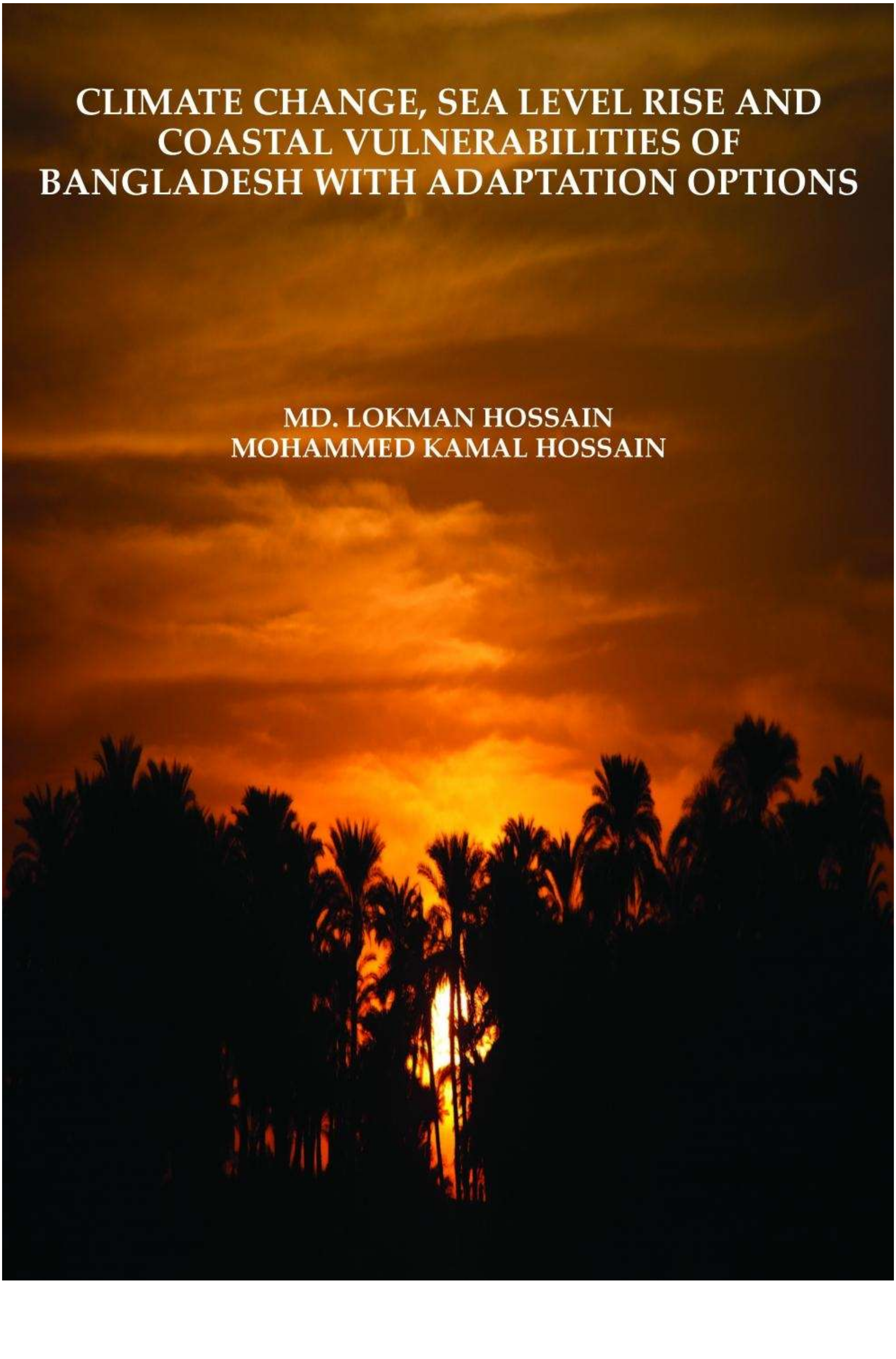

CLIMATE CHANGE, SEA LEVEL RISE AND COASTAL VULNERABILITIES OF BANGLADESH WITH ADAPTATION OPTIONS

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Acronyms and Abbreviations

BCAS .... Bangladesh Centre for Advanced Studies
BMD .... Bangladesh Meteorological Department
CC .... Climate Change
CCSLR........... Climate Change and Sea Level Rise
CEGIS .... Centre for Environment and Geographic Information System
CNG .... Compressed Natural Gas
CO_2 .... Carbon dioxide
cm .... Centimeter
CZPo .... Coastal Zone Policy
dS/cm .... Deci-simens per centimeter
DoE .... Department of Environment
GBM .... Ganges-Brahmputra-Meghna
GHGs .... Green House Gases
GoB .... Government of Bangladesh
GW .... Global Warming
IPCC............... Intergovernmental Panel on Climate Change
km^2 .... Square Kilometer
m .... Meter
mm .... Millimeter
MT.................. Metric ton
OECD............. Organization for Economic Co-operation and Development
SLR .... Sea Level Rise
SMRC .... SAARC Meteorology Research Centre
SPARRSO...... Space Research and Remote Sensing Organization
SRDI .... Soil Resources Development Institute
SST................. Sea Surface Temperature
Tk. .... Taka
UNDP............. United Nations Development Programme
UNFCCC........ United Nations Framework Convention on Climate Change
^0C.................... Degree centigrade
% .... Percent

ABSTRACT

Bangladesh is likely to be one of the most vulnerable countries in the world to climate change and sea level rise. This paper discusses the changing pattern of climatic conditions (temperature and rainfall), reviewing sea level rise scenarios and its impacts on coastal areas, people's opinion regarding sea level rise adaptation, and National and International initiatives taken to combat sea level rise. The study was conducted based on both primary and secondary information. Three coastal districts (Cox's Bazar, Bhola and Khulna) from three coastal regions (eastern, central and western) were selected purposively for the conduction of semi-structured questionnaire to collect necessary information regarding people's perceptions about sea level rise and its impacts, and adaptation and mitigation measures needed to combat adverse impacts of sea level rise. The study revealed that temperature and rainfall of Bangladesh were increased gradually during last three decades. Average temperature of last decade (2000-2009) was 0.08^{0}C and 0.07^{0}C higher compared to decade of 1990-1999 and of 1980-1989 respectively. Moreover, highest (2730 mm) rainfall was recorded in recent last decade (2000-2008) while lowest (2587 mm) was in 1990-1999. The study also revealed that a one meter sea level rise will affect the vast coastal area and flood plain zone of Bangladesh. Both livelihood options of coastal communities and the natural environment of the coastal zone will be affected by the anticipated sea level rise. It will also affect national and food security of the country. The Sundarbans, the most important ecosystem of the country will be totally lost with one metre rise in sea level. Khulna (60% people opined) is the worst sufferer to salinity problems in agricultural production followed by Cox's Bazar (50% people opined) and Bhola (13% people opined) respectively. Mitigation and adaptation are two options to minimize the impacts. A combined effort of Bangladesh Government, Bangladesh's people and International communities is emerge need to survive.

INTRODUCTION

1.1 Background

Climate change and sea level rise are now a reality. The recent finding of the fourth assessment report of the world scientific community, represented by the intergovernmental panel on climate change (IPCC), demonstrates that human activities are responsible for global warming and global climate change and sea level rise (UNDP, 2007).

Various human activities are making the world hot to hotter where the ultimate result is global warming, i.e. climate change. Anthropogenic causes responsible for global warming are expected to continue to contribute to an increase in global-mean sea level rise during this century and beyond (Church et al., 2001, IPCC; 2007).

It is commonly accepted that the global average surface air temperatures have risen by 0.74^0C (0.56^0C to 0.92^0C) over the last 100 year from 1906 to 2005. Eleven of last twelve years (1995–2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850) (IPCC, 2007).

Rising temperature in the atmosphere causes sea level rise and affects low lying coastal areas and deltas of the world. In 1990, Intergovernmental Panel on Climate Change (IPCC) estimates that with a business-as-usual scenario of greenhouse gas emission, the world would be 3.3°C warmer by the end of the next century, with a range of uncertainty of 2.2^0 to 4.9^0C (Warrick et al., 1993).

In response to continued greenhouse gas emissions, the recent increase in the rate of sea level rise is attributed to ocean thermal expansion, glacier melting, increased melting of the Greenland ice sheet, the ongoing response of the Antarctic ice sheet to changes since the last glacial maximum, and changes in permafrost and sediment deposition in the ocean (Douglas and Peltier, 2002; Munk, 2003; Cazenave and Nerem, 2004).

The major environmental effects of sea level rise include the loss of habitats and biodiversity due to inundation, shoreline retreat, increased coastal flooding, landslide and erosion during storm surges and rainstorms, and the intrusion of salt water into aquifers, estuaries, and wetlands (Titus et al., 1991). Sea level rise will increase the vulnerability of coastal populations and ecosystems via permanent inundation of low-lying regions, inland extension of episodic flooding, increased beach erosion and salinity intrusion of aquifers (Mclean et al., 2001).

Bangladesh is a disaster prone country. Bangladesh's geographical vulnerability lies in the fact that it is an exceedingly flat, low lying, alluvial plain covered by over 230 rivers and rivulets with approximately 710 kilometers of exposed coastline along the Bay of Bengal. As a result of its geography, Bangladesh is frequently suffers from devastating floods, cyclones and storm surge, tornadoes, riverbank erosion and drought as well as constituting a very high-risk location for devastating seismic activity (Sarwar, 2005).

Ahmed and Alam (1999) reported that the average increase in temperature in Bangladesh would be 1.3^0C and 2.6^0C by the year 2030 and 2075 respectively with respect to the base year 1990. Two estimates of potential future SLR for Bangladesh are 0.30-1.5 m and 0.30-0.50 m for 2050 (DoE, 1993). Analysis of meteorological data from 1977 to 1998 clearly shows annual sea level rise at the rate of 7.88 mm, 6 mm and 4 mm respectively in Cox's

Bazar, Chardanga at Hatiya and Hiron point in Sundarban (Shamsuddoha and Chowdhury, 2007).
Sea level rise has various impacts on Bangladesh. Its potential threats are coming even strongly in the future. Sea level rise will cause river bank erosion, salinity intrusion, flood, damage to infrastructures, crop failure, destruction of fisheries, loss of biodiversity etc. along this coast. World Bank (2000) projection showed 10 cm, 25 cm and 1 m rise in sea level by 2020, 2050 and 2100 which will affect 2%, 4% and 17.5% of the total land mass respectively.

Adaptation and mitigation are two options for Bangladesh. Of which, the first one is country specific, or even local specific, but mitigation demands collective efforts of global communities. Development of adaptation policies for different sectors will help Bangladesh to face the crucial hazards of sea level rise. Lobby in the international communities will be helpful to mitigate CO_2 emissions by developing countries, which is responsible for global warming and sea level rise. Proper mitigation plan and formulating adaptation policies are emerging need to minimize sea level rise impacts on the country.

Climate change and sea level rise have various significant impacts on economy, environment and security of Bangladesh and if these impacts are not integrated in the development plans, it will fail to attain sustainability. Thus, this study can help sustainable development of Bangladesh by pointing out potential sea level rise impacts and some possible recommendations that could be coordinated with the development activities of the country. The study was carried out in such coastal areas (Cox's Bazar, Bhola and Khulna) because these areas are unique place to agriculture, fishery, shrimp farming, salt cultivation and are highly vulnerable to sea level rise.

1.2 Objectives

The objectives of my study are as follows:

1. To assess the change in climatic conditions particularly temperature and rainfall of Bangladesh,
2. To assess sea level rise and projection analysis by different scenarios,
3. To identify people's perception regarding sea level rise and its possible impacts on the coastal productivity and
4. To identify the adaptation and mitigation measures taken by International, Regional, National and Local organizations.

LITERATURE REVIEW

2.1 Climate Change and Sea Level Rise

2.1.1 Global climate change

Due to various human activities (mainly burning of fossil fuel), carbon dioxide (CO_2) and other greenhouse gases (methane, nitrous oxide, ozone, chlorofluorocarbons and water vapor) are accumulated in the earth's atmosphere, resulting in climate change. Rising temperature expand the ocean volume in two ways. Firstly, it melts mass volume of ice of the polar region and secondly, it causes thermal expansion of water of the ocean.

Wigley and Raper (1987) comment that the relative contributions of thermal expansion and ice melting to this sea level rise are uncertain and estimates vary widely, from a small expansion effect through roughly equal roles for expansion and ice melting to a dominant expansion effect. These two factors increase volume of ocean water of the earth and rise in the sea level.

The human factor that is mainly responsible for global warming and sea level rise is burning of fossil fuels. Deforestation is another human activity, responsible for decreasing the CO_2 sink. Miller (2004) states that, 75% of the human caused emissions of CO_2 since 1980 are due to fossil fuel burning and the remainder is the result of deforestation, agriculture, and other human changes in the land use. Emissions of CO_2 from U.S. coal burning power and industrial plants alone exceeded the combined CO_2 emissions of 146 nations, which contain 75% of the world's people (Miller, 2004). As a small nation, Bangladesh plays an ignorable role for greenhouse gas emission (Sarwar, 2005).

According to National Adaptation Programs of Action (NAPA, 2002) dialogue, per capita CO_2 emission in Bangladesh is 0.2 ton per year. But, this figure for developing countries is 1.6, world average is 4.0, industrial world is 6.0 and the value for United State of America (USA) is 20.0 ton. The developing countries, representing nearly three-quarters of the world population, are responsible for less than one-quarter of the fossil-fuel carbon emissions. The OECD countries, with about 15% of the world population, account for around 44% of the total emission. One country, the USA, is solely responsible for 23% of the total yearly fossil-fuel carbon emission to the atmosphere. In contrast, Bangladesh contributes a minuscule 0.06% (Warrick at el., 1993). Besides, ice melting, thermal expansion and also some local factors like subsidence and siltation play role in the sea level rise process.

2.1.2 Global sea level rise scenario

Gutenberg (1941) was the first to publish an estimation of recent sea level rise in the world from tide gauge records. After him various studies have been done by different people around the world, which are given in table-1.

Table-1: Global sea level rise from tide-gauge records (Pirazzoli, 1993)

No.	Authors	Time period	Average rate of SLR (mm yr^{-1})
1	Gutenberg, 1941	1807-1937	1.1
2	Polli, 1952	1871-1940	1.1
3	Cailleux, 1952	1885-1951	1.3
4	Valentin, 1952	1807-1947	1.1
5	Listzin, 1958	1807-1943	1.1
6	Fairbridge and Krebs, 1962	1860-1960	1.2
7	Kalinin and Klige, 1978	1900-1964	1.5

8	Emery, 1980	1850-1978	3.0
9	Gornitz et al., 1982	1880-1980	1.2
10	Barnett, 1983	1903-1969	1.5
11	Barnett, 1984	1881-1980	1.4
12	Barnett, 1984	1930-1980	2.3
13	Gornitz and lebedeff, 1987	1880-1982	0.9-1.2
14	Peltier and Tushingham, 1989	1920-1970	2.4
15	Pirazzolli, 1989	1880-1980	0.52
16	Trupin and Wahr, 1990	1900-1979	1.75
17	Warrick and Orelemans, 1990	1888-1988	1.0-2.0
18	Woodworth, 1990	1850-1980	0.44
19	IPCC, 1990	1900-1990	1.0-2.0
20	Douglas, 1991	1880-1980	1.8

In 1990, Intergovernmental Panel on Climate Change (IPCC) estimated a 3.3^0C rise in the global temperature under business-as-usual conditions by 2100 with a range of uncertainty of 2.2^0 to 4.9^0C. Such a change in global temperature occurred naturally over past 10,000 years. IPCC's estimation of global sea level rise was 1.0 to 2.0 mm yr $^{-1}$ over the last century. With the high increasing rate of global temperature, sea level will rise at a faster rate of 2-6 times than the present rate (Kausher et al., 1993).

Wigley and Raper (1987) estimated that the greenhouse-gas-induced thermal expansion contribution to sea-level rise between 1880 and 1985 was 2-5 cm and for the period 1985-2025 the estimate of greenhouse-gas-induced warming was estimated to 0.6^0-1^0C. The resulting concomitant oceanic thermal expansion would raise sea level by 4-8 cm.

Nicholls et al. (1999) estimated that by the 2080s, sea-level rise could cause the loss of up to 22% of the world's coastal wetlands. When combined with other losses due to direct human action, up to 70% of the world's coastal wetlands could be lost by the 2080s. IPCC (1990) estimated that sea level rise would be 66 cm under business-as-usual conditions by 2100 with a range of uncertainty of 31 to 110 cm (Table-2). However, IPCC fourth assessment report (2007) predicts that in a low scenario sea level rise would be within a range of 18 cm to 38 cm and in a high scenario it would be 18 cm to 59 cm.

Table-2: Global warming (GW) and sea level rise (SLR) Scenario by 2010.

Model assumption	Global warming scenario by year (^{0}C)				SLR Scenario by year (cm)			
	2010	2030	2050	2100	2010	2030	2050	2100
Low	0.3	0.7	1.2	2.2	4	8	15	31
Business-as-usual	0.5	1.1	1.7	3.3	8	18	30	66
High	0.7	1.5	2.5	4.9	13	29	48	110

Sources: Bretherton et al., 1990; Cited in Warrick et al., 1993; Warrick and Oerlemans, 1990; Cited in Warrick et al., 1993

Globally, sea level has increased by 1.8 ± 0.5 mm year^{-1} from 1961 to 2003, but 3.1 ± 0.7 mm year^{-1} from 1993 to 2003 (Bindoff et al., 2007). Global and regional projections of the future rate of SLR also vary. Bindoff et al., (2007) predict that sea level will rise by 4 mm year^{-1}, with estimates of global SLR ranging between 0.22 and 0.42 ± 0.15 m by the mid 2090s.

However, more recent global projections suggest that the rate of SLR is greater than previously thought and that sea levels are likely to rise in excess of one meter by 2100 (Hansen, 2007; Pfeffer et al., 2008; Rahmstorf, 2007). Regionally, estimates range from 0.3 to 0.5 m by 2050 (Government of Bangladesh, 1993, 2005) and 0.3 to 1.0 m by 2100 (Agrawala et al., 2003; Government of Bangladesh, 2005).

2.1.3 Climate change scenarios for Bangladesh

There are various estimates of temperature rise in Bangladesh. Ahmed and Alam (1999) reported that the average increase in temperature in Bangladesh would be 1.3^{0}C and 2.6^{0}C by the year 2030 and 2075 respectively with respect to the base year 1990. The seasonal variation of temperature will be more in winter 1.3^{0}C than in summer 0.7^{0}C for 2030 and 2.1^{0}C for winter and 1.7^{0}C for summer for 2075.

Using the 1961-1990 baseline data for Bangladesh it was shown that annual mean maximum temperature will increase by 0.40^{0}C and 0.73^{0}C by the years 2050 and 2100 respectively. The mean minimum temperature will correspondingly rise by 0.04^{0}C and 0.08^{0}C. But the mean annual temperature will increase by 0.22^{0}C and 0.41^{0}C respectively (Karmakar and Shrestha, 2000).

Global warming will enhance evaporation and change in precipitation pattern. Ahmed and Alam (1999) showed that the average evaporation in Bangladesh would remain almost unchanged in 2030 but would be slightly higher in 2075 with respect to the base year 1990.

In 2030, precipitation will increase slightly in winter and moderately in summer. But, in 2075, evaporation would be much higher in winter. There would be more precipitation during the monsoon period and precipitation would decrease in winter. This means that increased rainfall would lead to more severe flood situation in summer, and low precipitation and higher temperature in winter will cause more drought like conditions in winter. On the other hand, in 2075, the change will be very pronounced in monsoon while there would not be any noticeable precipitation in winter (Ahmed and Alam, 1999).

In a study, Karmakar and Shrestha (2000) predict that annual total rainfall over Bangladesh is likely to increase by 295.94 mm and 542.55 mm by 2050 and 2100 respectively. Global warming will increase the intensity of south-west monsoon (SWM) which will, in turn, bring about catastrophic ravages like erosion, land sides and floods and have far reaching consequences on agriculture, habitat, economy, etc.

Table-3: Climate change scenario used in Bangladesh NAPA

Year	Temperature change (^{0}C) Mean (standard deviation)			Precipitation change (%) Mean (standard deviation)		
	Annual	Winter	Monsoon	Annual	Winter	Monsoon
2030	1.0	1.1	0.8	5	-2	6
2050	1.4	1.6	1.1	6	-5	8
2100	2.4.	2.7	1.9	10	-10	12

(Source: NAPA: cited in UNDP, 2007)

2.1.4 Sea level rise (SLR) scenarios for Bangladesh

Bangladesh is highly vulnerable to sea level rise, as it is a densely populated coastal country of smooth relief comprising broad and narrow ridges and depressions (Brammer et al., 1993).

Various scenarios have been predicted about SLR in Bangladesh. Two estimates of potential future SLR for Bangladesh are 0.30 to 1.5 m and 0.30 to 0.50 m for 2050 (DoE, 1993). Several factors such as non-uniform rise in temperature, accelerated rise in temperature, geological subsidence and sedimentation may influence this rate.

A study by Singh et al. (2000) shows that mean tidal level at Hiron Point ($21^0$48' N, $89^0$28' E), Char Changa ($22^0$08' N, $91^0$06' E) and Cox's Bazar ($21^0$26' N, $91^0$59' E) is showing an increase of 4.0 mm yr $^{-1}$, 6.0 mm yr $^{-1}$ and 7.8 mm yr $^{-1}$ respectively, which is much higher than the global rate. The higher rate has been attributed to subsidence. An increasing tendency in SLR from west to east along the coast has also been found.

Using tidal gauge records, researchers at the SAARC Meteorology Research Centre (SMRC) in Dhaka, Bangladesh found an increasing east-west trend of 4 mm to 7.8 mm year^{-1} rise in sea level for the Sundarbans from 1977 to 1998 (Alam, 2003; SMRC, 2003), which is greater than the average global SLR estimate during the same period.

Table-4: Sea level rise (SLR) scenarios in Bangladesh and its possible impacts

Impacts on	Projected year		
	2020	2050	2100
Sea level rise	10 cm	25 cm	1 m (high end estimate)
Land below SLR	2% of land (2,500 km^2)	4% of land (6,300 km^2)	17.5% of land (25,000 km^2).
Storm surge	-	Storm surge goes from 7.1 to 8.6 m with 0.3 m SLR.	Storm surge goes from 7.4 to 9.1 m
Flooding	20% increase in inundation.	Increase flooding in Meghna and Ganges floodplain.	Both inundation area and flood intensity will increase tremendously.
Agriculture	Inundate 0.2 million metric tons of production ;< 1% of current total.	0.3 m SLR inundate 0.5 Mmt. of production; 2% of current total.	Devastating flood may cause crop failure for any year.
Ecosystem	Inundates 15% of the Sundarbans.	Inundates 40% of the Sundarbans.	The entire Sundarbans would be lost.
Salinity	Increase	Increase	Increase

Source: World Bank, 2000.

2.2 Description of Coastal Zone of Bangladesh

2.2.1 Coastal Areas of Bangladesh

Bangladesh, a flood plain delta, is a land of rivers and canals (Sarwar, 2005). The country is sloping gently from the north to the south, meeting the Bay of Bengal at the southern end. The whole coast runs parallel to the Bay of Bengal, forming 710 km long coastline (CZPo, 2005). The coastal zone covers 19 out of 64 districts facing or in proximity to, the Bay of Bengal, encompassing 153 Upazilas (MoWR, 2006). Out of these 19 districts, only 12 districts meet the sea or lower estuary directly.

