Tropical Cyclones: Impact on Coastal Livelihoods

Investigation of the Coastal Inhabitants of Bangladesh

Bangladesh Country Office

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PREFACE

IUCN Bangladesh has been implementing the 'Promotion of Adaptation to Climate Change and Climate Variability Project' in the Noakhali Sadar and Subarnachar upazilas under the Netherlands Climate Assistance Programme (NCAP) Phase II. One of the objectives of NCAP is to build capacity for participating countries to mainstream climate change into development planning, which focuses on creating enabling conditions for promoting adaptation to climate change and climate variability in national policies and plans, and also at the community level.

Agriculture and fisheries are the major drivers of development in the coastal regions of Noakhali, although manifestations of climate change such as enhanced cyclonic trends pose as a major threat. In the event of climate change, there will be more and more damages to agriculture, fisheries and infrastructures aggravating further the fragile livelihoods of coastal inhabitants.

The current study was conducted using available data and information from various sources, fortified with adequate survey of literature, web search and consultations. It was revealed that for tropical cyclones occurring in the Bay of Bengal over the past 131 years, a total of 539 tropical cyclones were formed during that period. On an average, 4.1 tropical cyclones were formed per year of which 1.7 belong to intensive category, with wind speed greater than 88km/hour.

The tropical cyclones and associated storm surges have great impact on the life, property and economy of the coastal region and in particular crop and fisheries sectors. The increased frequency of more intensive cyclones and shorter return periods is a warning for the coastal zone.

We are indebted to Disaster Management Bureau, Bangladesh Meteorological Department, Bangladesh Agriculture Research Council, Space Research and Remote Sensing Organization for providing us with valuable information and time series data.

IUCN Bangladesh gratefully acknowledges the financial support received from the Netherlands Climate Assistance Programme through ETC International, Netherlands for supporting the 'Promotion of Adaptation to Climate Change and Climate Variability Project' in Bangladesh and publication of this report. In particular, we recognize the support of Ian Tellam and Bram Truijen of ETC Netherlands. I would also like to take this opportunity to thank Mr. Rakibul Haque, Mr. Raquibul Amin, Ms. Remeen Firoz, Sheikh Asaduzzaman and Ms. Eshrat Sharmen Akand who worked for this project and made this publication possible.

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ABBREVIATIONS

BARC	:	Bangladesh Agriculture Research Council
BDT	:	Bangladesh Taka
BMD	:	Bangladesh Meteorological Department
CDC	:	Climate Diagnostics Center
CS	:	Cyclonic Storms
D	:	Depression
DMB	:	Disaster Management Bureau
DoF	:	Department of Fisheries
FAO	:	Food and Agriculture Organization
FGD	:	Focus Group Discussion
GBM	:	Ganges Brahmaputra Meghna
GMT	:	Greenwich Mean Time
ICZM	:	Integrated Coastal Zone Management
IPCC	:	Intergovernmental Panel on Climate Change
IUCN	:	International Union for Conservation of Nature
KPH	:	Kilometer Per Hour
LGP	:	Length of Growing Period
MPH	:	Miles Per Hour
MSWS	:	Maximum Sustained Wind Speed
NCEP	:	National Center for Environmental Prediction
NOAA	:	National Oceanic and Atmospheric Administration
PRSP	:	Poverty Reduction Strategy Paper
R&D	:	Research and Development
SCS	:	Severe Cyclonic Storms
SCS-H	:	Severe Cyclonic Storms-Hurricane
SLR	:	Sea Level Rise
SMRC	:	SAARC Meteorological Research Center
SPARRSO	:	Space Research and Remote Sensing Organization
SRDI	:	Soil Resource Development Institute
SST	:	Sea Surface Temperature
SWC	:	Storm Warning Center
ToR	:	Terms of Reference

Chapter 1
EXECUTIVE SUMMARY

The coastal zone of Bangladesh is highly prone to disasters, particularly tropical cyclones and storm surges. Erosion, flood, drought, frequent inundation by high tide are other common hazards causing severe loss of live and property, with adverse impact on agriculture and fisheries sector. The extreme weather patterns in the coastal zone that includes the variability and trend of higher surface air temperature, sea surface temperature (SST), rainfall and wind speed during the monsoon season and most importantly the tropical disturbances (low pressure systems: depressions and cyclones) have adverse impacts not only on the resources, environment and infrastructures but also on the livelihood of the coastal inhabitants. The human casualties of the cyclones of 12 November 1970, 29 April 1991 and 15 November 2007 were 300000, 138882 and 3363 respectively due to the rampages of these killer cyclones. With the change in climate and observed increase in the frequency of severe cyclonic storms, majority of the coastal poor are going to suffer manifold with respect to their income and livelihood.

The effect of tropical cyclones and storm surges are severe; the agriculture and the fisheries sector suffer most. Among the major occupational groups in the coastal zone, agricultural labourers (25.1%) have the highest poverty incidence followed by the small farmers and fishers. This is attributed to low level of land productivity, incidence of cyclones and other extreme climatic events, low wage rate, uncertainty and scanty employment opportunity during 'risk days' (with warning signal number 3 and higher). The situation is going from bad to worse, because of increasing frequency of natural hazards and declining land and its productivity.

The current study 'Tropical Cyclones: Impacts on Coastal Livelihoods' was conducted using the available data and information from various sources, namely BMD, DMB, BARC and SPARRSO. In addition, adequate survey of literature, search of information in the web and consultation with knowledgeable sources were done. It was found that for the tropical cyclones of the Bay of Bengal for 131 years (1877-2007), a total of 539 tropical cyclones were formed during that period. On an average 4.1 tropical cyclones were formed per year of which 1.7 belongs to intensive categories with wind speed greater than 88 km/hour.

The analysis of the data for the last 38 years from 1970-2007

The analysis of the data for the last 38 years from 1970-2007 shows that the average number of tropical cyclones formed during this period was 3.13 per year, which is much smaller than 131 year average. This indicates decrease of tropical cyclone frequency in later time slab. The tropical disturbances formed in the Bay of Bengal have been categorized in our report as depressions (D), cyclonic storms (CS), severe cyclonic storms (SCS), and severe cyclonic storms with hurricane intensity (SCS-H) based on the maximum sustainable wind speed of the disturbances.

The tropical cyclones that hit the Bangladesh coast during the period of 48 years (1960-2007) have been compiled and the collated information on their formation, landfall point and date, duration, categories, wind speed, storm surges, human casualties and loss of assets and damages incurred are provided. It has been found that during this period , a total of 56 tropical cyclones hit the coast of Bangladesh of which 48.2 % are very strong cyclones (SCS-H), 17.9% are severe cyclonic storms (SCS) and the rests are CS. The analysis indicates that, the storm surge heights are dependent on the wind speed of the cyclones and landfall points. When the cyclones have the landfall in the eastern part of the coast, i.e. in the Meghna estuary and Chittagong-Cox's Bazar, the surge heights were high and reached up to 10-13 meter and when the storms hit the western part of the coast, the storm surge heights were lower. Interpretation of the cyclonic events shows that the damages and inundation of the coastal zone are strongly associated with the wind speed, wind generated storm surges and duration. The damages and inundation of the coastal zone are thus directly related to strength of the cyclone.

The time series analysis indicates that the frequency of the disturbances of all categories have been decreasing since mid-seventies except for SCS-H. The frequency of SCS-H remarkably increased from the middle of 1980s up to 2000; then the frequency drastically decreased. There were 11 cases of SCS-H from 1994-2000 (in 6 years) but not a single event of SCS-H during the 5 year period from 2001-2005. The distribution of the decadal total frequency of SCS-H for 1974-1983, 1984-1993 and 1994-2003 shows that the decadal frequency has increased. This indicates the apparent positive relationship of the frequency of SCS-H with SST, which has been found to increase by 0.47°C during the past half century. This means while the frequencies of D, CS and SCS are decreasing, the very intensive tropical cyclones (SCS-H) is increasing. It has further been seen that the return period of the most intensive tropical cyclones has decreased during the past 4 decades.

The annual rainfall over the coastal zone shows increasing trend for 7 stations. Bhola and Chittagong show a negative trend. The rainfall of the winter and pre-monsoon seasons were found to have increasing trend for all the stations except Bhola. The monsoon and post-monsoon rainfall shows increasing trend in some stations and decreasing trend in others.

The study investigated the status of climate change influencing cyclonic behaviors over the coastal zone of Bangladesh. The analysis of maximum and minimum temperature of 9 stations of the coastal zone using the data of maximum 56 years (1951-2006) shows significant warming trend of the air temperature within the range of 0.1-0.4°C/decade. The data for the period from 1971-2007 (36 years) show the warming trends up to 0.3-0.6°C/decade. This clearly depicts that the warming trends have accelerated in the recent decades. The Sea Surface Temperature shows an increasing trend at the rate of 0.094oC/decade. The increasing trends of SST are supposed to be responsible not only for the increased frequency of the SCS-H but also for faster and higher intensification. Under climate change situation, greater storm surges with rise in sea level are likely to inundate much larger areas of the coastal zone and disfunction the livelihood activities causing enormous loss to the agriculture, fisheries and other sectors. It is Interesting to note that about 48.2 % of the cyclones of Bangladesh are SCS-H type.

The tropical cyclones and associated storm surges have great impact on the life, property and economy of coastal Bangladesh and in particular on the crop and fisheries sector and thus on the livelihood of the coastal habitants. Under climate change induced cyclone and storm surges, with increasing frequency and quantum this effect will be enormous. As predicted, it is obvious that, with the rise of atmospheric temperature by 2° and 4°C by the year 2050 and 2100, the SST of the Bay of Bengal will also rise from the current level of > 27°C. According to the IPCC reports, global temperature rise during the last 130 years is 0.6-0.7°C. On the other hand SST over the last 100 years has increased by 0.9°C. Increased temperature means greater evaporation. Because of the rise in soil temperature, microbial activity will be higher resulting faster mineralization. Thus there will be rapid decline in organic matter content and nutrients, while proliferations of pest and disease will be more; consequence of which is decline in productivity and greater food insecurity.

Major part of the coastal livelihood is centered around agriculture followed by fisheries and thus the adverse effects, sufferings and loss in these sectors will be enormous. The variability and increasing trend of temperature and rainfall will cause enhanced droughts and severe floods affecting the crop agriculture and livelihood of the people. The increase of SST would affect the ecology of the aquatic lives and thus the fisheries and related industries and trades will suffer. Millions of people in the coast especially the small and marginal farmers and fishers will be forced to migrate to the cities. Strategy for adaptation to extreme climatic events needs to be evolved through R & D initiatives in order to sustain livelihood of the coastal inhabitants and to maintain socio-economic stability.

Land zoning by demarcation of highly saline areas for intensive shrimp farming and release of less saline area for crop agriculture ,introduction of specialized extension approach for the coastal zone development, change in land tenure system and R&D for development of salt tolerant crop cultivars (*Brridhan* 47 type), organized buffalo and sheep farming to utilize the available pasture land in the coast, investment and greater importance on marine fishery and other sea resources (e.g. shell, crab, sea weeds, corals in St. Martins) could create employment opportunity for the inhabitants and income during 'risk period' in order to maintain livelihood.

The increased frequency of more intensive tropical cyclones and shorter return period is a great warning for the coastal zone and the nation as a whole. This clearly indicates that, there is and with the change in climate – will be more and more damages to the agriculture, fisheries and infrastructures aggravating further the livelihood of the coastal inhabitants. It has been found that, most of the tropical cyclones have their landfall in the month of April-May and October-November which are the maturing period of *Boro* and *Aman* rice respectively. Thus the losses are very high adversely impacting the productivity and food security.

The information of warning signal number 3 and higher have been extracted from the BMD archive and collated in suitable form to investigate the significance of the various signals. The time series analysis of the annual total number of days with signal number 3 and higher shows that, on an average 44 days of the year remain under warning with the standard deviation of 26.4 days. The year 2007 was an unusual year with 130 days of warning. Higher duration obviously has negative impact on the coastal zone especially on the livelihood of the fishers. Further, qualitative improvement in short term forecasting and timely dissemination of disaster information and introduction of long term / seasonal forecasting for effective planning and farm management are necessary.

Peoples' involvement in strengthening community level disaster management and livelihood improvement, through social/community forestry and fishery, fish processing and similar other programs e.g. tillage equipment rental service, improved salt production, expansion and participatory maintenance of common property resources as well as greater support to the current approach of capacity building of not only the service providers but also to the service users i.e. inhabitants of the coast are absolutely crucial.

Problems in the coast are many, but because of the vastness towards land and sea, great diversity in wealth and untapped resources - the coastal zone could be one major areas of economic activity. The study has pointed out a number of steps and policy options for coping with the change and sustain livelihood activities using scientific, technological and institutional measures.

Chapter 2
BACKGROUND OF THE STUDY

The project 'Promotion of adoption to climate change and climate variability in Bangladesh', supported by the Netherlands Climate Change Assistance Program (Phase-II), primarily focuses on the vulnerability and adaptation mechanisms under changed climatic scenario of the most fragile ecosystem i.e. the coastal areas of Bangladesh. Noakhali Sadar and Shurbarno Char upazila have been selected as the project sites and several studies undertaken.

In reviewing the study results, FGD and local participants' opinion, it was felt necessary to undertake some additional activities. IUCN Bangladesh, thus proposed to execute the following two additional tasks:

a. To investigate the variability of the tropical cyclones in the coastal belt of Bangladesh

b. To study the impacts of tropical cyclones on the livelihood of the coastal inhabitants of Bangladesh

Because of the inter-relationship of these two tasks, the combined outputs as in ToR may be listed as under:

a. Identification of the events of tropical cyclones and storm surges during the last 35-40 years.

b. Review and categorization of the events by intensity and analysis of the temporal variability.

c. Investigation of the variability of air and sea temperature, wind speed, rainfall for characterizing climate change in the coastal zone.

d. Analysis of the events in relation to the early warning with particular reference to signal no. 3 for the last 15 years.

e. Analysis and interpretation of loss of assets, crops, and livelihood opportunities due to extreme climatic events.

f. Investigation of the impact of the changing patterns of climatic events with that of the livelihood of the coastal inhabitants (particularly fisheries and agriculture).

Chapter 3

INTRODUCTION

Coastal area of Bangladesh is highly prone to disasters, in particular of tropical cyclones and storm surges. Coastal erosion, flood, drought, frequent inundation by high tide are common causing severe loss of live, property and destruction of infrastructures. Because of these problems, coastal area is inhabited by little over half in terms of population density/sq. km compared to the Bangladesh average of nearly 950/sq. km. This however, is not going to remain so, as the population projections at present growth rate are 41.8 million in 2015 and 57.9 million in 2050.The large number of inhabitants in the coast are at high risk and annual displacement due to land/property loss. Coastal area of 2.85 mha in Bangladesh comprises 13 districts covering 64 upazilas of the country (Karim et al. 1990). Out of this area, 0.833 mha are salt affected. The Soil Resource Development Institute (SRDI) have redefined the salt affected coastal area based on their survey work of Upazila Nirdeshika and it is now said to be 2.36 mha distributed in 17 districts (SRDI, 2008).This means, over the years there has been greater intrusion of salinity towards inland because of storm surges, low water flow through the river system and anthropogenic activities. The ICZM (Islam, 2004) project taking into account the natural system, processes and events that govern opportunities and vulnerabilities, namely (a) tidal fluctuation (b) salinity of soil, surface/ground water and (c) cyclonic storm surge risk have delineated the coastal zone to be 4.72 mha (includes exclusive economic zone) covering 151 upazilas of 19 districts. According to their definition, 49 upazilas of 12 districts are exposed to the sea/lower estuaries and are termed as exposed coast; while the rest are interior coast.

Coastal dwellers' income is lower than the rest of the country. Among the major occupational groups, agricultural labourers (25.1%) have the highest poverty incidence followed by the small farmers and fishers. This is attributed to low level of land productivity, incidence of cyclones and other extreme climatic events, low wage rate, uncertainty and scanty employment opportunity during 'risk days'. The situation is going from bad to worse, because of increasing frequency of different natural hazards and declining land and its productivity. With the change in climate and observed increase in the frequency of severe cyclonic storms, majority of the coastal poor are going to suffer manifold with respect to their income and livelihoods; in the absence of appropriate adaptation measures.

