2010). *Global Forest Resources Assessment* : Main Report. Rome, FAO Forestry Paper 163, pp. 340. www.fao.org/publications

Fondriest Environmental, Inc. (2014): Conductivity, Salinity and Total Dissolved Solids. *Fundamentals of Environmental Measurements.* www.fondriest.com/conductivity-salinity-tds

Fondriest Environmental Inc. (2013): pH of Water. *Fundamentals of Environmental Measurements* (available at: https://www.fondriest.com/water-quality/ph).

Gain, Philip. (1997). Bangladesher Biponna Bon. In *The Endangered Forest of Bangladesh*. p.276. Society for Environment and Human Development (SEHD). Dhaka, Bangladesh.

Gazeau, Frédéric, Parker, Laura M. Laura, Comeau, Steeve et al. (2013). Impacts of ocean acidification on marine shelled mollusks. *Marine Biology 160(8)*.doi:10.1007/ s 00227-013-2219-3.https://www.researchgate.net/publication/ 236597535_Impacts _of_ ocean_ acidification_ on_marine _shelled_molluscs

Gazi, A.S.M. (2001). Bangladesher Bilupto Bannyaprani. In: *Extinct Wildlife of Bangladesh*. Pp.184. Bangla Academy, Dhaka.

General Economics Division (GED).(2012).*Perspective Plan of Bangladesh 2010-2021:Making Vision 2021 a Reality* . Bangladesh Planning Commission, Dhaka

General Economics Division (GED). (15th February, 2018). *Achievement of MDGs and Adaptation of SDGs: Bangladesh Context (Making Growth Work for the Poor)*. Bangladesh Planning Commission, Dhaka.

General Economics Division (GED). (2018).*Bangladesh Delta Plan 2100*. Bangladesh Planning Commission,Government of Bangladesh. Sher-e-Bangla Nagar, Dhaka 1207, Bangladesh www.plancomm.gov.bd

Godschalk, D.R. (2009).Coastal Zone Management. In: Marine Policy and economics (Ed.). (2010).Hoagland, Porter., Thorpe, Steve A., Turekian, K.K. Academic Press.

Guanqiong, Ye. et al. (2014). Evaluating the performance of Integrated Coastal Management in Quanzhou, Fujian, China. *Ocean and Coastal Managemen*t. Vol.96.Pp.112-122. doi.org/10.1016/j.ocecoaman.2014.05.010

Guanqiong, Ye. et al. (2015). Is integrated coastal management an effective framework for promoting coastal sustainability in China’s coastal cities? *Marine Policy.* Vol.56. Pp.48-55. doi.org/10.1016/j.marpol.2015.02.009

Hafez, Ahmad. (2019). Bangladesh Coastal Zone Management Status and Future Trends. *J Coastal Management*. 22 (1). doi:10.24105/2473-3350.22.466

Hailong He, Miles F.Dyck, Robert Horton, Min Li, Huijun Jin, Bingcheng Si.(2018). Chapter Five - Distributed Temperature Sensing for Soil Physical Measurements and Its Similarity to Heat Pulse Method. *Advances in Agronomy.* Vol.148, Pp173-230. Elsevier. https:// doi.org/10.1016 /bs.agron. 2017.11.003

Haishui Yang, Jiajia Zhou, Jinxia Feng, Silong Zhai, Weiping Chen,Jian Liu, Xinmin Bian. (2018).Chapter Five - Ditch-buried straw return: A novel tillage practice combined with tillage rotation and deep ploughing in rice-wheat rotation systems. *Advances in agronomy*.154. Pp. 257-290. https://doi.org/10.1016/bs.agron.2018.11.004

Haque,M. Asadul. (2018). Variation in Salinity through the Soil Profile in South Coastal Region of Bangladesh. *J. Bangladesh Acad. Sci.*, Vol. 42:1, Pp. 11-23. Department of Soil Science, Patuakhali Science and Technology University, Bangladesh

Haque, A., Nicholls, R.J. (2018). *Floods and the Ganges-Brahmaputra-Meghna Delta*. In: Nicholls R., Hutton C., Adger W., Hanson S., Rahman M., Salehin M. (eds) . Ecosystem Services for Well-Being in Deltas. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-319-71093-8_8

Hammond ,Allen, Adriaanse Albert, Rodenburg Eric, Bryant ,Dirk, Woodward , Richard.(1995). Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development . World Resources Institute. file:///C:/Users/User/Downloads/Documents/environmentalindicators_bw.pdf

Hasan, S. R. (2012). Environmental Laws. In: Islam, Sirajul M., Jamal, Ahmed A. (Eds.). *Banglapedia: The National Encyclopedia of Bangladesh* (Online ed.). Dhaka, Bangladesh: Banglapedia Trust, Asiatic Society of Bangladesh.

Helmut Kroiss, Helmut Rechberger and Lukas Egle. (2011). *Phosphorus in Water Quality and Waste Management, Integrated Waste Management*. Vol.II, Sunil Kumar, Intech Open, DOI: 10.5772/18482. https://www.intechopen.com/books/integrated-waste-management-volume-ii/phosphorus-in-water-quality-and-waste-management

Hena, Abu. M.K., Short,F.T., Sharifuzzaman, S.M., et al.(2007).Salt Marsh and Seagrass Communities of Bakkhali Estuary, Cox's Bazar, Bangladesh. *Estuarine, Coastal and Shelf Science*. V. 75.pp 72-78

Himmelstoss, E.A. (2009). DSAS 4.0 Installation Instructions and User Guide. In: Thieler, E. R., Himmelstoss, E.A., Zichichi, J.L., and Ergul, A., *Digital Shoreline Analysis System (DSAS), Version 4.0.: An ArcGIS extension for calculating shoreline change.* U.S. Geological Survey (USGS)

Hillel, Daniel. (2000).*Salinity Management for Sustainable Irrigation: Integrating Science, Environment, and Economics*. Environmentally and Socially Sustainable Development. Rural Development. World Bank

Hoque, M. Nazmul. (2005-2006). *The Legal and Scientific Assessment of Bangladesh's Baseline in the Context of Article 76 of the United Nations Convention on the Law of the Sea, United Nations*. National University of Ireland Galway, Republic of Ireland, Division for Ocean Affairs and the Law of the Sea Office of Legal Affairs, United Nations.

Hoq,Enamul, Haque,Mohammad Asraful and Islam,Md. Mohidul.(2016). Feasibility of Seaweed Culture in Inani and Bakkhali Coast of Cox's Bazar, Bangladesh .*Pakistan Journal of Marine Sciences*, Vol. 25(1&2), 27-36, 2016. Marine Fisheries and Technology Station Bangladesh. Fisheries Research Institute, Mymensingh 2201, Bangladesh (MEH), Bangladesh Fisheries Research Institute, Cox's Bazaar 4700, Bangladesh (MAH, MMI)

Hossain,Md. Shahadat and Lin ,C. Kwei. (2001).Land Use Zoning for Integrated Coastal Zone Management. *ITCZM Monograph No. 3 Series.* Remote Sensing, GIS and RRA Approach in Cox's Bazar Coast, Bangladesh)

Hossain ,M. Shahadat, Chowdhury, Sayedur Rahman, Chowdhury, M. Abu Taiyeb. (2007). Integration of Remote Sensing, GIS and Participatory Approach for Coastal Island Resource Use Zoning in Bangladesh. *Songklanakarin Journal of Social Science and Humanities*. 13(3) July: 413-433.

Hossain, Sumaya. (2015a).Causes of Sedimentation Problem in Bakkhali River Estuary, Cox's Bazar, Bangladesh. Water Resource Engineering Department, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh. *Asian Journal of Water, Environment and Pollution*, Vol.12:3, Pp. 65-69, 2015. DOI: 10.3233/AJW-150008

Hossain, Sumaya. (2015b). *Assessment of Sediment Movement Pattern along Nearshore Coastal Water of Cox's Bazar*. Unpublished PhD Thesis. Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000 http://lib.buet.ac.bd:8080/xmlui/handle/123456789/3823

Hossain, M.S., Chowdhury, S.R., Sharifuzzaman, S.M. (2017). Blue Economic Development in Bangladesh: A policy guide for marine fisheries and aquaculture. Institute of Marine Sciences and Fisheries, University of Chittagong, Bangladesh. In: Blue economic development in Bangladesh: A policy guide for marine fisheries and aquaculture.https://www.researchgate.net /publication /319454363_ Blue_economic_ development_ in_Bangladesh _A_policy_ guide_ for_ marine_ fisheries_and_ aquaculture

Hussain, M.G., Pierre F.,Karim, A.A.& Khurshed, M.A.(2018).Major opportunities of blue economy development in Bangladesh, Journal of the Indian Ocean Region,Vol.14:1.Pp.88-99, doi:10.1080/ 19480881. 2017. 1368250

Huq, Saleemul. (2019). A Tipping Point for Climate Change. *The Daily Star* ,July 3, 2019 (Last modified: December 26, 2018). https://www.thedailystar.net /opinion /politics-climate-change/news/2018-tipping-point-climate-change-1678693

Huq ,Hamidul.(2004). Proceedings of Preliminary Consultation on Coastal Development Strategy . Program Development Office for Integrated Coastal Zone Management Plan (PDO-ICZMP). Working Paper WP032. Saimon Center, Gulshan 1, Dhaka . www.iczmpbangladesh.org Dhaka, December 2004

Iftekhar,Sayed.(2006).Conservation and management of the Bangladesh coastal ecosystem: Overview of an integrated approach. *Natural Resources Forum* 30(3):230 - 237. doi: 10.1111/j.1477-8947.2006.00111.x

Iftekhar, M. S. & Islam, M. R. (2004). Managing mangroves in Bangladesh: A strategy analysis. *Journal of Coastal Conservation*.10:1–2.pp139–146. doi.org/10.1652/1400-0350 (2004) 010 [0139: MMIBAS] 2.0.CO;2

Igwe, J. C. and Abia A.A. (2006). A Bioseparation process for removing heavy metals from waste water using biosorbents. *African Journal of Biotechnology* . Vol. 5:12.Pp. 1167-1179. https://doi.org/10.5897/AJB2006.000-5056

Institute of Water and Flood Management (IWFM). (2008). *Sustainable Water Management: Cox's Bazar, Bangladesh*. University of Engineering and Technology (BUET), Bangladesh.