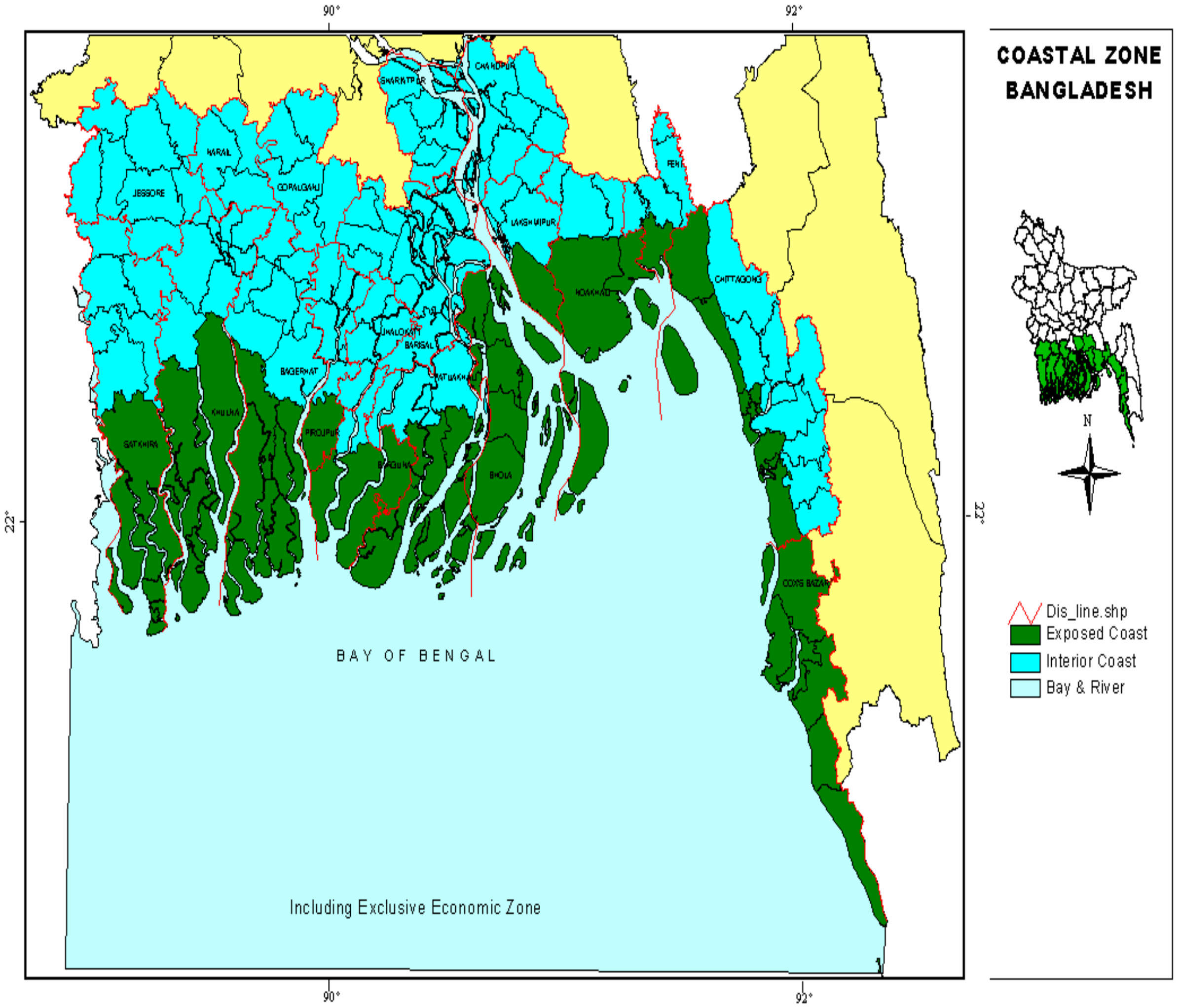


Figure-1: Coastal zone of Bangladesh (Source: Islam, 2004)

The zone is divided into exposed and interior coast according to the position of land. The Upazilas that face the coast or river estuary are treated as exposed coastal zone. Total number of Upazilas that fall on exposed coastal zone is 48 in 12 districts. A total of 105 Upazilas that are located behind the exposed coast are treated as interior coast (MoWR, 2006). The exposed coast embraces the sea directly and is subject to be affected highly by the anticipated sea level rise. The coastal zone covers 47,201 square kilometer land area, which is 32 percent of total landmass of the country (Islam, 2004).

The southern part of Bangladesh falls under coastal zone that receives discharge of numerous rivers, including Ganges-Brahmputra-Meghna (GBM) river system, creating one of the most productive ecosystems of the world. Except Chittagong-Cox's Bazar, all parts of the coastal zone are plain land with extensive river networks and accreted land, which is known in Bangladesh as char land. India is at the west of the zone whereas Myanmar is at the east of the coast. Pramanik (1983) has divided the Bangladesh coastal zone into three regions namely eastern, central and western coastal region. However, the shape of the coastal zone is quite unstable and changing with time due to erosion and accretion.

2.2.1.1 Eastern coastal zone

The eastern coastal zone starts from Bodormokam, the southern tip of mainland Teknaf to the Feni river estuary. This zone is very narrow. A series of small hills are run parallel to this zone. Karnafully, Sangu and Matamuhury river fall into the Bay of Bengal in this area. The Naf river falls to the Bay of Bengal dividing Bangladesh from Myanmar.

Soil characteristics of the eastern coastal zone are dominated by submerged sands and mudflats (Islam, 2001). Two of the country's most important sandy beaches from tourists' perspective, namely Patenga and Cox's Bazar are located in this coastal zone. Fish farming, fishing in the bay, salt production and tourism are main economic activities of the zone.

2.2.1.2 Central coastal zone

Central coastal zone extends from Feni river estuary to the eastern corner of the Sundarbans, covering Noakhali, Barisal, Bhola and Patuakhali districts. The zone receives a large volume of discharge from the Ganges-Bhrahmputra-Meghna river system, forming high volume of silty deposition. More than 70 % of the sediment load of the region is silt; with an additional 10 % sand (Coleman, 1969; cited in Allison et al., 2003).

Because of the sediment discharge and strong current, the morphology of the zone is very dynamic and thus erosion and accretion rates in the area are very high (Coleman, 1969; cited in Allison et al., 2003). Numerous islands are located in the area including the country's only island district Bhola. Many islands have been formed in last few years in the area by the process of land accretion. At the same time many charlands have been eroded or disappeared (Rahman et al. 1993; Pramanik 1988, Cited in SDNP 2004). Kuakata, an attractive sandy beach is located at the zone under Khepupara upazilla of Patuakhali district.

2.2.1.3 Western coastal zone

The western coastal zone is covered by the Sundarbans mangrove forest, covering greater Khulna and part of Patuakhali district. Because of presence of mangrove forest, the zone is relatively stable in terms of soil erosion. Mangrove swamps, tidal flats, natural levees and tidal creeks are characteristics of the zone.

Mangroves of the area support feeding and breeding grounds for fish and shrimps species, enriching the area in fisheries bio-diversity. The area lies at 0.9 to 2.1 metre above mean sea level (Iftekhar and Islam, 2004). Soil characteristics of the western coastal zone are silty loams or alluvium. Islam (2003) mentioned that mangrove dominated coastal areas have developed on soil formations of recent origin consisting of alluvium washed down from the Himalayas.

2.2.1.4 Islands

About 60 islands are identified in the coastal zone to date (Islam, 2004). Most of the islands are located in the central coastal zone, because of the dynamic river flow of the Ganges-Brahmputra-Meghna river system. Hatia, Sandweep and Maheshkhali are three upazilas and Bhola, an administrative district are four bigger islands in the zone. Some islands are limited to only in a small village. St. Martin is the only coral island of the country located in the Bay of Bengal, about 9.8 km to the southeastern side of mainland (Hossain, 2001) The island has an area of 7.5 km^2 and situated under Teknaf thana of Cox's Bazar district. A total number of 177 char lands are also identified in the coastal zone (Islam, 2004).

2.2.1.5 People and livelihoods

Total population living in the coastal zone is 35.1 million that represent 28 percent of total population of the country (Islam, 2004). Population density in exposed coast is 482 persons per square kilometer, whereas the value is 1,012 for the interior coast. Average population density of the zone is 743 per sq. km., and the same value for Bangladesh average is 839. Population density in interior coast is much higher than that of exterior coast and the country's average. There are about 6.8 million households in the zone of which 52 percent are absolute poor (Islam, 2004).

Fishing, agriculture, shrimp farming, salt farming and tourism are the main economic activities in the coastal area. The Sundarban is a major source of subsistence for almost 5 million people (Islam and Haque, 2004). Main activities in the Sundarban area are fisheries, wood collection and honey collection. Almost ten thousand households in the area have neither homestead land nor cultivable land. On the other hand, more than a million households in the area have only homestead but no cultivable land (Islam, 2004).

2.2.1.6 Infrastructures

There is 35,712 km of roads in the coastal zone including the rural earthen ways. But some of the remote areas of the zone are still inaccessible by road transport because of the river network. For that reason water ways are the main transportation mode in eastern and central coastal zone. Almost all small and big cities of the areas are connected with the capital Dhaka by waterways. There are also ship-breaking industries in the zone at Fauzderhat, 20 km South-west to Chittagong district, extending 16 km long sea beach (Anderson et al., 2000).

METHODOLOGY

3.1 Description of the investigated areas

3.1.1 Cox's Bazar

Cox's Bazar district is covered an area of 2491.86 sq km, bounded by Chittagong district on the north, Bay of Bengal on the south, Bandarban district, Arakan (Myanmer) and the Naf river on the east, the Bay of Bengal on the west. Annual average temperature is maximum 34.8^0C and minimum 16.1^0C; annual rainfall is 4285 mm (Banglapedia).

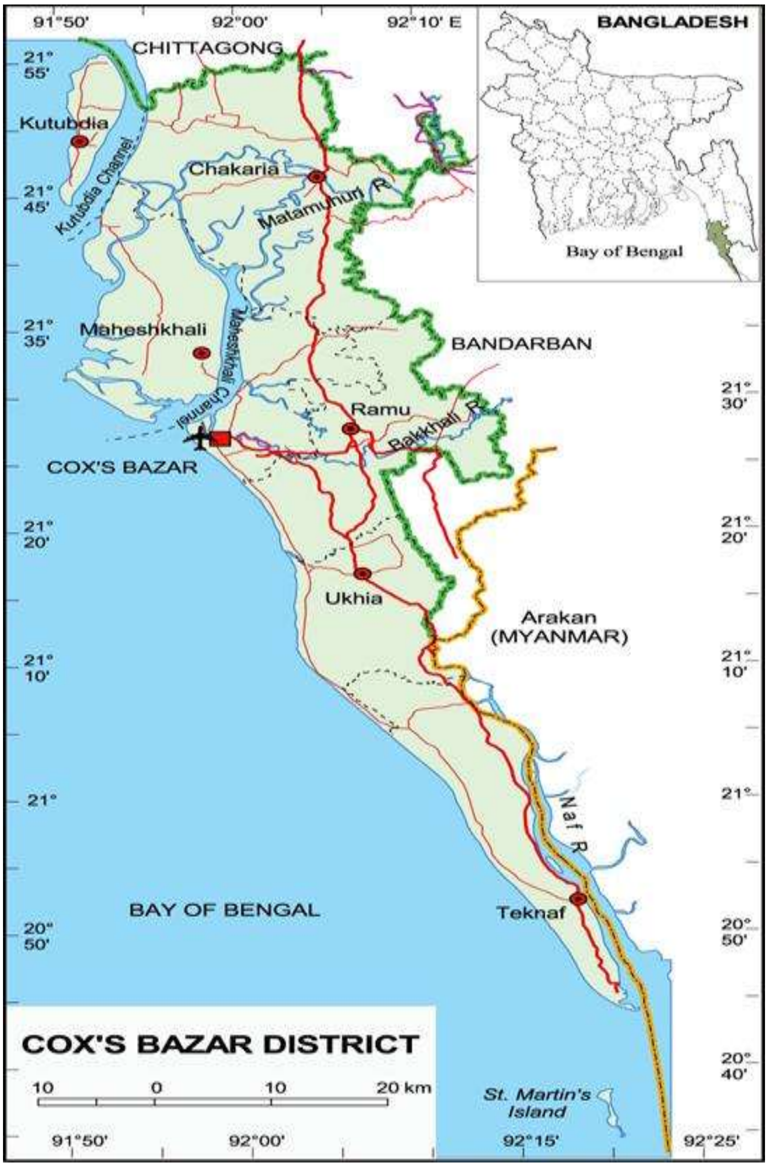


Figure-2: Map of Cox's Bazar district
Source: Banglapedia

3.1.2 Bhola

Bhola District is an offshore island with an area of 3403.48 sq km, bounded by Lakshmipur and Barisal districts on the north, Bay of Bengal on the south, Lakshmipur and Noakhali districts, Meghna (lower) river and Shahbazpur Channel on the east, Patuakhali district and Tentulia River on the west. Annual average temperature varies between highest 32.7^{0}C and lowest 11.6^{0}C and annual rainfall is 2360 mm (Banglapedia).

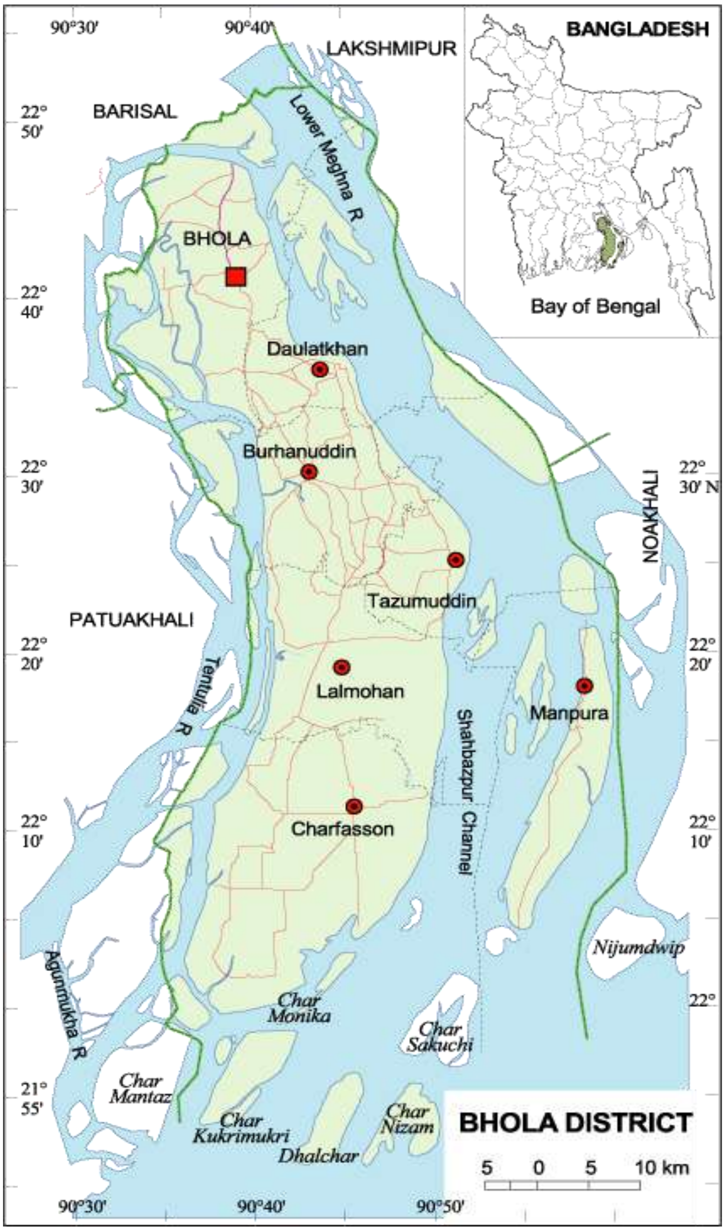


Figure-3: Map of Bhola district

Source: Banglapedia

3.1.3 Khulna

Khulna District covered an area of 4394.46 sq km, is bounded by Jessore and Narail districts on the north, the Bay of Bengal on the south, Bagerhat district on the east, Satkhira district on the west. Annual average highest temperature is 35.5^0C and lowest is 12.5^0C and annual rainfall is 1710 mm (Banglapedia).

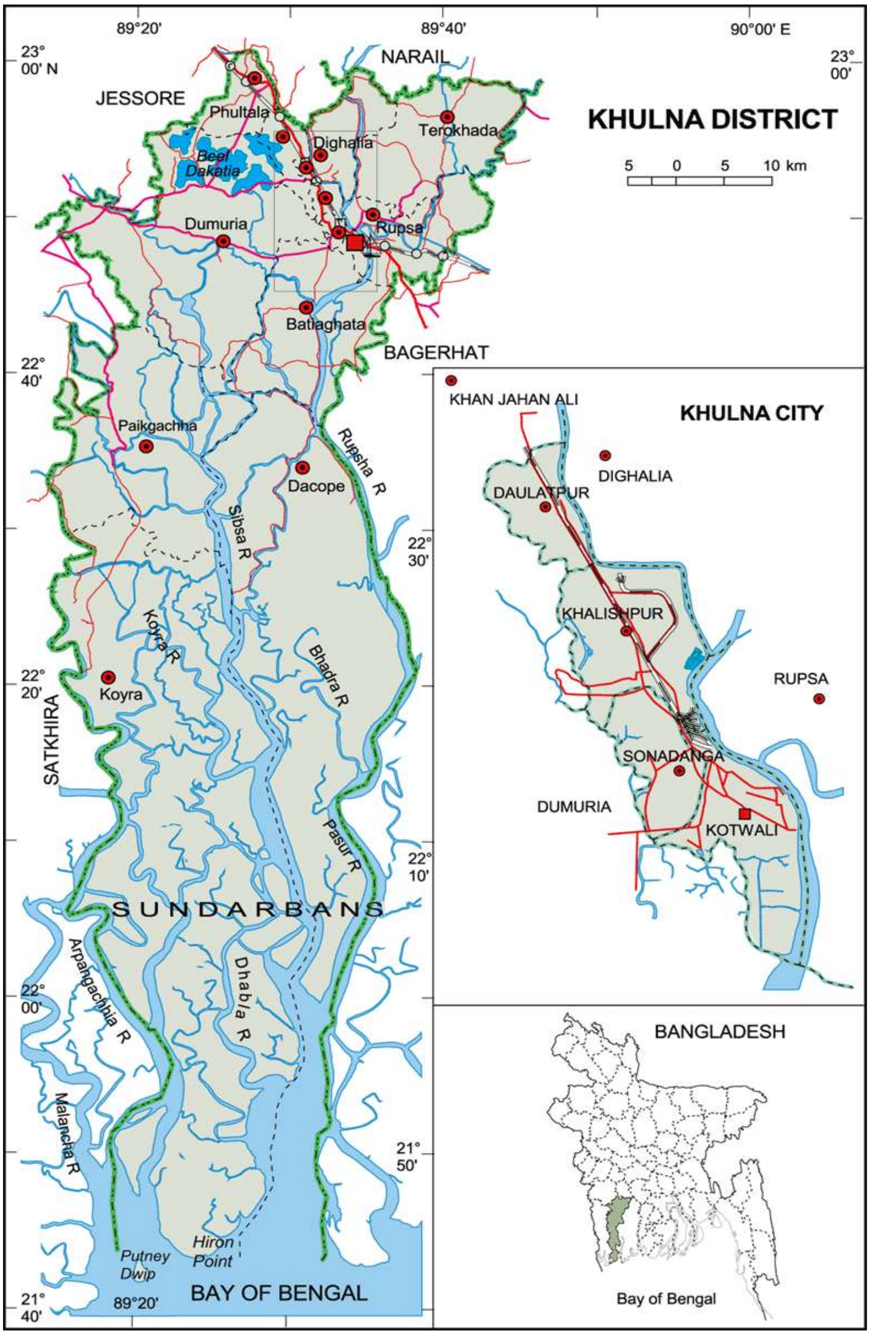


Figure-4: Map of Khulna district
Source: Banglapedia

3.2 Working procedure

3.2.1 Selection of the study area

The study was conducted based on both primary and secondary information. Primary data was collected to assess people's perception regarding sea level rise and its probable impacts. Three coastal districts from three coastal regions (eastern, central and western) were selected based on purposive sampling. A reconnaissance survey was done at three coastal districts prior to conduction of questionnaire survey.

3.2.2 Primary data collection

Ninety questionnaire survey (Thirty at each district) were conducted to know the people's perception about sea level rise, its impacts on different sectors like agriculture, settlement, embankment, fisheries, aquaculture, soil, livelihood, biodiversity, salt industry, tourism, health, security and coastal erosion; their adaptation and mitigation measures taken against sea level rise.

3.2.3 Secondary data collection

Climatic study is a long term study. It usually requires the observations and collection of data for a period of about two to three decades for measuring actually what is going on in the climate condition. Hence, it is very difficult to use primary data for any scientific inference. In the present study, the secondary data has been extensively used to investigate the ongoing changes (although very infinitesimal) of the climate. The secondary sources from where the information regarding climatic phenomena have been collected are; Space Research and Remote Sensing Organization (SPARRSO), Bangladesh Meteorological Department (BMD), Bangladesh Centre for Advanced Studies (BCAS), Coast and Equity Trust, books, journals, national and international publications, articles, newspapers and internet surfing.

3.2.4 Method of analysis

Using MS excel correlation and regression analysis of temperature and rainfall data were calculated.

RESULTS AND DISCUSSIONS

4.1 Analysis of Climatic Parameters

The surface air temperature of last thirty years (1980-2009) and rainfall of last twenty nine years (1980-2008) of Bangladesh have been analyzed to assess the trends of above mentioned climatic parameters.

4.1.1 Analysis of Temperature

The trends of temperature have been analyzed for 30 stations of Bangladesh using data of 30 years (1980-2009). The seasonal, yearly and decade variation of temperature of Bangladesh and yearly variation of temperature in three coastal stations (Cox's bazar, Bhola and Khulna) are illustrated here as representative examples.

4.1.1.1 Temperature of Bangladesh

Temperature of 18 stations out of 30 showed the increasing trends during the last thirty years. These are Rangpur, Rajshahi, Bogra, Sylhet, Ishurdi, Dhaka, Comilla, Chandpur, Jessore, Faridpur, Khulna, Barisal, Bhola, Feni, M. Court, Kutubdia, Cox's bazar and Chittagong. In contrast, the rest 12 stations namely; Mymensingh, Srimangal, Madaripur, Satkhira, Hatia, Sitakunda, Sandwip, Teknaf, Rangamati, Patuakhali, Khepupara and Dinajpur depicted the decreasing trends (Appendix-2).

4.1.1.1.1 Seasonal Variation of Temperature

Average temperature in winter was lowest (19.03^{0}C) in 1987 while highest (20.47^{0}C) in 1988. In case of pre-monsoon, annual average temperature varies between 26.55^{0}C in 1990 and 28.01^{0}C in 1995. However, average temperature in monsoon varied between 28.77^{0}C (highest) in 2005 and 28.04^{0}C (lowest) in 1986. Annual average temperature in post-monsoon was lowest (26.01^{0}C) in 1983 and highest (27.30^{0}C) in 1991 (Figure-5). Highest increasing trends of seasonal temperature was recorded in monsoon (R^2 = 0.2663) compared with pre and post monsoon, while winter showed the decreasing trend (Appendix-5).

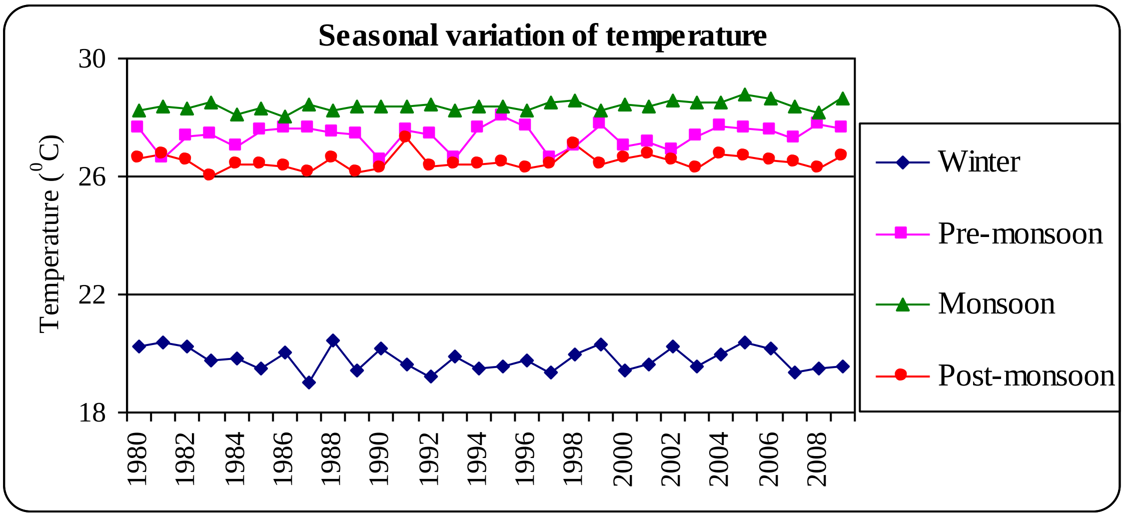


Figure-5: Seasonal variation of annual average temperature from 1980-2009.

4.1.1.1.2 Maximum and Minimum Temperature

In winter, maximum temperature was highest (31.16^{0}C) in year 1999 and lowest (28.22^{0}C) in 1992, whereas, minimum temperature was highest (11.55^{0}C) in 2006 and lowest (9.25^{0}C) in 1983. In case of pre-monsoon, highest (37.31^{0}C) and lowest (33.90^{0}C) maximum temperature was recorded in 1995 and in 1981 respectively, while highest (19.04^{0}C) and lowest (16.91^{0}C) minimum temperature was in 2005 and in 1984 respectively (Appendices-6 and 7).

