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in Geospatial Technologies

# IMPACT OF CLIMATE CHANGE IN BANGLADESH: WATER LOGGING AT SOUTH-WEST COAST

**Master´s Thesis**

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## Declaration of originality

This is to certify that the work is entirely my own and not of any other person, unless explicitly acknowledged (including citation of published and unpublished sources). The work has not previously been submitted in any form to the University of Münster or to any other institution for assessment or any other purpose.

Signed_____

Date 01/03/2010

# Abstract

Bangladesh is a densely populated, agriculture-based country and is recognized as one of the areas most vulnerable to the impacts of global warming and climate change. This is due to its unique geographic location, dominance of floodplains, low elevation, high population density, high levels of poverty, and overwhelming dependence on nature for its resources and services. The country experiences severe flood and cyclone events and, in recent years, water logging has become a catastrophic problem along the coast. These coastal areas play important economic and environmental roles in the country.

The present paper attempts to show the extent of water logged areas, caused by sea level rise and the sectoral impacts of settlement, agriculture and fisheries in the south-western coastal areas of Bangladesh. A multi-temporal analysis method has been used with remote sensing (LandSat 1975 and LandSat 2000) data. SRTM data has been used to show the actual land elevation and to predict the future height of water logging in the study area. In 2000, 182418 hectares area was inundated by water and almost 50 percent of the study area is classified having high vulnerability. Saline line has entered upto 20 to 35 km into the mainland since 1967 which has great impact on agriculture and health. Many educational institutions of the study area are in vulnerable condition as some of them inundated completely or partially and even some of them are being used as shelter by local victimized due to water logged into their fragile houses. The largest mangrove forest of the world is also at risk to water logging and saline intrusion from the sea.

To the Government of Bangladesh, NGOs, policymakers, planners and other interested parties it is important to measure and monitor present issues and to predict the future impacts of climate change. This will help to facilitate effective management and is particularly important where a lagre number of people are threatened. In this regard the present study is expected to be useful and will have strong implications in coastal planning and other climate change adaptation measures.

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# Chapter 1

# Introduction

## 1.1 Background of the study

To meet the needs of the world's increasing population, excessive extraction and exploitation of natural resources in developed and developing countries causes the global climate to lose its balance. Natural elements such as temperature, rainfall are expected to cause broader changes in glacier retreat, arctic shrinkage, worldwide sea level rise[1] and increase in the intensity of extreme weather events. A significant change in the pattern of precipitation may result in flooding and drought. Other expected effects of global warming include changes in agricultural yields, reduced summer stream flows and species extinctions. For the last century glaciers have been unable to regenerate enough ice during the winter to make up for ice lost during the summer months affecting the availability of fresh water for irrigation and domestic use.

The major concern of climate change[2] is sea level rise and its huge impacts along the coastal areas of the world. Bangladesh, an underdeveloped country located in south Asia, has a 710 km long coastal zone that plays an important role in the country´s economy and environment. This coastal zone is particularly vulnerable to the impact of climate change and its inhabitants frequently receive some extreme weather events such as cyclones and floods.

[1] A rise in the surface of the sea due to increased water volume of the ocean and/or sinking of the land.

[2] The climate of a place or region is changed if over an extended period (typically decades or longer) there is a statistically significant change in measurements of either the mean state or variability of the climate for that place or region. Changes in climate may be due to natural processes or to persistent anthropogenic changes in atmosphere or in land use.

Water logging[3] in the coastal areas caused by sea level rise poses permanent hazards to humans as there are no ready solutions except adaptation or migration. Remote sensing[4] and Geographic Information Systems (GIS) are used as tools to detect hazardous areas affected by water logging for advanced measurement and management. Remote sensing data can be used to analyze surface changes of the earth at local, regional and global scales over time. Remotely sensed imagery is used as a link between intensive, localized ecological research and regional, national and international conservation and management of biological diversity (Wilkie and Finn, 1996).

### 1.2 Statement of the problem

Water logging has already affected the coastal areas of Bangladesh with settlement inundation, salinity intrusion and loss in biodiversity. Its threats are even stronger in the south-west coastal zones of the country and the potential impacts are expected as a severe catastrophe to the people of those areas. There have been huge losses in the agricultural and fisheries sectors. Education and health systems have also broken down due to water logging and saline water intrusion (Sarwar, 2005). Substantial research is required to face the problem i.e., to find out the way of mitigation and adaptation. The government of Bangladesh has asked national and international researchers to investigate sea level rise and water logging in the country. The importance of measuring and monitoring present issues and predicting the future impacts of climate change are of importance not only to the government of Bangladesh but also to non-governmental organizations (NGOs), policymakers and planners. This study will help facilitate effective management and is particularly important where a large number of people are threatened. In this regard the present study is expected to be useful and will have strong implications in coastal planning and other climate change adaptation measures.