3.1 Coastal Ecosystem

To understand and to act on the coastal livelihood, we need to have an overall picture of the fragile ecosystem of the coast, its vulnerability and especially the agricultural environment which is the prime livelihood activity of the coastal inhabitants. The area coverage of the coastal zone is shown in figure-1.

3.1.1 Agricultural Environment

Out of the 30 agroecological zones recognized in Bangladesh, 10 (in total or partial) are present in the coast. Of them, Ganges tidal floodplain, High Ganges river floodplain, Young Meghna estuarine floodplain, Low Ganges river floodplain and the Old Meghna estuarine floodplain are the dominant ones. They are saline, calcareous and in some places non- calcareous. Medium highland (flooded upto 90 cm) dominates the land types followed by highland (with flooding upto 30 cm.) closely followed by medium lowland (flooding between 90-180 cm). Generally speaking, 85% of the coastal agricultural lands are subjected to inundation of over 30 cm. annually (FAO, 1998).

In case of salinity, S2 type (4-8 dS/m) occurs in the majority parts followed by S1 (2-4 dS/m). Salinity is highest during dry winter and goes down during monsoon. The length of growing period (LGP) which is one of the important determinants of cropping varies spatially in the coast. Kharif (monsoon season: June – October) LGP ranges from 190-240 days; *rabi* (dry winter: November-February) LGP 115-145 days and the pre-kharif (pre monsoon: (March-May) LGP only 30-70 days. The average rainfall in the coastal zone varies from 1700-1900 mm in the west and 3200-3500 mm in the east. Except December and January, rainfall always exceeds evaporation. Texture of the coastal soil varies from silty clay to clay. Coastal soils are poor in organic matter and total nitrogen content, with very few exceptions. Phosphorus availability is low to very low and copper and zinc deficiency is widespread. Boron toxicity occurs sometimes in the coastal saline soils. Deep and wide cracks develop in the coastal soils on drying during rabi season, making tillage difficult with country plough. This together with the scarcity of irrigation water forces vast land areas to keep fallow during dry winter. As such rainfed transplanted *Aman* is the dominant crop but that again is prone to cyclone and storm surges. Salt injury of field crops mostly occurs at germination and early vegetative stages.

Ground water is mostly saline but surface water is not saline during monsoon and early part of rabi. The degree of salinity of the ground water however has seasonal variation. Research result indicates that, limited use of brackish water for irrigation is possible. This is an indication that, some potential exists on the use of groundwater for irrigation in a particular period of the year. Coastal embankments built for protection of storm surges and polders built for drainage and irrigation management, if rightly administered could be of great use for total agricultural development covering crop, fisheries, forestry and related others.

3.1.2 Population and livelihood

Whatever be the case, it can be said that roughly over 30% of the total land area of the country with current inhabitant of over 36 million is directly or indirectly affected by the coastal environment. Out of the total coastal population, major occupational characteristics are: 33% of the households are agricultural labourers, 25.1% small farmers and 7% of the household fishers. If the non-farm agricultural activities (over20% of the households) are combined, employment/economic activity centering on and around agriculture comes to 85%. With 65% of the households directly involved in agricultural activity, they are the one to suffer most during extreme climatic events.

3.1.3 Tropical cyclones and climate change

The coastal zone of Bangladesh is an active delta, rich in water and land resources and highly prone to tropical cyclones and associated storm surges. It has a very flat topography and is characterized by a constantly changing geomorphologic situation. The Bay of Bengal is a breeding ground for tropical cyclogenesis. The

SST higher than 26.5°C is one of the necessary preconditions for tropical cyclone formation and the Bay of Bengal maintains a temperature much higher than this critical value-throughout the year. The extreme weather patterns in the coastal zone that includes the variability and trends of surface air temperature, SST, sea level, rainfall and wind speed during the monsoon season and most importantly the tropical disturbances (low pressure systems: depressions, and cyclones) have adverse impacts not only on the livelihood of the coastal inhabitants, but cause the death of millions and damages to the environment, infrastructures and resources. The human casualties of the cyclones of 12 November 1970, 29 April 1991 and 15 November 2007 were 300000, 138882 and 3363 respectively due to the rampages of these killer cyclones. The shocks of these losses in the economy and livelihood are irreparable and take a long time to settle the victims back to normal life. The climate change due to global warming is a matter of big concern especially for the coastal zone of Bangladesh, because of likely increase in frequency and intensity of the tropical cyclones and enhancement of the storm surges and sea level rise in the warmer conditions of the ocean and atmosphere. Some studies have reported that the temperature of Bangladesh has the increasing trends of about 0.1-0.3°C /decade for most part of the country during the last 3-4 decades and the rainfall is also increasing except for a few stations in the southeastern Bangladesh (Quadir et al. 2004, Choudhury, et al, 2003, 2005). Some impacts of these climate changes are already visible. In this study more detail investigation is conducted on the variability of the tropical cyclones and its impacts on agriculture, fisheries and livelihood of the coastal inhabitants of Bangladesh.

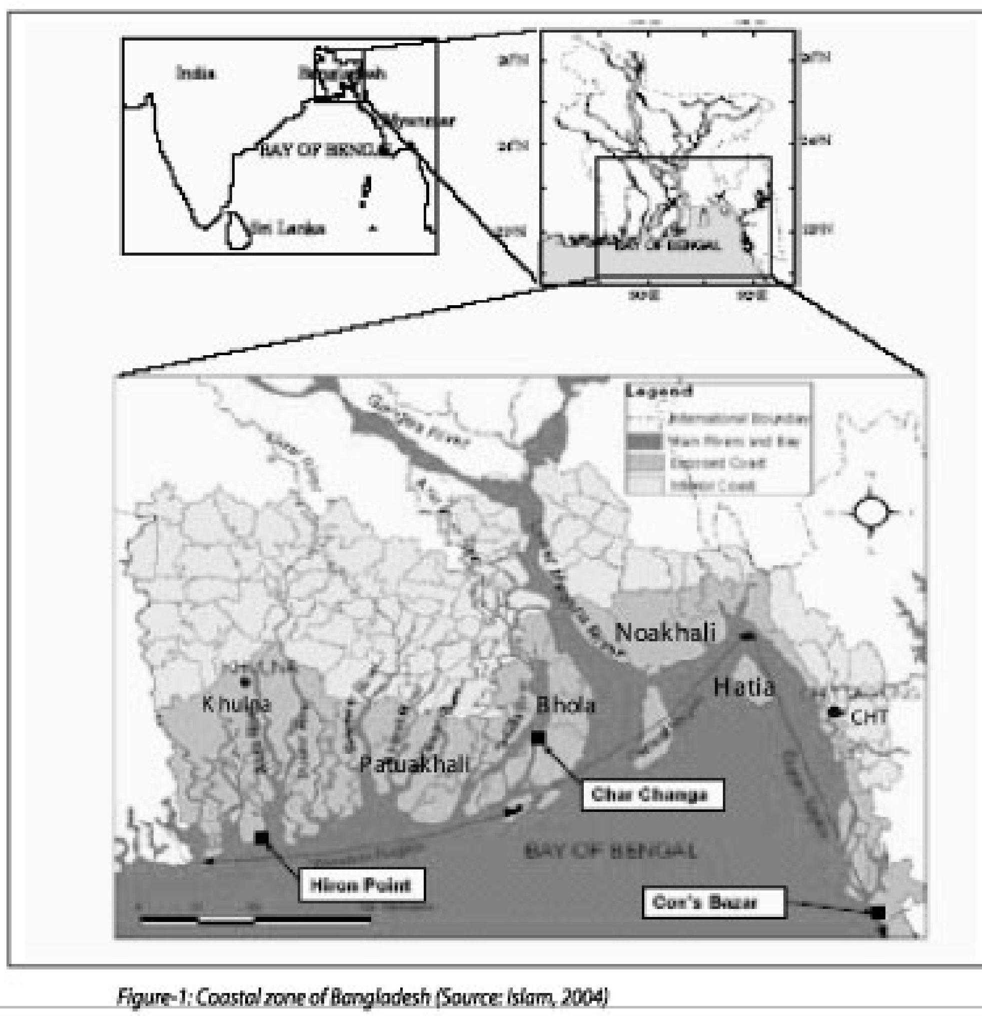


Figure-1: Coastal zone of Bangladesh (Source: Islam, 2004)

Chapter 4

TROPICAL CYCLONES OF THE BAY OF BENGAL

The tropical cyclone is the deadliest atmospheric system that originates in the warm tropical oceans as low pressure system and causes huge loss of lives and properties and damage to environment and ecology with its strong wind force and associated storm surges within its command area of about 500-1000 km diameter. The tropical cyclone has the wind speed higher than 62 km/hr near the surface; the speed can reach up to 300 km/hr for a very intense tropical cyclone. The Bay of Bengal is one of the most vulnerable basins of the world-ocean for tropical cyclogenesis. According to Gray (1975) about 80 tropical cyclones are formed over the world's water every year of which the north Indian Ocean get 6% and the Bay of Bengal shares about 5%. The share of Bay of Bengal may seem to be low, but severity of impacts and damages to life and property are immeasurable.

In an assessment of the tropical cyclones of the Bay of Bengal for the period of 131 years (1877-2007), it is found that a total of 539 tropical cyclones were formed during that period. On an average 4.1 tropical cyclones are formed per year of which 1.7 belongs to intensive categories with wind speed greater than 88 km/hour. In Bangladesh the cyclonic disturbances of the Bay of Bengal are classified into 7 categories based on the maximum sustainable wind (table 1). The categories 1-4 are pre-cyclone stages of the cyclonic disturbances. The tropical cyclone categories begin from the serial no. 5 which are: cyclonic storms (maximum wind speed 62-88 km/hr), severe cyclonic storms (88<maximum wind speed <118 km/hr) and severe cyclonic storm with hurricane intensity (maximum sustainable wind speed 118 km/hr). A classification with the nomenclature of Super Cyclones are used for tropical cyclones having wind speed 220 km/hr but has not been officially introduced by BMD.

Table-1: Classification of tropical cyclones for Bangladesh (Karmakar, 1999)

Sr. No.	Types of disturbances	Wind speed (km/hr)
1	Low (L)	<31
2	Well-marked low(WL)	31-40
3	Depression (D)	40-50
4	Deep Depression (DD)	51-61
5	Cyclonic Storm (CS)	62-88
6	Severe Cyclonic Storm (SCS)	89-117
7	Severe Cyclonic Storm of hurricane intensity (SCS-H)	>117

Note: *In the subsequent analysis Depression and Deep Depression are considered together as the category of Depression (wind speed 40-61 km/hr)*

One of the most important linked features of the tropical cyclone is the storm surges, which is responsible for most of the damages caused by the tropical cyclones. The major factor responsible for the generation of storm surge is the wind stress on the sea surface. The surge heights may go up to 10-13 meters in the Bangladesh coast. The surge waves rush inland with enormous force and wash every thing in its path. The storm surge is relatively high for the coast of Bangladesh compared to the other cyclone affected areas of the region because of the characteristic funnel shape of the Meghna estuary and shallow bathymetry of the continental shelf. The high astronomical tide exacerbates the situation further, if the landfall time of the tropical cyclones coincides with the timing of high tide. In the same way, the low astronomical tide would ease the situation to some extent. In fact for the high tide condition, the storm surge height is added with the tidal height causing a very high water wave entering inlands. But in the low astronomical tide resultant surge will be lower than that for a high tide or normal tide conditions. The Bangladesh coastal zone is characterized by shallow topography; as a result the storm surge can enter a long way inland.

4.1 Categorization of the cyclonic events and temporal variability

The tropical disturbances formed in the Bay of Bengal during the period of 38 years from 1970-2007 have been categorized in our report as depressions (D), cyclonic storms (CS), severe cyclonic storms (SCS), and severe cyclonic storms with hurricane intensity (SCS-H) based on the maximum sustainable wind speed of the disturbances following the classification provided in table-1. The categorized time series of the cyclonic disturbances along with the number of days of disturbances have been shown in table-2. The number of days with tropical disturbances has also been shown on yearly basis in this table. The data from 1970-2007 were obtained from the archives of BMD and suitably collated for various analysis.

Table-2: The tropical disturbances formed in the Bay of Bengal desegregated according to their intensity levels

Year	D	CS	SCS	SCS-H	SCS+SCS-H	Total	No of days with Disturbances
1970	9	1	*	*	3	13	
1971	3	0	*	*	5	8	
1972	6	2	*	*	5	13	
1973	7	0	*	*	4	11	Not Available
1974	8	2	0	1	1	11	25
1975	11	2	1	1	2	15	42
1976	4	5	2	0	2	11	32
1977	7	3	1	1	2	12	38
1978	4	3	1	1	2	9	36
1979	8	0	1	1	2	10	33
1980	4	2	1	0	1	7	23
1981	6	3	1	1	2	11	37
1982	6	0	3	1	4	10	25
1983	4	0	2	0	2	6	12
1984	2	0	1	2	3	5	16

1985	1	2	2	0	2	5	13
1986	3	0	0	0	0	3	5
1987	2	1	2	1	3	6	22
1988	1	0	1	1	2	3	13
1989	6	0	0	2	2	8	26
1990	6	0	1	1	2	8	22
1991	6	2	1	0	1	9	25
1992	3	2	0	1	1	6	21
1993	3	0	1	0	1	4	7
1994	1	1	0	1	1	3	8
1995	3	0	0	2	2	5	13
1996	2	4	1	1	2	8	24
1997	6	1	0	2	2	9	23
1998	3	1	0	2	2	6	16
1999	1	0	0	2	2	3	10
2000	1	3	0	1	1	5	24
2001	4	1	0	0	0	5	11
2002	2	2	0	0	0	4	13
2003	4	1	1	0	1	6	22
2004	1	1	0	0	0	2	7
2005	4	4	0	0	0	8	33
2006	7	0	0	1	1	8	19
2007	7	1	0	1	1	9	20

*D: Depression, CS: Cyclonic Storm, SCS: Severe Cyclonic Storms and SCS-H: Severe Cyclonic Storms with Hurricane intensity, Total=D+CS+SCS+SCS-H, *Indicates that the SCS and SCS-H were not available as individual categories for those years.*

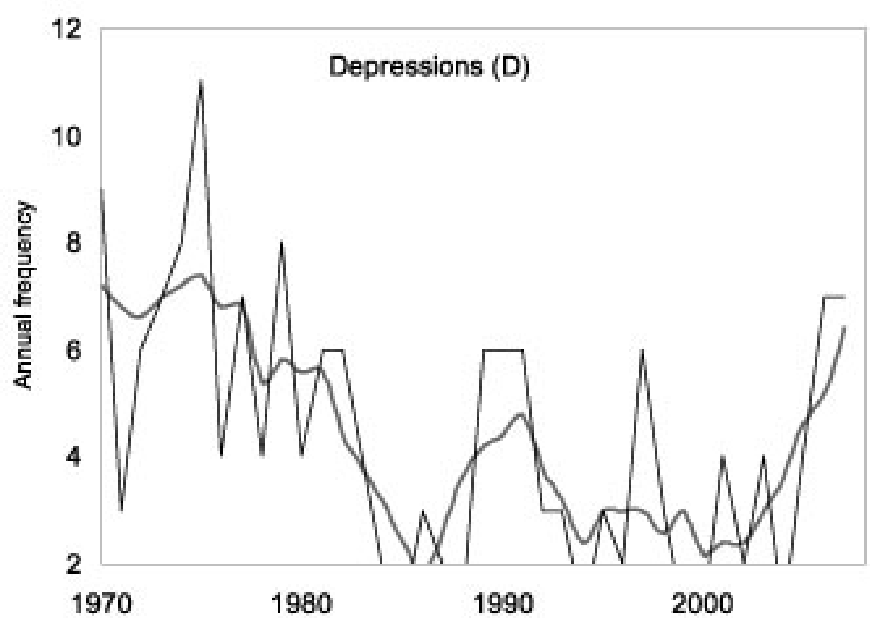
The sum, mean and standard deviation for the individual categories of the disturbances have been calculated and shown in table-3. On an average 3.13 tropical cyclones were formed per year during last 40 years; this is lower than 131 year average, which is 4.1 as mentioned in section 2.0. This clearly depicts that the frequency of tropical cyclones have decreased in the last 3-4 decades.