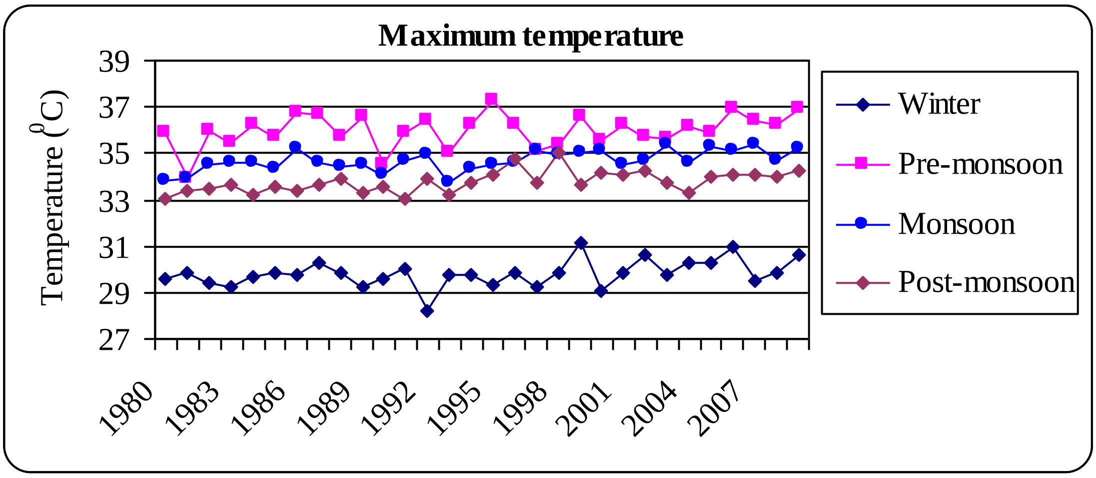


Figure-6: Seasonal variation of maximum temperature during last 30 years.

In monsoon, highest (35.41^{0}C) and lowest (33.76^{0}C) maximum temperature was recorded in year 2007 and 1993 respectively, in contrast, minimum temperature was highest (23.99^{0}C) in 2001 and lowest (22.60^{0}C) in 1984. However, maximum temperature in post-monsoon was highest (35.05^{0}C) in year 1998 and lowest (33.03^{0}C) in 1991 respectively, whereas, highest (20.97^{0}C) and lowest (18.45^{0}C) minimum temperature was in 1998 and in 1982 respectively (Appendices-6 and 7).

Considering four seasons, it is clear that maximum temperature was highest in pre- monsoon, while minimum temperature was highest in monsoon (Figures-6 and 7). Increasing trend of maximum temperature was highest in monsoon (R^2 = 0.3816) compared to other three seasons namely; post-monsoon (R^2 = 0.3094), winter (R^2 = 0.1436) and pre-monsoon (R^2 = 0.0939) respectively (Appendix-3). Moreover, minimum temperature showed an increasing trend for all seasons; where monsoon (R^2 = 0.5273) depicted the highest increasing trends followed by post-monsoon (R^2 = 0.3143) pre-monsoon (R^2 = 0.2444), and winter (R^2 = 0.0125) respectively (Appendix-4).

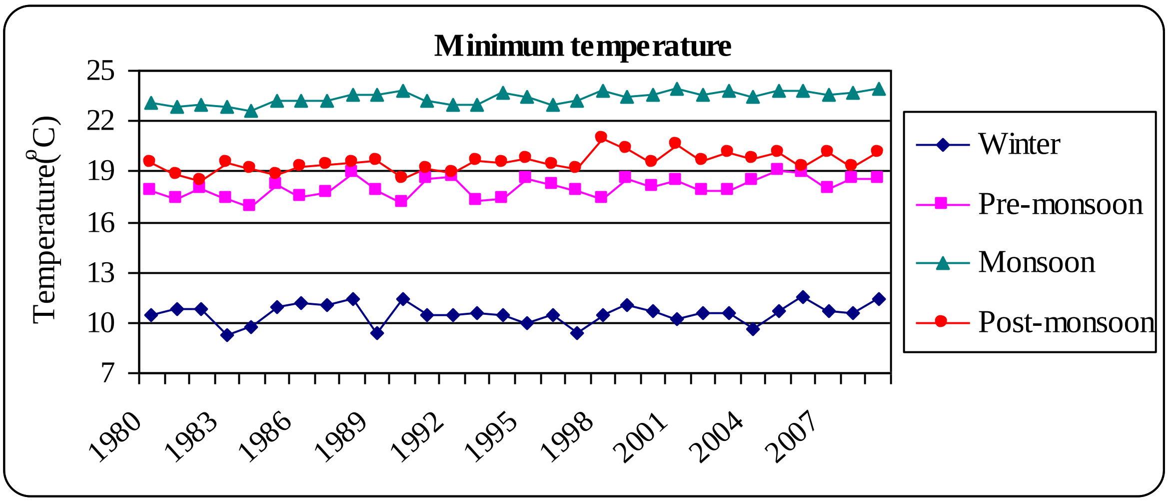


Figure-7: Seasonal variation of minimum temperature during last 30 years.

4.1.1.1.3 Yearly variation of Temperature

Annual average temperature of last three decades fluctuated widely and the variation was between 25.21^{0}C (lowest) in 1997 and 25.88^{0}C (highest) in 2005. The line diagram represents that temperature was in an increasing trends ($R^2 = 0.0364$) during last thirty years (Appendix-8).

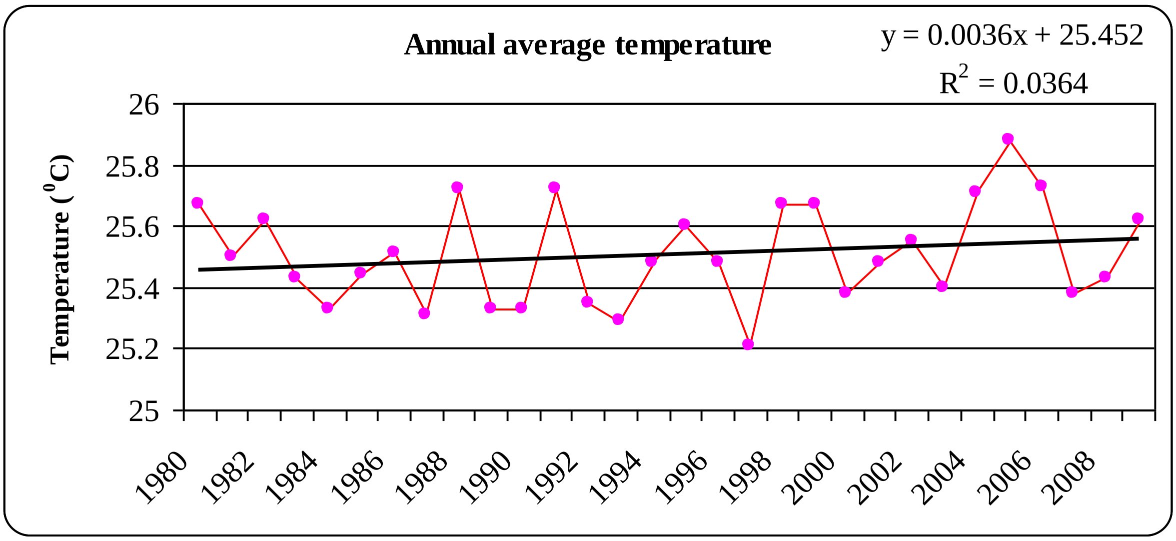


Figure-8: Variation of annual average temperature of Bangladesh from 1980 to 2009.

4.1.1.1.4 Decade variation of Temperature

Maximum (25.56^{0}C) decade average temperature was recorded in the recent last decade (2000-2009) and minimum (25.48^{0}C) was in 1990-1999. Decade average temperature in 2000-2009 was 0.07^{0}C and 0.08^{0}C higher compared to the decade of 1980-1989 and of 1990-1999. Though average temperature of decade 1990-1999 was lower compared to first and recent last decades temperature showed an increasing trend ($R^2 = 0.6861$) (Figure-9)

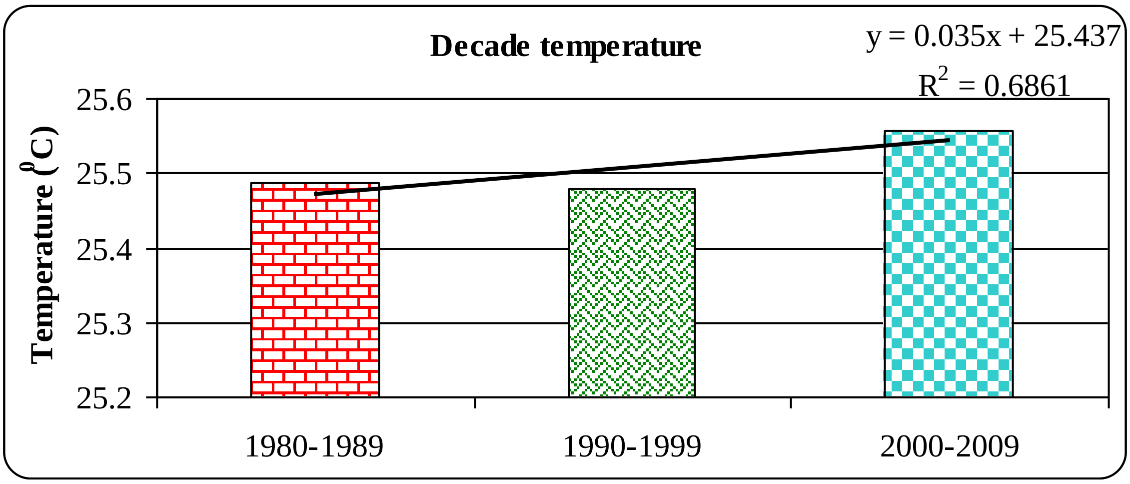


Figure-9: Variation of temperature during last three decades in Bangladesh.

4.1.1.2 Temperature of Three Coastal Stations

4.1.1.2.1 Yearly Variation of temperature

Maximum (26.55^{0}C) and minimum (25.18^{0}C) annual average temperature at Khulna was recorded in 2006 and in 1981 respectively. On the other hand, in case of Bhola maximum (25.94^{0}C) and minimum (25.05^{0}C) temperature was in 2006 and in 1984 respectively. However, at Cox's Bazar highest (26.4^{0}C) and lowest (25.48^{0}C) annual average temperature was recorded in 2004 and in 1992 respectively (Figure-10).

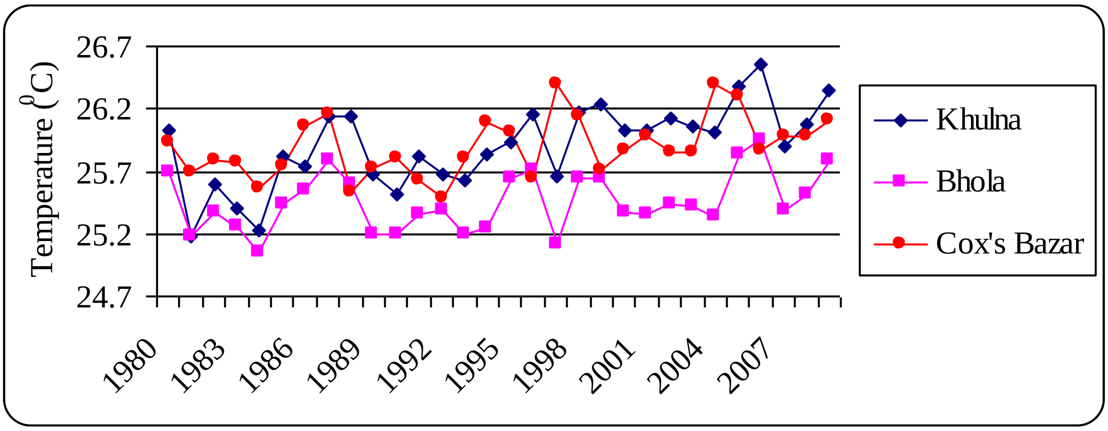


Figure-10: Yearly variation of annual average temperature in three Coastal stations.

4.1.2 Analysis of Rainfall

The seasonal rainfall for 18 stations have been analyzed as mentioned in appendix-9 for the period from 1980-2008 (29 years) to investigate variations and trends of rainfall. The seasonal, yearly and decade variation of rainfall for Cox's Bazar, Bhola and Khulna and overall in Bangladesh are illustrated here as a representative example.

4.1.2.1 Rainfall of Bangladesh

4.1.2.1.1 Seasonal variation of rainfall

From figure-11, it is seen that rainfall variation existed among different seasons as well as decades. Considering all decades figure-11 depicts that lowest (35.08 mm in first decade, 59.44 mm in second decade and 47.50 mm in recent last decade) rainfall were in winter season and highest (1539.68 mm in first decade, 1533.35 mm in second decade and 1584.67 mm in recent last decade) were in monsoon season. In winter, rainfall increased (24 mm) in second decade (1990-1999) in comparison with first decade (1980-1989) and in third decade rainfall decreased (12 mm) compared to second decade. In case of pre-monsoon rainfall went downward from first to last decade. However, in monsoon and post-monsoon highest (1584.67 mm in monsoon and 682 mm in post-monsoon) rainfall was recorded in 2000-2008.

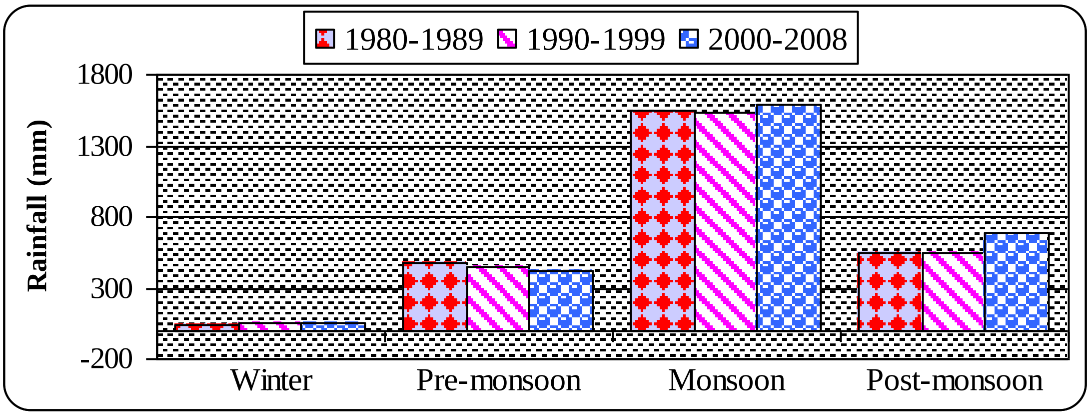


Figure-11: Seasonal variation of rainfall during last three decades in Bangladesh.

4.1.2.1.2 Yearly variation of rainfall

There was sharp fluctuation of rainfall during last 29 years and regression line represents that rainfall increment trend is lower. Maximum (3061mm) amount of rainfall was recorded in year 2007, whereas, minimum (1958 mm) was in 1992 (Appendix-9).

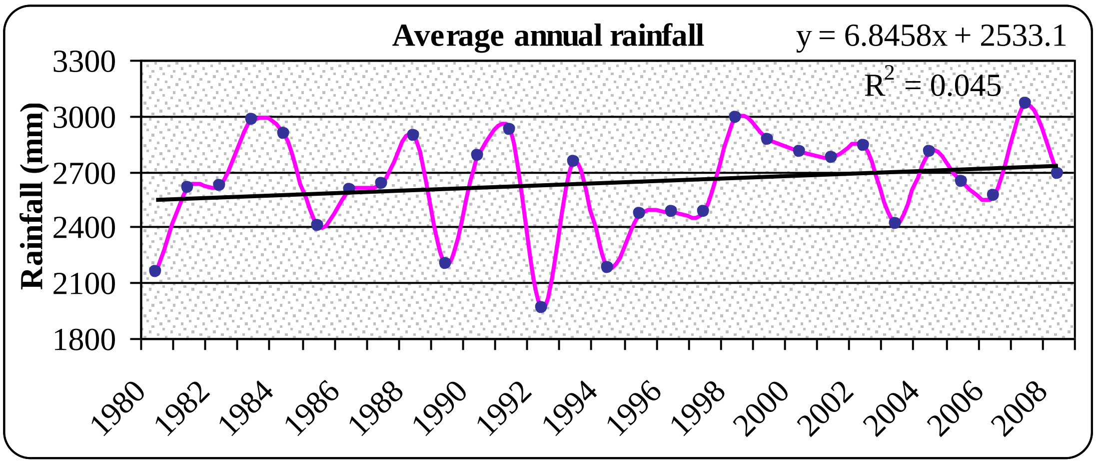


Figure-12: Variation of annual average rainfall of Bangladesh from 1980 to 2008.

4.1.2.1.3 Decade variation of rainfall

Highest (2730 mm) rainfall was recorded in recent last decade (2000-2008) while lowest (2587 mm) was in 1990-1999. Considering figure-13 it is seen that in second decade rainfall decreased (12 mm) compared to first decade, whereas, in last decade it went upward and exceeded both first and second decade. Regression analysis also shows that an increasing trend (R^2 = 0.6813) was existed among the rainfall of three decades.

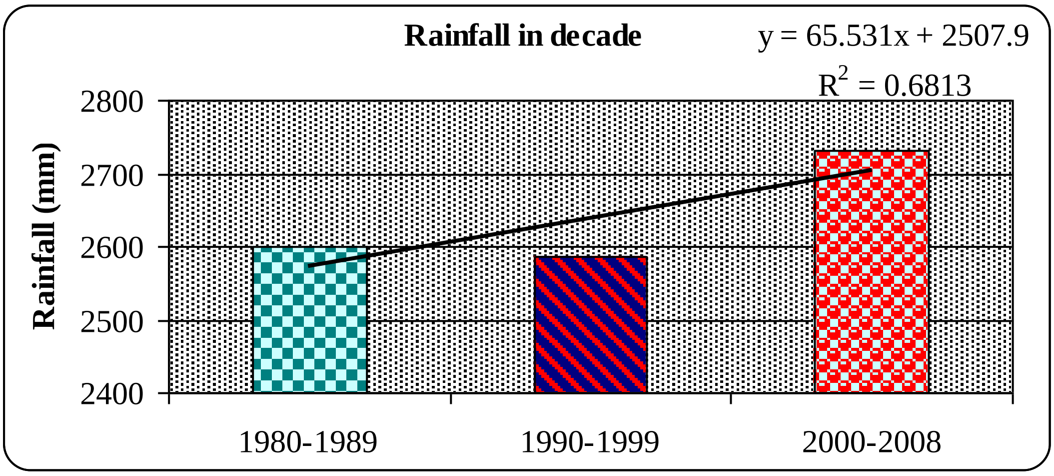


Figure-13: Variation of rainfall during last three decades in Bangladesh.

4.1.2.2 Rainfall in Three Coastal Districts

4.1.2.2.1 Rainfall at Cox's Bazar

At Cox's Bazar, highest (124 mm) amount of rainfall was recorded in winter season in year 1999 while in 1986, in 2004 and in 2006 no rainfall was occurred. During last decade (2000-2008) annual rainfall in winter did not exceed 65 mm that was occurred in 2007 and in 2008.

In case of pre-monsoon season, maximum (914 mm) rainfall was recorded in year 2006, whereas, minimum (144 mm) was in 1980. It can be said from the figure-14 that during last three decades, recent last decade (2000-2008) was the highest rainfall occurring decade in pre-monsoon season. So, from this analysis it is clear that trend in rainfall increment was positive in pre-monsoon.

Highest (3183 mm) and lowest (710 mm) rainfall in monsoon was recorded in year 1987 and in 1980 respectively. Maximum (1028 mm) and minimum (385 mm) amount of rainfall in post-monsoon was recorded in year 2007 and in 1994 respectively (Figure-14).
Considering four seasons, it is found that at Cox's Bazar, monsoon was the highest rainfall occurring season during last three decades.

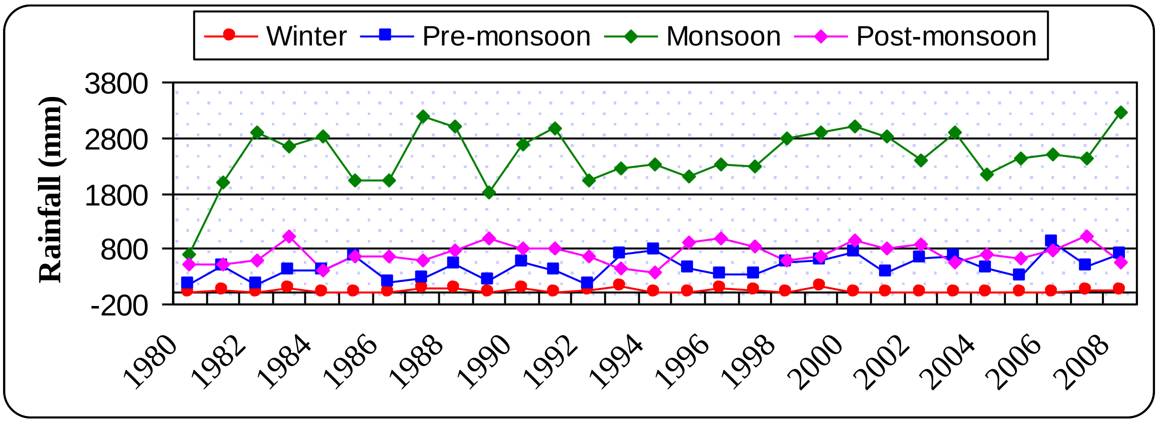


Figure-14: Seasonal variation of rainfall at Cox's Bazar station.

4.1.2.2.2 Rainfall at Bhola

At Bhola maximum (144 mm) rainfall was recorded in winter season in 1980, on the contrary, no rainfall was in 2004 and in 2006. In case of pre-monsoon, maximum (935 mm) and minimum (182 mm) rainfall was measured in 1980 and in 2008 respectively. The line diagram (Figure-15) depicts that rainfall in pre-monsoon went downward from first decade (1980-1989) to last decade (2000-2008).

In case of rainfall in monsoon, line diagram (Figure-15) represents that maximum (1828 mm) and minimum (911 mm) rainfall was occurred in year 1984 and in 1985 respectively. Only three years (1985, 1992 and 1997) has experienced rainfall lower than 1000 mm. However, highest (1276 mm) and lowest (132 mm) rainfall in post-monsoon was recorded in year 2004 and in 1994 respectively (Figure-15).
At Bhola, winter was the minimum rainfall occurring season during last three decades. However, monsoon was the highest rainfall occurring season. In case of pre-monsoon, total amount of rainfall declined from first decade (1980-1989) to last decade (2000-2008) while in case of post-monsoon it went upward.

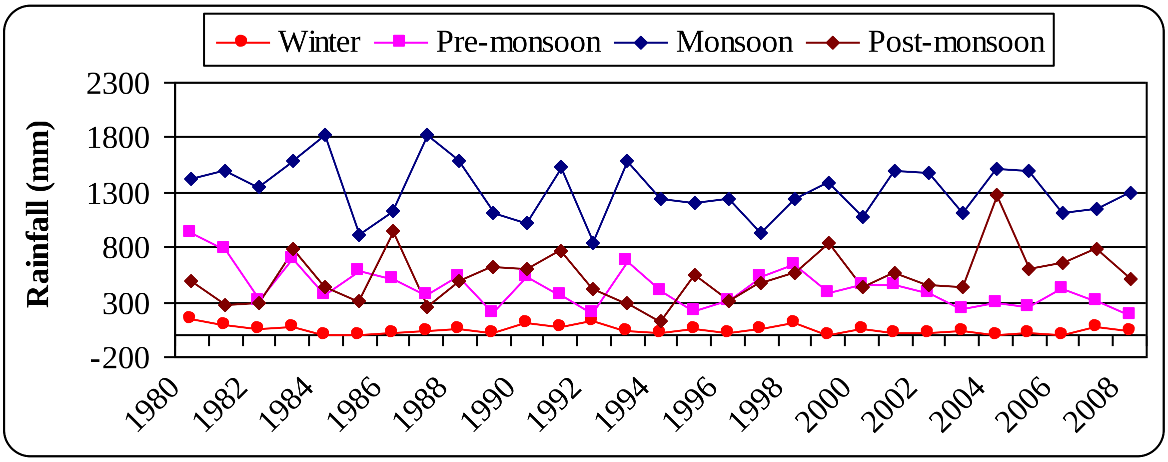


Figure-15: Seasonal variation of rainfall at Bhola station.

4.1.2.2.3 Rainfall at Khulna

At Khulna, maximum (216 mm) amount of rainfall in winter was observed in year 1992 while no rainfall was occurred in 1999, in 2004 and in 2006. Moreover, downward trend of rainfall was observed in pre-monsoon where maximum (803 mm) and minimum (174 mm) rainfall was recorded in year 1981 and in 1991 respectively (Figure-16).