Institute of Water and Flood Management (IWFM).(2008).Sustainable Water Management: Cox's Bazar.WFM 6209. Interdisciplinary Field Research Methodology in Water Management. Bangladesh University of Engineering and Technology (BUET). msalamkhan.buet.ac.bd teaching_msk_files › Reader_v1DOC

Iqbal,F.(11 May,2015).Shrimp Hatcheries in Cox's Bazar polluting sea water:Marine biodiversity under threat. The Daily Observer. www. observerbd. com / 2015 /05 /11/8166.php

Islam, K., Xue, X.-zhe, & Rahman, M. (2009). Successful Integrated Coastal Zone Management (ICZM) Program Model of a Developing Country (Xiamen, China) – Implementation in Bangladesh Perspective. *Journal of Wetlands Ecology*, 2(1).35-41. doi.org /10.3126/jowe.v2i1.1854

Islam, M. Aminul. (2015). Ecologically Critical Area. In Banglapedia: The National Encyclopedia of Bangladesh. Dhaka, Bangladesh: Banglapedia Trust, Asiatic Society of Bangladesh. ISBN 984-32-0576-6. OCLC 52727562.

Islam, M. Anwarul. (2014). Biodiversity. In Banglapedia: The National Encyclopedia of Bangladesh. Dhaka, Bangladesh: Banglapedia Trust, Asiatic Society of Bangladesh. ISBN 984-32-0576-6. OCLC 52727562.

Islam, Md. M, Khan,Md. S. Kuli, Hasan , Hoq,Jakia Enamul.(2017). Seaweed Hypnea sp. culture in Cox's Bazar coast, Bangladesh. *Bangladesh Journal of Zoology*. 45(1):37-46. DOI: 10.3329/bjz.v45i1.34192

Islam ,M. Rafiqul. (2002). Program Development Office for Integrated Coastal Zone Management (PDO-ICZM). *ICZM Dialogue on Conceptualization & Design Proceedings & Position*. Working Paper WP008. Gulshan 1, Dhaka 1212 www.iczmpbangladesh.org Dhaka, November 2002

Islam, M. Rafiqul & Ahmad, Mohiuddin. (2004). *Living in the Coast: Problems, Opportunities and Challenges*. Series: Living in the coast series, 2. Water Resources Planning Organization (Bangladesh); Integrated Coastal Zone Management Plan. Programme Development Office, Integrated Coastal Zone Management Plan.

Islam, M. Rafiqul. (2002). Vulnerabilities, Opportunities & Emerging Issues as Transpired from Four Regional Workshops .Program Development Office for Integrated Coastal Zone Management (PDO-ICZM). Working Paper WP003. Saimon Centre, Gulshan 1, Dhaka 1212. www.iczmpbangaladesh.com Dhaka, August 2002

Islam, M. S. (2015). Status of mud crab aquaculture in Bangladesh. In: E. T. Quinitio, F. D. Parado-Estepa,Y. C., Thampi, Sam Raj., & A. Mandal. (Eds). (10-12 April, 2013). Proceedings of the International Seminar-Workshop on Mud Crab Aquaculture and Fisheries Management. (pp. 1-6). Tamil Nadu, India: Rajiv Gandhi Centre for Aquaculture (MPEDA). http://hdl.handle.net/10862/3204

Islam , Rafiqul.(2004). *Pre-and post-tsunami coastal planning and land-use policies and issues in Bangladesh.* Integrated Coastal Zone Management program, Dhaka, Bangladesh. file:///D:/Phd.Literature%20Review/Aug%202020%20lit.review/coastal%20land%20use.pdf

Islam,Md.,Saiful, Proshad,Ram.,Ahmed, Saad. (2018). Ecological risk of heavy metals in sediment of an urban river in Bangladesh. *Journal of Human and Ecological Risk Assessment: An International Jurna*l.Vol.24:3, No.3.Pp.699-720.

Islam, S. M. Samiul, Tanim ,Ahad Hasan, Mullick, Md. Reaz Akter. (2020). Vulnerability Assessment of Bangladesh Coastline Using Gornitz Method (In book: Water, Flood Management and Water Security under a Changing Climate). DOI: 10.1007/978-3-030-47786-8_21

Islam, Shafi Noor. (2016).Deltaic floodplains development and wetland ecosystems management in the Ganges–Brahmaputra–Meghna Rivers Delta in Bangladesh. Sustainable Water Resource Management.Vol.2:237–256. Springer International Publishing Switzerland.doi:10.1007/s40899-016-0047-6

Islam, Shafi Noor. (2010). Threatened Wetlands and Ecologically Sensitive Ecosystems Management in Bangladesh, Front. Earth Sci. China (2010) 4: 438. doi.org/10.1007/s11707-010-0127-0

Islam,Sirajul M., Sajahan K., Mahfuza, A., Sabbir, (Eds.). (2015). Ecologically Critical Area. Banglapedia: The National Encyclopedia of Bangladesh (Online Ed.). Dhaka, Bangladesh: Banglapedia Trust, Asiatic Society of Bangladesh. ISBN 984-32-0576-OCLC 52727562.

Islam, S.M.R., Huq S., and Ali, A. (1999). Beach Erosion in the Eastern Coastline of Bangladesh. In: Huq S., Karim Z., Asaduzzaman M., Mahtab F. (Eds.). *Vulnerability and Adaptation to Climate Change for Bangladesh*. Springer, Dordrecht. doi.org/10.1007/978-94-015-9325-0_6

Islam,Syed Mamtajul.(2015). *A critical analysis of integrated coastal and ocean management in Bangladesh with lessons from global practices*. The Maritime Commons: Digital Repository of the World Maritime University. World Maritime University Dissertations .World Maritime University

Istiakh Ahmed, Riadadh Hossain, Tasfia Tasnim, Shahrin Mannan, Dr. Saleemul Huq.(2019).Resilience Panii Jibon (Water is Life) - Phase II. Research Report on Understanding Climate Change Vulnerability in Two Coastal Villages in Bangladesh and Exploring Options for Resilience. International Centre for Climate Change and Development (ICCCAD), HELVETAS Bangladesh & HELVETAS Swiss Inter-cooperation

IUCN Bangladesh. (2015). National Framework for Establishing and Managing Marine Protected Areas (MPAs) in Bangladesh. International Union for Conservation of Nature (IUCN). Bangladesh Country Office, Bangladesh. Pp. xi-106. ISBN: 978-984-33-9005-9

Jinnat, M.Ali, (Nov.23, 2013).Grabber Feast on Bakkhali River: Lax legal process encourages encroachers in Cox's Bazar. The daily Star (Last Modified: November 23, 2001).

Kabir, Humayun and Eva, Iffat Jahan. (2014). Environmental Impacts of Shrimp Aquaculture: The Case of Chandipur Village at Debhata Upazila of Satkhira District, Bangladesh. *J. Asiat. Soc. Bangladesh, Sci*. 40(1): 107-119.

Kankara,R.S.,Chenthamil, Slevan, S.,Raian,B.,Arockiaraj,S. (2014). An adaptive approach to monitor the Shoreline changes in ICZM framework: A case study of Chennai coast. NICAIR-CSIR. India. http://nopr.niscair.res.in/handle/123456789 /34438

KarenT.,Katharina H.,Bernd K.,Stefan S.,Sergio,G., Palomab.(2012).Does research applying the DPSIR framework support decision making? *Land Use Policy*.Vol.29:1. Pp.102-110. doi.org/10.1016/j.landusepol.2011.05.009

Khan, F.H. (1991).*Geology of Bangladesh*. The University Press Limited. Dhaka, Bangladesh.