Table-3: Sum, mean and standard deviation of the frequency of tropical disturbances (1970-2007)

Categories of TC	Total frequency	Mean	Std.
D	141	4.15	2.50
CS	50	1.32	1.36
SCS (1974-2007)	24	0.71	0.80
SCS-H (1974-2007)	28	0.82	0.72
SCS+SCS-H	69	1.82	1.25
CS+SCS+SCS-H	119	3.13	1.65
All cyclonic disturbances	240	7.06	3.05

The time series plots of the annual frequency of D, CS, SCS-H and the smoothed time series with a 5 year moving average have been shown in figures [2 and 3]. The figures clearly demonstrate that the frequency of the disturbances of all categories is decreasing since mid seventies except for SCS-H. The frequency of severe cyclonic storms (SCS) maintained relatively high values up to 1987 (Figure 3-upper panel). Thereafter the frequency decreased to very low values. In 18 years from 1989-2007, there were only 5 events of SCS. Not a single event of SCS from 1997-2002 (six years) is observed. The frequency of SCS-H is found to remarkably increase from the middle of 1980s up to 2000; then the frequency drastically decreased (figure 3-lower panel). There were 11 cases of SCS-H from 1994-2000 (in 6 years) but not a single event of SCS-H during the 5 year period from 2001-2005.

The distribution of the decadal total frequency of SCS-H for 1974-1983, 1984-1993 and 1994-2003 (Figure 4) shows that the decadal frequency has increased; this indicates the apparent positive relationship of the frequency of SCS-H with SST, which has been found to increase by 0.47°C during the past half century. This means while the frequency of D, CS and SCS is decreasing, the very intensive tropical cyclones (SCS-H) are increasing. Further investigations are needed to explore why the frequency of SCS-H came down to record lowest level in the twenties.



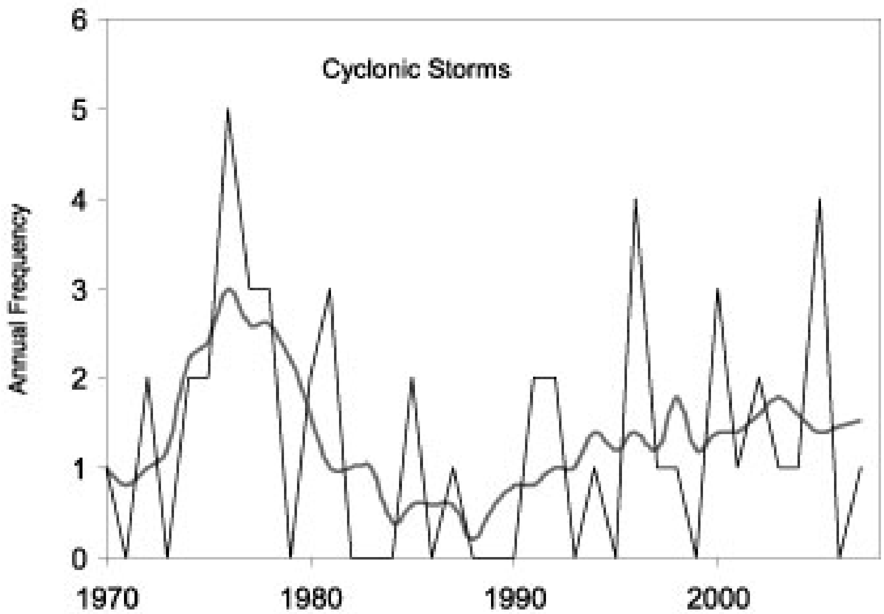
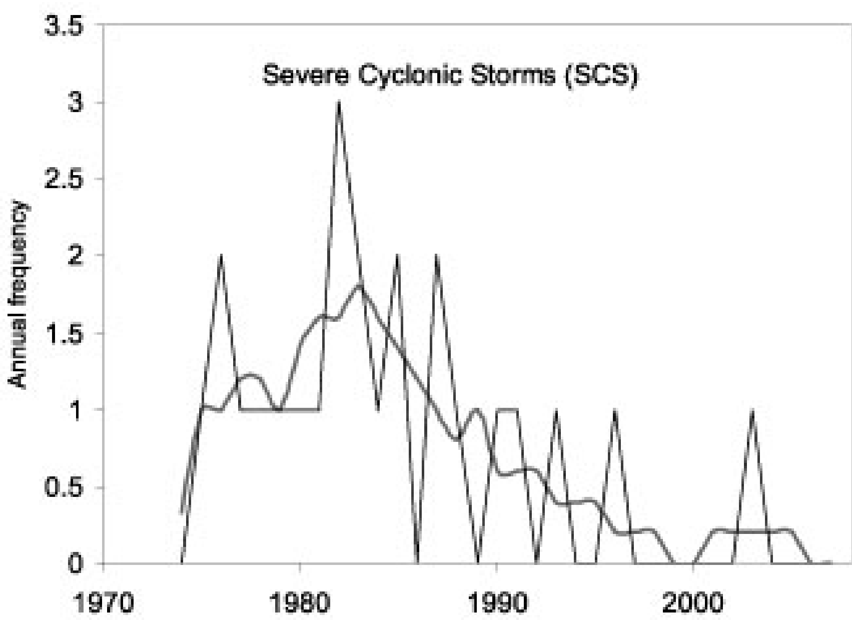


Figure - 2: The time series plots of the frequency of Depression (D) and Cyclonic Storms (CS) overlaid with the 5 year moving average.



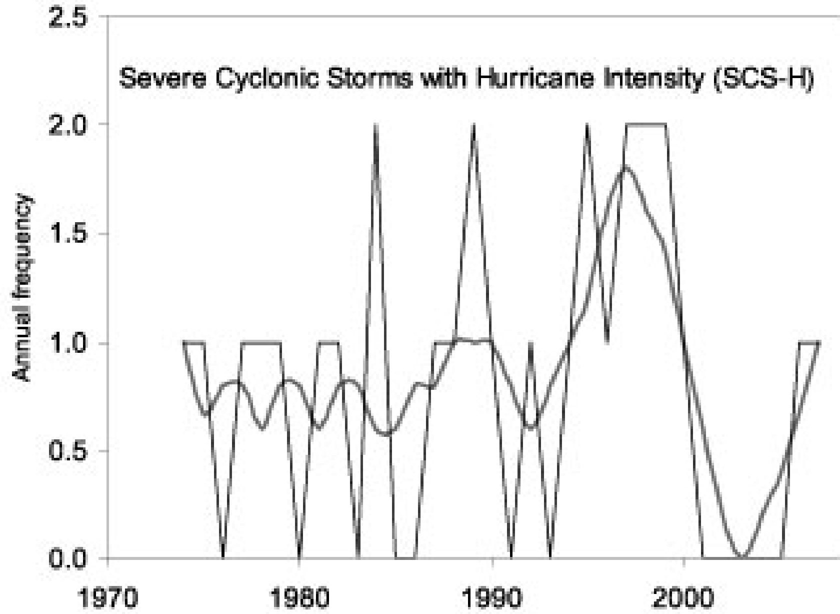


Figure - 3: The time series plots of SCS – upper panel and SCS-H – lower panel overlaid with the 5 year moving average of the respective frequencies. The data of 1970-1973 could not be plotted due to unavailability.

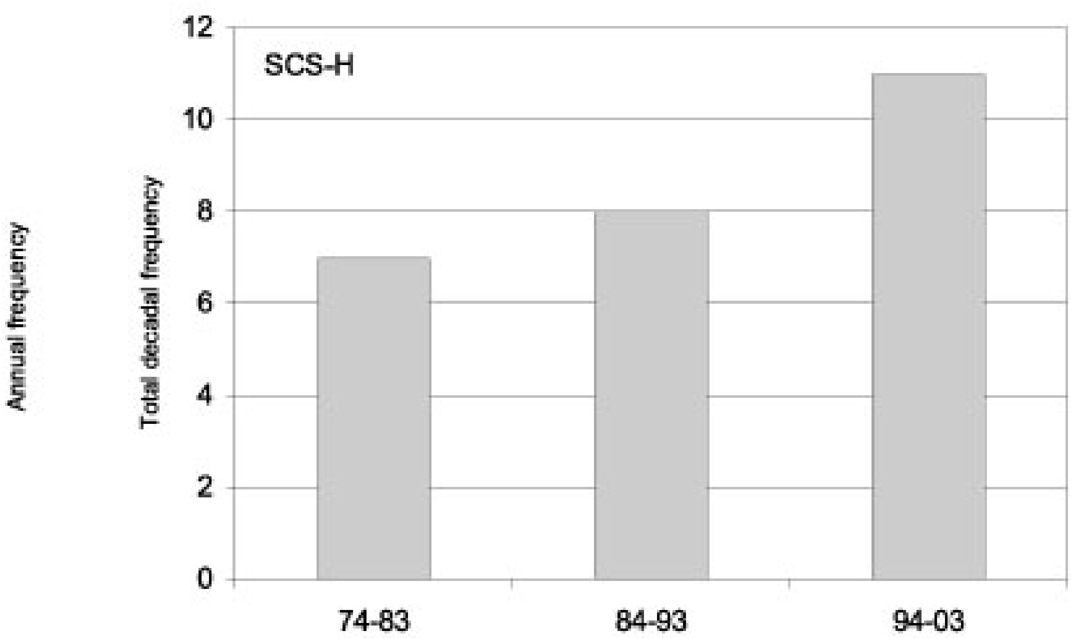


Figure - 4: Decadal frequency of severe cyclonic storm with hurricane intensity (SCS-H). The data of 1970-1973 are not available.

The 5 deadliest tropical cyclones (super cyclones) of the Bay of Bengal have been shown in table 4 of which one was formed in 1876 and is known as Great Bakergonj Cyclone and the other 4 had developed within the last 38 years. One is the 12 November, 1970 cyclone which hit Bhola coast of Bangladesh and had the return period of 94 years, another one is the 30 April, 1991 cyclone that hit the Noakhali-Chattagong coast and had the return period of 21 years and the other is the 29 October, 1999 cyclone that hit the Orissa coast and had the return period of 8 years.

Table 4: Tropical cyclones of Bay of Bengal with super cyclonic intensity (wind speed 220 km/hr) and their characteristics

Year of incidence	Date of Occurrence and coast of landfall	Maximum wind speed (km/hr)	Storm Surges (m)	Return period (years)
1876*	1 November Bakergonj (Meghna estuary), Bangladesh	220	13.6	-
1970	12 November, Bhola, Bangladesh	224	10	94
1991	31 April, Noakhali-Chittagong, Bangladesh	235	8.8	21
1999	29 October, Orissa coast, India	225	7.8	8
2007	15 November Sundarban-Patuakhali, Bangladesh	240-250	68	

** The great Bakergonj cyclone; about 200,000 people died (100,000 by drowning and 100,000 by post-cyclone hunger)*

The last one is the Sidr, which hit the coast of Sundarban-Patuakhali on 15 November 2007 and had the return period of 8 years again. This indicates that the number of highly intensive tropical cyclones has increased in the past 4 decades and their return period has decreased.

The figure 5 shows the plots of the data of the annual frequency of the tropical disturbances along with total duration of these cyclonic disturbances (in days) per year. It is seen that the annual total duration is well correlated with the annual frequency of the tropical disturbances. The average annual frequency of the tropical disturbances was found to be 7.24 and the annual average duration of the individual disturbances was around 3 days. It is seen that the frequency of the disturbances and their duration has decreased drastically since 1983. The average annual frequency of the disturbances was about 11 and the annual average duration was 32.3 days during the period 1974-1982. During 1983 to 2007 the average frequency was found to be 5.9 with average duration of 17days. This means the average annual frequency of the tropical disturbances and the average annual duration during this slab became almost half of those in the earlier slab.

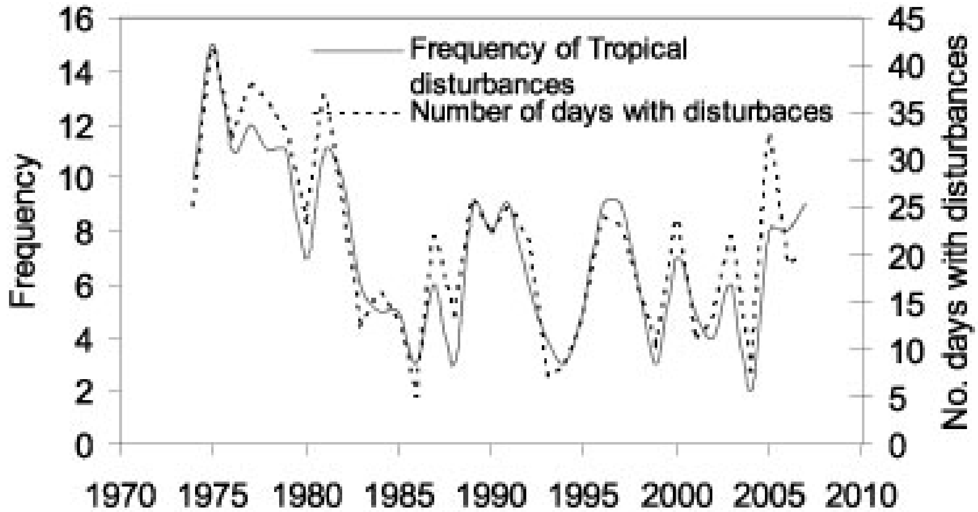


Figure - 5: The time series plots of tropical disturbances of all categories (D+CS+SCS-H) along with their annual total duration (days). The data of 1970-1973 are not available.

Chapter 5

CLIMATIC VARIABILITY INFLUENCING THE TROPICAL CYCLONES

The surface air temperature, SST of the Bay of Bengal, rainfall and monsoon wind speed have been analyzed for characterizing the status of climate change and variability influencing tropical cyclones on environment, agriculture, fisheries and livelihood. The climatic data as used in this study has been collected from BMD, SPARRSO, SMRC and BARC. The SST data were downloaded from the electronic sites of NOAA NCEP and CDC, NOAA. The data were analyzed using the graphical plots in the temporal domain for the 4 climatic seasons: winter (December-February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-November) and for the annual. The statistical regression analysis was also performed to estimate the long-term trends of the climatic parameters. The results are discussed below.

5.1 Surface air temperature

The trends of maximum and minimum temperature have been analyzed for 9 stations of Bangladesh situated in the coastal zone, using data of 57 years (1950-51 to 2006). Figure 6 shows the time series plots of minimum and maximum temperature of M. Court, where the straight lines represent the trend. The figures show that there are high year to year variations with dominant periodicity in the range 5-10 years. The temperature has the increasing trends in all seasons at M. Court. The trends of minimum temperature are higher than those of maximum temperature for winter and post-monsoon seasons and also for the annual; but the trends for maximum temperature of pre-monsoon and monsoon seasons are higher than those for minimum temperature (table-5). The pre-monsoon trends are low but the trends are found to gradually increase for monsoon and post-monsoon seasons (figure-7). The largest trends are found to occur in the post-monsoon season both for minimum and maximum temperature. The results for other stations are more or less similar with exceptions for Barisal and Khulna. The results are summarized in table 5.