Maximum (1689 mm) and minimum (576 mm) rainfall in monsoon were recorded in year 2002 and in 1989 respectively. In case of post-monsoon, though rainfall fluctuated year to year but it followed an upward trend, where highest (1163 mm) and lowest (199 mm) rainfall was recorded in 1986 and in1992 respectively (Figure-16).

Considering four seasons, it is found that at Khulna, monsoon was the highest rainfall occurring season during last three decades. Total rainfall during monsoon of 1980-1989, 1990-1999 and 2000-2008 was 9953 mm, 9226 mm and 8817 mm respectively. Monsoon rainfall went to downward trend from first decade (1980-1989) to last decade (2000-2008. Post monsoon was the second highest rainfall occurring season followed by pre-monsoon and winter season (Figure-16).

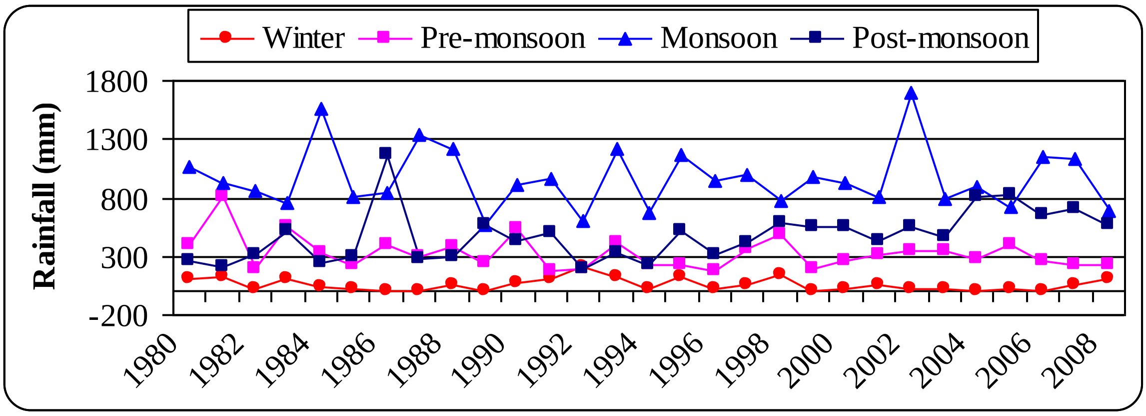


Figure-16: Seasonal variation of rainfall at Khulna station.

4.1.2.2.4 Yearly Variation of Rainfall in three Coastal Districts

In case of Cox's Bazar highest (4707 mm) and lowest (1382 mm) rainfall was exhibited in year 2000 and in 1980 respectively. On the other hand, at Bhola, annual maximum (3148 mm) and minimum (1609 mm) rainfall was occurred in year 1983 and in 1992 respectively. In case of Khulna, 2002 was the maximum (2594 mm) while 1994 was the minimum (1130 mm) rainfall occurring year (Figure-17).

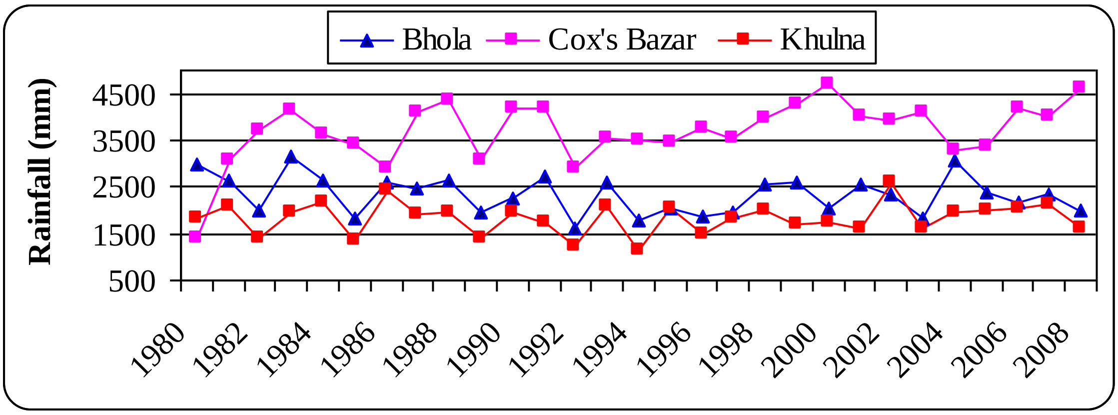


Figure-17: Yearly variation of rainfall at three coastal stations.

4.2 SEA LEVEL RISE IN BANGLADESH

Sea level rise scenarios given by different authors, government, non-government and international organizations were taken into consideration to review the sea level rise in Bangladesh.

4.2.1 Projection of World Bank (2000)

An estimate of World Bank (2000) showed that Bangladesh will be affected by sea level rise of 10 cm, 25 cm and 100 cm by the year 2020, 2050 and 2100. According to this projection it is seen that last half of the present century (from 2050 to 2100) sea level will rise 75 cm.

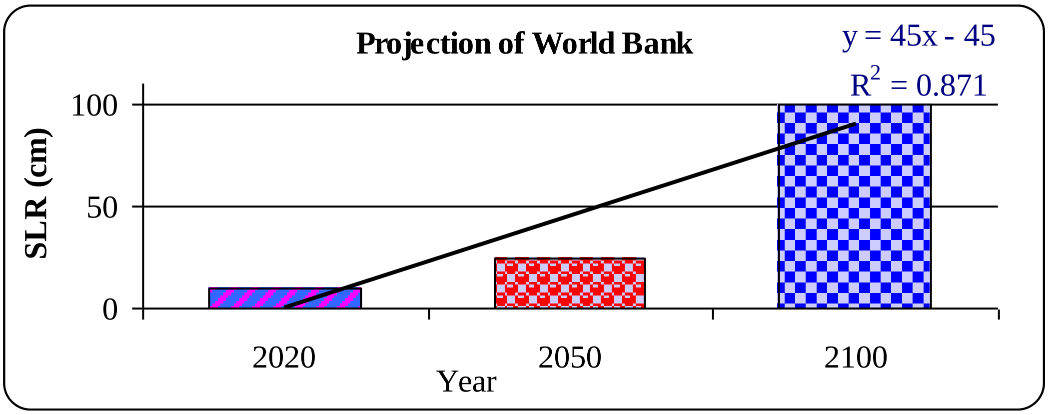


Figure-18: Sea level rise scenario for the year 2020, 2050 and 2100 projected by World Bank (2000)

4.2.2 Projection of SMRC (cited in Alam, 2003)

A study by SAARC Meteorology Research Centre (SMRC, cited in Alam, 2003) found that tidal level in Hiron Point, Char Changa and Cox's Bazar raised 4.0 mm/year, 6.0 mm/year and 7.8 mm/year respectively, observing tidal gauge record of the period 1977-1998. The rate of the tidal trend is almost double in the eastern coast than that of the western coast. This difference could be due to subsidence and uplifting of land. However, Sing (2002) mentioned that the difference is mainly due to land subsidence.

Table-5: Increase of tidal level in three coastal stations of Bangladesh coast. (Adapted from SMRC; cited in Alam, 2003)

Tidal Station	Region	Latitude (N)	Longitude (E)	Datum (m)	Sea Level Rise Trend (mm/year)
Hiron Point	Western	$21^0 48'$	$89^0 28'$	3.784	4.0
Char Changa	Central	$22^0 08'$	$91^0 06'$	4.996	6.0
Cox's Bazar	Eastern	$21^0 26'$	$91^0 59'$	4.836	7.8

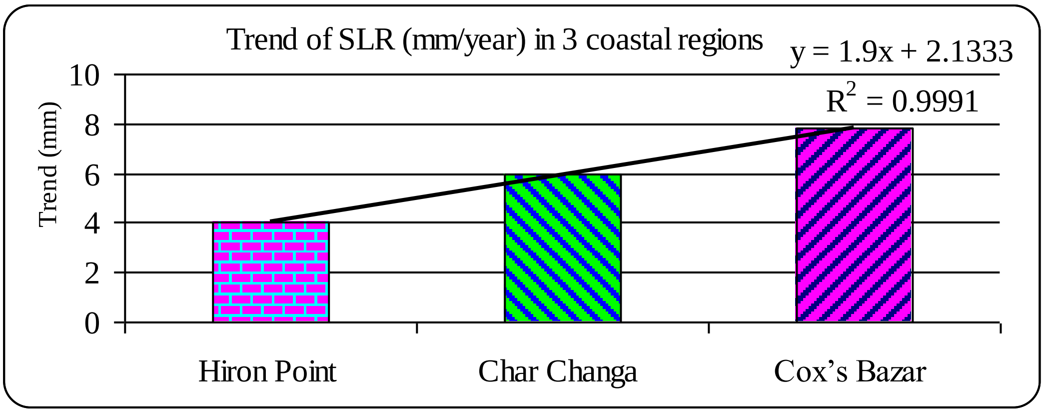


Figure-19: Trend of sea level rise (mm/year) in three coastal regions (Hiron point, Char Changa and Cox's Bazar) of Bangladesh projected by SMRC

4.2.3 Projection of Ali (2006)

Ali (2006) found that the rate of sea level rise at Sitakunda, Bhatiari and Cox's Bazar is 1.23 mm/yr, 0.88 mm/yr and 7.41 mm/yr respectively at local level and 6.0 mm/yr at national level.

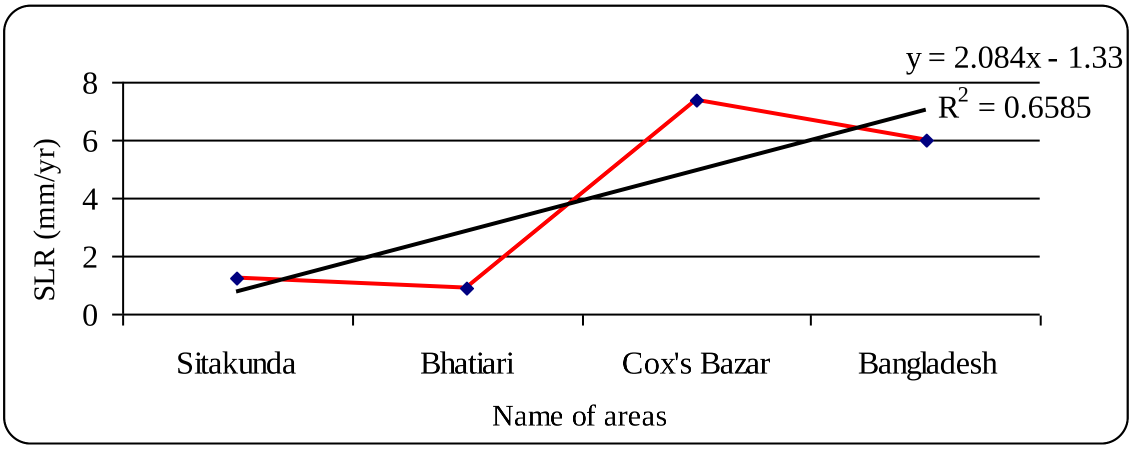


Figure-20: Trend of sea level rise (mm/year) in 3 coastal regions (Sitakunda, Bhatiari and Cox's Bazar) and overall in Bangladesh projected by SMRC

4.2.4 Projection of National Adaptation Programme of Action (NAPA, cited in: UNDP, 2007)

National Adaptation Programme of Action showed that 14 cm, 32 cm and 89.4 cm sea level rise in Bangladesh coast by year 2030, 2050 and 2100 respectively.

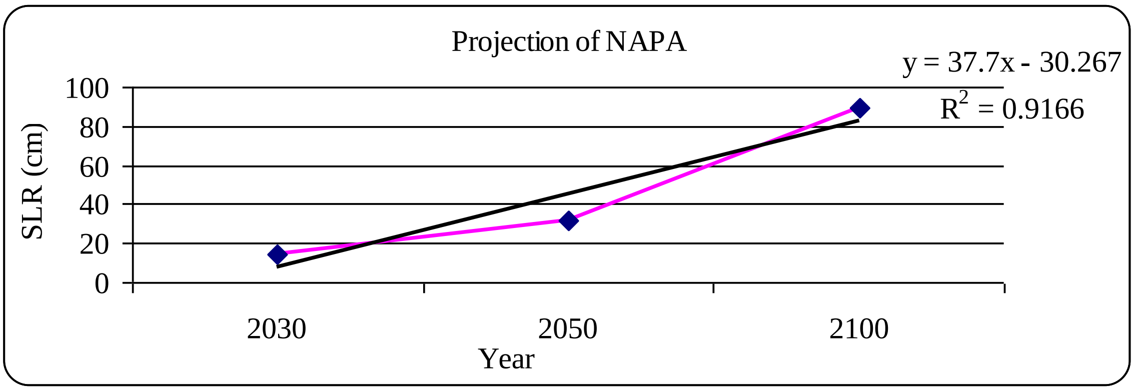


Figure-21: Sea level rise scenario for the year 2030, 2050 and 2100 projected by NAPA

4.2.5 Projection of IPCC

The projections given by IPCC showed that for 1 meter sea level rise 15 million people of coastal areas will be affected and 17,000 square kilometer land along the coastal areas will be submerged under water. Moreover, for 1.5 meter sea level rise 18 million people will be affected and 22,000 square kilometer land will be submerged under water.

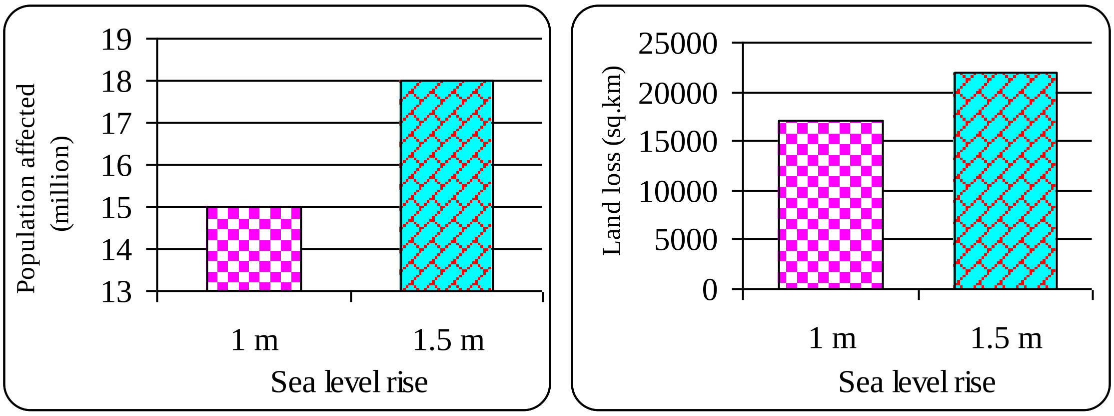


Figure-22: Potential population affected and land loss due to 1 m and 1.5 m sea level rise by the projection of IPCC

Figure-24: Projection for 1 meter sea level rise

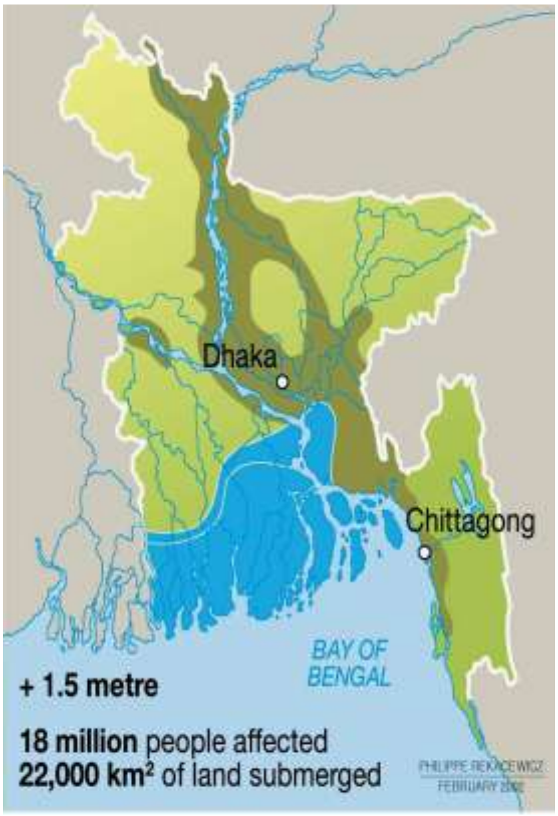


Figure-25: Projection for 1.5 meter sea level rise

4.3 Impacts of Sea Level Rise

4.3.1 Impacts of Sea Level Rise on the Coastal Zone of Bangladesh

4.3.1.1 Salinity intrusion

The main impacts of sea level rise on water resources are the reduction of fresh water availability by salinity intrusion. Both water and soil salinity along the coast will be increased with the rise in sea level, destroying normal characteristics of coastal soil and water. A water salinity map for the period of 1967 and 1997 (Figure-25) produced by Soil Resources Development Institute shows that the problem is already on the way (SRDI, 1998a). A comparative study between Soil Salinity map of SRDI (1998b, 1998c) for the period of 1973 and 1997 shows salinity intrusion in soil is much higher than water salinity (Figures-26 and 27). The map shows that soil of Jessore, Magura, Narail, Faridpur, Gopalgonj and Jhalokati was newly salinized in last 24 years of time expansion.

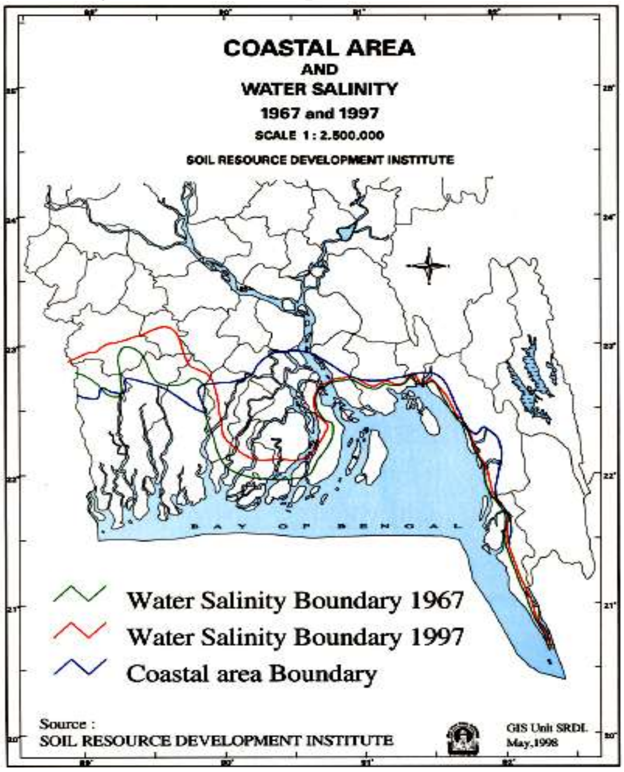
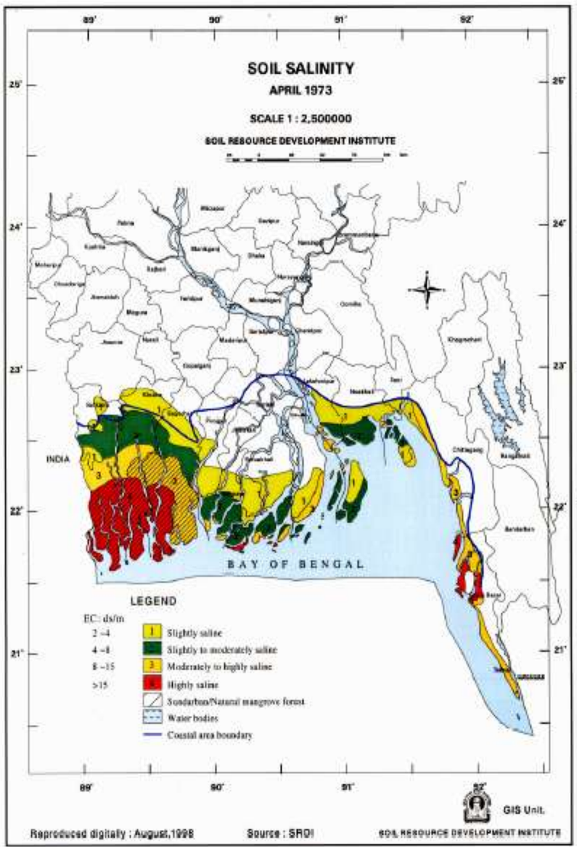


Figure-25: Water salinity map of Bangladesh (Source: SRDI, 1998a)

The coastal areas of Bangladesh have already been facing salinity problem which is expected to be exacerbated by climate change and sea level rise, as sea level rise is causing unusual height of tidal water. In dry season, when the flows of upstream water reduce drastically, the saline water goes up to 240 kilometers inside the country and reaches to Magura district. Presently around 31 Upazilas of Jessore, Satkhira, Khulna, Narail, Bagerhat and Gopalganj districts are facing severe salinity problem. Agricultural activities as well as cropping intensities in those Upazilas have been changing; now farmers can not grow multiple crops in a year (Shamsuddoha and Chowdhury, 2007).



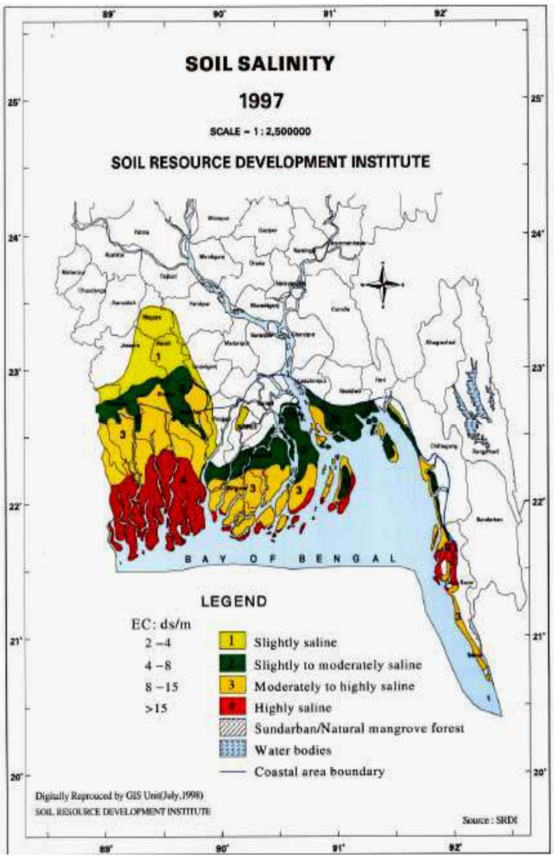


Figure-26: Soil salinity map of Bangladesh of the year 1973 (Source: SRDI, 1998b)

Figure-27: Soil salinity map of Bangladesh of the year 1997 (Source: SRDI, 1998c)

More than 30% of the cultivable land in Bangladesh is in the coastal area. About 1.0 million ha of arable lands are affected by varying degrees of salinity. Farmers grow mostly low-yielding, traditional rice varieties during the wet season. Most of the lands remain fallow in the dry season (January–May) because of soil salinity and the lack of good-quality irrigation water (Karim et al., 1990; Mondal, 1997).

4.3.1.2 Impacts on landmass and settlement

The SLR will inflict its impacts on Bangladesh in the coastal area and through the coastal area, on the whole of Bangladesh. About 2,500, 8,000 and 14,000 km^2 of land (with a corresponding percentage of 2%, 5% and 10% with respect to the total land area of the country) will be lost due to SLR of 0.1m, 0.3m and 1.0m respectively (Ali, 2000). The potential land loss estimated by IPCC (2001) is even worse. It reports 29,846 km^2 area of land will be lost and 14.8 million people will be landless by 1 m SLR.