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[3] Water logging is a verbal noun meaning the saturation with water.

[4] The science of acquiring information about the earth using instruments which are remote to the earth's surface, usually from aircraft or satellites. Instruments may use visible light, infrared or radar to obtain data. Remote sensing offers the ability to observe and collect data for large areas relatively quickly, and is an important source of data for GIS.

### 1.3 Study area

The present study was conducted in the south-west coastal area of Bangladesh, particularly in the Satkhira, Khulna, Bagerhat and Jessore Districts (Figure 1), where a large number people are resident. According to BBS (2007), the total number of residents is 2,520,961 (Khulna), 1,950,557 (Satkhira), 2,586,771 (Jessore) and 1,620,216 (Bagerhat). Maximum annual average temperature is 35.5°C, minimum annual average is 12.5°C and the annual rainfall is 1710 mm. The soil of this region is mainly alluvial floodplain. Main rivers are flowing through the area are Kobadak, Sonai, Kholpatua, Morischap, Raimangal, Hariabhanga, Ichamati, Betrabati and Kalindi-Jamuna (Rashid, 1991). The largest mangrove forest, the Sundarbans, is also in this area. Sundori, Goran, Geoa. are the main trees of this forest.

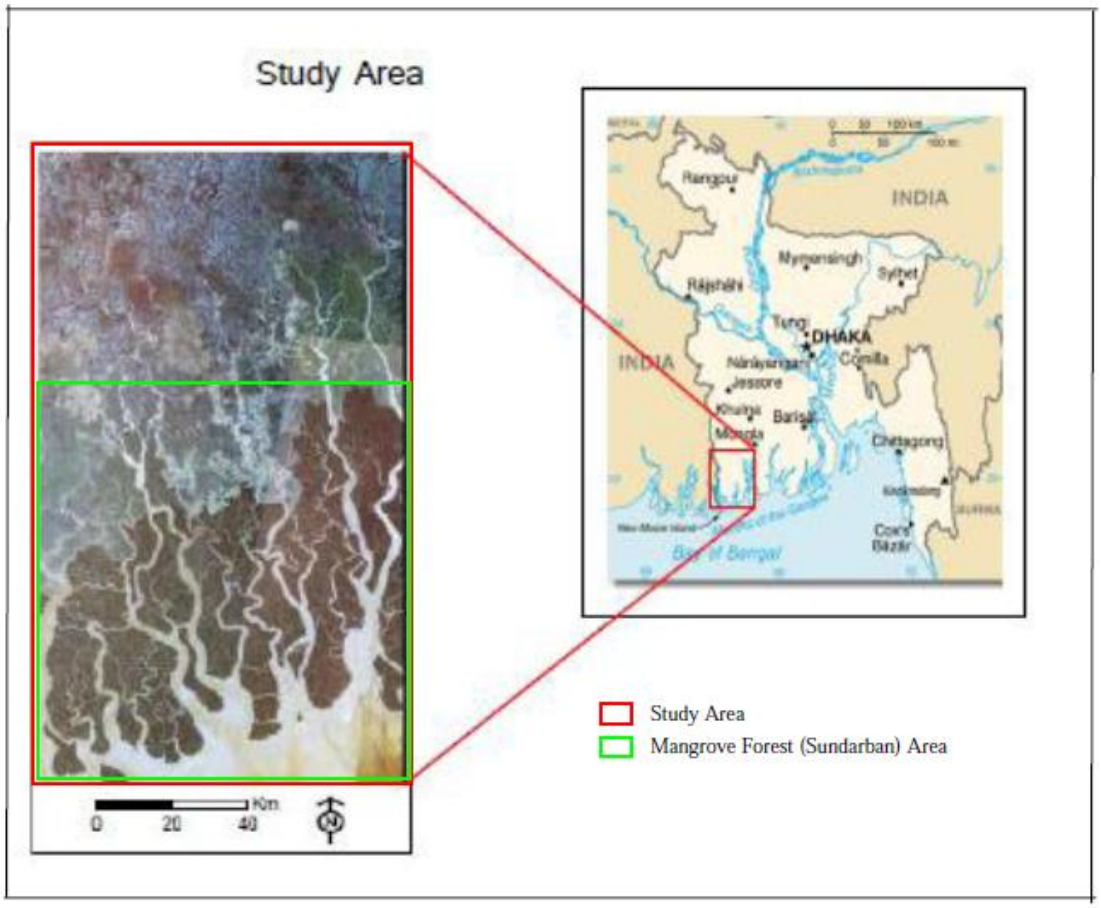


Figure 1: Study area

## 1.4 Objectives

Keeping the aforementioned problems in mind the research was executed with a view to find out the impact of climate changes. The main objectives are as follows;

a) to determine the actual extent of water logging at south-west coastal areas of Bangladesh using Landsat images of 1975 and 2000;
b) to assess the vulnerable areas using SRTM[5] data of the study area;
c) to delineate different sectoral impacts of water logging such as agriculture, health, settlement and education; and finally
d) to propose some implementable solutions.