Table-5: Trend of Minimum and Maximum Temperature for some selected stations in the coastal zone of Bangladesh (1951-2006) (trend is in the unit of °C/decade) [Data source: BMD]

Stations	Position		Winter		Pre-monsoon		Monsoon		Post-monsoon		Annual	
	Lon	Lat	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax
Barisal	90.37	22.75	-0.26	0.03	*-0.12*	*-0.07*	*-0.08*	0.11	*-0.09*	0.26	*-0.13*	0.07
Bhola	96.67	22.68	0.32	0.15	0.27	0.07	0.23	0.28	0.08	0.27	0.24	0.19
Chittagong	91.82	22.27	0.12	0.25	0.03	0.09	0.08	0.20	0.14	0.38	0.09	0.20
Cox's Bazar	91.93	21.43	0.35	0.28	0.19	0.29	0.14	0.34	0.22	0.41	0.22	0.31
Khulna	89.17	23.18	*-0.18*	*-0.17*	*-0.07*	*-0.08*	*-0.07*	0.17	0.10	0.21	-0.03	0.03
M. Court	91.10	22.87	0.41	0.15	0.07	0.15	0.16	0.27	0.37	0.31	0.23	0.17
Shatkhira	89.08	22.72	0.10	-0.03	0.04	-0.01	0.10	0.16	0.08	0.19	0.08	0.07
Hatiya	91.10	22.43	-0.12	0.18	-0.02	0.21	0.18	0.29	*-0.10*	0.28	0.01	0.23
Patuakhali	90.33	22.33	0.03	0.18	0.18	0.41	0.34	0.40	*-0.15*	0.14	0.11	0.30

Note: The shaded boxes indicate the warming trends. The white boxes with italic numbers indicate cooling trends. The rest of the boxes do not indicate significant trend.

Of all the stations, Cox's Bazar shows the strongest warming trends of 0.22 and 0.31°C per decade for the annual mean minimum and maximum temperature. The seasonal trend values in this station vary from 0.14-0.35°C for minimum temperature and 0.28-0.41°C for maximum temperature. Very strong warming trends of around 0.4°C per decade are observed for 3 stations but in different seasons: M. Court in the minimum temperature of winter, Patuakhali in the maximum temperature of pre-monsoon and monsoon seasons and Chittagong and Cox's Bazar in the maximum temperature of post-monsoon seasons. The number of shaded box clearly indicates the existence of dominant warming in the coastal zone. The strong increase of minimum temperature and weak decrease of maximum temperature in winter season for a few stations indicate that there are increasing activities of fog, cloudiness and rainfall.

The trend values show significant warming of the air temperature within the range of 0.1-0.41°C/decade. The results of the trend analysis of data for the period 1971-2007 (37 years) for a few stations of the coastal zone show the increasing trends ranging from 0.3-0.6°C/decade. This clearly depicts that the warming trends have accelerated in the recent decades. Such increase of the temperature may be fatal to the ecological balance, agricultural crops and livelihood of the people.

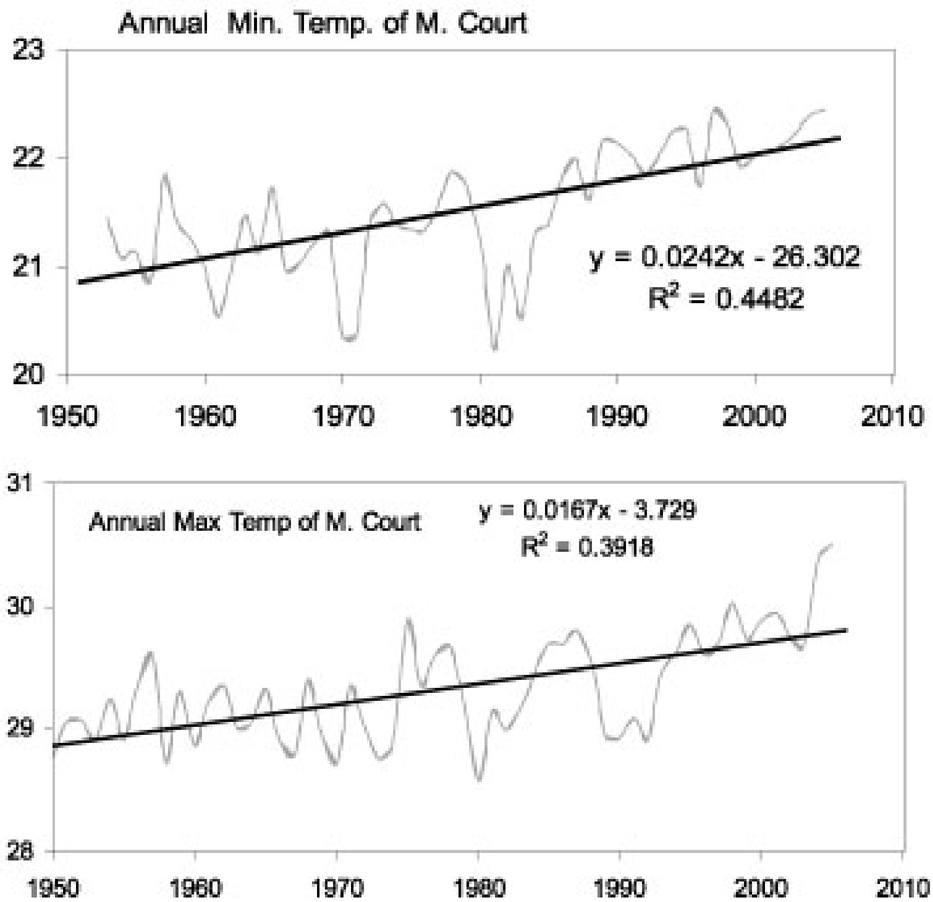


Figure-6: The temporal variation and trend of annual mean minimum and maximum temperature (upper and lower panel respectively) for M. Court (1950-51 to 2006)

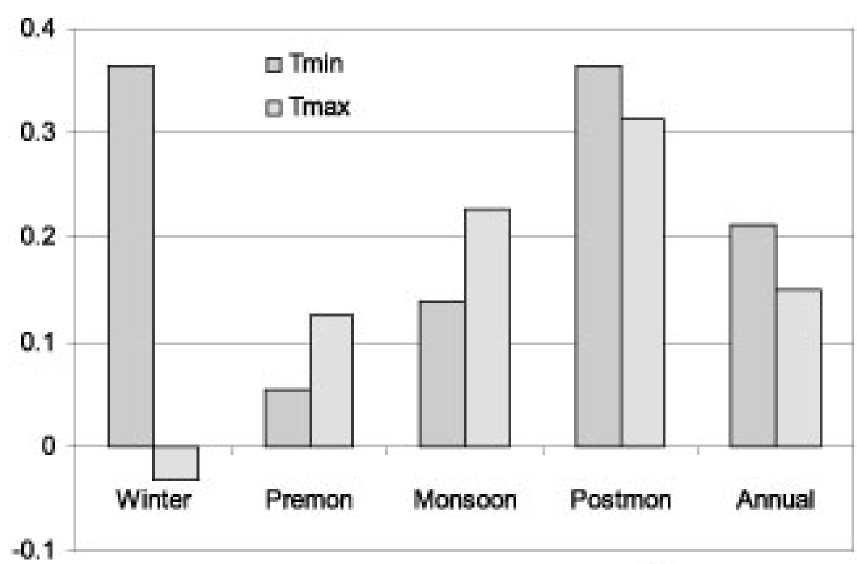


Figure-7: The figure showing the trends of minimum and maximum temperature for M. Court (°C/ decade)

5.2 Sea Surface Temperature of the Bay of Bengal

The Bay of Bengal maintains high SST (higher than 26.5°C) throughout the year (Figure-8). The figure indicates that the mean SST of the Bay of Bengal lies in the range 27.1 – 29.6°C with standard deviation ranging from 0.29 – 0.41°C. The maximum temperature was observed in the month of May. Thereafter, the temperature decreased due to monsoon cloudiness and rainfall. Then a secondary maximum was found in October (28.4°C). The minimum temperature of 26.5°C was observed in January 1976 and maximum temperature of 30.9°C in May 1998 during the period 1948-2007. The sea surface temperature above 26.5 C is one of the necessary conditions for tropical cyclone formation. This indicates that from the consideration of SST, the Bay of Bengal may have the tropical cyclone throughout the year; but in general, the tropical cyclones form in the months of April-June and September-December.

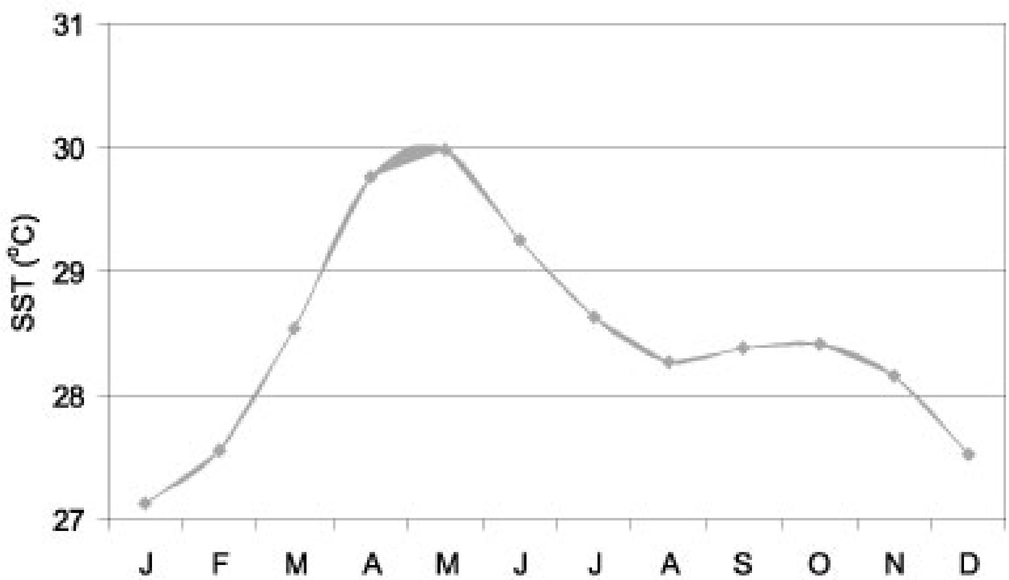


Figure-8: The climatology of mean SST in the Bay of Bengal from 1981-2007 data source: NOAA NCEP-Reanalysis data archive)

5.2.1 Trends of SST

The trend analysis of the SST anomaly over the Bay of Bengal shows that the annual mean SST is rising at the rate of 0.094°C / decade (Figure-9). This means the SST has increased by 0.47°C during the period of last 50 years. The highest warming was observed in 1998. The trend analysis of the SST anomalies was performed also for monthly data. The monthly trends are shown in figure-10. It is seen that the monthly trends are low during January-March. These monthly trends are found to increase from January to December showing high trends in October, November and December. The maximum warming rate is observed in the months of November and December (~0.13°C/decade). The trends are statistically significant at 1% level. The increase of SST is supposed to enhance the tropical cyclogenesis in the Bay of Bengal, especially in the months of October and November.

5.2.2 Sea Level Rise

The secondary impacts of the increase of the temperature of the global oceans are the Sea Level Rise (SLR). The SLR in the Bangladesh coast was studied by Khan et al. (1999) and Singh and Khan (2001) using the tidal data for the tide gauges in Hiron Point, Char Changa and Cox's Bazar. The study showed a reliable estimate of the relative SLR which is 4 mm/year at Hiron Point, 6 mm/year at Char Changa and 7.8 mm at Cox's Bazar. Another study by Hazra (2002) for the western Sunderbans coast in the Indian side found the sea level rise of 3.24 mm/year, which is comparable with the sea level rise at Hiron point. The above information clearly indicates that the relative SLR increases from the west to east. Khan et al. (1999) have pointed out that the relative sea level rise in this coast is the composite of sea level rise due to global warming and that due to physical subsidence of the tectonic plate caused by huge amount annual sediment deposit by the Ganges-Brahmaputra-Meghna (GBM) system into the Bay of Bengal.

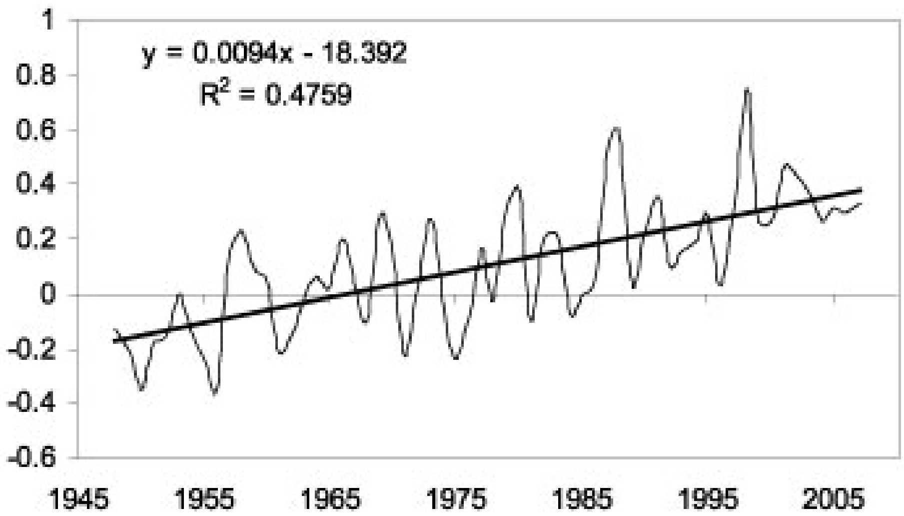


Figure-9. The variability and trends of annual Sea Surface Temperature (SST) anamaly of the Bay of Bengal averaged over the area 7.5-22.5 N and 72.5-92.5 E.

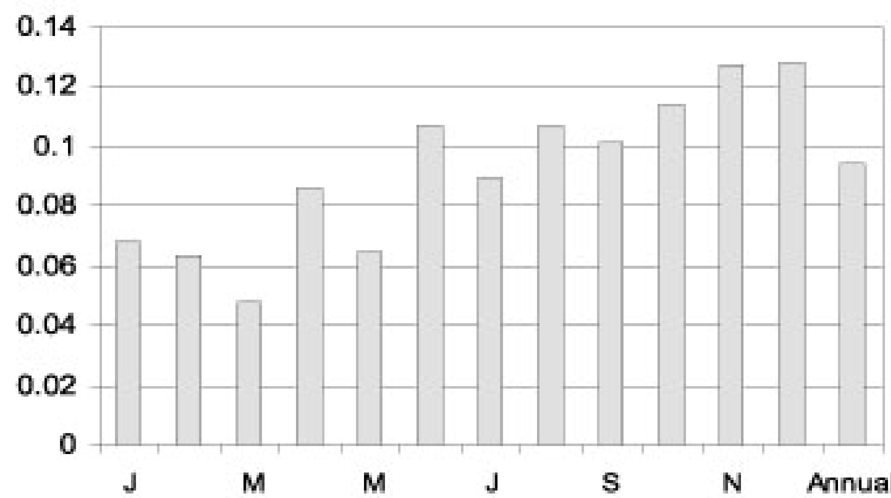


Figure-10: Trends (°C/decade) of monthly and annual SST.

Since the Bangladesh coastal zone is extremely flat, sea level rise is likely to inundate more areas under high tides and storm surges and permanently inundate the very low lying areas of the coast. This will also cause the coastal salinity front to shift northwards. Thus the valuable lands under agricultural and other land-use may lose their usability or be totally engulfed by sea. The mangroves may be affected due to sea level rise and enhancement of the salinity. This will affect the agriculture, fisheries, livelihood and other sectors to a great extent.

5.3 Rainfall

The seasonal rainfall was analyzed for 9 coastal stations as mentioned in table-6 for the period from 1951-2007 (58 years) to investigate the temporal variations and trends. The plots of the time series of rainfall for M. Court are illustrated here as the representative example (figure-11). The thick solid lines represent the trends. The analysis shows that the rainfall is highly variable from year to year. The trend values for the winter, pre-monsoon, monsoon and post-monsoon seasons are 2.83, 33.39, -9.12 and 1.1 mm per decade for M. court. Out of the nine stations, 5 exhibit increasing trends during the monsoon seasons. These are Khulna, Satkhira, Hatyia, Cox's, Bazar and Sandwip. The rest 4 stations, namely, Bhola, Barisal, Chittagong and M. Court exhibit negative trends of rainfall. The trend values are not statistically significant for most of the cases. The stations Bhola, Barisal, Chittagong, Hatia and Sandwip show negative trends in the post-monsoon season while the others exhibit positive trends. Winter and pre-monsoon seasons show increasing trend of rainfall in all stations except Bhola where all the seasons have negative trends, which is surprising. The pre-monsoon trends are relatively stronger. The trend of the pre-monsoon rainfall is high also over other parts of the country (Quadir *et al*. 2002). This indicates the possible increasing activities of thunderstorm and rainfall. This increased rainfall causes pre-monsoon flash floods affecting winter rice and vegetables. The increasing thunder storms in the coastal zone affects the movement of the fishing boats and fish catching in the estuaries and near shore and off shore areas of the Bay is affected. Such changes of climatic patterns thus disturb the livelihood of the coastal fishermen catching fishes in the sea and those earning from boat and trawler plying and related other livelihood activities.