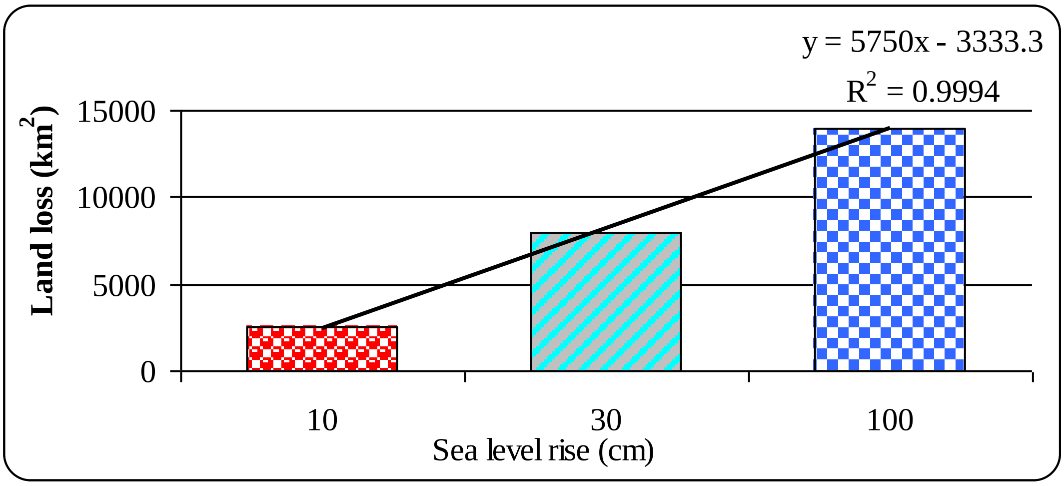


Figure-28: Land loss of Bangladesh due to anticipated sea level rise of 10 cm, 30 cm and 100 cm (Ali, 2000)

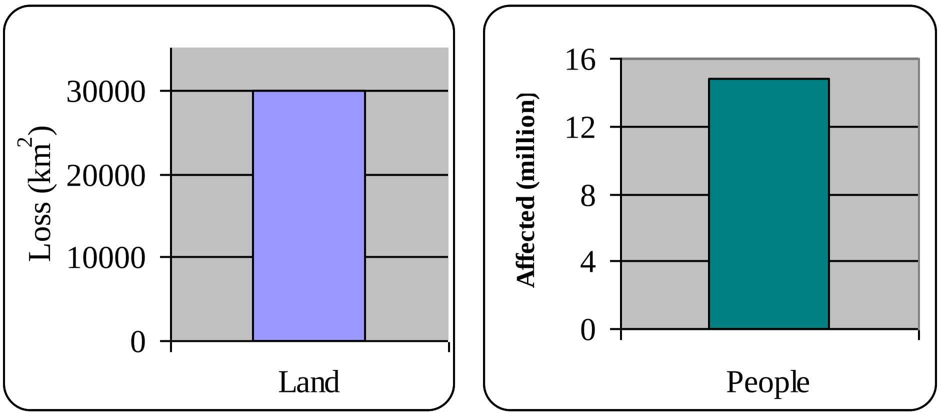


Figure-29: Potential land loss (km^2) and people affected due to 1 m sea level rise. (Projection of IPCC, 2001)

Most vulnerable shore types to sea level rise are shoaly, sandy and silty shore (Kont et al., 1997). Coastal areas of Bangladesh are formed of silty and sandy soils which make them vulnerable to sea level rise. Sandy and silty shores are easily eroded by sea level rise. It is supported by Vellinga (1988; cited in SDNP, 2004) stating that sea level rise of 1.0 metre will cause an erosion of a sandy shore in the order of 100-500 metre. Erosion rate due to sea level rise along the Bangladesh coast is high.

The forecasted land erosion will cause displacement of coastal population. A study by Hutton and Haque (2003) observed that people even displaced ten times during the period of 1981-1993, because of river bank erosion of the Jamuna river. Thus, erosion will cause financial loss for the displace-people to build their new houses. World Bank (2000) projection showed 10 cm, 25cm and 100 cm rise in sea level by 2020, 2050 and 2100 which will affecting 2%, 4% and 17.5% of the total land mass respectively (Table-4). Milliman et al. (1989; cited in Frihy, 2003) reported 1.0 cm per year sea level rise in Bangladesh is going on.

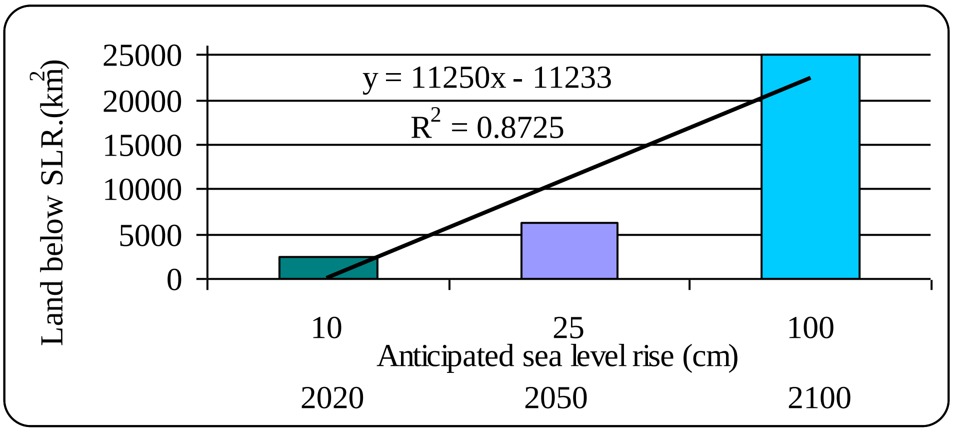


Figure-30: Potential land loss due to anticipated sea level rise by the projection of World Bank (2000)

UNEP (1989) showed 1.5 m sea level rise in Bangladesh coast by 2030, affecting 22,000 km^2 (16% of total landmass) area with a population of 17 million (15% of total population) will be affected. Since this scenario was calculated in 1989, the expected rate of sea level rise has been modified because of uncertainty. At present expected rates, this situation will occur in about 150 years from now. However, number of potential population affected by the projection of World Bank by one metre sea level rise (17.5 million) and that of UNEP by 1.5 metre sea level rise (17 million) is similar.

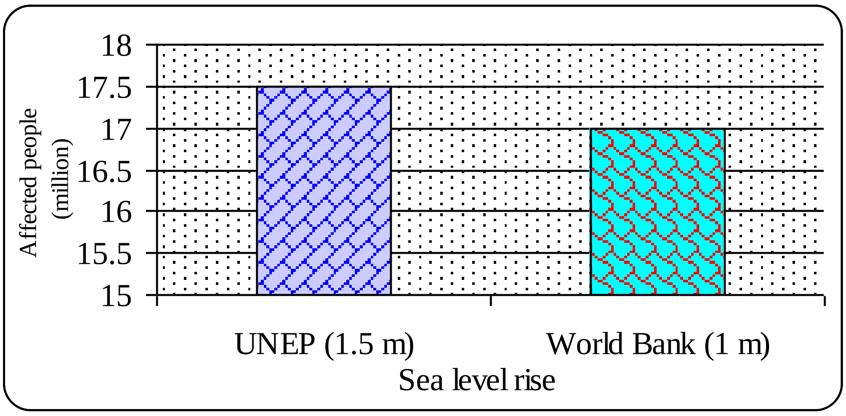


Figure-31: Potential population affected by the projection of World Bank (1 m sea level rise) and UNEP (1.5 m sea level rise).

Sea level rise will increase morphological activities in the river, inducing increased river flow. Accelerated river flow will increase river bank erosion too (Alam, 2003). Bank erosion is severe in char areas and sometimes it may wipe out chars from the map of Bangladesh. About 196 square kilometers of char area was eroded and a total of 11 chars were disappeared from Meghna river estuary area during the period of 1972-1987 (Pramanik, 1988; cited in SDNP, 2004).

From the projection of BCAS (1994), it is seen that entire area of Patuakhali and Barguna will be lost from the map of Bangladesh. Barisal, Bhola, Jhalokhati and Pirojpur will also be affected severely (99.1 % of the entire area) by 1 m sea level rise. 64.7 % area of Khulna, Satkhira and Bagerhat and 44.2 % of Noakhali and Lakshmipur will be submerged under water by the predicted sea level rise. Considering the whole country 15.8 % area will be lost due to anticipated sea level rise by 1 metre (Appendix-1).

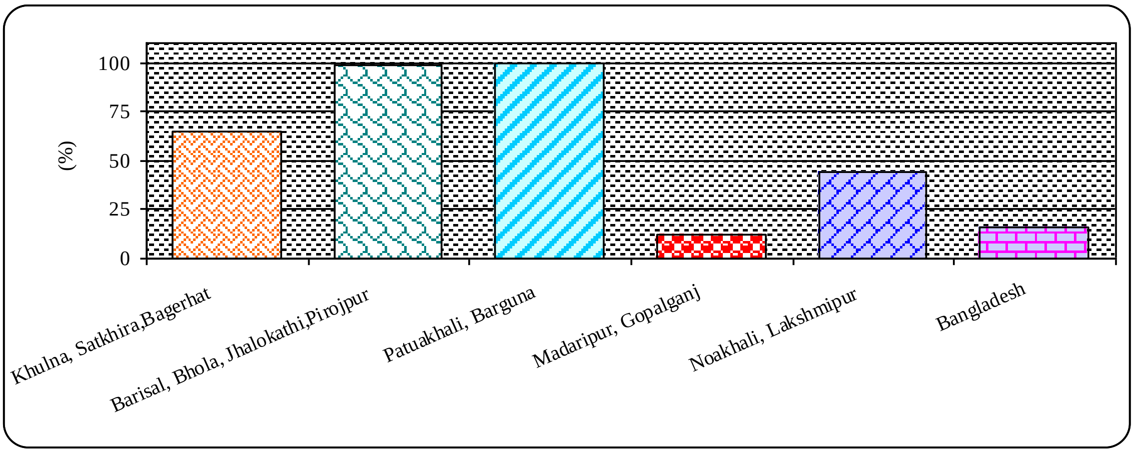


Figure-32: Percentage of land area likely to be affected due to sea level rise by 1 m.

4.3.1.3 Impacts on fisheries and aquaculture

Sea level rise would change the location of the river estuary, causing a great change in fish habitat and breeding ground. Penaid prawns breed and develop in brackish water, where salt water and fresh water mix. Sea level rise would turn this interface backward, changing habitat of prawn. There are 60 shrimp hatcheries and 124 shrimp processing plants in the coastal zone (Haque, 2003). The hatcheries are located at Teknaf, Ukhia and Sadar thana of Cox's Bazar district. Some hatcheries have also started test production in Chittagong and Satkhira coast.

It is to be mentioned that all the above districts are located in the coastal zone (Figure-1). As the zone is vulnerable to sea level rise, shrimp hatcheries and shrimp fields are also vulnerable to the phenomena. However, sea level rise is helping shrimp farming by introducing salinity in the coastal area, but it is also environmentally harmful.

There are 21 government fisheries service centres in the coastal zone. These centres facilitate the fishery sector with fuel supplies, landing, whole sale, icing, inland transportation and other activities with an aim to improve the yield of the sector. These service centres are much closed to coastline or estuaries and are potential to be inundated by sea level rise. There are some areas in the coastal zone that are far from city or fisheries service centre and have no icing facilities. Fishermen of such areas dry fishes in open sunlight to avoid spoilage. The dry fish industry will also be affected by anticipated sea level rise.

4.3.1.4 Impacts on agriculture

Salinity intrusion due to sea level rise will decrease agricultural production by unavailability of fresh water and soil degradation. Salinity also decreases the terminative energy and germination rate of some plants (Rashid et al., 2004; Ashraf et al., 2002). Ali (2005) investigated the loss of rice production in a village of Satkhira district and found that rice production in 2003 was 1,151 metric tons less than the year 1985, corresponding to a loss of 69 per cent. Out of the total decreased production, 77 percent was due to conversion of rice field into shrimp pond and 23 per cent was because of yield loss (Table-6).

Table-6: Declining rice production because of soil degradation (Ali, 2005)

Year		1985	1990	1995	2003
Area and months under rice and shrimp farming	HYV Aman July - Nov.	345.5 (100)	344.6 (100)	332.4 (97.0)	314 (91.9)
	HYV Boro	200.4 (58)	269.6 (78.2)	122.4 (32.8)	58.2

in ha (% crop land)	Dec. - May				(17)
	1 shrimp cycle Dec. – Jan.	36.5 (10.6)	75.0 (21.8)	210.0 (67.2)	255.8 (91.0)
	2 shrimp cycle Dec. – Nov.	0	0	20.6 (3.0)	55.0 (8.0)
Expected total rice production (MT)		1373	1689	1679	1673
Observed total rice production (MT)		1265	1260	745	522
Decline in rice production (MT)	Area	108	221	670	890
	Yield	-	208	264	261
Total loss of rice production (MT)		108	429	934	1151

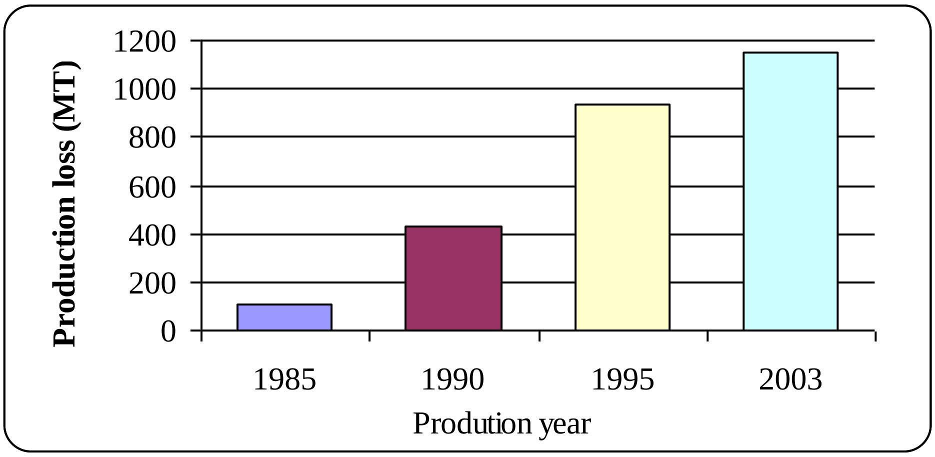


Figure-33: Loss of rice production in a village of Satkhira district.

A World Bank (2000) study suggests that increased salinity alone from a 0.3 metre sea level rise will cause a net reduction of 0.5 million metric tons of rice production. Sea level rise affects coastal agriculture, especially rice production in two ways. Salinity intrusion degrades soil quality that decrease or inhibit rice production. When the rice fields are converted into shrimp ponds, total rice production decreases because of decreased rice field areas.

It was estimated earlier that farmers of the country have 10,000 rice varieties in their collection (Brammer et al., 1993). These varieties include Aus, Aman, Boro and IRRI group. Most of the varieties are in the Aman group.

Sea level rise will increase flood frequency and flooding duration, affecting Aman production. A study by BARC (1999; cited in Islam, 2004) concluded that salinization will cause a reduction of wheat production equivalent to US$ 586.75 million. Miller (2004) stated that high projected rise in sea level of about 88 cm would flood agricultural lowlands and deltas in parts of Bangladesh. Agricultural lands in the coastal area will be affected by salinity; soil quality will be degraded and flooding event will loss the agricultural production of the coastal land of Bangladesh. Thus sea level rise will have an impact on agricultural production, especially on food production, leading Bangladesh to fail, obtaining food security.

4.3.1.5 Impacts on salt industry

Bangladesh is one of the salt producing countries of the world. Cox's Bazar coast of Bangladesh coastline is suitable for salt production. About 19,670 ha area has been used for salt production along the Cox's Bazar coast of the country. There are 216 salt pans, having an area of 8,153 ha only in Chakaria and Cox's Bazar Sadar thana of the district, producing 175,030 metric tons of salt annually (Hossain and Lin, 2001).

All the activities (sea water collection, storing in reservoir, condensing and crystallizing) of salt production that are handled by salt farmers are performed in the close area of the coastline. Moreover, salt mills are also located very close to the coastline. A one metre sea level rise will inundate all the salt fields and will ruin the sectors. Salt farmers can't move upwards land for the purpose because, physical properties of the soil of the present salt field will not move backwards with sea level rise. About 20 million people are directly or indirectly related in salt production (Hossain and Lin, 2001) and/or trading in Bangladesh. Sea level rise, by inundating salt fields will force this huge number of people to be unemployed.

4.3.1.6 Impacts on tourism

A significant part of Bangladesh coast is sandy beaches that attract tourists. Kuakata beach in Patuakhali district, Patenga beach in Chittagong district and Cox's Bazar beach in Cox's Bazar district are attractive tourist areas of the country. Cox's Bazar sea beach is the world's largest unbroken sandy beach having a length of 145 km (Hossain and Lin, 2001), attracting the tourists of home and abroad. Out of 18 tourist areas identified by Bangladesh Parjatan Corporation (BPC), five spots namely Chittagong, Cox's Bazar, Kuakata, Khulna and the Sundarbans are located in the coastal zone (Bangladesh online, 2005).

Numerous tourism related infrastructures are situated in the coastal zone. Bangladesh Parjatan Corporation has seven motels in Cox's Bazar and one motel in Chittagong and Khulna district each. Besides BPC establishments, private owned hotel, motel, guest house or other mode of tourist accommodations would be around 500 in the same areas. All the tourist facilities in the coastal zone will be affected by sea level rise directly or indirectly. Tourism sector of Kuakata will suffer the most because all the facilities are very close to the coastline and the area is more vulnerable comparative to Cox's Bazar and Chittagong. However, all the mentioned areas are highly vulnerable in terms of sea level rise related natural disaster, e.g. flood, storm surge, etc.

4.3.1.7 Impacts on health

Sea level rise may increase the risk of health hazards like diarrhea, cholera, etc. Cholera is an infectious disease of the small intestine of human beings and is common in the coastal area of Bangladesh. *Vibrio cholerae* is the causing microbe of cholera that survive longer with salinity level ranging from 2.5 ppt to 30 ppt and need Sodium ion (Na^+) for growth (Borroto, 1998). Average salinity of sea water is 35 ppt or 3.5%. Most of the salt present in the sea water is sodium chloride (NaCl) that breaks up into Na^+ and Cl^- ion when dissolved in water. For the reason, coastal area is breeding and nursery ground of cholera disease.

Water salinity of the coastal area of Bangladesh varies from 0 ppt to 20 ppt (Jakobsen et al., 2002). Water salinity and its distribution in the coastal area are increasing with the increase of sea level rise (Faisal and Parveen, 2004; Alam, 2003; IPCC, 2001a; World Bank, 2000). With the increased density and distribution of salinity, cholera germs are getting favorable habitat and spreading in the coastal area. This hypothesis is also supported by Colwell and Huq (2001) that states, most major epidemics that have occurred during the last 50 years originated in coastal region. So, coastal water and its saline environment have close association with cholera disease. Outbreaks of cholera often occur after flooding, because the water supply becomes contaminated (Eco-health Glossary, 2005). Thus, sea level rise, by increasing flood risk, increase the risk of cholera outbreak too.

Increased stress on the fresh water zone by saline sea water will decrease fresh water availability in the coastal zone (IPCC, 2001a). Increased unavailability of fresh water will force people to drink contaminated water leading to cholera, diarrhea and other water born diseases. Again, increased salinity in the coastal zone will decrease food production in the area, causing malnutrition for the coastal people. So, sea level rise will accelerate water born diseases and malnutrition in the coastal area.

4.3.1.8 Impacts on ecosystem

The Sundarbans will be completely lost with 1 metre sea level rise (World Bank, 2000). Loss of the Sundarbans means great loss of heritage, loss of biodiversity, loss of fisheries resources, loss of life and livelihood and after all loss of very high productive ecosystem.

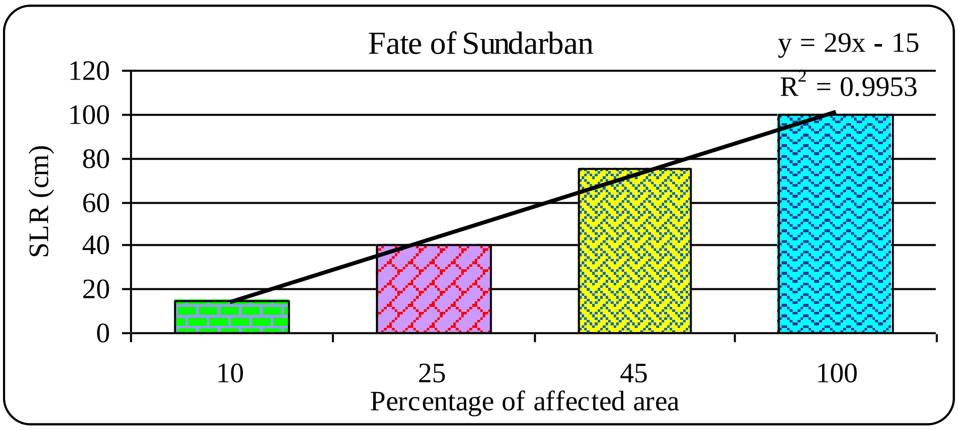


Figure-34: Ultimate fate of Sundarban due to projected sea level rise given by World Bank (2000)

The Sundarbans mangrove forest is the world's largest unique chunk of mangrove forest, located at the south of the tropic of cancer, the southwest part of Bangladesh, covering part of Khulna, Satkhira and Bagerhat district (Iftekhar and Islam, 2004). The area of the Sundarbans varies each year because of soil erosion or land accretion. However, its present area in Bangladesh part is 6,500 square kilometer (FAO, 2003; Cited in Islam & Haque, 2004). Sea level rise will cause rise in the salinity concentration in the water and soil of the Sundarbans. Increased salinity will change the habitat pattern of the forest. Sundari, the most dominating trees of the Sundarbans is thought to suffer from Top dyeing disease because of increased salinity (Kausher, et. al., 1993). Aquatic organisms will migrate inward, because of increased salinity too.

The Sundarbans is very rich in biodiversity. It is the hotspot for vast amount of flora and faunas. It is the last habitat of Royal Bengal Tiger. A study conducted in 1993 revealed that the Sundarbans is home to about 362 Royal Bengal Tigers. The site is home to a number of unique and globally or nationally endangered species of plants like rare Sundri, Gewa, Passur, animals like endangered Royal Bengal Tiger, vulnerable Pallas, Fishing Eagle and Masked Fin foot, and critically endangered River Terrapin, all listed in IUCN Red Book, rare species of shark and very rich avifauna. At this transitional zone between freshwater supplied by rivers and saline water pushed by high tides from open sea, many fish species such as *Peneaus monodon*, *Macrobrachium rosenbergii*, *Lates calcarifer*, *Metapeneaus monoceros* and *Pangaisus pangaisus* depend for spawning and juvenile feeding on the Sundarbans aquatic habitat (Rabbiosi, 2003).

Considering the high biodiversity value of the coastal zone, some parts of the zone is declared as protected areas. The protected areas include reserved forest, two national parks, one eco-park, five wildlife sanctuaries, one game reserve, one Ramsar site, three Ecological Critical Areas, two world heritage sites, one marine reserve and one fish sanctuaries (Table-7). About 7 species of fishes, 2 species of amphibians, 7 species of reptiles, 8 species of birds and 8 species of mammals are threatened animal species living in these protected areas (Islam, 2004). Excluding Himchari national park, Sitakunda eco-park, Chunati wildlife sanctuaries and Teknaf game reserve- all the protected areas in the coastal zone will be inundated by one metre sea level rise, destroying the area and its valuable wild and threatened animal species.

Table 7: Protected areas in the coastal zone of Bangladesh

Type	Name	Area (ha)	Location	Will 1-m SLR affect?
Reserved Forest		885,043	Bagerhat, Barguna, Bhola, Chittagong, Cox's Bazar, Feni, Khulna, Lakshmipur, Noakhali, Patuakhali, Satkhira	Yes
National park	Himchari	1,729	Cox's Bazar	No
	Nijhum Dweep	4,232	Hatiya, Noakhali	Yes
Eco-park	Sitakunda	808	Chittagong	No
Wildlife sanctuary	Sundarban East	31,227	Bagerhat	Yes
	Sundarban South	36,970	Khulna	Yes
	Sundarban West	71,502	Satkhira	Yes
	Char Kukri Mukri	2,017	Bhola	Yes
	Chunati	7,761	Chittagong	No
Game Reserve	Teknaf	11,615	Cox's Bazar	No
Ramsar Site	The Sundarbans	601,700	Bagerhat, Satkhira, Khulna	Yes
Environmental Critical Areas	Sonadia	4,916	Cox's Bazar	Yes
	Teknaf beach	10,465	Cox's Bazar	Yes
	St. Martin Island	590	Cox's Bazar	Yes
World Heritage Site	Wildlife Sanctuaries of the Sundarbans		Bagerhat, Satkhira, Khulna	Yes
	Shaat Gombuz Mosque	0.16	Bagerhat	Yes
Marine Reserve		69,800	Bay of Bengal	Yes
Fish Sanctuaries		15,614	Barisal, Bagerhat, Bhola, Patuakhali, Narail, Khulna, Jessore, Lakshmipur, Feni	Yes

4.3.1.9 Impacts on security

Food, clothing, housing, health and education are the basic needs of the people of Bangladesh. Table-8 explains how sea level rise affects the basic needs of large number of people of the country. Affecting basic needs, sea level rise becomes a threat to food security and other well-being securities.