Khan, Tariq M.Ali, Singh,O. P., Rahman, Md. Sazedur. (2010). Recent Sea Level and Sea Surface Temperature Trends along the Bangladesh Coast in relation to the frequency of intense Cyclones. *Marine Geodesy 23(2)*. DOI: 10.1080/01490410050030670

Khan, M. Z. H., Hasan, M. R., Khan, M., Aktar, S., & Fatema, K. (2017). Distribution of Heavy Metals in Surface Sediments of the Bay of Bengal Coast. *Journal of Toxicology.* Vol.2017.Article ID 9235764. https://doi.org /10.1155 /2017/9235764

Komol, Md. K.Uddin. (2011). Numerical Simulation Of Tidal Level At Selected Coastal Area of Bangladesh. Department of Water Resources Engineering. Bangladesh University of Engineering and Technology. Dhaka, Bangladesh (Unpublished Thesis for the Degree of Master of Science in Water Resources Engineering)

Kristensen, Peter. (2004). *The DPSIR Framework.*(Workshop presentation on comprehensive / detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach). National Environmental Research Institute, Denmark. Department of Policy Analysis. European Topic Centre on Water, European Environment Agency. https://wwz.ifremer.fr/dce/content/ download/ 69291/ 913220/ file/ DPSIR.pdf

Kulshreshtha,et al. (2018). *A Review on Bioremediation of Heavy Metals in Contaminated Water*. Department of Chemistry, Jiwaji University Gwalior (M.P.).India. www.researchgate.net/publication / 274125025_

Kumar, A., Bisht, B.S., Joshi, V.D. and Dhewa, T. (2011). Review on Bioremediation of Polluted Environment: A Management Tool. *International Journal of Environmental Sciences*.Vol.1. Pp.1079-1093. Dolphin Institute of Biomedical and Natural Sciences. INDIA. doi: 10.4236/abb.2015.62013.In: *Banerjee*,S., Gothalwal, R.,Sahu, P.K.,

La Sara. (2011). Challenges for Implementing Coastal Management: Lesson Learnt from Southeast Sulawesi, Indonesia). In: Plenary session of the 2nd Coral Reef Management Symposium on Coral Triangle Areas. *Coral Reefs: Global Threats and Opportunities*, Kendari, Southeast Sulawesi. 28– 30 September 2011.

Leal, P.P., Hurd, C.L., Sander, S.G. et al. (2018). Copper pollution exacerbates the effects of ocean acidification and warming on kelp microscopic early life stages. Sci. Rep 8, 14763. https://doi.org/10.1038/s41598-018-32899-w

Li,P.,Jiang,L.,&Feng,Z.(2014).Cross-Comparison of Vegetation Indices derived from Landsat-7 Enhanced Thematic Mapper Plus (ETM+) &Landsat-8 Operational Land Imager (OLI) Sensors. *Remote Sensing*.Vol.*6:*1.Pp.310-329. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China. https://doi.org/10.3390/rs6010310

M.A.K. Ashraful, Z.B. Assim, Norhadi Ismail. (2009).Monitoring and assessment of heavy metals levels in littoral sediments from the north eastern part of the Bay of Bengal coast, Bangladesh. *Journal of Industrial Pollution Control*. Vol. 25:2. Pp.105-111. www.researchgate.net/publication/285941005_Monitoring_and_assessment_of_heavy_metals_levels_in_littoral_sediments_from_the_north_eastern_part_of_the_Bay_Of_Bengal_coast_Bangladesh

Mahmuduzzaman,Md., Ahmed, Zahir Uddin, Nuruzzaman ,A. K. M., Rabbi ,Fazle, Ahmed Sadeque.(2014). Causes of Salinity Intrusion in Coastal Belt of Bangladesh. *International Journal of Plant Research*. 4(4A): 8-13. Community Climate Change Project, Palli Karma-Sahayak Foundation (PKSF), Agargaon, Dhaka, Bangladesh. doi:10.5923/s.plant.201401.02

Market Research.com. (2016). *Copper Market in Bangladesh to 2020 - Market Size, Development, and Forecasts.* Global Research & Data Services Oy. www.marketresearch.com /Global-Research-Data-Services-v3891/Copper-Bangladesh-Size-Development-Forecasts-10332154/

Marit B. Brommer and Lisette M. Bochev-van der Burgh. (2009). Sustainable Coastal Zone Management: A concept for forecasting Long-Term and Large-Scale Coastal Evolution. *Journal of Coastal Research*:Vol.25:1.Pp.181–188.doi.org/10.2112/07-0909.1

Mascaro,Osuna,Bustos,C.Teresa, Marie, Benjamin et al. (2015). Heavy Metals in Mollusk Shells: A quick method for their detection. *Key Engineering Materials* 672.doi: 0.4028/www.scientific.net/KEM.672.340

Matin, M.A. & Baig, Z.U.(2006). Morphological assessment of Muhuri accreted area in the Feni estuary. *Journal of Civil Engineering (IEB).*Vol.34:1.Pp.57-69.Department of Water Resources Engineering. Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh. www.jce-ieb.org › doc_file

Mertens J., Smolders E. (2013) .*Zinc*. In: Alloway B. (eds) Heavy Metals in Soils. *Environmental Pollution, vol 22*. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-4470-7_17

Ministry of Housing & Public Works. *Mirsharai Upazila Development Plan (MUDP)*. (2017-2020).Urban Development Directorate (UDD).

Ministry of Water Resources. (2017). Coastal Embankment Improvement Project, Phase-1 (Ceip-1) Terms of Referrence (Tor) for Consulting Services for Independent Panel of Expert (Ipoe) for Design Expertin Embankment and Hydraulic Structures Package. Bangladesh Water Development Board. No.Ceip-1/D1/S19 https://bwdb.gov.bd/tender_doc/4611.pdf

Minister of Environment and Forest. (2009). Bangladesh Climate Change Strategy and Action Plan (BCCSAP).GoB. xvii+ pp76

Mominul Islam,M., Md. Rezaul Karim, Xin Zheng and Xiaofang Li. (2018).Heavy Metal and Metalloid Pollution of Soil, Water and Foods in Bangladesh: A Critical Review. *International Journal of Environmental Research and Public Health* — Open Access Journal. ISSN 1660-4601. file:///E:/Bangladesh%20Bioethic%20Society/ Heavy%20 metal %20and%20metalloid%20pollution.pdf

Neff, J.M. (2002). *Cadmium in the Ocean*. In book: Bioaccumulation in Marine Organisms.DOI:10.1016/B978-008043716-3/50006-3. www.researchgate.net/ Cadmium_in_the_Ocean.

New Age Bangladesh. (Dec. 07, 2016). Works on Cox's Bazar-Teknaf-Sabrang Marine Drive. *Bangladesh Sangbad Sangstha.* www.newagebd.net /article/4340/ works-on-coxs-bazar-teknaf-sabrang-marine-drive-on#sthash.9F17jLsr.dpuf

Nishat, Ainun, Rahman, M.Rezaur, Ahmed, Ahsan Uddin, Ali M.Shawkat & Haque, Md. Ziaul.(2016). Assessment of Sea Level Rise on Bangladesh Coast through Trend Analysis. Climate Change Cell Department of Environment Ministry of Environment and Forests, Bangladesh Address: Room No. 514, Paribesh Bhaban E-16, Agargaon, Sher-e-Bangla Nagar, Dhaka- 1207 .www.climatechangecell.org.bd

Nishat,A., Huq,S.M., Imamul,Barua,S.P., Reza,Ali. A.H.M.Khan, Moniruzzaman, A.S. (eds.). (2002). *Bio-ecological Zones of Bangladesh.* IUCN Bangladesh. Country Office, Dhaka,Bangladesh. https://www.iucn.org/content/bio-ecological-zones-bangladesh

Noor, R., Ahmed, T. and Munshi, S.K. (2017), State of Bioremediation in Bangladesh: Current Concept and Implementation Compared to Global Approaches. *Clean Soil Air Water,* 45. doi:10.1002/clen.201500622

Norici, Alessandra, Hell ,Ruediger & Giordano,Mario.(2005).Sulfur and primary production in aquatic environments: an ecological perspective. *Photosynthesis Research.*86: 409–417Ó. Springer.DOI: 10.1007/s11120-005-3250-0

Organization for Economic Co-Operation and Development (OECD). (2001).*OECD Environmental Indicators: Towards Sustainable Development.* https://www. oecd.org /site/worldforum/33703867.pdf

Organization for Economic Development and Co-operation (OECD). (2008). Key Environmental Indicators. OECD Environment Directorate Paris, France

Patricia Foster-Turley, Rishiraj Das, Md. Kamrul Hasan, Peerzadi Rumana Hossain. (2016). *Bangladesh Tropical Forests and Biodiversity Assessment.* United States Foreign Assistance Act, Section 118/119 Report. *Prepare under "*Restoring the Environment through Prosperity, Livelihoods and Conserving Ecosystems (REPLACE) Contract, Award Number AID-388-TO-16-00001". USAID Bangladesh. *https://www.usaid.gov/sites/default/files/documents/1865/ Bangladesh -Tropical-Forests-and-Biodiversity-Assessment-2016.pdf*

Peng Li, Luguang Jiang and Zhiming Feng. (2014). *Cross-Comparison of Vegetation Indices Derived from Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Landsat-8 Operational Land Imager (OLI) Sensors.*Institute of Geographic Sciences and Natural Resources Research. Chinese Academy of Sciences.Beijing 100101, China.

Prasad, M.N.V. (2018). A State-of-the-Art report on Bioremediation: Its Applications to Contaminated Sites in India. Department of Plant Sciences, University of Hyderabad, Hyderabad. http://www.moef.nic.in/downloads/public-information / Bioremediation Book.pdf

Prasad,Rajendra, Shivay, Yashbir Singh.(2016). Sulphur in Soil, Plant and Human Nutrition. Proceedings of the National Academy of Sciences, India - *Section B: Biological Sciences*. DOI 10.1007/s40011-016-0769-0

Program Development Office Integrated Coastal Zone Management (PDO-ICZM). (2002). *Previous Initiatives and Base Conceptual Documents.* Working Paper WP001. Joint Donor Identification Mission IDA /NEDA /WFP. 1999. https:// warpo.portal.gov.bd / sites/default/ files/files/warpo. portal.gov.bd/ page/ aa04373f_0ca3 _49a5_b77e_ 5108186638dc/ wp001.PDF

Program Development Office Integrated Coastal Zone Management (PDO-ICZMP). (2002). *Previous Initiatives and Base Conceptual Documents.* Working Paper WP001. Ministry of Water Resources. Water Resources Planning Organization (WARPO). GoB

Provin ,T.L and Pitt ,J.L.(). Phosphorus – Too Much and Plants May Suffer.

https://agrilifeextension.tamu.edu/library/gardening/phosphorus-too-much-and-plants-may-suffer/#:~:text=The%20buildup%20of%20phosphorus%20in,those%20nutrients%20in%20the%20soil.