Table-6: Trends (mm/decade) of seasonal rainfall at 9 stations of the coastal zone (1951-2007)

Station	Lon	Lat	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Bhola	90.65	22.68	-4.1	-9.40	-52.20	-1.05	-66.00
Barisal	90.37	22.75	4.35	20.30	-10.50	-5.05	8.70
Khulna	89.17	23.18	8.48	13.74	21.66	5.98	51.94
Satkhira	89.08	22.72	8.18	16.17	37.93	4.57	65.54
Chittagong	91.82	22.27	7.03	39.17	-14.32	-2.51	-5.25
Hatiya (1967-2007)	91.1	22.43	4.75	24.94	83.52	-0.51	140
M. Court	91.1	22.87	2.83	33.39	-9.12	1.1	19.43
Cox's Bazar	91.93	21.43	6.68	35.3	78.16	8.82	117.54
Sandwip (1967-2007)	91.43	22.48	5.93	70.72	45.22	-6.2	152.02

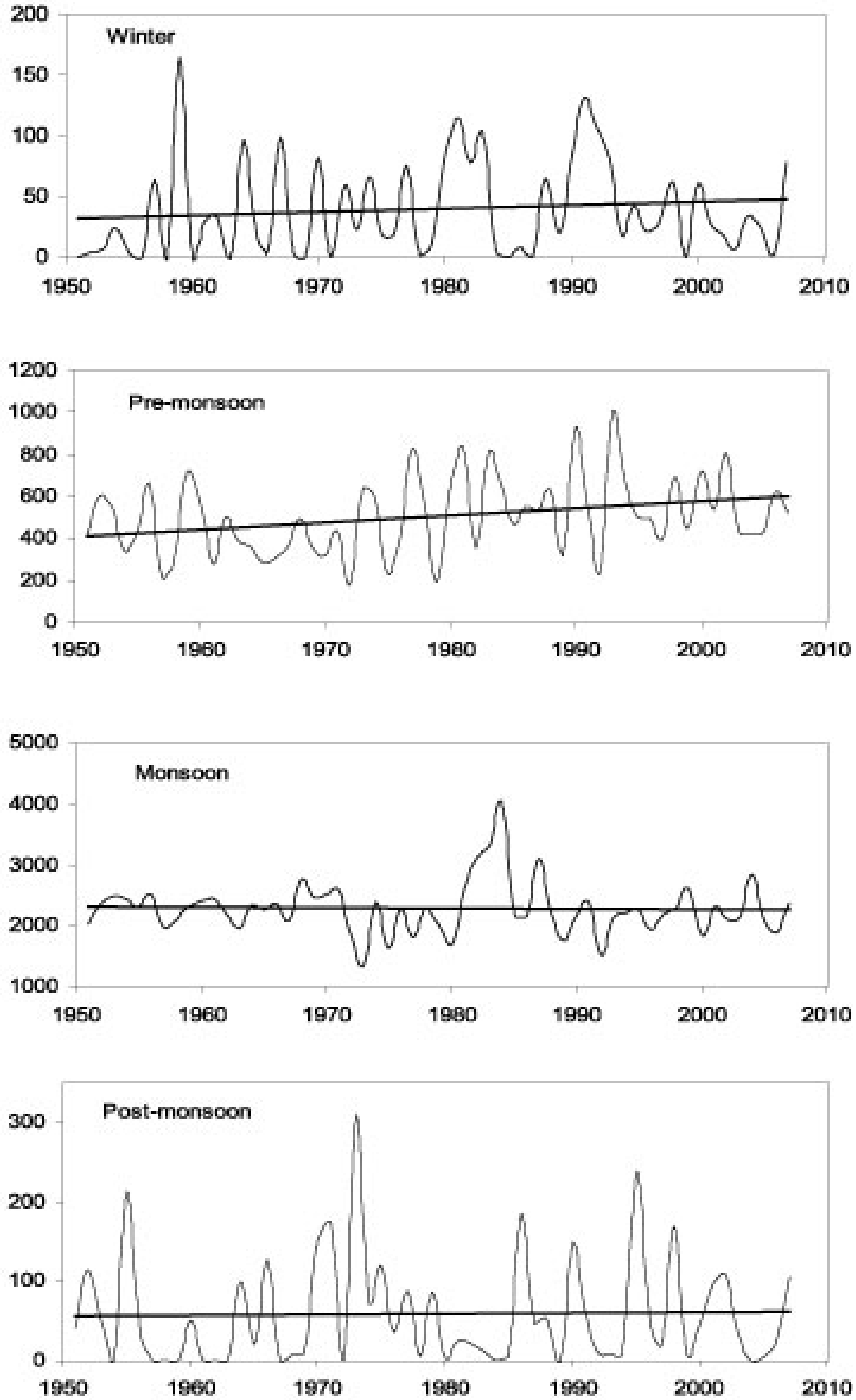
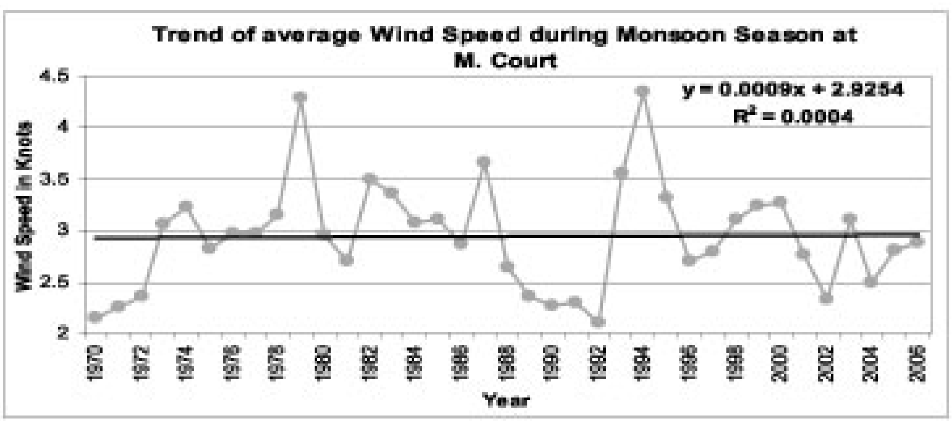


Figure-11: The time series plots of seasonal rainfall for M. Court. The thick line represents the trends

5.4 Inter annual variation of wind speed in the monsoon season and impacts

The strong monsoon wind are associated with deep convections, thunderstorm activities, dense cloud overcast, lows, depressions, tropical cyclones and steep pressure gradients in the monsoon system. The strong monsoon wind causes the sea to be rough and the warning signal no 3 or more is issued. In such weather the fishermen and boatmen are advised not to go out in the sea. The increased variability of the winds would exacerbate the difficulties. From this consideration the average wind speed data for the monsoon period have been analyzed for the period 1970-2006 for a number of stations in the coastal zone. The stations are Chittagong, Cox's Bazar, Bhola, Hatiya, Sandwip, Teknaf, Potuakhali, M. Court, Barisal, Khulna and Satkhira. The time series plots with regression lines have been shown for two stations: M. Court and Cox's Bazar (figure-12). The time series indicate the existence of short and long term variability. The wind speed has mild decreasing trends in all these stations except for M. Court, where no noticeable trend has been detected. Such lowering of the monsoon wind speed may be related with the decrease of frequency of monsoon depressions in the recent decades. Thus it appears that the mean monsoon winds do not indicate much threat except the high winds associated with weather extremes.



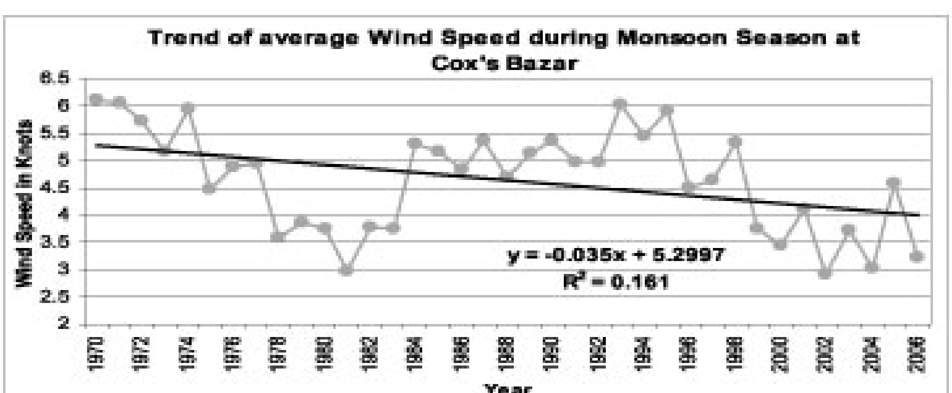


Figure-12: Annual average surface wind speed at M. Court and Cox's Bazar (1970-2006)

5.5 Tropical cyclones under changed climate

The SST above 26.5°C is a necessary but not adequate condition for formation of the tropical cyclone. It is almost certain that an increase of SST is accompanied by corresponding increase in cyclonic intensity. Higher SST enhances the evaporation causing higher supply of energy in the form of latent heat through the boundary layer. Emanuel (1987; 2005) has developed a relationship between maximum sustained wind speed (MSWS) and SST which suggests that a 1°C rise of SST will increase the MSWS by 4 %, 2°C by 10% and 4°C rises by 22% respectively. A model simulation study by Quadir (2003) has demonstrated that the intensity and the intensification rate increase with the increase of SST. The increased wind stress on the water surface is proportional to the square of the wind speed. Thus the impact of enhanced SST on wind speed vis-à-vis on storm surge height would be quite large. Considering 2°C and 4°C rise of SST, Ali (1996) developed scenarios of storm surge heights. It was found that storm surge would increase by 21% and 49% with respect to the present.

The present study has shown that the SST of the Bay of Bengal has increased by 0.47°C during the past half century. It has further shown that though the Bay of Bengal cyclones of moderate intensities have decreased but the frequency of the intensive tropical cyclones have increased in the recent decades. The return period of the tropical cyclones with super cyclonic intensity has been found to decrease as well. This implies that SST being one of the necessary conditions of tropical cyclone formation, its increase might have some influence on the frequency and intensity of the tropical cyclones of the Bay of Bengal. Although significant advances have been made and models developed to understand the behavior of the tropical cyclones, little has been done to examine a relation between global warming and cyclone intensities and frequencies.

Chapter 6

CYCLONIC EVENTS AND LOSS RELATIONSHIP

Comprehensive information of the tropical cyclones in the categories of CS, SCS and SCS-H hitting the coast of Bangladesh is compiled from various sources and presented in table-7. The information were obtained from the archives of BMD, DMB, literature survey (Karmaker, 1999) and internet sources (Wikipedia, 2008). The table contains the information about the date of formation and landfall, duration, category, maximum sustainable wind speed, storm surges, human casualties and damages to resources, environment and ecology. The damages due to some deadliest cyclones are listed in table-8 in details.

The storm surge associated with cyclonic landfall causes major part of the damages to assets, crops, life and property. The wind speed, storm surge height, area coverage and subsequent duration of water logging by saline sea-water determine mainly the loss in crop and fisheries sector. Although, there is scarcity of information, some inference could be drawn from the table-7. In general, higher the cyclonic intensity, higher is the storm surge and thus area affected and associated losses. It is alarming to note that, though frequency of cyclones have been reduced over the past three decades, the number of cyclones with hurricane intensity has remarkably increased. If the loss of life and property are taken into account, recorded data shows that nearly 50% of the global disastrous cyclones have occurred in Bangladesh.

The investigation of the impacts of cyclonic storms which have the wind speed of 62-88 km/hr have the storm surges between 1.3-2.5 m as per records. The warning signal numbers 5, 6 and 7 are imposed for cyclonic storms. The people in the risk areas are advised to take shelter in the cyclone shelters. The boats, trawlers and ships are also advised to go to a safe place. These are the tropical cyclones of moderate intensity and the casualties were found to be about 40-50 persons, varying from case to case. There were boat capsize and reports of missing fishermen. The houses, crops, vegetables and fruit gardens were damaged in the command areas of the storms. The shrimp ponds and salt beds were also damaged due to flooding caused by the storm surges. The heavy rainfall from these cyclones also caused damage to resources. The victims lose their cattle, poultry, stocks of food, seeds, boats, nets and other appliances for cultivation and fish catching.

Table-7: Historical events of Tropical cyclones hitting Bangladesh Coast (1960-2007)

Sr. No.	Year	Landfall date	Duration	Category	Landfall	Wind speed (km/hr)	Storm Surges (m)	Human Casualties	Economic Loss
1	1960	10 October	8-10	SCS-H	M.Court	129	5.7	3000	62725 houses and Crops on 94000 acres (380 km2) were destroyed
2	1960	31 October	30-31	SCS-H	Noakhali Chittagong	193	6.1	10000	27783 Cattle died 568161 houses destroyed 5-7 Vessels capcised
3	1961	9 May	5-9	SCS-H	Meghna estuary	161	3.1	11468	25000 Cattle died Railway track between Noakhali and Harinarayanpur damaged
4	1961	30 May	27-30	SCS-H	Feni	131	4.11	-	-
5	1962	October	26-30	SCS-H	Feni	193	3	1000	Many domestic cattle died
6	1963	29 May	28-29	SCS-H	Noakhali Chittagong	202	6	11520	32617 cattle died, 376332 houses, 4787 boats and standing crops were damaged
7	1965	12 May	9-12	SCS-H	Barisal-Noakhali	162	3.7	19279	-
8	1965	1 June	May 26-June1	CS	Near Hatia	87			
9	1965	15 December	7-15	SCS-H	Cox's Bazar	184	3.6	873	Houses Damaged-35636 Rice harvest loss 40-50% Much damage was caused to fishing boats and nets. 40000 salt beds were inundated
10	1966	1 October	Sep 23-Oct 1	SCS-H	Noakhali	139	6.7	850	309000 housed damaged, 65000 cattle was lost, poultry damaged was 185000 and betel leaf damaged was 3659 acres, govt. food grain damage was 5595 tons. Total population affected was 3500000 of which 1500000 were badly affected.
11	1966	12 December	7-12	CS	Cox's Bazar	81			
12	1967	11 October	8-11	SCS-H	Khulna	150		1000 (in India)	Cattle lost 50000 (in India) and 219 were missing in Bangladesh.

13	1967	23 October	20-24	SCS-H	Cox's Bazar	148		51	
14	1969	10 October	1-10	CS	Khulna	74			
15	1970	7 May	2-7	SCS-H	Cox's Bazar	148		300	People rendered homeless = 40000
16	1970	23 Oct	18-23	SCS-H	Bang. Sundar-ban - near Kolkata	163			
17	1970	12 November	8-13	SCS-H	Bhola, Meghna estuary	224	10	300000	Colossal damage had occurred by the cyclone.
18	1971	8 May	3-8	CS	Meghna Estuary	81	4.24		
19	1971	29 September	28-30	SCS	Sundar-ban	120	0.6		
20	1971	6 November	3-6	SCS	Noakhali-Chittagong				
21	1973	18 14-18 November	SCS	Noakhali-	102 Chittagong				
22	1973	9 December	3-9	SCS	Near Barisal	111	4.55	1000	
23	1974	30 May	27-30	CS	Patuakhali	83			Damages were caused to crops and houses
24	1974	15 August	13-15	SCS	Near Khulna				
25	1974	28 November	24-28	SCS-H	Chittagong Cox's Bazar	161	5.1	50	People missing 280, cattle killed 1000, houses damaged 2300 and considerable damage to properties were caused
26	1975	7June	4-8	CS	Near Chittagong		83		Fisher men missing 50 Lot of crops and other damages took place
27	1975	12 7-11 November	CS	Near Meghna Estuary	74				
28	1976	21 October	15-21	CS	Noakhali Chittagong	80			
29	1977	13 May	9-13	SCS	Patuakhali Bhola	100			
30	1978	3 October	1-3	CS	Khulna-74 Sundarban				
31	1981	10 December	6-10	SCS-H	Khulna and Sundarban	120	4.5 5	72 (Bang.) 200 (Ind.)	