Dalby (2002) explains that ‘ecosystem people’ are locally based populations who use their own labor to survive by cultivating and harvesting food and other resources from specific localities. Many of these people have been displaced from their homes in recent decades becoming ‘environmental refugees’. Sea level rise will create such ecological or environmental refugees in the country, forming ‘ecological marginalization’ (Homer-Dixon, 1998). Barnett (2003) states, 5.5 million people living on the Ganges delta in Bangladesh who will be forced to relocate with a 45 cm rise in sea level may seek to move inland within Bangladesh. Robert Kaplan (1994; Cited in Elliott, 2004) highlighted that different environmental problem including sea level rise will prompt mass migration, and in turn, incite group conflicts. There is a long term conflict between Bangladesh and India, regarding the distribution of water of the Ganges river (Nishat and Faisal, 2000; Ronnfeldt, 1997; Swart, 1996; Swain, 1993), refugees and other issues. Sea level rise induced environmental refugees may trigger the conflict. Environmental refugees created by sea level rise will cause even worse situation that may trigger conflict between the two countries. Thus, sea level rise might be a threat to national security of Bangladesh.

Table-8: Impacts of sea level rise on the basic needs of the people of Bangladesh

Basic needs	How sea level rise affects it	Authors
Food	Rise in sea level would flood agricultural lowlands and deltas in parts of Bangladesh (Miller, 2004; Bennett et al., 1991) that will decrease food production, causing shortage of food. Only salinity intrusion due to sea level rise will reduce 0.2 million metric ton of rice production.	World Bank, 2000
Cloths	Sea level rise will increase poverty. Increased poverty will decrease cloths buying capacity of the people of Bangladesh	Dalby, 2002
Housing	In Bangladesh, 29,846 sq. km. area of land will be lost and 14.8 million people will be landless by sea level rise, losing their house.	IPCC, 2001a
Health	Sea level rise by extending coastal area and by increasing salinity in the area will increase the risk of cholera. It will accelerate flood intensity facilitating transmission of diarrheal disease.	World Bank, 2000
Education	Sea level rise will cause destruction of infrastructure including educational institutes. Besides, students of flood, or other sea level rise affected family will leave school/ college, in search of work to support their family.	

A study of Earth Policy Institute (2004) shows the problem more seriously, that about 40 million people of Bangladesh out of 144 million will become environmental refugees due to 1 m sea level rise.

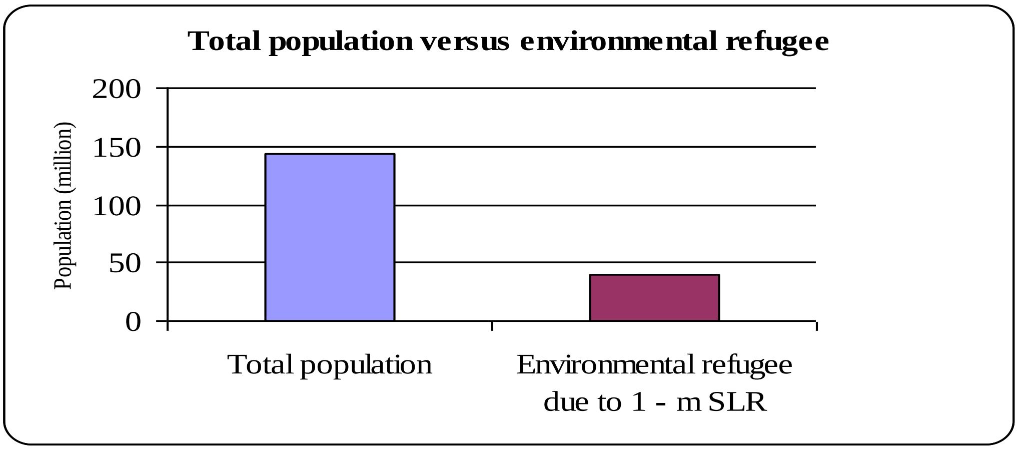


Figure-35: Environmental refugee due to 1- metre sea level rise.
Data source: Earth Policy Institute, 2004.

4.3.1.10 Impacts on tropical cyclones and storm surges

Bangladesh is already vulnerable to extreme climate events such as cyclones, storm surges and floods. The CCSLR will add fuel to the fire.

The Bay of Bengal is a favorable breeding ground of tropical cyclones and Bangladesh is the worst suffer of all cyclonic casualties in the world. About 5.5% cyclonic storms (wind speed greater than or equal to 62 km/hr) form in the Bay of Bengal and about 1% cyclonic storm of the global total hit Bangladesh (Ali, 1996, 1999a, 1999b).

On the other hand, if the tropical cyclone disasters due to each of which the minimum death tolls were 5,000 are considered, then it is found that a death toll of about 53% of the global total occurred in Bangladesh (Ali, 1999a). Thus it is seen that with 1% cyclones hitting Bangladesh, it is the worst sufferer in terms human casualty. If, on the top of that, the CCSLR affects cyclone activity, Bangladesh may suffer even more.

Two major aspects of cyclones that are most likely to be affected by climate change are cyclone frequency and cyclone intensity, as well as the storm surges accompanying a cyclone. Ali (1996, 1999a, 1999b) has made a somewhat in-depth study on the impacts of climate change and SLR on cyclones and storm surges in the Bay of Bengal and Bangladesh.

An analysis of all the cyclones that formed in the Bay of Bengal during the period 1877-1997 showed no corresponding increase in cyclone frequency in the Bay of Bengal, rather an oscillation of about 40 years. A recent study by Singh and Khan (1999) shows that the annual frequency of tropical cyclones over the north Indian Ocean (the Bay of Bengal and the Arabian sea) has shown a decreasing trend of one cyclone per hundred years.

It may be mentioned here that during the period 1877-1997, about 366 cyclones did not strike any country and they died in the Bay. If it is assumed that any increase in the sea surface temperature (SST) would have activated them and made them landfall, then the percentage increase of striking cyclones would be about 32. That is, in the event of climate change, the number of land-falling cyclones would increase by about 32% in the Bay of Bengal, bringing in more disastrous situations for the littoral countries.

There does not seem to be any study on the increase of cyclone intensity in the Bay of Bengal. But theoretical considerations show that a 1^0C rise in SST will increase the cyclone intensity by 4%, 2^0C rises by 10% and 4^0C rises by 22% (Emanuel, 1987).

Most of the cyclonic casualties are caused by storm surges. Surge heights as high as 10 m (occasionally even more) are not uncommon in Bangladesh. An increase in cyclone intensity will cause an increase in storm surge heights and the horizontal extent of flooding. A model analysis by Ali (1996) shows that storm surge heights will increase by 21% and 47% for a corresponding rise in SST by 2^0C and 4^0C respectively for a particular location along the north eastern coast of Bangladesh.

Plate-1: Loss of land due to river bank erosion.

Plate-2: Salt cultivation practice is growing popularity in coastal areas of Bangladesh.

Plate-3: Burning of paddy field due to excessive soil salinity.

Plate-4: Survivality of paddy tree is hard due to inundation of saline water.

Plate-5: Collapse of embankment protection.

Plate-6: Preparation of salt bed by clear felling of died Jhau trees.

Plate-7: Unprotected coastal island.

Plate-8: Intrusion of river water due to break down of embankment.

Plate-9: Living with fluctuated water in the coastal areas of Bangladesh.

Plate-10: Living is uncertain with SLR.

Plate-11: Affected people have to travel far away to collect drinking water.

Plate-12: A real victim of climate change.

Plate-13: Left over house adjacent to coast

Plate-14: Settlement was shifted but still drinking water collected from previous tube well.

Plate-15: Drinking water collection in adverse situation.

Plate-16: Netting in agricultural land.

Figure-36: Photographs of adverse effects of climate change, sea level rise and its consequent disasters.

4.3.2 People's Perceptions Regarding Impacts of Sea Level Rise on their Livelihood

4.3.2.1 Perceptions about declination of agricultural productivity

Farmer's opinion regarding the declination of agricultural productivity was considered depending on five broad aspects. These are salinity, top soil erosion, inundation or long prevailing submerged condition, lower rainfall and inadequate fresh water supply.

Salinity is the major problem area for productivity declination in Cox's Bazar and Khulna. In case of Cox's Bazar, 50% people opined that salinity is the major problem where as, in case of Khulna it is 60%. Salinity problem is lower (13% people's opinion) for the production of agriculture in Bhola.

Declination of productivity due to soil degradation via top soil erosion is highest (20% people opined) in Bhola, while lowest (7% people opined) in Cox's Bazar. Moreover, inundation or long prevailing submerged condition is more in Bhola (33% people opined) compared to Cox's Bazar (7% people opined) and Khulna (20% people opined).

Three coastal districts also suffer from less rainfall during production season. 10% people both in Cox's Bazar and Bhola opined that their cultivation is hampered due to lack of timely sufficient rainfall. Inadequate supply of fresh water (river, pond, canal and ground water) is also concern problem for Cox's Bazar and Bhola. 27% people in Cox's Bazar and 23% in Bhola showed their opinion that due to inadequate supply of fresh water their productivity declining day by day.

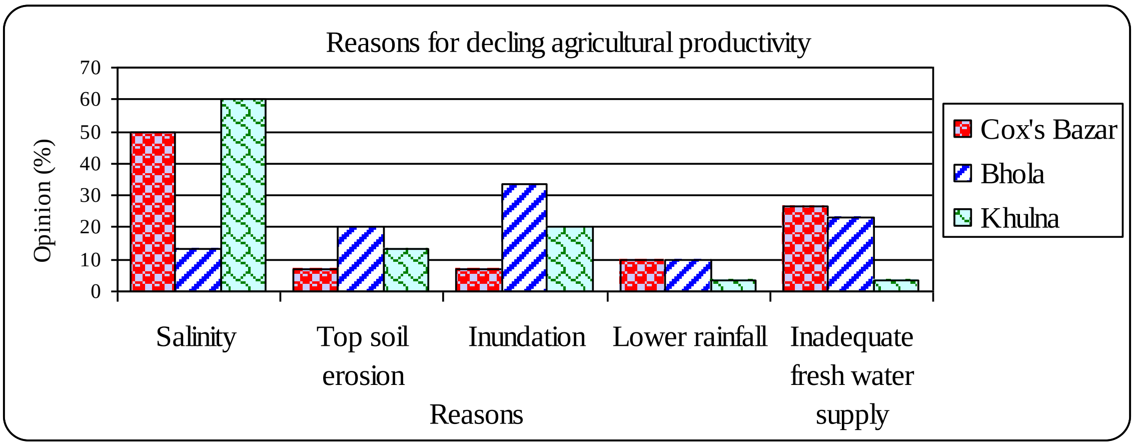


Figure-37: Farmers opinion regarding major reasons for the declination of agricultural productivity in three coastal districts

4.3.2.2 Disturbance pattern of agricultural productivity in different seasons

Hampering of productivity in four seasons (winter, pre-monsoon, monsoon and post-monsoon) varied widely in three coastal districts. Maximum disturbances in Cox's Bazar and Khulna occurred in winter season. 40% farmers in Cox's Bazar and 47% in Khulna opined that in winter soil suffer from water stress and salinity range goes upward, so productivity is declining day by day.

Maximum (47%) farmers in Bhola opined that in pre-monsoon productivity hampering is more than other seasons because of river bank erosion, flood, and inundation of low land along the coast during high tide, and so on.

Farmers in Cox's Bazar (20%), Khulna (30%) and Bhola (37%) showed their argument that monsoon season also severely affects their agricultural productivity because flood in coastal areas is a common phenomenon nowadays.

Moreover, 10%, 13% and 7% farmers in Cox's Bazar, Khulna and Bhola respectively told that post-monsoon also exerts detrimental effect on agricultural productivity

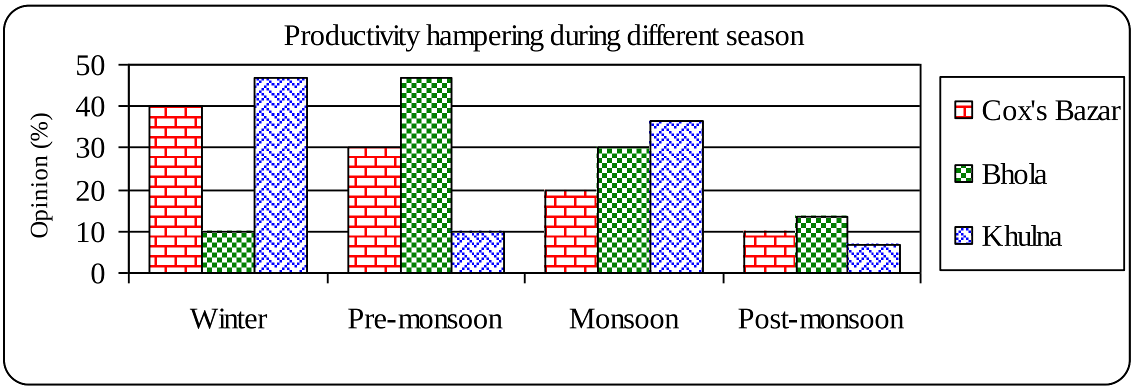


Figure-38: Farmers opinion regarding seasonal effects for declination of agricultural productivity in three coastal districts

4.3.2.3 River bank erosion and people's perception

Monsoon is the highly erosion causing season in all coastal districts. On the other hand, no erosion occurs during winter season. 80% coastal people of Bhola argued that in monsoon flow of river water gets its highest intensity which causes river bank erosion. Similarly, 70% and 65% coastal people of Cox's Bazar and Khulna respectively gave the same opinion. In addition, few people said that pre-monsoon and post-monsoon also accelerate river bank erosion.

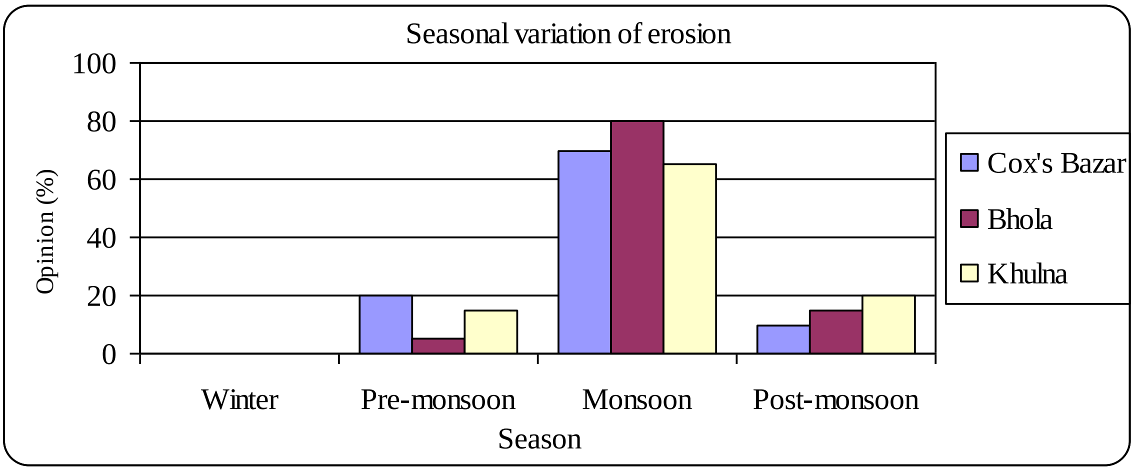


Figure-39: Farmer's opinion regarding the seasonal variation of river bank erosion in three coastal districts

Plate-10: Severe river bank erosion in coastal areas during monsoon monsoon season

4.3.2.4 Opinion regarding ground water salinity

Ground water salinity is one of the major problems in the coastal areas. Salinity in shallow aquifer found near 35-40 ft in Cox's Bazar, near 25-30 ft in Bhola and near 30-35 ft in Khulna. Moreover, salinity also found upto the depth of 240 ft in Khulna, 220 ft in Bhola and 170 ft in Cox's Bazar. This is because saline water intrudes through vertical and lateral movement both in winter and monsoon.

Table-9: Ground water salinity occurs in three different districts according to people's opinion.

Study area	Saline water found in shallow aquifer (ft)	Saline water found in deep aquifer (ft)
Cox's Bazar	35-40	≤170
Bhola	25-30	≤220
Khulna	30-35	≤240

4.3.2.5 Opinion regarding changes in occupation

Formerly, agricultural production was the ultimate choice of farmers in the coastal areas of Bangladesh. But very recently this occupation is being changed due to net lower production. Farmers of Cox's Bazar and Khulna changed their occupation and move forward into salt cultivation, shrimp farming and fishing.

This is because due to sea level rise saline water intruded into prime agricultural fields and makes the land unsuitable for agricultural production. So, farmers along the Bay of Bengal start to salt cultivation. If salt cultivation and shrimp farming continues to grow with the availability of saline water, agricultural practice will be lowered. In Bhola, agriculture (54% people opined) is still prime occupation because salt cultivation practice yet not started and shrimp farming started in lower scale. So, from the findings it can be said that due to sea water intrusion, people have nothing to do except changing their occupation.

Table-10: More popular occupation of the poor people adjacent to the Bay of Bengal and river in three coastal districts

Ranking	Occupation district wise					
	Cox's Bazar	%	Bhola	%	Khulna	%
1	Fishing	38	Agriculture	54	Fishing	41
2	Agriculture	19	Fishing	27	Agriculture	26
3	Salt cultivation	15	Day labor	8	Shrimp farming	18
4	Shrimp farming	13	Business (agri-sector)	6	Salt cultivation	11

5	Business (tourism sector)	10	Shrimp cultivation	3	Business (tourism sector)	2
6	Others	5	Others	2	Others	2

4.3.2.6 People's opinion about adaptation measure necessary to combat sea level rise

Peoples in the coastal areas showed the argument that adaptation options (priority basis) are unavoidable to combat sea level rise and its adverse impacts. Embankment construction or repairing the older one, coastal afforestation, polder establishment, cultivation of salt tolerant species and construction of elevated house and others (floating vegetable cultivation, fish culture in cage etc.) are some adaptive measures.

70% people in Cox's Bazar and 82% people in Bhola gave their opinion that embankment construction is the prime requisite to combat the adverse effects of sea level rise. In Khulna this percentage is lower (40%) because embankment construction is not possible along the river or bay due to the presence of Sundarban, the single largest mangrove forest in the world that requires inundation of saline water 2 times a day.

However, 48% people in Khulna opined that coastal afforestation is the only way to adapt with sea level rise. Salinity tolerant species cultivation is growing popularity among the people in the coastal areas.

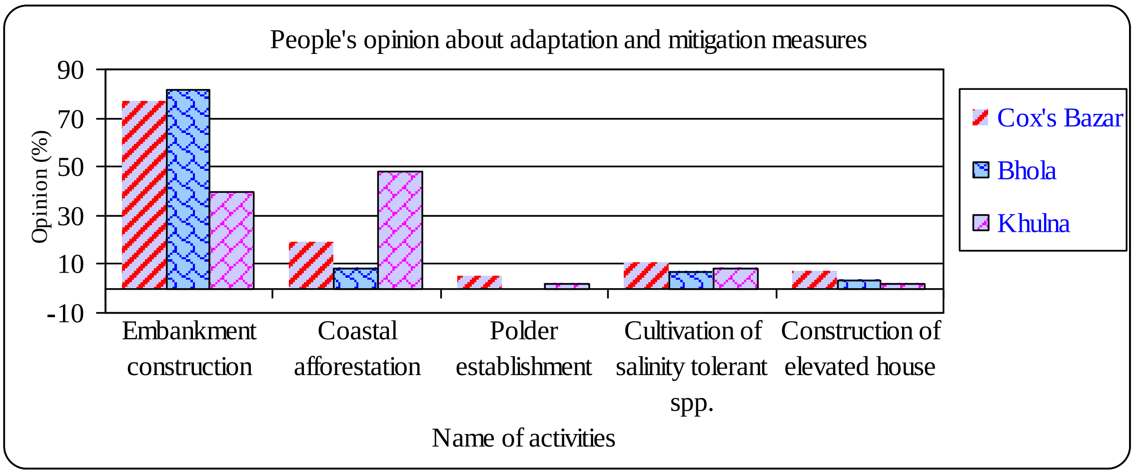


Figure-40: People's opinion regarding adaptation measures needed to combat adverse effect of sea level rise in three coastal districts

4.3.2 People's perceptions regarding impacts of sea level rise on their livelihood

4.3.2.1 Perceptions about declination of agricultural productivity

Farmer's opinion regarding the declination of agricultural productivity was considered depending on five broad aspects. These are salinity, top soil erosion, inundation or long prevailing submerged condition, lower rainfall and inadequate fresh water supply.

Salinity is the major problem area for productivity declination in Cox's Bazar and Khulna. In case of Cox's Bazar, 50% people opined that salinity is the major problem where as, in case of Khulna it is 60%. Salinity problem is lower (13% people's opinion) for the production of agriculture in Bhola.

Declination of productivity due to soil degradation via top soil erosion is highest (20% people opined) in Bhola, while lowest (7% people opined) in Cox's Bazar. Moreover, inundation or long prevailing submerged condition is more in Bhola (33% people opined) in comparison to Cox's Bazar (7% people opined) and Khulna (20% people opined).

Three coastal districts also suffer from less rainfall during production season. 10% people both in Cox's Bazar and Bhola opined that their cultivation is hampered due to lack of timely sufficient rainfall. Inadequate supply of fresh water (river, pond, canal and ground water) is also concern problem for Cox's Bazar and Bhola. 27% people in Cox's Bazar and 23% in Bhola showed their opinion that due to inadequate supply of fresh water their productivity is declining day by day (Figure-4.36).

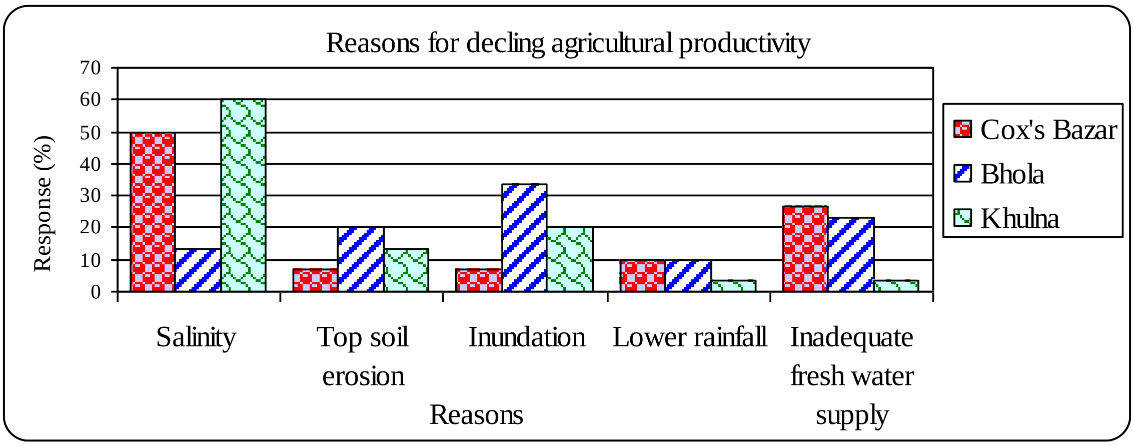


Figure-4.36: Farmers opinion regarding major reasons for the declination of agricultural productivity in three coastal districts.

There is a significant correlation exists between inundation and top soil erosion of three coastal districts at 1% level of significance. Moreover, lower rainfall and fresh water shortage also significantly correlated with one another at 5% level of significance. It means that when land become water logged during monsoon season, top soil erosion appears. In addition, availability of fresh water depends on rainfall. That means, if rainfall increase fresh water storage increase and vice versa (Appendix-20).

4.3.2.2 Disturbance pattern of agricultural productivity in different seasons

Decreased productivity in four seasons (winter, pre-monsoon, monsoon and post-monsoon) varied widely in three coastal districts. Maximum disturbance was in Cox's Bazar and Khulna during winter season. 40% farmers in Cox's Bazar and 47% in Khulna opined that in winter soil suffer from water stress and salinity range goes upward, so productivity is declining day by day.

Maximum (47%) farmers in Bhola opined that during pre-monsoon, productivity hampering is more than other seasons because of river bank erosion, flood, and inundation of low land along the coast during high tide, and so on.

Farmers in Cox's Bazar (20%), Khulna (30%) and Bhola (37%) showed their argument that monsoon season also severely affects their agricultural productivity because flood in coastal areas is a common phenomenon nowadays.

Moreover, 10%, 13% and 7% farmers in Cox's Bazar, Khulna and Bhola told that post-monsoon also exerts detrimental effect on agricultural productivity.