[5] The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000.

# Chapter 2

# Literature Review

## 2.1 The changing climate

Global climate is a continuous changing phenomenon. The earth has long been subjected to sequential glacial, inter-glacial and warm periods, and some parts of it have been warmer and cooler at various times in the past (Bhatti et al, 2005). In glacial periods global temperature was $4 - 5^0$ C less, and interglacial periods $1–2^0$ C more, than the temperature we are facing in the present time (Harris, 2004). The average temperature near the earth surface was increased by about $0.74^0$ C over the past century and eleven of the last twelve years rank among twelfth hottest years on record since 1850. The second half of the twentieth century was the warmest fifty abbreviate in the last 1300 years (IPCC[6], 2007). Like temperature, precipitation, the other important factor of climate, has changed significantly its trend to upward with most of the increase occurring in the first half of twentieth century. In high latitudes of both hemispheres the trend of precipitation has increased and across the tropical regions the trend has decreased (National Climatic Data Center, 2008). The past feature was totally natural in origin when population size on earth was minimal, but now humans are also responsible significantly to make variation in global climate along with the nature (Harris, 2004).

Most of the observed increasing globally average temperatures are very likely due to the observed increasing human produced greenhouse gas concentration. The climate model project summarized by IPCC (2007) indicates that the average global surface temperature will likely rise from $1.1^0$ C to $6.4^0$ C during the $21^{st}$ century. And these ranges of values result from the use of different scenarios on future greenhouse gases use. Evidence for global warming includes the recent strength of very warm years, scientists record the 1998 was the warmest year in measured history, and 2005 comes in second (Figure 2).

[6] The **Intergovernmental Panel on Climate Change** (IPCC) is a scientific intergovernmental body tasked with evaluating the risk of climate change caused by human activity. The panel was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), two organizations of the United Nations.

The green house effect begins with the sun and the energy radiates to the earth. The earth and the atmosphere absorb some of this energy, the rest are radiated back into the space (Wuebbles et al, 1991).

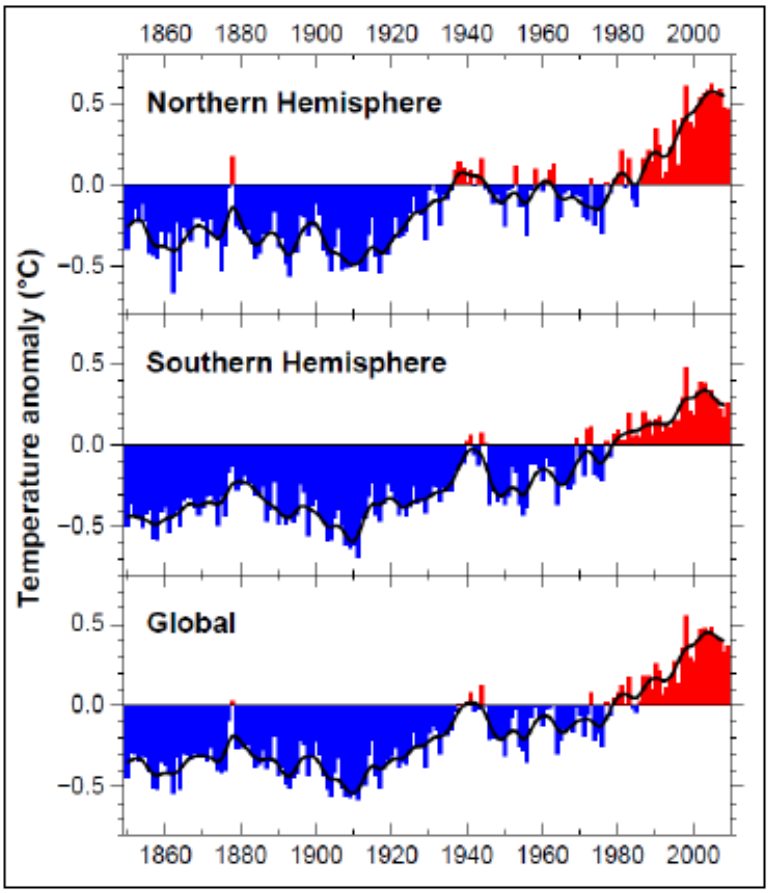


Figure 2: Hemisphere and global average temperature (*Source: Jones, 2008)*

Volcanic eruptions, ocean outgassing and decomposition and respiration which are known as natural processes are continuously releasing greenhouse gases such as water vapor, carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) into the atmosphere. Scientists now believe that the green house effect has been intensified by extra greenhouse gases that are released by humans. Human activities since the industrial revolution have increased the concentration of various greenhouse gases like $CO_2$, methane, ozone, chlorofluorocarbon (CFC) and nitrous oxide (Mastrandrea, 2005). The biggest factor of present concern is the increase in the $CO_2$ levels (Figure 3). The 2005