32	1983	15 October	14-15	CS	Chittagong Coast near Feni river	85		43	Fishermen and boat missing over 100. Aman rice damaged over 20%.
33	1983	9 November	5-9	SCS-H	Chittagong Cox's Bazar near Kutubdia	135	1.5		Fishermen missing 300, Boat missing 50 and Katcha houses destroyed 2000
34	1985	25 May	22-25	SCS-H	Noakhali	154	4.5 5	4264 (6805 missing)	There was colossal damage.
35	1986	9 November	7-9	SCS	Patuakhali	110	0.61		
36	1988	21 October	19-21	CS	Barisal-Patuakhali				
37	1988	18 November	16-18	SCS-H	Southeast coast of Teknaf	135			
38	1988	29 November	24-30	SCS-H	Khulna	165	4.4	5683	People missing- 6000, Deer killed -15000, Royal Bengal Tiger killed–9, Cattle heads lost -65000, crop damaged of Tk. 940 million and fishing equipment destroyed Tk.150 million.
39	1990	18 December	16-18	SCS	South of Cox's Bazar	115			Caused considerable damage in the coastal zone of Bangladesh
40	1991	29 April	25-30	SCS-H	Noakhali Chittagong	235	7.6	133882	The Cyclone caused colossal damage. The total loss in money is Tk. 145 billions
41	1991	2 June	May 31-Jun 2	CS	Patuakhali Noakhali	83	2.5	300	fishermen were missing Considerable number of houses and crops were damaged.
42	1992	18 May	17-19	SCS	Near Teknaf	115			
43	1992	22 October	20-22	CS	Cox's Bazar	62			
44	1992	21 November	16-21	SCS-H	Teknaf	210			
45	1994	2 May	Apr 24-May 2	SCS	Teknaf Cox's Bazar	190	4.85	184	The cyclone caused huge damage to environment with huge impact on economy (table 8)
46	1996	8 May	7-8	CS	Chittagong Teknaf				

47	1996	28 October	26-28	CS	Sundarban	75	1.5	9 (Fishermen missing-2000)	Livestock killed-15000, Houses damaged: 40000 Crop destroyed completely-50000 acres, partly-235000 acres, road damages: 1398 km, embankment damaged -150 km
48	1997	19 May	15-19	SCS-H	Chittagong /Sitakundu	200	4.6	155	People affected-2835472 Livestock killed – 3118, House damaged – 211717, crop damaged – 97333 acres, salt washed away-2232000 acres. Besides there were damages of roads, embankments, schools, cyclone shelters , plants etc.
49	1997	26 August	24-26	SCS-H	Hatia	150	4.6	67	Vast area and population and resources were affected. Missing 1000 persons
50	1998	20 May	17-20	SCS-H	Sitakundu	186			
51	1998	22 November	19-22	SCS-H	Sundarban	140	2.44		
52	2000	28 October	25-28	CS	Sundarban	87			
53	2002	11 November	11-12	CS	Sundarban	95	2.3		
54	2004	19 May	17-19	CS	Cox's Bazar Akyab	90 85	1.3		
55	2007	14 May	13-14	CS	Grazing Chittagong Cox's Bazar coast				
56	2007	15 Nov	11-16	CSC-H	Sundarban Borguna	250	6 -8	2388	Severe damage to crops, Sundarban mangrove forest, huge uprooting of plants, damage of houses, shrimp and fish ponds, roads and embankments

Note : Compilation by the consultants

Table-8: Damages due to some intensive tropical cyclones of Bangladesh

Tropical cyclone	Damaged entities	Damages occurred
12 November 1970	People killed	300000
	Population affected	47000000
	Crop lost	Tk. 4.41 billions (63 million US dollar)
	Loss of Cattle	280000
	Loss of poultry	500000
	House Damaged	400000
	School damaged	35000
	Marine fishing boats damaged	9000
	Inland ware fishing boat destroyed	90000
26 May 1985	People killed	4264
	People missing	6805
	Affected area	4288 sq km
	Affected population	1310935
	Damage to crops	90381 ha
	Houses damaged	125526
	Livestock lost	135033
	Embankment damaged	80 km (fully) and 284 km (partly)
	Road damaged	60 km
	Trees Destroyed	1200
29 April 1991	No of peoples killed	138882
	No of people injured	139054
	No of people missing	1225
	No. of affected districts	19
	No of affected upazilas	102
	No of affected municipalities	9
	No. of affected population	10798257
	Damage to crops in acreage	Fully: 133272 Partly: 791621
	No. of houses destroyed/damaged	Fully: 819608 Partly: 882705
	No of educational institute damaged	9666
	Earth road damaged	1222 km
	No. bridges and culvert damaged	496
	Embankment damaged	Fully: 3865 km Partly: 5801 km
	No. of domestic animal killed	1061029
	Total loss in terms of money	Tk. 145 billions

15 November 2007 (Sidr)	People Killed	3363
	People wounded	55282
	Missing People	871
	People affected	8923259
	Families affected	2064026
	Districts affected	30
	Livestock killed	1778507
	Houses damaged (fully	564967
	Houses damaged (partly	957110
	Crops damaged (fully)	505660 ha
	Crops damaged (partly)	1177086 ha
	Roads damaged (fully)	1714 km
	Roads damaged (partly)	6361 km
	Embankment damaged	1875 km
	Bridge & Culverts damaged	1687
	Educational & Religious Institutions damaged (fully)	4231
	Educational & Religious Institutions damaged (partly)	12723

Source: BMD and DMB

From table-7 it may be seen that during the period of 48 years (1960-2007), a total of 56 tropical cyclones hit the coast of Bangladesh of which 48.2% are very strong cyclones (SCS-H), 17.9% are severe cyclonic storms (SCS) and the rests are CS. It is reported in Section 5.1 that the frequency of very severe cyclonic storms is increasing. This makes the coastal zone of Bangladesh highly vulnerable. The analysis further shows that there are two peaks in tropical cyclone occurring in Bangladesh- one in April-May (number of cyclones is 16) and another in October-November (number of cyclones is 15 and 14 respectively with a total of 29 cyclones). The number of SCS-H in April-May was found to be 9 and in October and November was 7 and 9 respectively (total 16 cyclones). Thus the peak seasons of tropical cyclones coincide with the stages of maturity of winter/ Boro rice in April and May and Aman rice in October and November. Thus the food security is particularly at risk in the coastal zone due to the tropical cyclones as the Boro rice and Aman rice are the two major food crops of the country.

The command area of the cyclonic damages depends on the size of the cyclones. The intensive cyclones generally have larger size and cause damage over larger areas. Most of the impacts occur in the core areas of the cyclone, covered by the radial distance of 100-200 km from the centre of the cyclone. Away from this core the impacts are relatively low.

The information as produced in table-7 shows that the tropical cyclones with its strong wind action and associated storm surges have enormous destructive force. The storm surge is dependent on the geographical area. It is high over the Meghna estuary and in Noakhali, Chittagong and Cox's Bazar coasts. The surge is relatively low in the western part of Bangladesh coast (Sundarban-Khulna) and to the south of Cox's Bazar.

and the storm surge height. As a result, the impact is much stronger compared to the cyclone passing during low tide phase. The storm surge records in Bangladesh show that it can go as high as 10-13 meters depending on the track and landfall position, maximum wind speed of the cyclone and the condition of the astronomical tide. In case of the tropical cyclone of 19 May 1997, which had a wind speed of about 200 km/hr, although it passed the coast at low tide condition, the storm surge was relatively low (6.7 m). The damages were mainly caused by the wind action.

Though the causes of damage are many (early warning, evacuation, elevation and surface form, forest cover, effectiveness of protection embankments etc.), the wind speed, storm surge height, area coverage and subsequent duration of water logging by saline sea water account for the loss in crop and fisheries sector.

The great cyclone Sidr

The tropical cyclone Sidr attained the wind speed of about 250 km/hr before hitting the Sundaran-Patuakhali coast on 15 November 2007. The very large size of Sidr with clear eye, and well developed inner core around the eye can be seen in the NOAA AVHRR 1 km resolution image (figure 13). The image shows that the cyclone had a diameter of about 600 km and engulfed the entire coast of Bangladesh. The cyclone Sidr passed the coast at the mid way of the tide; as a result, the surge was not tidally enhanced. Moreover, the surges are generally low in the areas. The storm surge was around 6 m according to BMD, but the theoretical assessment indicates that the maximum storm surge could be as high as 8 m. Since the Sundarban-Patuakhali area is very flat, the surge water entered about 20 km inward (Hossain et al. 2008) and the saline water logging affected agriculture, fisheries and other activities for quite some time. The signal number 10 was hoisted for Khulna and 9 for Chittagong and Cox's Bazar. The damage due to Sidr was colossal. It affected the coastal zone of Bangladesh. The number of people killed was 3,363, because, most of the severely affected areas were thinly populated. Besides, the landfall and timing of the landfall of the cyclone were well forecasted with adequate lead time for taking necessary precautions including moving to the nearby shelters. A big chunk of the Sundarbans was totally wiped out (figure 14). The damages to Aman crops, vegetables and other crops, fish ponds, installations and infrastructures were massive. The details may be seen in table-8.

From the above, the following may be summed up on the impacts of the tropical cyclones. The strong wind action and the high storm surges associated with the cyclone shatter every thing in the command areas along its path (depending on the strength of the cyclone). They cause human casualties and injuries, death of wild animals, livestock and poultry, loss of properties, damages to natural resources, crops and trees, fish ponds, salt beds, dry fishes and fish processing plants, infrastructures, houses, food and seed storage, cold storages and other buildings, cyclone shelters, embankments, road networks, power networks, boats, ships, fishnets, food stocks, supply of drinking water, death of fishes due to the turmoil of the water and many others. There are always innumerable injuries to human beings, outbreak of diseases and lack of food, drinking water and medicine, sanitation, etc., which become the most acute problems of the survived victims. The damages due to a cyclone like those that occurred in 1970, 1991 and 2007 are colossal and need about a decade to repair the economic, infrastructure and social damages. Besides, the storm surge water can enter 20-30 km landward and pollute the surface water with salinity and create temporary water logging and increase soil salinity. The decomposed dead bodies, dead fishes and insects heavily polluted the areas after the event. The women, children and elderly were the worst victims of the tropical cyclone impacts. The storm surge water brought the saline water and huge sediments to the coastal land areas, which left the lands unusable for due to high salinity and sandiness of the soil. All these impacted agriculture, fisheries and other sectoral activities adversely, affecting the livelihood of the people living in the coastal zone and of the country in general.

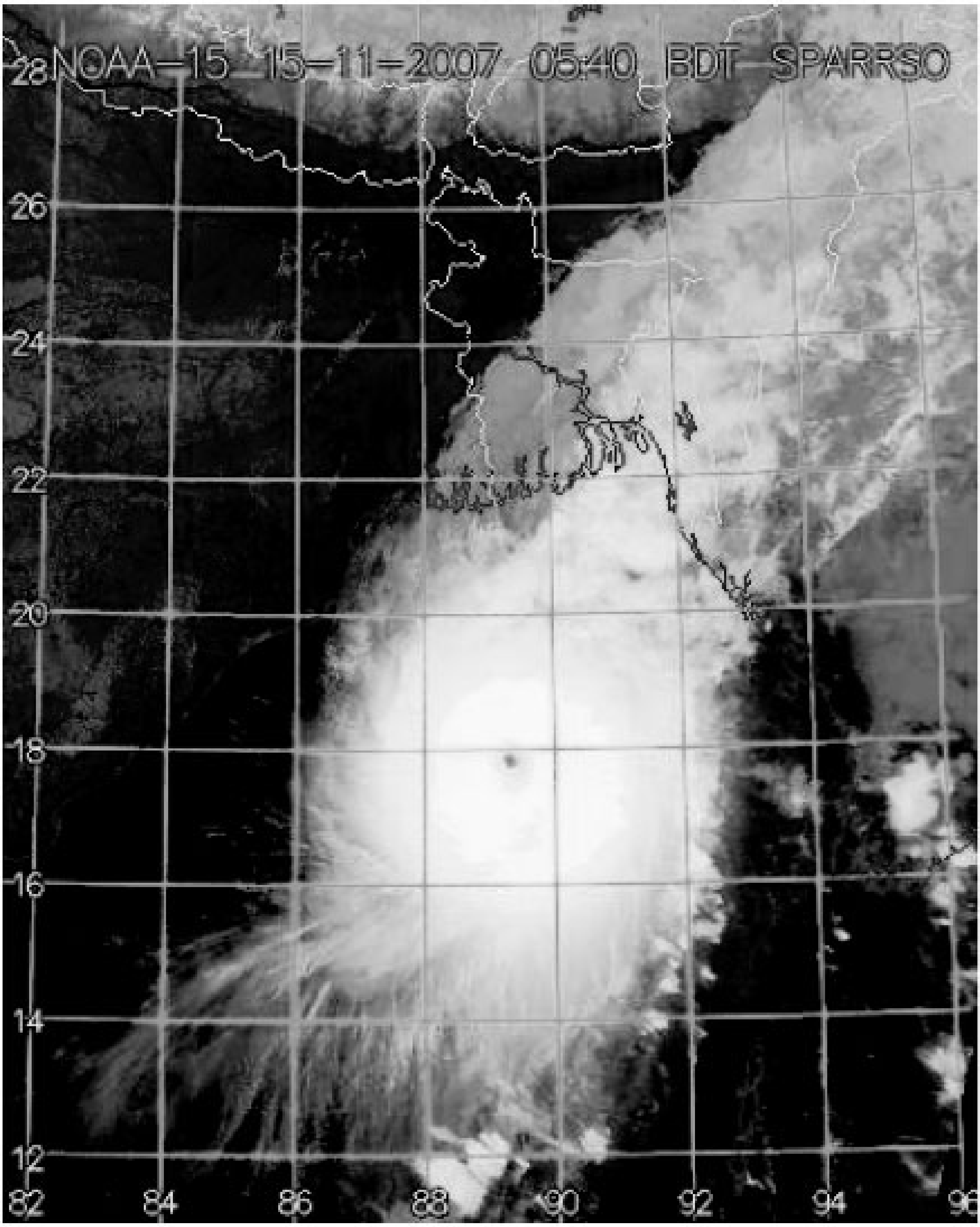


Figure -13: The NOAA AVHRR image of Sidr on 15 November 2007 (Acquired at SPARRSO Ground Station)