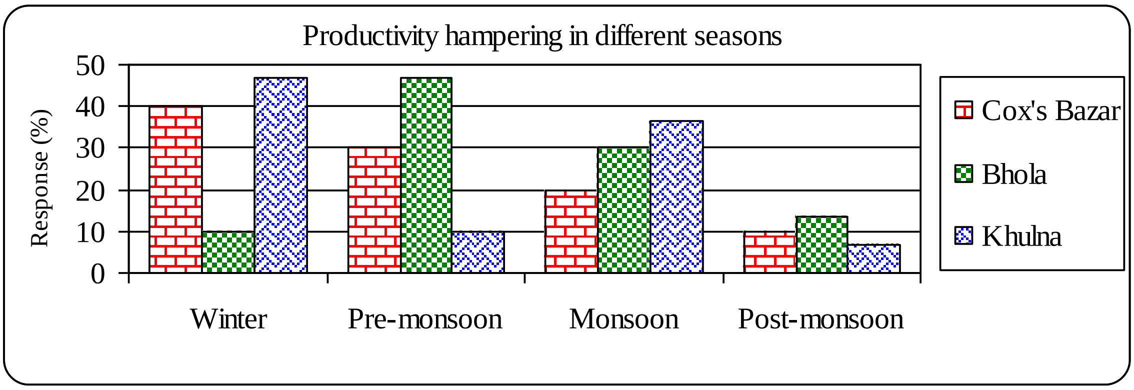


Figure-4.37: Farmers opinion regarding seasonal effects for declination of agricultural productivity in three coastal districts.

4.3.2.3 River bank erosion and people's perception

Higher erosion is causing in monsoon season in all the coastal districts, whereas, no erosion occurs during winter season. 80% coastal people of Bhola argued that in monsoon flow of river water gets its highest intensity and speed which causes river bank erosion. Similarly, 70% coastal people of Cox's Bazar and 65% of Khulna gave the same opinion. In addition, few people said that pre-monsoon and post-monsoon also accelerate river bank erosion.

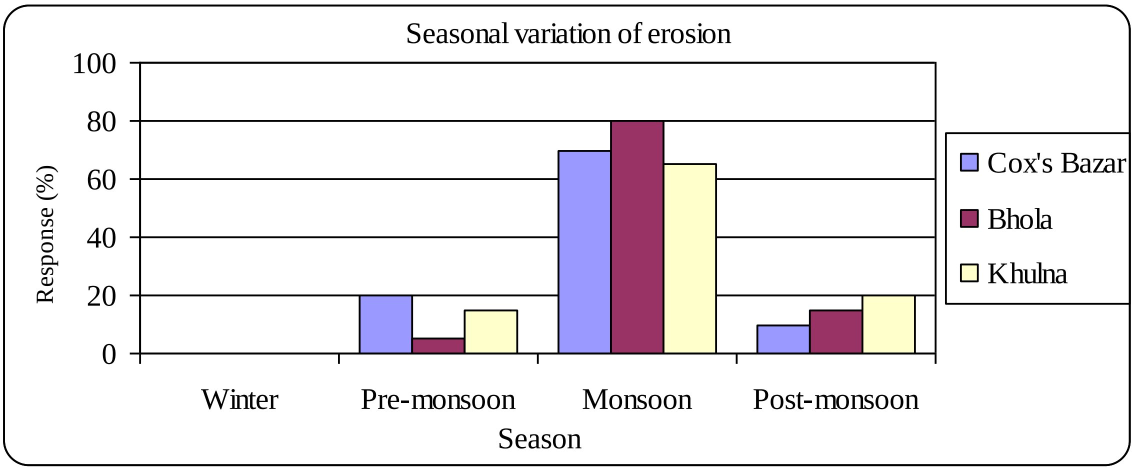


Figure-4.38: Farmer's opinion regarding the seasonal variation of river bank erosion in three coastal districts.

Plate-16: Severe river bank erosion in coastal areas during monsoon.

4.3.2.4 Opinion regarding ground water salinity

Ground water salinity is one of the major problems in the coastal areas. Salinity in shallow aquifer found near 2.0-3.0 m in Cox's Bazar, near 3.0-4.0 m in Bhola and near 2.5-3.5 m in Khulna. Moreover, salinity also found upto the depth of 75 m in Khulna, 55 m in Bhola and 60 m in Cox's Bazar. This is because saline water intrudes through vertical and lateral movement both in winter and monsoon.

Table-4.6: Ground water salinity occurs in three different districts according to people's opinion.

Study area	Saline water found in shallow aquifer (m)	Saline water found in deep aquifer (m)
Cox's Bazar	2.0-3.0	≤60
Bhola	3.0-4.0	≤55
Khulna	2.5-3.5	≤75

4.3.2.5 Opinion regarding changes in occupation

Formerly, agricultural production was the ultimate choice of farmers in the coastal areas of Bangladesh. But, very recently this occupation is being changed due to net lower production. Farmers of Cox's Bazar and Khulna changed their occupation and became interested for salt cultivation, shrimp farming and fishing (Figure-4.39 and 4.41).

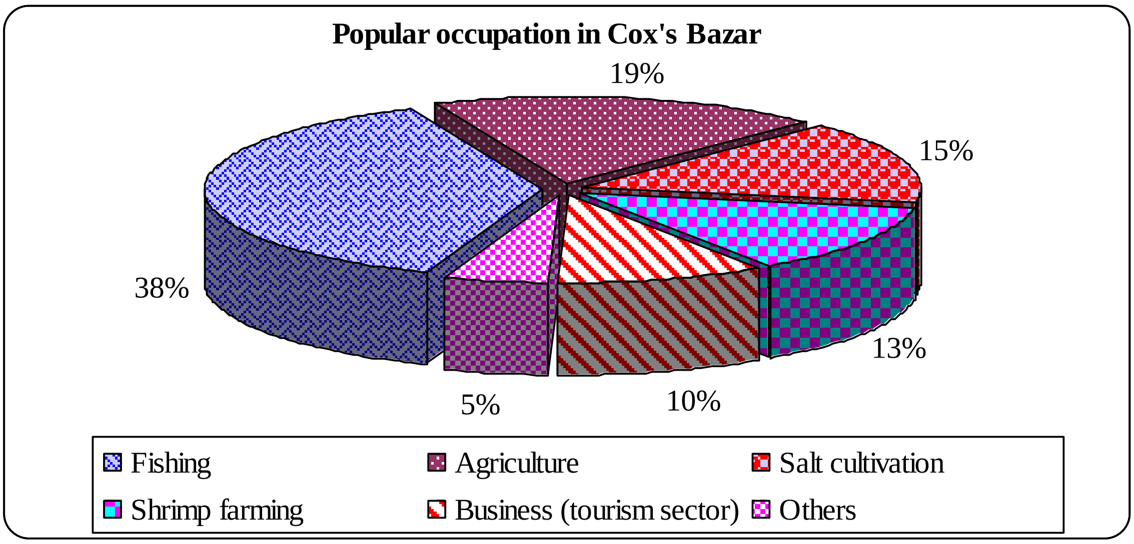


Figure-4.39: Popular occupation of coastal people in Cox's Bazar district.

This is because due to sea level rise saline water intruded into prime agricultural fields and makes the land unsuitable for agricultural production. So, farmers along the Bay of Bengal start to salt cultivation. If salt cultivation and shrimp farming continues to grow with the availability of saline water, agricultural practice will be declined. In Bhola, agriculture (54% people opined) is still prime occupation because salt cultivation practice yet not started and shrimp farming started in small scale areas (Figure-4.40).

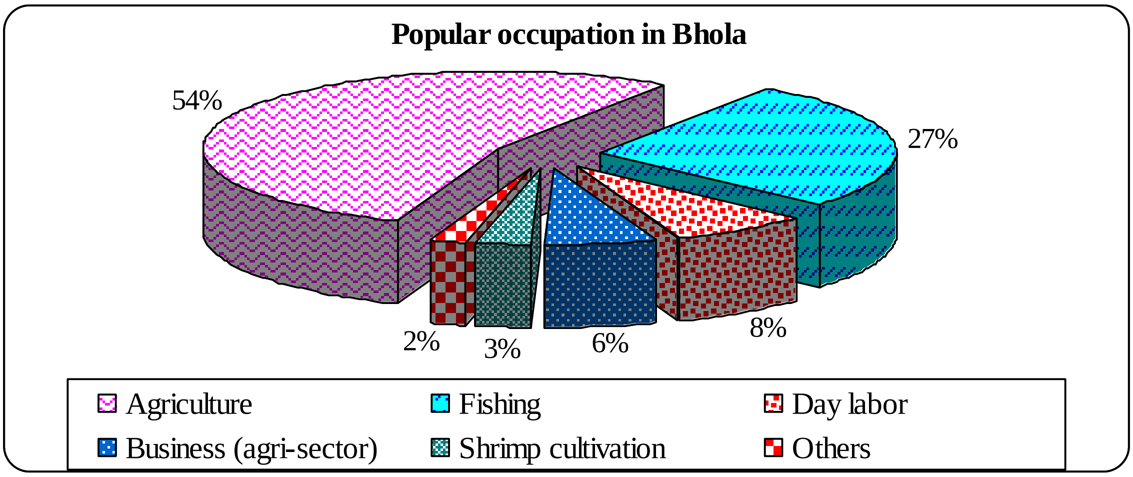


Figure-4.40: Popular occupation of coastal people in Bhola district.

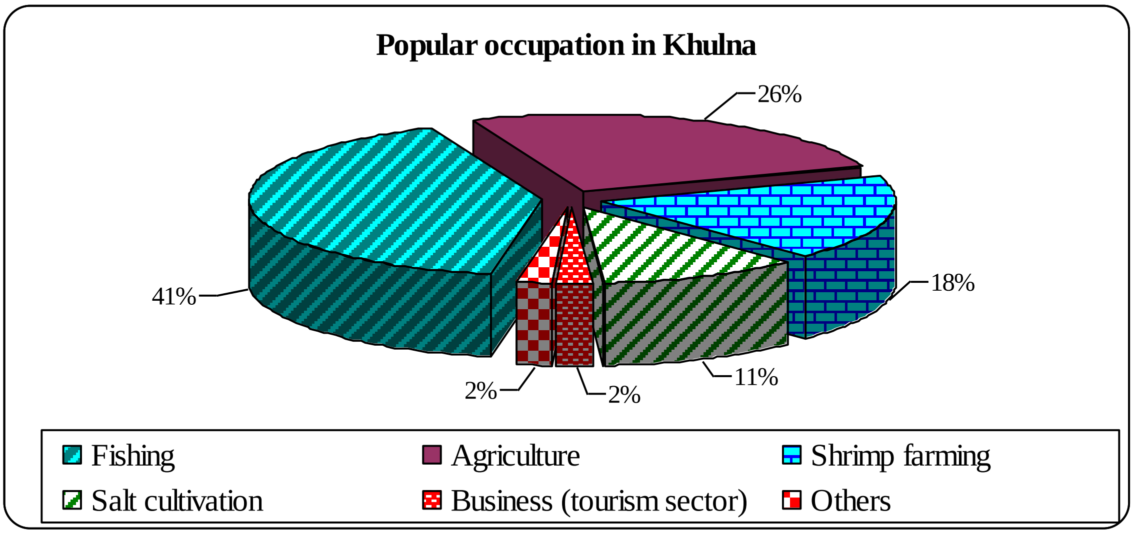


Figure-4.41: Popular occupation of coastal people in Khulna district.

With the change in ecosystem and productivity, occupation of coastal people also changed because farmers, fishermen and others have opined that they are changing their occupation due to carry on their survivality in society with changing situation. One mentionable matter is that farmers and fishermen communities showed their sympathy that former highly productive land are now being turned into less productive land only due to intrusion of saline water and untimely rainfall. So, from the findings it can be said that due to sea water intrusion, people have nothing to do except changing their occupation.

4.3.2.6 People's opinion about adaptation measures necessary to combat sea level rise

People in the coastal areas showed that adaptation options (priority basis) are unavoidable to combat sea level rise and its adverse impacts. Embankment construction or repairing is the older option, whereas, coastal afforestation, polder establishment, cultivation of salt tolerant species and construction of elevated house and others (floating vegetable cultivation, fish culture in cage etc.) are some new adaptive measures.

70% people in Cox's Bazar and 82% in Bhola gave their opinion that embankment construction is the prime requisite to combat the adverse effects of sea level rise. In Khulna this percentage is lower (40%) because embankment construction is not possible along the river or bay due to the presence of Sundarban, the single largest mangrove forest in the world that requires inundation of saline water 2 times a day.

However, 48% people in Khulna opined that coastal afforestation is the only way to reduce the impact of sea level rise vulnerabilities. Salinity tolerant species cultivation is getting popularity among the people in the coastal areas.

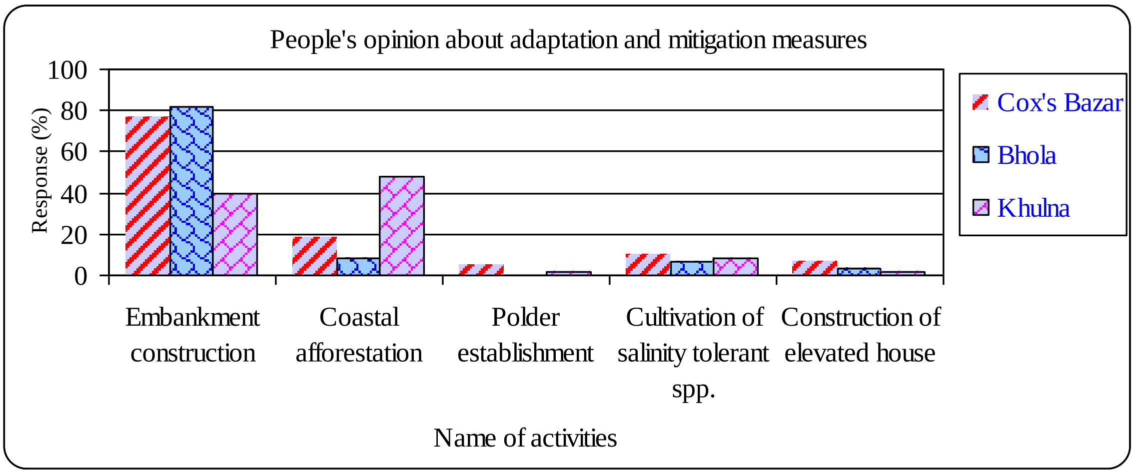


Figure-4.42: People's opinion regarding adaptation measures needed to combat adverse effect of sea level rise in three coastal districts of Bangladesh.

4.4 Adaptation and Mitigation Measures Needed to Combat Sea Level Rise

From the discussion of impacts of sea level rise and people's perception regarding adverse impacts of sea level rise, it is clear that Bangladesh has to face the crucial effects of sea level rise. But Bangladesh or even any country in the world cannot overcome this problem overnight. So, global communities are paying their attention to minimize the impacts of climate change and one of its ultimate results, sea level rise. The output to minimize the impacts is either mitigation or adaptation.

4.4.1 Adaptation

Adaptation seeks to reduce the adverse effects of sea level rise on living organisms, including human and the environment. Sea level rise adaptation can be addressed by changes in policies that lessen pressure on resources, improve management of environmental risks, and enhance adaptive capacity. As most of the population of the coastal communities of Bangladesh is fishermen and farmers, the adaptation options should be emphasized on these two sectors to overcome the problems of the anticipated issues.

The area of Bangladesh coast that will be inundated by sea level rise should be prepared for alternative mode of cultivation. The vast submerged area in the coastal zone could be used for cage and pen culture. A cage is a net-built pocket submerged in water where fish could be cultivated. Cage culture is suitable in the coastal areas with relatively weak water current. Swann et al. (1994) mentioned that 800-1000 fish could be stocked in a cage having a small volume of 3.6 cubic meters. So, the culture permits high stocking density that helps to have a high yield of fisheries in the land scarce coastal areas.

Adaptation should be introduced in agriculture, including crop changes and resource substitutions (IPCC, 2001b). Salinity tolerant species (e.g. BRRI-47 paddy) could be introduced in agriculture, fisheries and in the coastal forestry. A study by Rashid et al. (2004) showed that *Albizia. lebbek* could survive in varies salinity range. These type of salinity tolerate species should be developed or find out to extent plantation in the coastal areas. The species *Heritiera fomes, Sonnerata apetala* and *Avicennia officinalis* are suitable for mangrove afforestation in the coastal zone of Bangladesh. Mangrove afforestation will protect soil erosion because its roots help to compact soil. Decomposition of dead leaves of mangrove will add organic matter to the soil, turning coastal land fertile.

Salt tolerant T. Aman varieties like BR-23, BRRI dhan 40 and BRRI dhan 41 may be the solution to overcome salinity impact in the coastal areas of Bangladesh. Tomato, Okra and Aroid are some vegetable crops that can be cultivated under improved management practices with raised bed and mulch in the medium saline soils.

Bangladesh is a land scarce country and surrounding people start to settle there in 5-6 years (Iftekhar and Islam, 2004). Human settlements should be prohibited in the new lands for the designated 20 years time expansion. The forest department should have a special team to protect the areas from this type of illegal settlement. People should be motivated in such a way that they understand about the benefits they will get, when the land gets maturity.

People engaged in the salt industries should be provided information regarding possible impacts of sea level rise on the sector. Lands that are used as salt-bed should be protected by polders. Existing salt mills that are very close to the coastline should be relocated towards landward parts of the country.

Efficient research can find out salinity tolerant species for the coastal fisheries sector. Species selection should be done for low, moderate and high saline environment.

Adaptation to the change in ecosystem is very hard task and sometime impossible, even. As the Sundarban is predicted to be affected most by sea level rise, attention should be paid on this ecosystem mostly. Sundri is the dominating tree species that covers 62.4% of the Sundarban (Iftekhar and Islam, 2004). Massive loss of the Sundri tree species by top dying disease is believed, due to salinity increase in the water and soil of the ecosystem. Diagnosis of the top dying disease should be done properly and possible scientific solutions should be sought. The protected areas that are under potential threats of sea level rise should be studied extensively to point out the problems of the areas from environmental point of view and to find out the solutions.

Animal species of the Sundarbans and other vulnerable coastal zones should be transferred to new mangrove plantation areas. Safe zone should be created in the forest for the specified tiger where all human activities will be prohibited including activities of the forest department, so that it can have safe breeding to increase the number of the species.

Training about advanced agricultural techniques and seeds of high yield varieties of rice should be provided to the farmer. Initiatives should be taken to develop salinity tolerate species. People should be motivated and trained to do area specific business, suitable for their areas. Coastal poor people should be provided with small scale soft loan of less than 5% interest rate to operate those area specific livelihood activities.

The fishermen invest their year long savings, which are under threat to be destroyed by sea level rise induced disasters like flood. Coastal communities should be prepared to face these adverse situations by having disaster preparedness activities. The fishermen should be updated about the disaster and their duties to minimize the potential loss by the event. A disaster calendar that considers disaster intense time, disaster prone zone and salinity will help the farmer and fisher community to have a safe production and also safe harvest.

Weather forecasting should be in easy language, so that the target groups can understand it easily and completely and can react with the direction of the forecast. Local radio stations should broadcast weather forecast in local dialect. Besides forecasting, local radio station should broadcast special programmes that communicate coastal communities about different issues of sea level rise.

Participatory community fund is another option that will enhance the fishermen’s capacities. Individual’s weekly savings will be collected and deposited into the group’s bank account. The savings will be used in case of harvest failure or in case of other natural disaster that affect their fish farms. In case of no environmental hazard or natural disaster, the fund could be used to form a cooperative that will bring more financial gain to the poor fishermen. Adapting with disaster and having financial solvency, the coastal community will gain resiliency. Again, money invested in fisheries sector could be used for artificial mangrove afforestation. Mangroves provide breeding ground for shrimp, increasing the number of natural shrimp larvae (Islam and Haque, 2004; Hossain, 2001).

Vegetable gardening in floating beds (hydroponics) is a traditional agricultural practice in the coastal areas of Bangladesh. This technology involves the cultivation of traditional crops on beds floating on water rather than in soil. The floating beds used by the farmers are usually made of water hyacinth and paddy straw. The main crops cultivated in floating gardens include okra, cucumber, bitter gourd, kohlrabi, tomato, turmeric and potato. Moreover, fish culture in cage is also become popular adaptation option during seasonal fluctuation of water in the coastal areas of Bangladesh.

More specifically, we have three adaptation options namely; retreat, accommodation and protection. In view of high population density and shortage of land, retreat is not possible. We should pursue the two other options. Some of the adaptation options are: raising of forest all along the coast, protection of mangrove forests, changing cropping pattern and variety in the coastal area, construction of embankments where feasible, construction of safe shelters for emergency situations like extreme events, etc. In fact, many of these options are already in operation, in a limited scale though. Adaptation has cross-cuttings of different disciplines and hence a multi-disciplinary and integrated approach needs to be taken up to reduce vulnerability.

Adaptation is a need for today, can not be a long term solution of climate change and sea level rise. The imperative of green house gas emission forces many communities to adapt now in their habitats; continue agricultural productivity, infrastructural damage management, public health protection, disaster risk reduction and addressing climate induced migration. But adaptation has limits. When ecosystems or human societies collapse, the adaptation potential has come to an end. Hence, we must build resilience in human and natural systems to reduce the risk and vulnerability of climate change and sea level rise through reducing the GHG emission drastically and providing risk reduction strategies and actions.

Plate-17: Fish culture in cage in coastal areas of Bangladesh

Plate-18: Cultivation of crops on raised bed and mulch in moderately saline soil

Plate-19: Vegetable cultivation on floating garden in coastal areas of Bangladesh

Plate-20: Harvesting of vegetable from floating garden

Plate-21: Preparation of floating garden for cultivation of crops

Plate-22: Repairing of embankment to protect intrusion of saline water

Plate-23: Protection of river bank erosion using polder

Plate-24: Housing system in coastal areas as an adaptation measure of flood and sea level rise

Plate-25: Cultivation of salt tolerant paddy (BRRI-47) in coastal areas

Plate-26: Mobile education given to displaced children on floating boat

Plate-27: Jhau plantation that acts as shelter belt

Plate-28: Mangrove plantation

Plate-29: Cultivation of salt tolerant paddy

Plate-30: Drying of fish

Figure-41: Photographs of some adaptation measures taken by coastal people to cope with adverse effects of sea level rise.

4.5 Adaptation and mitigation measures needed to combat sea level rise

From the discussion of impacts of sea level rise and people's perception regarding adverse impacts of sea level rise, it is clear that Bangladesh has to face the crucial effects of sea level rise. But, Bangladesh or even any country in the world cannot overcome this problem overnight. So, global communities are paying their attention to minimize the impacts of climate change and one of its ultimate results, sea level rise. The output to minimize the impacts is either mitigation or adaptation.

4.5.1 Adaptation

Adaptation seeks to reduce the adverse effects of sea level rise on living organisms, including human and the environment. Sea level rise adaptation can be addressed by changes in policies that lessen pressure on resources, improve management of environmental risks, and enhance adaptive capacity. Most of the population of the coastal communities of Bangladesh is fishermen and farmers, so the adaptation options should be emphasized on these two sectors to overcome the problems of the anticipated issues.

4.5.1.1 Adaptation in fishery sector

The area of Bangladesh coast that will be inundated by sea level rise should be prepared for alternative mode of cultivation. The vast submerged area in the coastal zone could be used for cage and pen culture. A cage is a net-built pocket submerged in water where fish could be cultivated. Cage culture (Plate-17) is suitable in the coastal areas with relatively weak water current. Swann et al. (1994) mentioned that 800-1000 fish could be stocked in a cage having a small volume of 3.6 cubic meters. So, the culture permits high stocking density that helps to have a high yield of fisheries in the land scarce coastal areas. *P. monodon* is very sensitive to salinity and its required salinity for maximum growth is 15-25ppt (Chanratchakool, 2003). Indian White Shrimp (*P. indicus*) and Western White Shrimp (*P. vannamei*) are more flexible in terms of salinity tolerance. Indian white shrimp can tolerate salinity up to 42 ppt and Western White Shrimp can tolerate a wide range of salinity starting from 0.5 ppt to 45 ppt. These two prospective shrimp species could be introduced in the shrimp sector of Bangladesh.

Pearl culture may be another option to be introduced in the zone. By practicing these cultivations, people can maintain their domestic demand and earn money by selling surplus products, which could be used to adapt with other sea level rise impacts. Some sea foods (e.g. crab, oyster, etc.) are not treated as food in Bangladesh, even though they have high nutrient value. People should be motivated to consume sea food.

4.5.1.2 Adaptation in agriculture sector

Adaptation should be introduced in agriculture, including crop changes and resource substitutions (IPCC, 2001b). Salinity tolerant species (e.g. BRRI-47 paddy) (Plate-25) could be introduced in agriculture. Salt tolerant T. Aman varieties like BR-23, BRRI dhan 40 and BRRI dhan 41 may be the solution to overcome salinity impact in the coastal areas of Bangladesh. Tomato, Okra and Aroid are some vegetable crops that can be cultivated under improved management practices with raised bed and mulch in the medium saline soils (Plate-18).

Vegetable gardening in floating beds (hydroponics) is a traditional agricultural practice in the coastal areas of Bangladesh (Plate-19 and 20). This technology involves the cultivation of traditional crops on beds floating on water rather than in soil. The floating beds used by the farmers are usually made of water hyacinth and paddy straw. The main crops cultivated in floating gardens including okra, cucumber, bitter gourd, tomato, turmeric and potato. It is reported that some farmers in Gournadi upazilla of Barisal district is practicing floating agriculture in their lowlands, submerged by water (Mian, 2005).