Quazi , Abdul Halim .(1986). Geological framework of Bangladesh . GEOSEA V Proceedings. Vol. II. *Geol. Soc. Malaysia*. Bulletin 20, pp. 73-80. School of Physics Universiti Sains Malaysia, Minden Heights Penang, Malaysia.

Rahman, S. H., et al. (2014). Vulnerability and Impact Assessment to Climate Change and Ecosystem based Adaptation in a Drought prone area of Bangladesh applying DPSIR Framework. *Jahangirnagar University Environmental Bulletin*,Vol.3.Pp.69-82.http://banglajol.info/index.php/JUEB

Rahman, M.M., Islam,M.A., Haque S.M. & Wahab,A.(2017).Mud Crab Aquaculture and Fisheries in Coastal Bangladesh. World Aquaculture. https://www.researchgate.net/profile/M_Ashraful_Islam/publication/318250461_Mud_crab_aquaculture_and_fisheries_in_coastal_Bangladesh/links/595ed882458515a357814835/Mud-crab-aquaculture-and-fisheries-in-coastal-Bangladesh.pdf

Rashid, Er. Haroun. (1991). *Geography of Bangladesh*. The University Press Ltd. Dhaka, Bangladesh.

Rashid, T., Hoque, S., Akter, F. (2013). Ocean Acidification in the Bay of Bengal. Vol.2.Pp.699.*Open Access Scientific Report*. Elsevier.doi:10.4172/scientificreports.699.

Rashid, T., Hoque, S. and Akter, S. (2015). Pollution in the Bay of Bengal: Impact on Marine Ecosystem. Open *Journal of Marine Science*.Vol.5.Pp.55-63. doi.org/10.4236/ojms.2015.51006

Raknuzzaman,Md.,Kawser,M.A.,Saiful,I.,.M.,Mamun,A.H.,Tokumura,Masahiro.Sekine, Makoto., Masunaga, Shigeki.(2016). Assessment of Trace Metals in Surface Water and Sediment collected from polluted coastal areas of Bangladesh. *Journal of Water and Environment Technology*.Vol.14:4.Pp.247-259. https://doi. org/10.2965/jwet.15-038

Rashed, Noor et al.(2017). State of Bioremediation in Bangladesh: Current Concept and Implementation Compared to Global Approaches. Clean Soil Air and Water. *CLEANCSAWAC.* 45:1.Vol. 45:1.Royal Society of Chemistry

Rhoades, et al.(1992).Classification of Waters. Chapter 14.Book Editor(s): D.L. Sparks A.L. Page P.A. Helmke R.H. Loeppert P. N. Soltanpour M. A. Tabatabai C. T. Johnston M. E. Sumner. First published: 01 January 1996. doi.org/10.2136/sssabookser5.3.c14file:///D:/Phd.Literature%20Review/Aug%202020%20lit.review/Classification%20of%20waters[Rhoades,%201992]%20(1).pdf

Roy, Binata. (2016). Temporal Analysis of Land Use Pattern Changes in Chittagong District of Bangladesh using Google Earth and ArcGIS. Conference: Annual International Conference on Chemical Processes, Ecology & Environmental Engineering (ICCPEE'16) Pattaya, Thailand. https://www.researchgate.net/publication/309160752_Temporal_Analysis_of_Land_Use_Pattern_Changes_in_Chittagong_District_of_Bangladesh_using_Google_Earth_and_ArcGIS [accessed Aug 19 2020].

Roy, J., P. Tschakert, H. Waisman, S. Abdul Halim, P. Antwi-Agyei, P. Dasgupta, B. Hayward, et al.(2018). *Sustainable Development, Poverty Eradication and Reducing Inequalities*. In: Global Warming of 1.5°C. (Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla,et al.(eds.)

RRP BAN 45207.*Irrigation Management Improvement Investment Program.*(August 2013).Project Number: 45207.TA 8154: Preparing the Irrigation Management Improvement Program

Sabha, M.El. et al. (1998). Coastal Management and Sustainable Development: From Stockholm to Rimouski. *Ocean & Coastal Managemen*t.Vol.39:1–2. P.1-24. https://doi.org/10.1016/S0964-5691 (98)00009-X

Sajal, Imtiaz. Ahmed. (2018). *Managing Ecologically Critical Areas in Bangladesh.* (Country Report: Bangladesh). Bangladesh Army International University of Science and Technology. https://www.researchgate.net/publication/ 325471666_Managing Ecologically Critical Areas in_Bangladesh /citations

Samakal Correspondent. (26 Feb 2019). Consultation on Bay of Bengal Literacy. Daily Samakal. https://en.samakal.com/bangladesh/article/1902150/consultation-on-bay-of-bengal-literacy

Samarakoon, J. et al. (2011). *Review of Community based Integrated Coastal Management: Best Practices and Lessons Learned in the Bay of Bengal, South Asia*. Colombo: Ecosystems and Livelihoods Group, Asia, IUCN.Pp.xxix-116.*https://dokumen.tips/documents/boblme-review-report-boblme-sa-march-22-2011.html*

Sao,S.(2015). Microbial observation in bioaccumulation of heavy metals from the Ash Dyke of Thermal Power Plants of Chhattisgarh, India. *Advances in Bioscience and Biotechnology.*Vol.6. Pp.131-138. SciRes. doi: org/10.4236/abb.2015.62013

Sánchez, Efraín Tovar, Plata, Isela Hernández, Martínez, Miguel Santoyo, et al. (2018). Heavy Metal Pollution as a Biodiversity Threat. In book: Heavy Metals.doi: 10.5772/intechopen.74052

Sarwar, M.G.M. and Woodroffe, C.D. (2013). Rates of shoreline change along the coast of Bangladesh. *J Coast Conserv*.Vol:17. Pp.515–526. doi:10.1007/s11852-013-0251-6

Sarwar , Golam Mahabub & Islam, Aminul. (2013). Multi Hazard Vulnerabilities of the Coastal Land of Bangladesh (In book: Climate Change Adaptation Actions in Bangladesh). DOI: 10.1007/978-4-431-54249-0_8

Shamsuddoha, Md. & Chowdhury, Rezaul Karim. (2007). Climate Change Impact and Disaster Vulnerabilities in the Coastal Areas of Bangladesh. COAST Trust . www.coastbd.org and Equity and Justice Working Group (EJWG). Shaymoli, Dhaka 1207

Shahid M., Dumat C., Khalid S., Niazi N.K., Antunes P.M.C. (2016). *Cadmium Bioavailability, Uptake, Toxicity and Detoxification in Soil-Plant System*. In: Gunther F.A., de Voogt P. (eds) Reviews of Environmental Contamination and Toxicology Volume 241. Pp.73-137. (Continuation of Residue Reviews), vol.241.Springer,Cham. https://doi.org/10.1007/398_2016_8

Shamsuzzaman, M.M.& Islam, M.M.(2018). Analyzing the Legal Framework of Marine Living Resource Management in Bangladesh: Towards Achieving Sustainable Development Goal 14. *Marine Policy.* Vol.87. Pp.255-262. https://doi.org/ 10.1016/ j.marpol.2017.10.026

Shardul Agrawala, Tomoko Ota, Ahsan Uddin Ahmed, Joel Smith and Maarten van Aalst.(2003). Development and Climate Change in Bangladesh: Focus on Coastal Flooding and the Sundarbans. Environment Directorate Development Co-Operation Directorate. Working Party on Global and Structural Policies. Working Party on Development Co-operation and Environment . Organisation for Economic Co-operation and Development. https://www.oecd.org/env/cc/21055658.pdf

Sirak Robele Gari, Alice Newton, John IcelyGari, S.R., Newton, A., & Icely,J. (2015). A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems. Ocean &Coastal Management. Vol. 103. Pp.63-77. doi:10.1016/j.ocecoaman.2014.11.013

Smeets, Edith. & Weterings, Rob. (1999). *Environmental indicators: Typology and overview*. (Technical report No. 25).TNO Centre for Strategy,Technology and Policy. The Netherlands European Environment Agency(EEA). Copenhagen. file:///D:/Ph.D/Review%20Done/Environmental%20indicators%20Typology%20and%20overview.pdf

Smith,C.,Papadopoulou,N., Barnard,S., Eronat,H.(2014).*Conceptual models for the effects of marine pressures on biodiversity*. Technical Report. www.researchgate.net /publication/263515353_Conceptual_models_for_the_effects_of_marine_pressures_on _biodiversity

Sobhan, Istiak. (Ed.). (2012). *Framework for the Establishment and Management of Marine Protected Areas (MPA) in Bangladesh.* International Union for Conservation of Nature (IUCN), Bangladesh.

Soil Survey Division. (1993). *Soil Survey Manual. Chapter 3, Selected Chemical Properties*. Soil Conservation Service, U.S. Department of Agriculture Handbook 18.