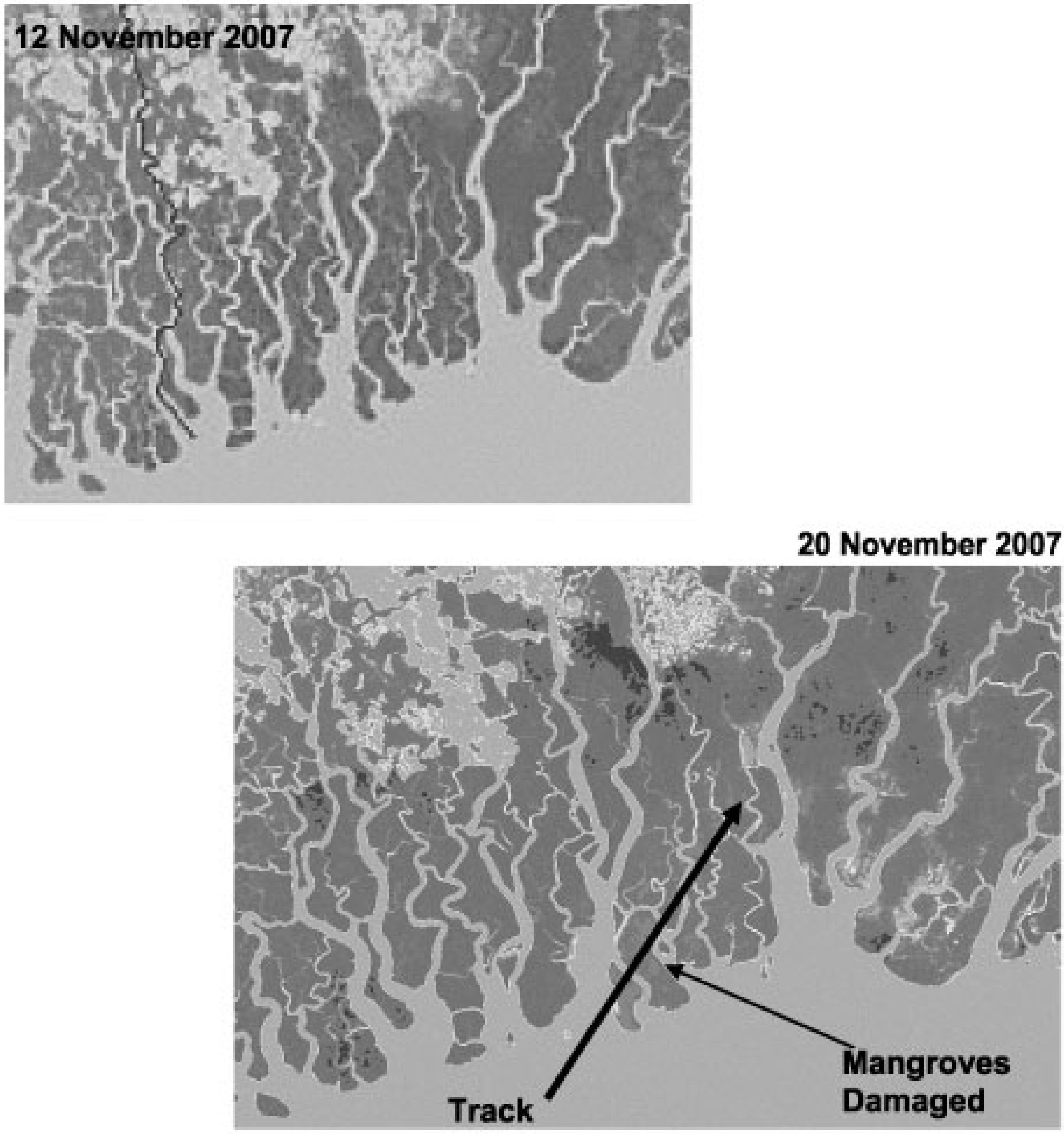


Figure-14: Vegetation Index image from the Terra modis satellites before Sidr (upper one) and after Sidr (the lower one). The light tone around the track indicates the damage of Sundarbans. [The images of the individual dates were obtained from Goddard Space Flight Centre (GSFC) active archives].

Chapter 7

SIGNALING SYSTEM FOR THE MARITIME PORTS

Bangladesh Meteorological Department (BMD) is the mandated agency of the Government to observe climatic phenomenon and to disseminate warning signals as and when necessary. Currently there are eleven storm warning signals for the maritime ports, which are equally applicable for other regions of the coast of Bangladesh for taking precautionary measures in case of an extreme weather event such as tornado, squalls, thunder storms, strong monsoon winds, steep pressure gradients, dense cloud clusters and deep convections and tropical disturbances of various intensities. The details of the signals are shown in Annex-I.

The signals are:

1. Distant Cautionary Signal No. I
2. Distant Warning Signal No. II
3. Local Cautionary Signal No. III
4. Local Cautionary Signal No. IV
5. Danger Signal No. V
6. Danger Signal No. VI
7. Danger Signal No. VII
8. Great Danger Signal No. VIII
9. Great Danger Signal No. IX
10. Great Danger Signal No. X
11. Failure of Communications: XI

The Signal No. I and II are the distant cautionary signals due to a low pressure system or depression formed in the distant sea.

The signal No. III is a local cautionary signal which indicates that the ports (and thereby the coastal areas of Bangladesh) are threatened by squally weather of transient nature with surface wind speed of 41-51 km/hr or squalls due to nor'westers. The port itself and ships in it are in danger. *All fishing boats and trawlers over deep sea shall come close to the coast and proceed with caution so as to take shelter at a short notice.* So in such weather situation with Signal III is not safe for fish catching in the near shore or off shore. The boats and trawlers are not safe for plying. Heavy precipitation is expected from the weather of such categories. In the pre-monsoon and monsoon seasons if the low pressure systems pass across the Chittagong-Cox's Bazar coast, it may generate heavy rainfall and cause landslides and mud floods.

The Local Cautionary Signal No. IV provides the indication that the port (and the coastal zone) is threatened by a storm with wind speed of 52-61 km/hr but does not appear that the danger is yet sufficiently great to justify extreme measures of precaution. The port itself and ships in it are in danger. *All fishing boats and trawlers over deep sea shall come close to the coast and take shelter immediately.*

The danger signals No. V, VI and VII represent the similar weather conditions and provide the indication that the port (and the coastal zone) will experience severe weather due to a storm of slight or moderate intensity (wind speed 62-88 km/hr) that is expected to cross the coast to the south of the port for Signal V, north of the port for signal VI and over or near the port for signal VII. The port itself and the ships and the nearby regions are in danger. *All fishing boats and trawlers over North Bay shall remain in shelter till further notice.*

The Great Danger Signal No. VIII, IX and X signifies that a severe cyclonic storm has been formed and the port is going to experience very severe weather from a storm of great intensity (severe cyclonic storm of wind speed 89-117 km/hr or severe cyclonic storm with hurricane intensity with wind speed 118 km or above). The Signal No. VIII is given if the storm is likely to cross the coast to the north of the port, Signal No. IX if the storm passes south of the port and Signal No. X is hoisted if the storm crosses the coast over or near the port. This is a great danger signal and the ships, boats and people are required to take extreme precautionary measures. *The people are required to move to cyclone shelters.*

Signal No. XI implies the failure of communication with the Storm Warning Centre with the area where the tropical cyclone made its landfall and the local officer considers that there is danger of very bad weather.

7.1 Assessment of the warning signals for the last 15 years

Storm Warning Centre (SWC) of BMD issues the weather bulletins every three hours as soon a squally weather, nor'westers, deep convection and dense cloud mass, steep pressure gradient and strong monsoon wind, low pressure system or a depression forms in the distant bay with cautionary signal No. I or II depending on its intensity level. If the systems threaten port and the coast of Bangladesh, the Signal No. 3 is given for the maximum wind speed of 32-51. Then the signals are raised as the intensity rises with the gain of higher wind speed. The Signal No 3 and above signifies danger for the Bangladesh coast. The perception of the people of the coastal zone regarding the signal numbers is that, the higher the signal stronger is the storm and more is the danger. So while collecting data from the fields on people's perceptions about the impacts of the weather hazards, especially the tropical cyclones on the livelihood, it would be easier to communicate with the vulnerable people through the conception of signal numbers, which in fact implies the intensity of the tropical weather activities and disturbances. Instead of asking the questions whether frequency of tropical cyclones has increased or decreased, it may be asked whether the occurrence of signal no 3 or higher have increased or decreased. From this consideration, the consultants have gone back to the individual weather bulletins in the archives of BMD and extracted information on the signal no. 3 or above for individual cyclones for the period of over 17 years from 1991-2008 and collated in tabular form in a database. Table-9 shows this information on the warning signals of 3 or more for the year 1998 as an example. It can be seen that most of the warning signal 3 are given for squally weather from nor'westers, deep convections, dense cloud, steep pressure gradients, strong monsoon winds and lows and depressions (table-10). The signals for tropical disturbances (lows, depressions and tropical cyclones) have been separated year-wise in table 10. The number of days with warning signal 3 or more has been calculated and compiled in table-11 for the years 1991-2007 in the form of yearly time series.

Table-9: The warning signal data for the year 1998 for demonstration purpose

Year	Month	Days	Weather Systems	Chittagong	Cox's Bazar	Khulna	Landfall Point
1998	May	17- 20	SCSH	9	9	6	Sitakunda
		19		3	3	3	
		21	lower signal				
	May	27	Squall line	3	3	3	
		28	lower signal				
	June	9	V monsoon	3	3	3	
		11	lower signal				
	June	14	D	3	3	3	
		15	lower signal				
	July	4	Steep PG	3	3	3	
		5	lower signal				
	July	11	Steep PG	3	3	3	
		14	lower signal				
	July	28	WL	3	3	3	
		30	lower signal				
	October	18	WL	3	3	3	
		22	lower signal				
	November	19 to 22 20	SCS-H	9 3	4 3	10 3	Sundarban
		24	lower signal				

Note: WL: Well marked Low, D: Depression, PG: Pressure Gradient, V. Monsoon: Very active Monsoon

Table-10: The Warning Signals for cyclonic events for the Bangladesh coast

Year	Month	Duration days	Category of Storms	Signal No. 3 or higher		Khulna	Point of Landfall
				Chittagong	Cox's bazar		
1991	Apr	25-29	SCS-H	10	9	8	Chittagong - Cox's Bazar
	May-June	31- 2	CS	6	6	7	Bhola
	Nov	12-15	CS	2	2	2	Tamilnadu
1992	May	17 -19	CS	7	6	4	Teknaf
	Nov	3-7	CS	2	2	2	Visakhapattanam
	Nov	17-21	SCS-H	10	9	5	Teknaf-Myanmar
1993							
1994	Apr-May	29 - 2	SCS-H	10	9	5	Chittagong - Cox's Bazar
1995	Nov	7 - 9	SCS-H	6	6	7	Puri, India
	Nov	21-25	SCS-H	10	9	10	Cox's Bazar
1996	Jun	13-16	CS	4	4	4	Kalingapattanam
	Oct	26-28	CS	5	5	5	
	Nov	5 -6	SCS-H	3	3	3	Kakinada
	Nov-Dec	28-2	CS	7	7	5	weakened
	Dec	3 -5	SCS	2	2	2	Madras
1997	May	15 -19	SCS-H	10	10	8	Sitakundu
	Sep	24-26	SCS-H	10	9	8	Hatia
	Nov	5 -8	CS	2	2	2	Weakened
1998	May	17- 20	SCS-H	9	9	6	Sitakundu
	Nov	14 -15	CS	2	2	2	Kakinada-Vishakhapatnam
	Nov	19 -22	SCS-H	9	4	10	
1999	Oct	16-17	SCS-H	4	4	4	Gopalpur, Orissa, India
	Oct	25 -29	SCS-H	4	4	6	Paradip
2000	Mar	29 -31	CS	2	3	2	
	Oct	14-19	CS	3	3	3	
	Nov	26 -29	SCS-H	2	2	2	Chennei
2001	Oct	15-16	CS	2	2	2	Nelore

2002	Oct	11 -12	CS	6	6	7	Coast
	Oct	24-29	CS	2	2	2	Weakened
2003	May	10 -18	SCS	3	3	3	Weakened
	May	19-20	CS	5	5	3	Myanmer coast
	Dec	12-16	SCS	2	2	2	Ongole & Machilipatnam
2004	May	17 -19	CS	5	7	3	Teknaf and Akyab
2005	Dec	6 -12	CS	1	1	1	Weakened
2006	April	25-29	SCS-H	4	4	2	Akyab
2007	May	13 -14	CS	7	7	5	Chittagong
	Nov	11-15	SCS-H	9	9	10	Khulna-Barisal
2008	Apr-May	27-2	SCS-H	4	4	2	Bassain (Myanmar)

It can be seen from the table 10 that during the 15 years there were 8 tropical cyclones that hit the coast of Bangladesh for which the highest signals 8, 9 and 10 were served. Let us take the case of 29 April 1991, when warning signal no. 10 was issued for Chittagong. It was predicted that the cyclone having strength of severe cyclonic storm with hurricane intensity (SCS-H) will pass over or near Chittagong port; Khulna had the danger signal 8 because the cyclone was thought to pass to the south of Khulna and Cox's Bazar had the danger signal 9 as the cyclone was predicted to pass to the north during the landfall.

There were 7 cases of tropical cyclones (CS) having the danger signal no. 5, 6 or 7. Let us consider the case of the cyclonic storm of 31 May- 2 June, 1991 that hit the coast of Bhola. Since the cyclone was predicted to have the land crossing at Bhola, Chittagong and Cox's Bazar had the danger signal no 6 obviously because the cyclone was supposed to pass north of these places and Khulna had the signal number 7 as the cyclone was supposed to pass close to Khulna during the landfall. The severe cyclonic storm of 9 November, 1995 hit the Puri coast of India, which is near Bangladesh. The signal no 6 was hoisted for Khulna and 4 for Chittagong and Cox's Bazar.

Again, there were 7 cases of signal number 4 during the period of 17 years from 1991-2007. First example of signal 4 is the 15 November 1991 cyclone which hit the coast of Teknaf. The prediction was that the cyclone would pass near Chittagong during the landfall, as a result the danger signal number 7 was given for Chitagong and signal number 6 for Cox's Bazar; but Khulna being at a large distance from the probable landfall point of the cyclonic storm, signal number 4 was given for this place. In most of the cases they belonged to the cyclones which had their landfall at Myanmar coast or in the Indian coast close to Bangladesh.

In addition to the squally weather threatening the Bangladesh coast, the signal 3 for the Bangladesh coast was hoisted whenever the cyclones hit either the nearby coasts of India and Myanmar or had dissipated in the sea.

7.2 Analysis of the events with particular reference to signal number 3

Let us begin the analysis with the very recent tropical cyclone of 15 November 2007 which is popularly known as Sidr. This devastating cyclonic event of 15 November 2007 has been analyzed with respect to the early warning with particular reference to warning signals. The system was first formed in the deep sea as depression on 11 November and was positioned at 9.5°N and 9.2°E at 06:00 UTC (Universal Time Constant or simply GMT). The wind speed was within 40-50 km/hr. SWC issued distant cautionary signal 1. Within 18 hours at 00 UTC of 12 November, it turned in to a Deep depression and moved to a position of 10°N and 91.5°E. The SWC issued signal number 2. Within 6 hours it intensified into a Cyclonic Storm with wind speed 62-88 km/hr and moved northwest ward at the position of 10.5°N and 91°E. The signal 3 was issued for the Bangladesh coast. After 6 hours it turned in to a Severe Cyclonic Storm with wind speed 90-115 km/hr and had its position at 11.2° N and 90.3°E and signal no 4 was issued. In the next day the system further intensified and began to move towards the coast of Bangladesh. The prediction was made from various sources including BMD and it was anticipated that the system would move to the coast of Bangladesh. The satellite imagery interpretation had already indicated that the system had gained wind speed of more that 200 km/hr. The warning signal number 10 was given for Khulna-Barisal and 9 for Chittagong and Cox's Bazar.

Another depression was formed at 13.5°N and 82.5°E with wind speed of 40-50 km/hr at 09:00 UTC of 11 November 2002. The distant cautionary signal number 2 was hoisted by BMD. At 6.00 UTC of 12 November it intensified to deep depression with wind speed of 50-60 km/hr. Warning Signal no. 3 was hoisted for the Bangladesh coast. The position was 18.5°N and 85.5°E. Within 3 hours it intensified in to a cyclonic storm. The prediction was made that the system will have its land fall on the Sunderban coast at 18:00UTC. The danger signals no. 7 was issued for Khulna and 6 for Chittagong and Cox's Bazar.