4.5.1.3 Adaptation in tourism sector

Tourism in the coastal area should be developed under the principle of eco-tourism. Tourism infrastructure should be protected by polder and where polder construction is not feasible from environment point of view, it should be relocated. Further tourism infrastructures should be constructed with full consideration of sea level rise.

4.5.1.4 Adaptation in settlement

Bangladesh is a land scarce country and surrounding people start to settle in the raised accreted land in 5-6 years (Iftekhar and Islam, 2004). Human settlements should be prohibited in the new lands for the designated 20 years time expansion. The forest department should have a special team to protect the areas from illegal settlement. People should be motivated in such a way that they understand about the benefits they will get, when the land gets maturity. Moreover, construction of raised houses is one of the adaptation options in the coastal areas of Bangladesh (Plate-24).

4.5.1.5 Adaptation in salt industry

People engaged in the salt industries should be provided information regarding possible impacts of sea level rise on the sector. Lands that are used as salt-bed should be protected by polders. The areas where polder construction is not possible, the salt farmers of those areas should be motivated to alter their professions and one of the choose livelihood practice might be fish farming suitable for that environment. Existing salt mills that are very close to the coastline should be relocated towards landward parts of the country.

4.5.1.6 Adaptation in forestry sector

A study by Rashid et al. (2004) showed that *Albizia lebbek* could survive in a wide salinity ranges. These salinity tolerant species should be developed or find out to extent plantation in the coastal areas. The species *Heritiera fomes, Sonneratia apetala* and *Avicennia officinalis* are suitable for mangrove afforestation in the coastal zone of Bangladesh. Mangrove afforestation will protect soil erosion because its roots help to bind the soil. Decomposition of dead leaves of mangrove will add organic matter to the soil, turning coastal land fertile and few for marine resources.

Adaptation to the change in ecosystem is very hard task and sometime impossible, even. As the Sundarban is predicted to be affected most by sea level rise, attention should be paid on this ecosystem mostly. Sundri is the dominating tree species that covers 62.4% of the Sundarban (Iftekhar and Islam, 2004). Massive loss of the Sundri tree species by top dying disease is believed, due to salinity increase in the water and soil of the ecosystem. Diagnosis of the top dying disease should be done properly and possible scientific solutions should be sought. The protected areas that are under potential threats of sea level rise should be studied extensively to point out the problems of the areas from environmental point of view and to find out the solutions. Animal species of the Sundarbans and other vulnerable coastal zones should be transferred to new mangrove plantation areas. Safe zone should be created in the forest for the specified tiger where all human activities will be prohibited including activities of the forest department, so that it can have safe breeding to increase the number of the species.

4.5.2 Involvement of various disciplines

4.5.2.1 Mass media

Weather forecasts in Bangladesh *Betar* (Radio) and Bangladesh Television, whose target groups are mostly illiterate coastal farmers and fishermen, are developed and delivered by educated people in highly educated language. These fisher and farmer communities don't know what El-Nino is or what Nimnochaap (Depression) is. Weather forecasting should be in easy language, so that the target groups can understand it easily and completely and can react with the direction of the forecast. People of different coastal zone have different dialects. Local radio stations should broadcast weather forecast in local dialect. Besides forecasting, local radio station should broadcast special programmes that communicate coastal communities about different issues of sea level rise.

4.5.2.2 Education and training

Training about advanced agricultural techniques and seeds of high yielding varieties of rice should be provided to the farmer. Initiatives should be taken to develop salinity tolerant species. People should be motivated and trained to do area specific business, suitable for their areas.

4.5.2.3 Forecasting anticipated disaster

The fishermen invest their year long savings, which are under threat to be destroyed by sea level rise induced disasters like flood. Coastal communities should be prepared to face these adverse situations by having disaster preparedness activities. The fishermen should be updated about the disaster and their duties to minimize the potential loss by the event. A disaster calendar that considers disaster intense time, disaster prone zone and salinity will help the farmer and fishermen community to have a safe production and also safe harvest.

4.5.2.4 Financial support

Participatory community fund is another option that will enhance the fishermen's capacities. Individual's weekly savings will be collected and deposited into the group's bank account. The savings will be used in case of harvest failure or in case of other natural disaster that affect their fish farms. In case of no environmental hazard or natural disaster, the fund could be used to form a cooperative that will bring more financial gain to the poor fishermen. Adapting with disaster and having financial solvency, the coastal community will gain resiliency. Again, money invested in fisheries sector could be used for artificial mangrove afforestation. Mangroves provide breeding ground for shrimp, increasing the number of natural shrimp larvae (Islam and Haque, 2004; Hossain, 2001). Coastal poor people should be provided with small scale soft loan of less than 5% interest rate to operate those area specific livelihood activities.

4.5.2.5 Medical centre

Coastal water should be monitored to detect the presence of germs of cholera disease. There is a government health complex in every Upazila in Bangladesh. The coastal health complexes can do this job regularly or at least weekly. One doctor in the coastal health complex should have expertise in cholera issue. If cholera germs are found in any area, necessary steps should be taken to stop the outbreak of cholera. Oral saline, which is essential for the treatment of dehydration, should be easily accessible in the coastal area and free saline should be distributed in cholera outbreak portion of coastal zone. Coastal people should be trained how to make oral saline at home, simply using salt, sugar and clean water.

4.5.2.6 Research

Efficient research can find out salinity tolerant species for the coastal fisheries sector. Species selection should be done for low, moderate and high saline environment. After selecting different species for different zones or saline environments, the fishermen should be trained about breeding, cultivation and harvesting of the species. Research will also point out new or advanced technology for the sector. For example, cage cultivation, which is practicing in small scale Bangladesh, could be introduced in large scale in coastal areas of weak current flow. By cultivating salinity tolerate species and by practicing advanced fisheries techniques, coastal communities can adapt with sea level rise.

More specifically, we have three adaptation options namely; retreat, accommodation and protection. In view of high population density and shortage of land, retreat is not possible. We should pursue the two other options. Some of the adaptation options are: raising of forest all along the coast, protection of mangrove forests, changing cropping pattern and variety in the coastal area, construction of embankments where feasible, construction of safe shelters for emergency situations like extreme events, etc. In fact, many of these options are already in operation, in a limited scale though. Adaptation has cross-cuttings of different disciplines and hence a multi-disciplinary and integrated approach needs to be taken up to reduce vulnerability.

Adaptation is a need for today, can not be a long term solution of climate change and sea level rise. The imperative of green house gas emission forces many communities to adapt now in their habitats; continue agricultural productivity, infrastructural damage management, public health protection, disaster risk reduction and addressing climate induced migration. But, adaptation has limits. When ecosystems or human societies collapse the adaptation potential has come to an end. Hence, we must build resilience in human and natural systems to reduce the risk and vulnerability of climate change and sea level rise through reducing the GHG emission drastically and providing risk reduction strategies and actions.

4.5.3 Mitigation

There is a renowned proverb in medical science that ‘Prevention is better than cure’. Emission control is the prevention of climate change and sea level rise. Though, Bangladesh emits a negligible volume of greenhouse gases, the country should take necessary steps even to cut down its emissions. Stopping deforestation and controlling of fossil fuel use are essential for the purpose. IPCC (2001a) indicates the main greenhouse gas emission reduction measures which are: i) Demand reduction and/or efficiency improvement, ii) Substitution among fossil fuels, iii) Switch to nuclear energy, iv) Switch to biomass, v) Switch to other renewable energy, vi) CO_2 scrubbing and removal, and vii) Extensive afforestation. Bangladesh should follow its level best, the above mentioned seven measures.

To reduce demand, Bangladesh needs to control its excess population growth. World Commission on Environment and Development (WCED, 1987) expresses for Common Future that, ‘Excessive population growth diffuses the fruits of development over increasing numbers instead of improving living standards in many developing countries’. So, population control should be given the first priority in Bangladesh, where population density is the highest in the world. The recently introduced Compressed Natural Gas (CNG) driven vehicle that produce low hydrocarbon, carbon monoxide (CO) and CO_2 (Miller, 2004) is an exemplary step of Bangladesh to minimize greenhouse gas emission. As CNG is more than three times efficient (in terms of cost) than octane, people will use this low emission natural gas if favorable environments could be ensured. The country should adapt this low emission technology to other fields. Introducing biomass (e.g. biogas), using renewable resources (e.g. windmill, solar photovoltaic) is also need to adopt.

Bangladesh has a plan to bring all its citizens under national electricity grid by the year 2020. To fulfill this noble vision, the country should seek possible renewable resources. Favourable natural conditions like sufficient sunshine and wind-speed exist for promotion of renewable energy in the country. In Bangladesh, average absorbable solar radiation is 0.193 kW/m^2 (Islam and Huda, 1999). Bangladesh receives a constant supply of 28 TW^5 energy from the sun, which is nearly 200 kW per capita for a population of 140 million. The annual per capita consumption of electricity in Bangladesh is estimated as 112 kW, which is available only for 18% of the population (Samrina, 2004). In comparison to the present electricity consumption, solar energy availability is a huge amount of energy. A World Bank survey reports that 500,000 households of Bangladesh may be potential market for solar home system (Sarkar et al., 2003). So, Bangladesh has a potential for solar energy.

An extensive afforestation programme in the coastal zone will increase the forest cover and act as carbon sink (Binkley et al., 2002). Mangrove plantation in the zone will be good means of coastal protection against cyclones, storm surges and soil erosion. By protecting the soil from erosion, increased mangrove afforestation will increase the plantation survival rate in the area. Hossain and Lin (2001) identified 1,929 ha and 1,895 ha suitable and moderately suitable land for mangrove afforestation in Chakoria and Cox's Bazar Sadar Upazila of Cox's Bazar district. Site suitability, provision for the second rotation crop, encroachment and insect infection are major problems for the mangrove plantation in the coastal zone (Iftekhar and Islam, 2004). If these specified problems are solved, area of mangrove forest will be increased in the coastal zone.

4.5 Analysis of soil salinity

Soil salinity of three coastal districts varied from location to location and season to season. Maximum soil salinity was observed in pre-monsoon, whereas, minimum was in monsoon in all coastal districts. It was observed that soil salinity starts increasing from post-monsoon and continued to increase pre-monsoon when it reached the highest level. Highest (1.14 dS/cm) soil salinity was measured in pre-monsoon at Shahporir Dwip (Teknaf) of Cox's Bazar district while lowest (0.82 dS/cm) was in monsoon at Alaipur union (Rupsa) of Khulna district. Highest average soil salinity in winter (1.09 dS/cm) and in pre-monsoon (1.12 dS/cm) was measured at Cox's Bazar while minimum average soil salinity in winter (1.02 dS/cm) and in pre-monsoon (1.04 dS/cm) was in Bhola (Table-4.7). Soil salinity at different sites of three coastal areas showed significant correlation with one another in winter and pre-monsoon seasons at 1% level of significance (Appendix-21).

Table-4.7: Soil salinity values (dS/cm) at nine sites of three thanas in three coastal districts during four different seasons.

Study area			Seasonal variation			
District	Thana	Location	Winter	Pre-monsoon	Monsoon	Post-monsoon
Cox's Bazar	Teknaf	Shahporir Dwip	1.09	1.14	0.89	0.95
		Sabrang	1.07	1.08	0.92	0.98
		Teknaf Beach	1.11	1.13	0.88	0.96
		Average	1.09	1.12	0.90	0.96
Bhola	Lalmohan	Janata Bazar	1.01	1.03	0.86	0.93
		Mangolshikdar	1.01	1.02	0.91	0.95
		Kamarer Khal	1.05	1.06	0.87	0.98
		Average	1.02	1.04	0.88	0.95

Khulna	Rupsa	Jabusha	1.06	1.07	0.88	0.96
		Alaipur	1.08	1.09	0.82	0.98
		Kharabad Baintala	1.07	1.09	0.89	0.99
		Average	1.07	1.08	0.86	0.98

From the findings it can be said that soil salinity depend on annual rainfall and evaporation. In monsoon, soil gets enough water and soil salinity decreases as rain water dilutes the concentration of salt in the soil. In post-monsoon, soil salinity starts to increase because of lower rainfall and higher evaporation of moisture from soil surface. Increasing soil salinity continues upto pre-monsoon when soil becomes water stress condition. My findings coincided with the finding of Karim et al. (1990), where he showed that soil salinity starts increasing from August and continued to increase until April.

DISCUSSION AND CONCLUSION

5.1 Discussion

Sea level rise is a great threat to the 40 million people of Bangladesh, who are projected to be environmental refugees. It is threatening potentially to the basic human right to the large number of population. So, Bangladesh government has to save this big population from the danger.

5.1.1 Role of Bangladesh government to reduce sea level rise impacts

Ministry of Water Resources of the Government of the People's Republic of Bangladesh has formulated a Coastal Zone Policy in 2005 that pays very little attention about sea level rise (CZPo, 2005).

Article'c' of the section 4.8.3 of the policy expresses 'efforts shall be made to continuously maintain sea-dykes along the coastline as first line of defense against predicted sea-level rise'. Article'd' of the same section tells, 'an institutional framework for monitoring/detecting sea level rise shall be made and a contingency plans for coping with its impact.'

However, the policy doesn't explain how the dykes will be made. It doesn't discuss the possible environmental impacts of the proposed dykes too. The policy wants an institutional framework that will monitor sea level rise and will have contingency plans for coping. But it doesn't say how the contingency plan will be made. It doesn't tell anything about mitigation plan of the problem. Government should have an integrated policy to save its large number of population that is going to be affected by the anticipated rise in the sea level.

For adaptation, the government should take initiatives to improve irrigation efficiency, runoff management, and agricultural productivity and to promote risk management to compensate loss in agriculture.

Government should develop and promote the use of hybrids and to develop infrastructure for post harvest management, marketing and agribusiness (IPCC, 2001a). IRRC (2003) concluded, BRRI Hybrid Dhan-1 variety showed 0.5 to 1.0 ton/ha yielded over that of other rice varieties, produced in Bangladesh.

Farmers of the coastal zone should be provided free agricultural education and necessary support for its modification to adjust with sea level rise situation.

Introduction of salinity tolerate species for agriculture, fisheries and forest resources is the best adaptation option for the coastal zone. Bangladesh Rice Research Institute (BRRI) can conduct research to develop salinity tolerate species whereas Bangladesh Agricultural Research Council (BARC) could be engaged to develop salinity tolerate species of other agricultural crops.

Bangladesh Agricultural Research Institute (BARI) has found that using raised beds, mulches, and drip irrigation; it is possible to grow high value horticultural crops like tomato, chilli, watermelon and cucumber in saline soils of 4.5 to 11.0 dS/m (Rashid and Islam, 2007).

Department of Agricultural Extension (DAE) of Ministry of Agriculture (MoA) could be involved to disseminate new species and its cultural techniques. Bangladesh Forest Research Institute (BFRI) could be engaged to develop salinity tolerate species of wood plant species like mangrove.

Mass media communication could be used to disseminate new ideas about SLR. Bangladesh Betar (radio) and Bangladesh Television can play the role.

Sea level rise affected people could be resettled in cluster village method with some adjustments. Accreted land or government abundant land could be used for the settlement of the affected people. It should be taken into account that new village have a safe distance that should be one kilometer minimum from existing population settings. Besides housing and sanitation facilities, there should be sufficient agricultural land, open water for fisheries or other means of subsistence. The houses and the land should be registered against the settler families.

To raise the income of the settlers, they should be facilitated with micro-finance programmes, to create job opportunities in the village. An NGO that has wide experience in micro-credit should be involved with the process. Seed money for the micro-finance programme should come from government and handled by the NGO. After the targeted time period, the NGO will recover the money from the settler. When the settler will enter into the micro finance activities, there will be flow of money that will create job opportunities for the settlers.

As Bangladesh is the densely populated country in the world, relocation of coastal people to the landward part is not possible because of land unavailability. So, local level management of sea level rise impacts is the first priority. For the purpose, coastal zone should be protected where it is environmentally viable. Where protection is not possible, attention should be put for a better management of the area.

For the normal functioning of sluice gates, necessary sluice gates should be constructed on the existing polders to facilitate drainage systems. The areas that are not protected by dykes in the central and eastern coastal zone should be protected by dyke construction with adequate drainage facilities and necessary Environmental Impacts Assessment (EIA). However, the western coastal zone couldn’t be protected by dyke construction because of the presence of the Sundarban mangrove forest that requires an interface between land and sea.

Lessons should be taken from other countries in the world that have shown great success to handle the problem. The Netherlands is the pioneer nation to control the sea and thus saved the country. Though there are differences between the two countries in terms of environmental settings, technical knowledge and financial resources, Bangladesh can take lessons from the country to handle the upcoming misfortune carefully.

Finance is an important issue for Bangladesh to adapt with sea level rise impacts. To increase domestic financial resources for adaptation purposes, government should raise funds from the coastal zone sources. Coastal fisheries, coastal agriculture, salt industries, wood collectors, honey collectors and coastal tour operators are completely dependent on the zone. These business groups should play important role for the adaptation to sea level rise as these sectors are in great threat by the impacts. These business groups should pay a disaster preparedness tax that will be used to adapt with the impacts.

Frozen food is the second largest foreign exchange earners sector of Bangladesh. Shrimp hatcheries, shrimp ponds and shrimp processing plants are located in the coastal zone. The shrimp industry should pay an added tax that will be invested in adaptation process. Government provide license to coastal fishermen to fishing in the coastal zone, timber businessmen to collect wood from the Sundarban and honey collectors to collect honey from the same forest, for a period of one year. A fixed amount of license fee should be saved and used for the adaptation of sea level rise.

As Bangladesh is salt producing country, price of salt is very cheap here, which is roughly to an amount of US$0.08 per kilogram. The price of the salt should be raised a little bit and money saved by this economic instrument should be used for the adaptation of sea level rise. However, salt is an everyday essential food material and has high influence on public opinion. To save the salt industry from sea level rise impacts, a lower raise in the price of salt should be accepted morally. Ministry of Industry can collect the money from salt sector.

The projected sea level rise will destroy the Sundarban completely and affect Cox's Bazar partly. The tourism sector should contribute to adaptation cost as their existence is under threat by it. Tourism service organizations or unit should pay a specific tax for the job. The tax could be collected from the organizations that are getting new license or renewing them. A certain portion of the license fee should be used for sea level rise adaptation.

For mitigation, government should take initiatives to stop deforestation and control the use of fossil fuel to reduce greenhouse gas emission and to rehabilitate degraded forests and watershed (IPCC, 2001a).

A study (Anon, 1999; cited in Iftekhar and Islam, 2004) reports that Bangladesh has 18% of the land designated as forest but the actual coverage is less than 7%, and these remnants are further disappearing at a rate of 90 km^2 per year. The country should arrest its deforestation and take measures for plantation to maximize carbon dioxide sink.

However, the government of Bangladesh claimed that the country had 9% forest cover in 1990 and was upgraded to 10.2% by the year 2000 (GoB and UN, 2005). As part of indicator proportion of land area covered by forest of target 9 of goal 7 of the Millennium development Goals, Bangladesh should have 20% forest cover by 2015. The country should put strong efforts into achieving the specified target.

The government of Bangladesh can take initiative to form a forum with the countries of common field of interest that are highly vulnerable to SLR and raise world voice for global justice against greenhouse gas emissions. The forum will work independently and with international organizations (e.g. IPCC, UNEP) to formulate a policy to press USA and high emitting countries for mitigation target and implement it. The government should lobby to international community for implementing Kyoto Protocol of UNFCCC (1997) and for necessary support of technical and financial issues.

5.1.2 Role of the international community

The 1997 Kyoto Protocol strengthens the UN Framework Convention on Climate Change agreed at Rio in 1992 by committing developed countries to reduce their collective emissions of six key greenhouses gases by at least 5% below 1990 levels throughout the 2008-2012 periods. The EU, Switzerland, most central/ east European states need to decrease 8%; the USA needs to decrease 7%; Canada, Hungry, Japan and Poland need to decrease 6%, of their emission, to reach the target. Although the USA subsequently rejected the protocol, 178 countries eventually reached a binding agreement for its implementation at Bonn in July 2001 (Carter, 2001). The USA's recent offer of a 17% reduction of GHG by 2020 from a baseline of 2005 does not deceive the world. This is equivalent to less than 5% reduction form 1990

level. This basically means that USA intends to achieve the Kyoto target of 5% reduction of 2012 by 2025.However, European Union committed to reduce 20% by 2020 from the baseline of 1990.
Global carbon dioxide emission was reduced only 1.7% from 1990 to 1998 (UN, 2005). Section 1, Article 3 of Kyoto Protocol set the emission target as reducing their (Annex B countries) overall emissions of such gases (CO_2 and other GHGs) by at least 5 percent below 1990 levels in the commitment period 2008 to 2012. It is too early to comment about the emission cut of greenhouse gases. But CO_2 emission reduction of 1.7 % is too small figure comparatively to the target.

The Copenhagen Accord (COP-15) highlighted the fact that increase in global temperature should be below 2^0C by the end of the century. Emphasis was given to adaptation and mitigation measures of adverse effect of climate change. As a binding commitment developed countries should come forward to raise fund and distribute among least countries and who are the worse sufferer.

Copenhagen accord stated that developed countries would raise funds of $30 billion from 2010-2012. It also set a goal for the world to raise $100 billion per year by 2020, from a wide variety of sources, to help developing countries cut carbon emissions (mitigation).

Failure to reach the CO_2 emission target will increase the possibility of global warming that will affect positively on sea level rise. All the countries, including the USA should follow the Kyoto protocol to solve the global climate change problems, as well as sea level rise problems of Bangladesh.

The UN agencies and other International Development Agencies should help the country to meet the challenges of sea level rise impacts. Most of the international development organization including ADB, UNDP, SIDA, CIDA, CARE (International), USAID, World Bank, JICA, Oxfam (GB) are operating various development activities in the country. The organizations should integrate the sea level rise impacts on Bangladesh in their development activities in the country.

Besides international organizations, developed countries should step forward to mitigate sea level rise impacts and to formulate and implicate adaptation policies for the nation, as Bangladesh is not responsible to create the problems. The GHG emitter countries are responsible for the problem in fact. It is their moral responsibility to be attentive to solve the problems.

Bangladesh deserves cooperation from developed countries to meet SLR impact cost. If Bangladesh totally stops the emissions all at a sudden, the problem will remain in the same degree. Cooperation from international development organizations and developed countries should be financial, as well as technical. The entire scientific communities should come forward to face this challenge, providing technical knowledge and support to minimize foresee impacts of sea level rise and thus save Bangladesh and its great population of almost 140 million.

Conclusion

Climate change and sea level rise are on the verge of a tipping point. The consequences of climate change and sea level rise are dire and they are already taking place. Floods are getting more common, storms are getting tougher, and land droughts are getting longer. The melting of the ice caps in Greenland and the Arctic is picking up pace and sea levels are rising. The habitats of plants and animals are threatened, and food production is under pressure.

Climate change and sea level rise impacts are really high for Bangladesh, though the country plays very little role in greenhouse gas emissions, leading to climate change and sea level rise. By affecting different livelihood activities and important ecosystem of the country, sea level rise imposes a great threat to the existence of Bangladesh. Therefore, Bangladesh government need to pay keen attention to the issue and should develop strategy to combat sea level rise impacts and thus safe its citizen.

It will not be wise to think that sea level will not rise at all, or to wait to see what happen in future. So, development and implementation of adaptation policies and taking initiatives for mitigation measures are the right ways to respond to sea level rise impacts. It deserves research to find the solutions of the potential problems, in practice and to develop salinity tolerant species for agriculture and fisheries sectors.

Cyclone shelter centres construction plan and necessary steps to resettle the potential disaster affected people should be initiated. The coastal protection activities should be done with sufficient drainage facilities. Adaptation cost should be recovered from coastal resources using economic instruments. Research also needs to find out the way to save the country's wide range of biodiversity, threatened by the upcoming event.

If Bangladesh stops its total CO_2 emissions at once, the problem will remain at the same extent, because it is an outcome of excess GHG emitting countries. Helps of the international communities are necessary for technical and financial supports to combat the impacts of sea level rise on the country. Helps of technical experts and international development organizations are also essential. Bangladesh is not self-sufficient to face such a large scale problem, either. So, global initiative should be taken to save the country, as it is a global problem, to a greater extent.

Adaptation and mitigation are two options for Bangladesh. Of which, the first one is country specific, or even local specific, but mitigation demands collective efforts of global communities. Development of adaptation policies for different sectors will help Bangladesh to face the crucial natural and anthropogenic hazards. Proper mitigation plan and formulating adaptation policies are emerging need to minimize the impacts of climate change, sea level rise, floods and cyclones on the country.

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