Solomon,S. R. Pierrehumbert, D. Matthews, J. S. Daniel and P. Friedlingstein. (2012). Atmospheric *composition, irreversible climate change, and mitigation policy*. https://geosci.uchicago.edu/~rtp1/papers/WCRP Anthropocene2012.pdf

Sorensen, Jens. (2000). Baseline Background Report: The Status of Integrated Coastal Management as an International Practice. Urban Harbors Institute Publications. https:// scholarworks.umb.edu/uhi_pubs/31

Stefels ,Jacqueline.(2007).Sulfur in the marine environment. In book: Sulfur in Plants an Ecological Perspective. DOI: 10.1007/978-1-4020-5887-5_4

Strove, F.M. (1993). *The Feni River Closure Dam: Reviewed*. (Master Thesis). TU Delft, Delft University of Technology, Faculty of Civil Engineering, Hydraulic and Geotechnical Engineering Division, Hydraulic Engineering Group. http://resolver.tudelft.nl/uuid:1c3fa642-1984-4bb3-805b-75d7940a81fb

Sultana,S., K. M. Ahmed, A. S. M. Woobaidullah, M. M. Rahman, M. J. Alam, M. Hasan., T. Afroz. (2011). *Identification of Potable Water Sources in a Complex Geological Terrain: A Case Study of the Teknaf Peninsula*. Department of Geology, University of Dhaka, Bangladesh. researchgate.net/publication/293488007_ Identification_ of_Potable_Water_ Sources_in_a_ Complex_ Geological_Terrain-A_Case_Study_of_ the_ Teknaf_ Peninsula

Sultana, Zakia , Ershad Ali,Md., Sala Uddin,MD, and Mominul Haque, MD. (2013). Study on Implementation of Effluent Treatment Plants for Safe Environment from Textile Waste. *Journal of Research in Environmental Science and Toxicology*.Vol. 2(1). pp. 9-16. http://www.interesjournals.org/JREST

Sun et al., 2018; Yi et al. (2008). Chapter Five - Ditch-buried straw return: A novel tillage practice combined with tillage rotation and deep ploughing in rice-wheat rotation systems. *Advances in Agronomy*. Volume 154, 2019, P. 257-290. (cited in Haishui Yang,et al.,2019). doi.org/10.1016/bs.agron.2018.11.004

TA 8154: Preparing the Irrigation Management Improvement Program. (August 2013). BAN: Irrigation Management Improvement Investment Program (Rrp Ban 45207). Initial environmental examination. Project number: 45207.

Tathya Kanika: *National Tree Planting Campaign and Tree Fair*. (2016). Forest department, Ministry of Environment and Forests. Pp. 48.

Tao, Lin.,et al. (2007). Analysis of Coastal Wetland Changes Using the “DPSIR” Model:A Case Study in Xiamen, China. Journal of Coastal Management.Vol.35:2-3. Pp.289-303.doi.org/ 10.1080/ 089207 50601169592

The Center for Agriculture, Food and the Environment. (2019).Soil Lead: Testing, Interpretation, & Recommendations. Soil and Plant Nutrient Testing Laboratory .203 Paige Laboratory .161Holdsworth. Way University of Massachusetts Amherst, MA 01003

The Independent. (6th May,2017).Marine Drive to Unlock Cox’s Bazar’s Potentials: PM. Independent Online Desk. http://www.theindependentbd.com/post/93427

Thia-Eng, C. (1993). Essential elements of integrated coastal zone management. Ocean and Coastal Management.Vol.21:1-3.Pp.81-108. doi.org/10.1016/0964-5691(93) 90021-PGet rights and content

Thia-eng. Chua (1999). Marine Pollution Prevention and Management in the East Asian Seas: A Paradigm Shift in Concept, Approach and Methodology. Marine Pollution Bulletin. Vol. 39:1–12. Pp. 80-88 doi.org/10.1016/S0025-326X (99)00085-5

Thia-Eng Chua. (2013). Coastal and ocean governance in the seas of East Asia: PEMSEA's experience. Coastal Management.Vol.41:2. doi: 10.1080/ 08920753. 2013. 768517

Toropova, C., Meliane, I., Laffoley, D., Matthews, E. and Spalding, M. (Eds.). (2010). Global Ocean Protection: Present Status and Future Possibilities. Brest, France. Agence des aires marines protégées, Gland, Switzerland, Washington, DC and New York, USA: IUCN WCPA, Cambridge, UK : UNEP-WCMC, Arlington, USA: TNC, Tokyo, Japan: UNU, New York, USA: WCS. 96pp. https://pipap.sprep.org/content/ ocean-protection-present-status-and-future-possibilities

Turley, P.F., Das, R., Hasan, M.K., Hossain, P.R. (2016). Bangladesh Tropical Forests and Biodiversity Assessment: United States Foreign Assistance Act. Section 118/119 Report. USAID Bangladesh. In: The Restoring The Environment Through Prosperity, Livelihoods And Conserving Ecosystems (REPLACE) Contract, Award Number AID-388-TO-16-00001. Integra Government Services International. Washington, DC. Www.Integrallc.Com

United Nations. (1987). *Coastal Environmental Management Plan for Bangladesh*. Vol.1: Summary. Project: KWP-collection. United Nations Economic and Social Commission for Asia and the Pacific Bangkok, Thailand ST/ESCAP/618. http://resolver.tudelft.nl/uuid:396a661a-e0d5-48de-bb70-8687814eb210

United Nations Conference on Sustainable Development (UNCSD). (1992). AGENDA 21. United Nations Conference on Environment & Development Rio de Janerio, Brazil. June 1992. Sustainable development. https://sustainabledevelopment.un.org /outcome documents/agenda21

UNFPA . (2000). Millennium Development Summit of the United Nations. United Nations. New York, United States. https://www.unfpa.org/events/millennium-development-summit-united-nations

UNFPA. (2011).Population Projection: 2021.United Nations Population Fund Association, UNFPA.www.unfpa-bangladesh.org/charts/Population Projection 2021.

United Nations Economic and Social Commission for Asia and the Pacific. Bangkok, Thailand. (1987).Coastal Environmental Management Plan for Bangladesh. Vol.1: Summary. Project KWP-collection. http://resolver.tudelft.nl/uuid:396a661a-e0d5-48de-bb70-8687814eb210

United State Department of Agriculture (USDA). (2014). Soil Electrical Conductivity. Natural Resources Conservation (NRC) Services; https://cropwatch.unl.edu/ documents/ USDA_NRCS_EC_guide.pdf

USDA Natural Resources Conservation Service. (1998). Soil Quality Information Sheet. Soil Quality Indicators: pH. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052208.pdf

United States Environmental Protection Agency (EPA). (2013). Introduction to In Situ Bioremediation of Groundwater.542-R-13-018, Office of Solid Waste and Emergency Response, USA. UNESCO. (2017). United Nations Decade of Ocean Science for Sustainable Development (2021-2030). https://en.unesco.org/ocean-decade

United States Environmental Protection Agency (USEPA). (2006). Monitoring Manual Chapter 11: pH and Alkalinity. Volunteer Estuary Monitoring Manual: A Methods Manual. EPA-842-B-06-003. http://www.epa.gov/owow/estuaries/monitor/ Voluntary Estuary

United States Environmental Protection Agency (USEPA). (2003). Ecological Soil Screening Level for Iron. Interim Final. OSWER Directive 9285.7-69. Office of Solid Waste and Emergency Response 1200 Pennsylvania Avenue, N.W. Washington, DC 20460

UNESCO. (2017).United Nations Decade of Ocean Science for Sustainable Development (2021-2030).United Nations. https://en.unesco.org/ocean-decade#

United Nations Resource Conservation and Recovery Act (RCRA) 1976: Federal Government of United States of America.www.epa.gov/aboutepa/about-office-land-and- emergency- management # orcr

U.S. Geological Survey. (2015). Digital Shoreline Analysis System (DSAS).Version 4.3 transects with end-point rate calculations for sheltered shorelines between Point Barrow and Icy Cape for the time period 1947 to 2012.Geospatial_Data_Presentation_Form: vector digital data. Open-File Report. Issue Identification: 2015-1030. Pacific Coastal and Marine Science Center.Santa Cruz and Menlo Park, CA. U.S. Geological Survey, Coastal and Marine Geology Program. https://pubs.usgs.gov/of/2015/1030/downloads/EastChukchi_sheltered_transects.zip

USGS. (n.d.).Phosphorus and Water. Water Science School. https://www.usgs.gov/special-topic/water-science-school/science/phosphorus-and-water?qt-science_center _objects =0#qt-science_center_objects

Van, Tran Thi. & Binh, Trinh Thi. (2008). Shoreline Change Detection to Serve Sustainable Management of Coastal Zone in Cuu Long Estuary. International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences, GISIDEAS, December 4-6, 2008. http://gisws.media.osaka- cu.ac.jp

Wanfei, Qiu. et al. (2018). Lessons from initiation to implementation of ICM programs in Xiamen: Key drivers and enabling environment for achieving social, environmental and economic sustainability. Ocean and Coastal Management. doi.org/10.1016 / j. ocecoaman. 2018.09.001

Wang, A., Kawser, A., Xu, Y. et al. SpringerPlus. (2016). Heavy metal accumulation during the last 30 years in the Karnaphuli River estuary, Chittagong, Bangladesh.Vol.5:2079.https://doi.org/10.1186/s40064-016-3749-1

WARPO. (2004). *Contribution of Integrated Coastal Zone Management Plan Project towards formulation of the Poverty Reduction Strategy Paper (PRSP) for Bangladesh*. Ministry of Water Resources, GoB. https://warpo.portal.gov.bd/sites/default/files/ files/ warpo. portal.gov.bd/ page/aa04373f_ 0ca3_49a5_ b77e_5108186638dc/prsp%26iczmp.PDF

Water Resources Planning Organization (WARPO). (2005).Coastal Zone Policy (CZPo). Ministry of Water Resources. GoB file:///C:/Users/User/Downloads/ Documents/ Costal-Zone-Policy-2005_3.pdf

WARPO. (2005). Integrated Coastal Zone Management Plan (ICZMP) Project

Output of the ICZMP project. Water Resources Planning Organization. Ministry of Water Resources, GoB. http://old.warpo.gov.bd/index.php/home/iczmp

Water Resources Planning Organization (WARPO). (2006). Coastal Development Strategy (CDS). Ministry of Water Resources. GoB file:///C:/Users/User/Downloads/ Documents/ bgd175355. pdf

WARPO. (2006).*Coastal Development Strategy* . Water Resources Planning Organization. Ministry of Water Resources, GoB. file:///C:/Users/User/Downloads /Documents/ bgd175355.pdf

Warrick, R.A., Ahmad, Q.K., (Eds.). (1996). The Implications of Climate and Sea Level Change for Bangladesh. Kluwer Academic Publishers, Dordrecht, The Netherlands.