Analysis revealed that, most of the warning signals 4 were issued for those cyclones that hit the nearby coast of Bangladesh or India or Myanmar. Let us take the example of the severe cyclonic storm that hit the Paradip coast of Orissa on 29 October 1999. The system was identified in the Bay of Bengal as a depression at 18:00 UTC of 25 October 1999 and was positioned at 12°N and 97°E. The system intensified and moved towards Orissa coast as a super cyclone and as per prediction was supposed to make the landfall on 29 October. The Sundarban coast of Bangladesh being close to Orissa was supposed to experience threat from this cyclone. As a result a danger signal no 6 was hoisted for the Khulna area. The Chittagong and Cox's Bazar were much away from this cyclone and thus signal no. 4 was given for these coasts.

7.3 Analysis of the temporal variations on the frequencies of signal number 3 and higher

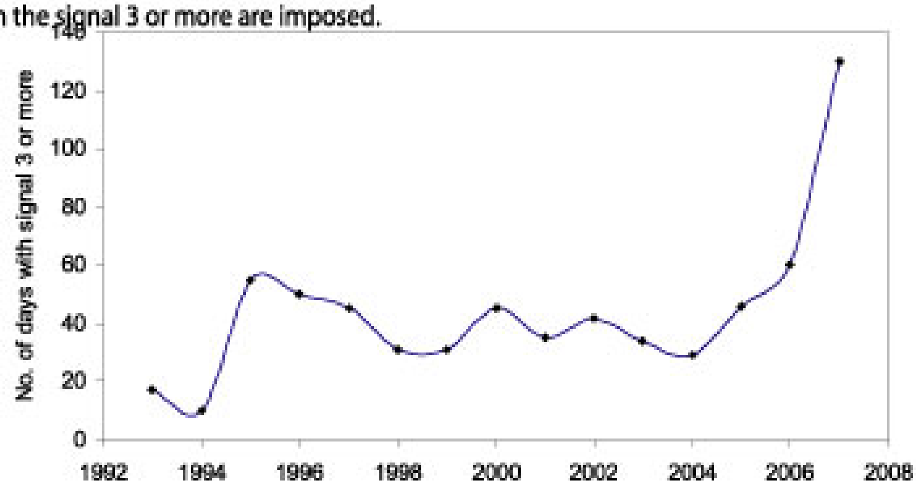
The number of days with warning signal 3 or higher were extracted from the warning bulletin from 1993-2007. A time series of number of days in a year with signal no. 3 or above is generated using the data of signals corresponding to the tropical cyclones. This time series is shown in table-11. The time series is plotted in figure-15. Both the table and the figure show that there is considerable variation of the annual signal days in the time series with low values in 1993-94. The relatively high values are obtained in 1995 (55 days), 1956 (50 days) and 2006 (60 days). The maximum was found in 2007, which seems to be an unusual year with 130 days of warning signals in one year. On an average 44 days of the year remain under warning with the standard deviation of 26.4 days.

Table -11: Annual time series of the days with signal 3 or above for tropical cyclones from 1993-2007

Year	Number of days with signal no. 3 or more
1993	17
1994	10
1995	55
1996	50
1997	45
1998	31
1999	31
2000	45
2001	35
2002	42
2003	34
2004	29
2005	46
2006	60
2007	130

Note: Generated by the consultants based on BMD data

The signal no. 3 is quite frequent during the pre-monsoon and monsoon seasons. In addition, the well marked lows, depressions and tropical cyclones are formed, when the signal number 3 and above are imposed. As a results the fishing boats, trawlers and those running for transportation are refrained from going to the sea. This affects the livelihood of the people who have the professions related to fish catching, fish trading and processing and those who are earning on boat plying. They remain out of job for the period during which the signal 3 or more are imposed.



Chapter 8

COASTAL AGRICULTURE AND LIVELIHOOD

Agricultural development in the coastal zone is besieged with many different climatic, physical, chemical and socio-economic problems. These cause adverse impacts on the coastal and national economy and on the livelihood of the inhabitants. Depending on the type of cyclone and storm surges-the loss of human live, livestock, poultry, fisheries resources and infrastructure varies. The people exposed to the sea are more vulnerable. In terms of profession and income, the fisheries people are greatly affected (occupational percentage, however, lower than crop agriculture) as they not only lose their boats but also have to refrain from going to the sea when storm warnings are issued. The majority of people involved in crop agriculture suffer in two ways; first, they lose the standing crop and second, they can't immediately start field activities until lands are cleared of accumulated salts, debris and others. The small and share croppers' sufferings are much more as they can't arrange capital to restart production activities immediately after a disaster strikes. In general, the constraints in pursing agricultural activity for livelihood and income in the coast are as under:

1) High risk in investment as cyclones and storm surges cause serious loss of life and property. This is a major problem for employment and livelihood in the coast.

2) Transplanted Aman- the primary field crop in the coastal zone suffers most. Loss in harvest inflicts many different economic and social problems.

3) Inundation by storm surges sometimes cause total loss to cultured fisheries, especially coastal shrimp and salt production. Induction of salinity and drainage congestion impedes crop production for a certain time.

4) Scarcity in drinking water for the human and livestock gives rise to diseases and thus hampers productive capacity. Contamination of surface water by salts and similarly to shallow under ground water through leaching creates problem in flushing out of salt on the surface as well as for irrigation.

5) Coastal saline soils being silty clay/clay in texture, gets hard on drying. Cracks develop, making tillage operation difficult. This is a major problem in the coastal zone since turn over period after harvest/damage of monsoon

season *aman* is short, land preparation has to be done quickly to avail optimum time for *rabi* cropping. Deep tillage using tractor could be useful for the purpose.

6) Big land ownership by absentee farmers is a major obstacle towards higher productivity in the coast. Short term lease for share cropping demotivates adoption of modern technology.

7) Only a few salt tolerant crop cultivars are available and extension program is not specialized to the coastal zone's need as yet. Further mono-cropping of aman serves as a great host to different pests and diseases. R&D activities need to be strengthened.

8) Efficient polder management including operation and maintenance of sluice gates are essential pre-requisites for adoption and practice of modern cultivars (Iqbal and Roy, 1992). Unauthorized channel digging for shrimp culture, drainage congestion etc. prevents economic activity, livelihood and gives rise to social conflicts.

9) Right to water bodies and to government owned khas land by the actual fishing community are not ensured. Providence of seed money for aquaculture and facilitating institutional capacity building for production and management by the genuine fishers/farmers are absent.

Chapter 9

IMPACT OF CHANGING CLIMATIC EXTREMES ON AGRICULTURE, FISHERIES AND LIVELIHOOD

Under climate change induced cyclone and storm surges, with increasing frequency and quantum, adverse effects on crops and fisheries sector and thus on the livelihood will be enormous. Under the predicted climate change situation, it is obvious that, with the atmospheric rise of temperature by 2° and 4°C by the year 2050 and 2100, the SST of the Bay of Bengal will also rise from the current level of >27°C. According to IPCC (1995), global temperature rise during the last 130 years is 0.6-0.7°C. On the other hand SST over the last 100 years has increased by 0.9°C. If that is the case, definitely cyclonic disturbances will be much more as SST is one necessary but not sufficient condition for formation of tropical cyclones. This is vividly demonstrated by the fact that, the area just west of Central America in the Pacific having SST of about 29°C has the highest frequency of tropical cyclones in the world (Ali, 1999).With the increase in cyclonic intensity, rise in sea level and more rainfall in the summer, there will be increased flooding and coastal erosion displacing more population.

9.1 Agriculture

Increased temperature means greater evaporation. Because of the rise in soil temperature, microbial activity will be higher resulting faster mineralization. Thus there will be rapid decline in organic matter content and nutrients, while proliferations of pest and disease will be more; consequence of which is decline in productivity and greater food insecurity. As we know, major part of the coastal livelihood is centered around crop agriculture followed by the fisheries and thus their sufferings will be the most.

The high maximum temperature especially of October and November severely affects the *Aman* rice yield (Quadir, 2007). The rapid increasing trend of post-monsoon maximum temperature would severely impact *Aman* rice yield. The negative correlation between the trend eliminated *Aman* rice yield and the country's mean maximum temperature is -0.65. It further shows that rainfall of August has negative correlation of -0.48 and that for the month of October has the positive correlation of 0.51. This indicates that the increase of rainfall would cause more floods affecting the crops and the increase of rainfall in October will help the booting, flowering and grain formation processes. Quadir (2003) has shown that wheat yield is negatively with the minimum temperature of December, January and February. The winter minimum and maximum temperature have been found to increase with strong positive trends for most of the studied stations. As a result the wheat cultivation and its yield are likely to be severely affected by the increase of minimum temperature.

The pre-monsoon rainfall exhibits very strong increasing trends. The rainfall in this season is mainly due to the thunder storm activities associated with tornadoes and hails. Thus, these activities have impacts on agriculture and fisheries sectors and livelihood of the farmers, fishermen and others. The waring signals are hoisted for the rivers and sea in the conditions of thunder storms and squally winds. The increased rainfall in pre-monsoon season would cause flash floods and damages to the standing crops and over flow the fish / shrimp ponds and inundate salt beds.

The increase of SST would affect the ecology of aquatic lives. The higher SST will bleach the corals, shells and snails. The high temperature causes the increase of salinity and decrease in concentration of Dissolved Oxygen in water. This will hamper the fish and vegetation growth in the Bay of Bengal.

For the dominating small/marginal farmers and share croppers in the coastal zone, getting land for cropping and arranging farming capital will be a major problem. Loss of standing crops by cyclones and storm surges and second generation problems like erosion, drought and flooding will increase their misery manifold. Prolonged water congestion due to back water effect will deprive the farmers to go for land preparation and cropping to cover up the loss through post-disaster activities. Under 'Business-as-usual' scenario, farmer's crop choice will be less and this may be a major problem in undertaking post-disaster rehabilitation activities. As discussed earlier, tillage of land during dry *rabi*; together with further scarcity of quality irrigation water will be a major hindrance in winter season crop expansion. With climate change induced extreme weather situations and thereby more cyclonic events-will further aggravate the situation. Again, as predicted, reduction in winter season precipitation, greater salt accumulation on the top soil, delay in surge water recession, will force greater part of the coastal land to keep fallow. Increased evaporation will demand more irrigation for crops. Reduction in organic matter and faster mineralization will give rise to decline in fertility and thus productivity, resulting in extra burden and economic stress on the poor farmers. Absentee big land owners will be reluctant because of risk and uncertainty, to invest capital in agriculture and take the view of 'wait-and-see'. All these will substantially impact the present livelihood and income of the coastal dwellers.

9.2 Fisheries

In Bangladesh total marine fish harvest is only 20% (4, 87,438 metric tons) of the total fish catch, while nearly 40% (5.10 lakh) of the total fishers (12.80 lakh) are engaged in marine fishing. Out of the total (11.50 lakh) shrimp farmers, which is 38% of the total fish farmers, over 8.0 lakh are engaged in coastal salt water *Bagda* shrimp production. As regards total export earnings of BDT 3352.89 crore in 2006-07, frozen shrimps contribution was nearly 90%, of which coastal salt water shrimp's share was over 80%. Dried fish export was highest in 1993-94 (BDT 41.83 crore) but during the last few years it is ranging between BDT 1.34-4.16 crore only. Export earnings from turtle, crab etc. was BDT 61.48 crore in 1996-97 but has gone down to BDT 15.48 crore only during 2006-07 (DoF, 2008). According to the Department of Fisheries, only 127 trawlers are engaged in marine fishing. Besides 21,433 engine boats, 22,527 big non-mechanized boats and 43,960 traditional boats are engaged in fishing in the sea. This information is useful and required to understand the vulnerability and livelihood of the marine fishers and coastal fish farmers.

Rise in sea level will engulf significant part of the low and flat coastal terrain of Bangladesh. This along with the inundation by cyclonic storm surges will eliminate functionality of many offshore water bodies presently under shrimp and other fish culture. Because of higher cyclonic frequency, there will be more and more cautionary signals preventing fishers to go to the sea. Both marine and culture fishery and even open water fishery will suffer due to greater salt water intrusion. As resource loss in respect of boat/trawler sunk, death of ocean going fishers will increase; thus there will be drastic reduction in the total volume of fish catch. This will subsequently hamper the performance of fish drying industry as well. Boat owners will be facing problem in repayment of outstanding loans and thus reluctant to invest further on quick boat replacement. This sort of situation will deprive the poor fishers from immediate employment and income. In majority of the cases, ownership and lease of government owned water bodies in the coastal zone are with influential groups. Actual fish farmers- having no arm on water bodies' management have to work at the will of the powerful few. This is one of the key reasons for land degradation, low productivity and ill income of the hard working fish farmers. Salt manufactures will suffer through inundation and washing out of the salt bed. Livelihood of those fishers and farmers who find partial employment in the salt industry and in fish drying during 'risk period' will be deprived of income.

Millions of people in the coast, especially the small and marginal farmers and fishers will be forced to migrate to cities. Strategy for adaptation to extreme climate events need to be evolved through R&D initiatives in order to sustain livelihoods of the coastal inhabitants and maintain socio-economic stability.

Chapter 10

OPPORTUNITIES FOR COASTAL LIVELIHOOD DEVELOPMENT

Despite proneness to natural (cyclone, storm surges, flood etc) and manmade hazards (water logging, salinity etc.) the population density/sq. km is not that low in the coastal zone. High dependence on agricultural activity- the performance of which rises and falls with the frequency and magnitude of disasters; exerts enormous stress on the livelihood of the coastal dwellers. Extent of poverty in the coast thus, is higher than the country average; 52% are poor and 24% extreme poor (ICZM, 2003).

In spite of the problems detailed in the earlier pages many opportunities are also there in coastal zone. This is primarily because, coastal zone has a great diversity in natural resources (both terrestrial and aquatic) and above all the resilience of coastal inhabitants are the highest. The brave people of the coast are living with the disasters and resettling at an unprecedented speed after disasters. According to the population census 2001, average literacy rate in the coastal districts is higher (nearly 53%) than the national average. A mix of modern agriculture and agro-based industries, greater expansion in the service sector e.g. tourism, further development of the ports and export processing zones; would not only create employment opportunities and income but will also contribute towards national economic development. Government's poverty document (PRSP, 2005) rightly has stressed on these issues and these initiatives and development are necessary for the coastal inhabitant's livelihood. Comprehensive development approach is thus urgently required for the coastal zone integrating the predicated change in climate. Coastal Zone Policy of the government among others does have the objectives of (a) reducing poverty and creating alternative livelihood for the coastal community (b) reduction of vulnerabilities and development of coping capacity and (c) sustainable management of coastal resources. It's the time to act accordingly and bring this plan into reality.

Chapter 11

SUSTAINABILITY OF COASTAL LIVELIHOOD

Because of the great diversity of wealth and natural resources, the coastal zone in spite of the present and upcoming problems, could be a major area of economic activity. Steps may be as follows to turn these problems into much needed opportunities for development and sustaining the livelihood of coastal inhabitants:

1) Land zoning and demarcation of highly saline areas for intensive shrimp farming and release of less saline area for crop agriculture is a pre-requisite for coastal agricultural development. Long term lease system would be beneficial in this respect.

2) Introduction of specialized extension approaches for coastal zone development. Integration of climatic vulnerability e.g. cyclones and storm surges etc. with the development initiatives in the coast is essential.

3) Qualitative improvement in short term forecasting and timely dissemination of disaster information and introduction of long term/seasonal forecasting for effective planning and farm management.

4) Change in land tenure system and R&D for development of salt tolerant crop cultivars (Brri dhan 47 type), and land-soil-water management. Transformation from traditional to semi-intensive/ intensive shrimp farming, rice-cum-shrimp/fish culture would help to create employment and improve livelihoods of the people.

5) Organized buffalo and sheep farming to utilize the available pasture land in the coast. Switching over from mono aman cropping to greater salt resistant crops like wheat, barley, soybean, maize, groundnut, chilli, cabbage etc.

6) Investment and greater stress on marine fishery and other sea resources (e.g. shell, crab, sea weeds, corals in St. Martins) development for 'risk period' employment and income.

7) Conservation and expansion of mangroves, durable coastal embankment, and forests/green belt development for retardation of wind speed, storm surge, salinity intrusion.

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