William E. Godsey. (2017). Fresh, Brackish or Saline Water for Hydraulic Farcs: What are the Options? Geologic Environmental Services, EPA. Longview, Texas. bill.godsey@geologicenvironmental.com

Weier, John, and Herring, David. (2000). Measuring Vegetation (NDVI & EVi). https://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring _ vegetation_2.phpWorld Commission on Environment and Development (WECD).(1987).United Nations.

World Bank. (2005*).Coastal Embankment Rehabilitation Project (Credit 2783-Bd)*. Project Performance Assessment Report No.: 31565. Sector: Thematic and Global Evaluation Group. Operations Evaluation Department, Bangladesh.

World Bank.(1990).*Bangladesh-Muhuri Irrigation Project, ID-P009380*, Project completion Report, No-8555. Washington D.C.

World Bank. (2016). *Climate Change Poses Urgent Threat to Poor of Coastal Bangladesh*. www.worldbank.org/en/news/feature/2016/06/24/climate-change-poses- urgent-threat-to-poor-of-coastal-bangladesh

WARPO. (2005). Integrated Coastal Zone Management Plan (ICZMP) Project: Output of the ICZMP project. Water Resources Planning Organization. Ministry of Water Resource. GoB . http://old.warpo.gov.bd/index.php/home/iczmp

Xu, Hanqiu. (2006). Modification of Normalized Difference Water Index (NDWI) to Enhance Open Water Features in Remotely Sensed Imagery. *International Journal of Remote Sensing*.Vol.27: (14):3025–3033. doi:10.1080/01431160600589179

Zhu, Mao & Hao, Kong. (2018). What results in the success of Xiamen's ICM practices - A new study of the ICM system from the perspective of “Paradigm Shift”. *Ocean and Coastal Management*. doi.org/10.1016/j.ocecoaman.2018.12.001

Zia Uddin Ahmed, ed. (2009). Encyclopedia of Flora and Fauna of Bangladesh. Asiatic Society of Bangladesh, NHBS. ISBN 984-300-000286-0. Archived from the original on 2017-06-06. Retrieved 2017-07-07.

Appendix A: Stakeholder’s Recommendations

Appendix A:

Cyclone Preparedness Program (CPP), Bangladesh

Among all the stakeholders working in the east coast, whether national, public or private; the CPP is the most dynamic authority, working jointly under the Red Crescent and GoB since 1972. Since then the organization has been regulating its extensive commanding area of 40 Upazilas in 13 coastal districts, with its total 55,260 volunteers. The CPP disseminates their information and commands through a wide-ranging wireless network as well as by the field level volunteers during the cyclones. Though exclusively established to combat with the devastating cyclones and their aftermath in the coastal zone of Bangladesh, the CPP at present has been assigned to deal with the Rohingya issues at Ukhia.

However, the CPP officials stated that, the organization is not yet been assigned to deal with the environmental deterioration along the east coast, for instance, illegal encroachment of river shore, garbage and waste dumping into the rivers, and logging of natural vegetation in the study area. Nevertheless, the Chattogram and Cox's Bazar Deputy Directors, Union Team leaders and Unit Team leaders stated that, at present they have been creating awareness to conserve the existing as well as regenerate the destroyed areas of the forests in the Rohingya Camp areas of Kutupalong, Baharchara, Leda, Nayapara, Unchiprung areas at Teknaf.

The CPP officials also mentioned that, they are committed to take the responsibilities to create awareness, conduct trainings, and operate different projects regarding the reduction and mitigation of the geo-environmental deterioration and bio-diversity loss along the east coast, if instructed by the GoB. The recommendations mentioned by the CPP officials and volunteers have been listed below.

A. CPP, Chattogram and Cox's Bazar: Deputy Directors

i) Initiatives have to be taken to build awareness at community level about the significance of a balanced environmental condition or ecosystem.

ii) The CPP Field level officials, Union Team leaders, and Unit Team leaders need to be trained about the causes, sources, and as well as the mitigation measures against pollution and toxicity.

iii) The CPP Unit Team leaders need to be trained about proper household and industrial waste disposal to ensure the reduction of toxicity in the environment. The local communities at village level would then be trained by the Unit Team leaders about the proper household garbage disposal.

iv) Awareness has to be built to inspire the volunteers about reforestation as well as afforestation, and the conservation of the existing area of vegetation coverage.

v) Awareness has to be built among the CPP volunteers about biodiversity conservation at grass root level, which will be disseminated among the localities through them.

vi) Trainings have to be conducted for the Union Team leaders regarding the dissemination of the conservation, mitigation and management strategies at community level.

vii) Joint collaboration and coordination among different concerned government and non-government organizations during the occurrence of any natural hazards has to be effectively strengthened.

viii) The financial and other logistic supports provided by the GoB as well as different organizations, such as, the American Red Cross, German Red Cross, United Nations, and World Bank is the core need of the CPP to carry out the activities in such a vast area with a large number of volunteers.

B. CPP, Chattogram and Cox's Bazar: Union Team Leaders and Unit Team Leaders

i) Institutional trainings about the causes, sources, mitigation and management measures to protect the coastal environment has to be conducted for the volunteers.

ii) Adequate logistic supports from the CPP to disseminate awareness, and knowledge among the local communities has to be initiated and ensured.

iii) Supply of adequate equipments to combat the natural hazards has to be ensured.

iv) The underprivileged volunteers have to get engaged in different occupation to ensure their livelihood.

During the Present Study field survey through the years 2016-2018, the activities of the CPP have been closely observed. The field level officials, the Union and Unit Team leaders have been sincerely engaged in dealing with the natural as well as social hazards along the coastal area. For instance, the recent active participation of the CPP officials and volunteers in the Rohingya camps has depicted their commitment as well as motivation to safeguard the land and people from any types of hazard. Hence, the Present study advocates the commitments of the CPP officials and volunteers to be trained and engaged in protecting the geo-environment of the east coast in a collaborative approach with the other concerned organizations.

Bangladesh Fisheries Research Institute (BFRI): Scientists

The BFRI, Cox's Bazar has been investigating about the cultivation of the sea weeds or sea algae, pearl producing bi-valves, as well as breeding the turtles and tortoises and Mud crabs in captive environment. After achieving success at experimental level, the scientists assured the successful cultivation of the Coastal and Marine floral and faunal resources in captive environment. The recommendation of the scientists of BFRI has been listed below.

i) The BFRI suggested the strict implication of the conservation acts, plans and policies to reduce the increased level of heavy metal concentration as well as pollution in the Bay of Bengal along Bangladesh, which were formed at the workshops namely, 'Support to Sustainable Management of the BOBLEME'. The workshops were held in two important cities of the east coast, the Chattogram and the Cox's Bazar in 2010 and 2012 consecutively.

ii) The scientists emphasized upon the commercial cultivation of *hypnea* species of sea-weeds at the inter-tidal zones of the Bakkhali River estuary and the Inani, as the east coast is very fertile, with suitable physio-chemical characteristics for sea weed cultivation.

iii) The BFRI scientists opined that, the sea-weeds or the algae should be grown to maintain the food-chain balance in the Coastal and Marine ecosystem and as an alternative healthy staple food.

iv) The scientists also emphasized the commercial production of the *Agar* species of sea weeds, as these species is used as the raw materials for dairy products, medicines, textiles, paper mills, animal fodder, fertilizer in agriculture and salt farming.

v) Commercial breeding of turtles and tortoises has been recommended as these are the scavengers of the nature as well as the source of protein for the indigenous people along the east coast.

vi) Crab cultivation, especially of the Mud Crab species has been recommended as an alternative to shrimp culture. The Mud crab fries can be produced easily in the shrimp ponds instead of collecting from natural sources. Moreover, the crab cultivation has been referred as more eco-friendly.

vii) The Pearl producing Bi-value mollusk cultivation has been recommended by the Scientists after the successful experimental production of these at the Bakkhali River estuary and in a pond near Reju khal, Inani.

viii) The BFRI emphasized the supply of sufficient fund, machineries, and other logistic supports for the commercial production the fisheries resources.

The Present Study field survey in 2018, observed the achievement of the BFRI scientists in producing the above mentioned floral and faunal species in captive environment. The suitable pH level (7.5-8.5) for sea weed cultivation is still now found in the soil and water of the Bakkhali River estuary, though the amounts have reached the last limit for both soil (pH 7.2) and water (pH 7.3). Added to these, the wide shallow continental shelf along the east coast is the natural habitat of the Pearl producing Bi-Valves in Bangladesh. The Bakkhali River estuary, the Nuniarchara of Cox's Bazar and the Teknaf coastal zone along with the Moheshkhali, Sonadia, Matarbari, Kutubdia, Ukhia and St.Martin are the major pearl producing bi-valve habitats. The Present study found the declining percentage (59% in average) of CA content in the mollusk shell samples, collected from the Bakkhali river estuary. Hence, immediate measures to restore the pearl producing bi-valve production environment have been strongly recommended by the BFRI Scientists. The study advocates the recommendation for the implementation of conservation acts, plans and policies as well as the commercial production of the fisheries resources to provide alternative staple food and to generate permanent source of livelihood.

Forest Division, Cox's Bazar and Forest Division, Chattogram: Divisional Forest Officer

During the Present Study field survey, the Divisional Forest Officers of the Forest division, Cox's Bazar and Chattogram has suggested some steps to be taken to reduce deforestation process as well as initiate reforestation programs. The recommendations provided by the Forest Officers of both Forest Divisions have been cited below.

i) High priority has to be given by the GoB to stop the deforestation process of the natural vegetation among huge areas of the east coast; whether the lands has to be cleared for logging, firewood, or for any type of structural development at the east coast in the recent years.

ii) Conservation, reforestation as well as afforestation programs have to be implemented and preservation of the mangrove forests along the east coast has to be ensured.

iii) Mass reforestation of the Jhaubon and other coastal indigenous trees has to be carried out along the Marine Drive to protect this highly erosion prone coast line.

iv) Proper maintenance of the newly planted forest coverage has to be ensured by the concerned authorities. More well trained and sufficiently equipped man power has to be employed to protect the illegal logging of the forest trees.

v) Immediate and proper execution of the reforestation and aforestation programs, such as the 'Coastal Forest Plantation' in 705 hectors and 'Jhaubon Plantation' in 60 hectors of land, planned for the Cox's Bazar district has been recommended by the Forest division.

The Present Study field survey observed that, the old mangrove forests along the river estuaries and the Jhaubon along the Marine Drive sample areas has been cut down almost entirely. However, the mangrove tress, known locally as the Parabon, has been planted along the Bakkhali River west bank along the Nuniarchara Industrial area and at the mouth of the Jalkadar River estuary. Nevertheless, the fruit tree plantation has taken over the indigenous tress along the Feni River estuary. Reforestation has been observed along the Marine Drive sample areas, especially in the ECA between the Himchari and Sonarpara. On the other hand, the mangrove forest at the Kasturi ghat area of the Bakkhali River has been entirely destroyed as a consequence of garbage dumping in an area of about one acre near the Badar Mokam mosque. The river has retreated about 1.5 km from the ghat as the area has been filled up to reclaim land to construct the Khurushkul Bridge. Hence, the recommendations of the Forest Officers should be advocated in the present study considering the present shoreline change scenario, environmental deterioration as well as bio-diversity loss at the sample areas.

Bangladesh Water Development Board (BWDB), Chattogram: Chief Engineer

i) The Dams, Embankments and Sluice Gates have to be maintained and monitored regularly.

ii) The well trained and equipped man power has to be employed to monitor the slice gates, embankments and spurs along the east coast rivers.

Banshkhali Union Parishad, Banshkhali, Chattogram:

A. Chairman and CPP Union Team Leader

i) The Jalkadar River has to be re-excavated to ensure sufficient water flow during dry season.

ii) The earthen coastal protection dam has to be repaired and elevated up to 30 feet to protect the local people from storm surge, and even high tides.

iii) Construction of small sluice gates on the Jalkadar River near the estuary to prevent toxic wastes and garbage to flow into the Bay water.

B. Unit Team Leader and Local Journalist

i) Plantation of local indigenous species of trees with deep roots has been suggested, as the long trunk, short rooted acacia trees fall upon the houses even during a moderate scale cyclone.

ii) Different indigenous plants have been suggested to be planted upon the earthen dam. These would provide fire wood, and fruit, while protecting the localities from the high tides, cyclone and associated storm surge.

iii) Proper maintenance as well as monitoring of the planted trees on the dam has to be ensured by the forest division, as the trees are cut down at night by the illegal loggers.

iv) Mass plantation of indigenous trees has to be done to protect the erosion prone coastal zone of the upazila.

The field survey for the present study revealed the deteriorating geo-environmental condition along the Jalkadar River estuary. The Chhanua and the Gondamara unions have been observed to experience an erosive trend along the river estuary, which is 401.4 meters across the estuary mouth. The field survey and the NSM of the Jalkadar River accentuate the erosional characteristic of the river. Nevertheless, basing upon the recommendations of the local stakeholders the present study attempted to advocate several initiatives for an integrated coastal zone management plans.

Appendix B: Case Studies

Case Studies

The purpose of conducting the Case Studies was to investigate the geo-environmental hazards occurring in Banshkhali upazila, through which the Jalkadar River traverses in a north-south direction and debouches into the Bay of Bengal. The geo-environmental condition of the river estuary was investigated to analysis the overall degradation of the ‘Terrestrial’ and ‘Coastal and Marine’ ecosystem of the sample area. The research results revealed that, besides geo-environmental deterioration, the ecosystems of the area has also been damaged. The floral and faunal bio-diversity of the area was investigated and analyzed as well. The study revealed that, the bio-diversity has been experiencing decline in quality and quantity. Nevertheless, two case studies were conducted with (i) the Chairman and CPP Union Team Leader of Baharchhara, and (ii) the Union Team Leader and local Journalist of Sharal union of Banshkhali upazila. The information collected from both respondents accentuated, as well as, explained the causes of the geo-environmental deterioration of the river estuary. Both respondents provided in-depth perceptive about the existing problems in the upazila. However, as the team leaders of the only government organization the ‘Cyclone Preparedness Program’, they also mentioned about the limitations of performing their duties during disasters, and provided recommendations regarding mitigation techniques and management policies for the coastal zone along Banshkhali upazila. Further, both respondents discussed bout the resilience techniques, practiced by local communities to adapt with the degradations. These case studies are accepted to contribute knowledge base for coastal zone management along the east cost of Bangladesh.

Case Study # 1

Chairman and CPP Union Leader of Baharchhara Union, Banshkhali Upazila

1) What kinds of geomorphic hazards occur in Banshkhali Upazila?

i) The mud and clay built embankments, constructed after the 1991 severe cyclonic storm has become fragile and keeps breaking due to strong tidal waves along the coast

ii) Massive damages were done to the lives and properties owing to tidal water surge intrusion through the embankment crevices and eroded parts of the embankments during cyclone Aila.

iii) The tidal saline water break into the localities and cannot flow back to the bay, which causes water stagnation

iv) The stagnant water damages crop fields and disrupts community lives and properties for couple of weeks

v) Water also intrudes through the coastal embankments during Nor'westers, storms, heavy rain fall

vi) The saline water of the bay makes the embankments fragile enough to instigate length of coastal erosion up to 2 km in the west along Banshkhali coast

vii) Sand from the coast enters with water during diurnal tides and decline productivity of the crop fields

Loose earth and soil is carried down as landslides during heavy rainfall and causes damages to life and properties

viii) Water flow from the hills during heavy rainfall collects in Hatkhali & Kodala khals, resulting in overflow

2) What kinds of environmental degradations occur in Banshkhali Upazila?

i) The Cyclone in April 1991 & Cyclone in 1997 powerful cyclone struck the southeastern coast of Bangladesh and the port city of Chittagong on Monday. The cyclones crossed over the Upazilas Baharchhara, Sharal, Gondamara

ii) The consequent storm surges and high tidal surges

iii) Water was stagnant for weeks and caused environmental pollution

iv) The illegal encroachment and land grabbing turned the khals cress-crossing through the upazila into polluted and sluggish water bodies

3) What kinds of biodiversity changes and/or declines occur in Banshkhali Upazila?

Wild elephants from the hills attack the local communities in search of food

1) Causes death of 5/6 people and injury for many people per year as they stampede the local villages, crop fields, and market areas along the main road of the upazila

2) The mangrove forests along the Bahar Chara Union coast depleted due to coastal erosion by diurnal tidal surges

4) What kinds of socio-economic problems occur in Banshkhali Upazila?

i) During the 1991 cyclone, thousands of people died and was given a mass-burial

ii) During 1997 cyclone, the casualties were lesser as the pre-disaster management activities were better since CPP started to operate in the area after the devastating cyclone in 1991

Recommendations

i) The CPP volunteers should be trained & equipped with modern gears and gadgets for rescue and response functions

ii) Sufficient fund for relief and rehabilitation is needed

iii) Remuneration and permanent sources of income for the local CPP volunteers is required to ensure their livelihood

iv) Replace sand-bags with comment blocks to protect coastal embankments

v) Sluice gates should be constructed along Hatkhali khal & Kodala khals to prevent over flow during heavy rainfall

vi) Replacement of earthen embankments with cemented blocks is needed to prevent coastal erosion permanently.

vii) The coordination and cooperation between the Government and local stakeholders has to be strengthened

viii) The recommendations coming from the grass root level should be considered to be in corporated into the management policies

Case Study # 2: Journalist/CPP Union Leader of Sharal Union, Banshkhali Upazila

1) What kinds of geomorphic hazards occur in Banshkhali Upazila?

i) Extensive coastal erosion from Khankhanabad to Bahar Chara Union
ii) Landslide from hills during rainy season clog the water bodies
iii) Water-logging in the Pouroshobha area due to heavy rain, poor drainage
iv) Cyclone storm surge washes the
v) Inundation by regular tidal surge inside the upazila Proper
vi) Siltation in five khals of the Upazila
vii) Khal erosion
viii) Weak & evolved embankments (37km long, along **polar** to Chhanua)

2) What kinds of environmental degradations occur in Banshkhali Upazila?

i) Water & Soil pollution
ii) Accelerated toxicity of soil and water due to drainage of toxic effluents
iii) Increased salinity intrusion in coastal zone soil
iv) Flash flood from hills

3) What kinds of biodiversity changes and/or declines occur in Banshkhali Upazila?

i) Wild elephants from the hills at the east side of the upazila regularly attack the local communities in search of food
ii) Causes death of 5/6 people and injury for many people per year as they stampede the local villages, crop fields, and market areas along the main road of the upazila
iii) The mangrove forest along the Sharal Union coast depleted due to coastal erosion by tidal and storm surge
iii) Thousands of fish **fry** are caught and dies when fishers capture them in their electric fish nets from open sea

4) What kinds of Socio-economic changes occur in Banshkhali Upazila?

i) Occupation shift of fishing communities, due to three reasons –

a) Insecure fishing environment as pirate populates has been increasingly attacking the fishing boats, capturing fishers, taking ransom, and if failed, killing them
b) Ban of electric fishing net
c) Frequent environmental disaster occurring in the Bay of Bengal demotivates the fisher communities to go in the deep sea for fishing
d) Depletion of fish population due to declining fish breeding and spawning environment

ii) Population increase resulting in demand-supply imbalance

iii) Illegal khal encroachment (Jaliakhali khal) results into water body depletion

iv) Unethical and irrational practice of 'Social Forest Land Tenureship' by external stakeholders causing-

a) The Forest Division, Chattogram and Cox's Bazar; as well as, the Bangladesh Water Development Board (BWDB) controls most of land allocation procedures of 'Social Forestation'

b) In most cases these government bodies hand responsibilities to external parties rather than the Local communities

c) Consequently, in majority cases, one acre of land, leased for 10-15 years, receives least nurturing by its owner

d) This consequences in deterioration of the social forestry resources and gradually into declination of floral biodiversity

Recommendations

i) Re-excavate the 10-15 filled up charas for normal water flow

ii) Remove and prohibit household and industrial garbage and waste disposal in khals and charas to allow natural rain water drainage

iii) Create awareness and knowledge pool about pre, during and post disaster management

iv) Incentives and/ or awards should be rewarded to the concern stakeholders for their good achievement

v) People should be inspired to protect the environment

vi) Forest clearing & logging should be restricted, and prohibited to protect hill slope

vii) Aforestation programs should be conducted for crating mangrove forest to alone the coastline.

viii) Re-allocate the cattle grazing fields from the mangrove forest to protect it's density

Case Study # 3

Scientists, Bangladesh Fisheries Research Institute, Cox's Bazar Sadar,Cox's Bazar

Q. 1) What are the major fisheries recourses along the coastal zone of Bangladesh?

i) Crabs, Turtles, Pearl producing bi-valves, and Sea weeds

Q. 2) What are the previous projects of the institution?

Crab Breeding and Rearing

i) In 2015, the crab breeding hatcheries were established
ii) Afterwards in 2017, the project outcome was still not satisfied
iii) The crab breeding initiatives were carried out in the ponds of the institute
iv) In 2016, at the time of the present research survey, the eggs were not hatched
v) Moreover, the crab cultivation has been referred as more eco-friendly

What are the reasons of Crab breeding in hatcheries in Bangladesh?

i) The coastal zone of Bangladesh is the dwelling of 16 species of crabs, among which
ii) the 'Mud crab' or the 'Mangrove crab' is the most commercially important species in Bangladesh.
iii) Though crab farming in Bangladesh is dependent upon two sources like-
   (a) the Hatcheries and (b) open bay water
iv) Majority of the crab seeds are collected from the natural habitats
v) Though the crab fry are available round the year, the months of May to August (Summer) and December to February (Winter) are the peak seasons
vi) The hatching rate is close to 100 percent, but mortality is highest during changes between Zoea, Megalopa and Juveniles.
vii) Highly saline sea water (25-53 PPT) is best for larval rearing
viii) The abandoned shrimp ponds are used as crab fattening ponds
ix) Besides, traditional shrimp ghers and integrated paddy-cum shrimp culture are also used as crab farm, while shrimp is cultured as the main crop
x) Due to the commercial demand of the crabs, the catch of crab fry from natural habitats has increased extensively
xi) Along with over-exploitation, loss of natural habitats of the crabs, the mangrove forests, and the coastal environmental degradation his worsening the situation
xii) Consequently, the natural populations of mud crab are declining throughout the coastal zone of Bangladesh

Pearl Producing Bi-Valves

i) The wide shallow continental shelf along the east coast is the natural habitat of the Pearl producing Bi-Valves in Bangladesh.

ii) The Bakkhali River estuary, the Nuniarchara of Cox's Bazar and the Teknaf coast along with the Moheshkhali, Sonadia, Matarbari, Kutubdia, Ukhia and St.Martin are the major natural habitats of pearl producing bi-valves.

iii) The specific species, named 'Kartal Jhinuk' were only available at Moheshkhali Ghutiganga, during the neap-tide, far into the offshore region of Inani

iv) The artificial rearing of Pearl producing bi-value mollusk in the Bakkhali River estuary and a pond near Reju khal, Inani was successful in 2015

v) But the unavailability of ponds to rear the mollusks, as well as, the lack of working force has limited the process

vi) Moreover, the mollusks are attacked by insects which end into death of the artificially reared mollusks

vii) The first year they successfully collected the bi-valves with the produced pearls to see how long they survive in captivity. They did not last long

viii) Next year the project was renewed for bi-valve rearing and then breeding

ix) They tried rearing in a pond with tidal changes and noticed better survival and growth

x) The bi-valves grew by 0.254 grams per

Seaweed Cultivation

i) Seaweed is a macro marine algae and has many species, around one thousand worldwide, growing in inter-tidal zones

ii) Total 140 species have been reported in Bangladesh, but the institute has identified and collected 85-90 species

iii) Highest diversity and density is found in St. Martins, followed by Teknaf to Inani, then Bakkhali River, and mangrove regions

iv) While other areas have 4-5 species, there are around 60 species in St.Martin island

v) The physio-chemical parameters of water around St.Martin are favorable for seaweed

vi) The coral reefs are the substratum upon which the seaweed can grow

vii) In St.Martin the seaweed is golden brown while it is black in Bakkhali River, due to high amounts of ammonia, phosphate and iron in the river water

viii) The upper surface water of the St.Martin (within visible range) has dead corals

ix) However, in deeper water, live corals can be found

x) Water quality deterioration and coral extraction, toxic affluent infiltration has been

xi) destroying the coral ecosystem and hence the habitats for seaweeds

xii) The pH level (7.5-8.5) of the Bakkhali River estuary water is suitable for seaweed cultivation

Egg laying, hatching and breeding of Marine Turtles:

i) At the Inani coast, even though the ecosystem has deteriorate, turtles lay eggs

iii) However, the turtles who came for the first time is not getting favorable environment for laying eggs

iv) The favorable habitats for turtle breeding and rearing of turtles has been declining due to the increasing congested human settlement

v) Total five types of turtles regularly reside in the coastal habitats of Bangladesh

vi) Loggerhead turtles are the most common and they lay eggs during full moon, around the month of January

vii) However, a minimum level of light and noise pollution functions as an obstacle in laying eggs

viii) Turtles are the scavengers of nature

ix) Public awareness is required for creating and conserving favorable environment for Turtle rearing and breeding

x) Due to lack of awareness the public ends up consuming the eggs, resulting in decrease in turtle population

Q.3 What are the ongoing projects of the institution?

i) The research projects are focused at commercial crab seed production in hatcheries and nurseries operated by the institution

ii) To reduce the crab fry catch from natural habitats, the institution has been trying to breed them in their Cox's Bazar, Chattogram and Paikgacha, Khulna center

Q.5 What are the projects planned for future?

i) Molecular analysis of the highly demanded seaweed species (as food, medicine raw material), pearl producing bi-valves, crabs, and turtles at the east coast for culture, especially at Bakkhali River and Inani.

Three objectives for **Seaweed Project**

i)Formulate Checklists to record-

a. the types of species in St.Martin
b. the seasons when they flourish
c. the amount present in the nature

ii) Seaweed culture technique development

iii) Analysis of cultures seaweed

Q. 6 What are the initiatives needed for the successful completion and application of the projects of the institution?

i) This institute can only work on annually assigned projects and cannot do research beyond that

ii) There is a lack of resource, financial support, government initiation and proper project implementation

iii) While a lot of work has been done since the institute opened in 2000, the building, ponds has been destroyed

iv) December 2018-December 2020; New building, Lab and ponds will be constructed

v) Supply of sufficient fund, machineries, and other logistic supports for the commercial production the fisheries resources.

vi) Part of St.Martin island should be conserved for turtle breeding, hatching, and rearing