level was highest over the last 650,000 years and the same rise in the $CO_2$ concentration at the end of ice ages took over 5000 years while even a bigger rise has happened only at industrial age. Fossil fuel burning has produced approximately three-quarters of the increase of $CO_2$ from human activities over the past 20 years. Land use changes such as deforestation in the tropics, paddy rice farming, wetland changes and land fill emission among other factors are leading to the higher methane atmospheric concentration. Agricultural activities including the use of fertilizers lead to higher nitrous oxide concentration (Southwest Climate Change Network, 2009).

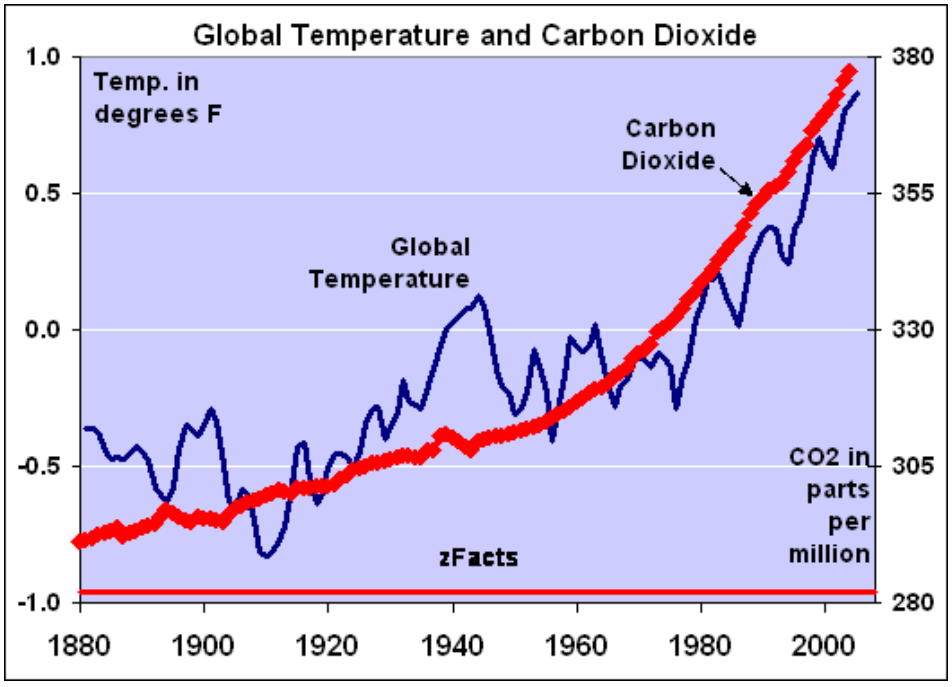


Figure 3: Carbon dioxide and global temperature (Source: zFacts, 2007)

## 2.2 Impacts of climate change: global perspective

As ocean temperature is rising due to anthropogenic causes which increase greenhouse gas concentration and hurricanes of the Pacific and Atlantic Oceans are becoming more and more powerful. In a research conducted by a team of scientist at NCAR[7] showed that over the past century the rising sea surface temperature (SSTs) and human activities are highly linked. The research reveals that about 84 percent of the total hurricane formed in the Pacific and Atlantic oceans for the period of 1906-2005 due primarily to SSTs by green house gas emissions through human activities (The National Science Foundation, 2009). It is observed that each year there are about 80 hurricanes, also known as typhoons or tropical cyclones, occur around the tropical oceans. Mexico, Japan, USA and some other countries of the world have bitter experiences of facing such devastating hazard. A low lying country like Bangladesh is particularly vulnerable to the storm surges associated with tropical cyclones where in 1970 over 500,000 people drowned (Houghton, 2009).

Floods are the other forms of climate change effect. Prolonged intense rainfall, river siltation or water from the sea into the land or coastal areas are the major causes of floods. There has been some example of such devastating calamities in China, Venezuela, USA, and Bangladesh in the recent past decades (Houghton, 2009).

Sea water is expanding itself through warming and as a result the volume of the global ocean is increasing (Bhatti et al, 2005). According to IPCC report (2007), from 1961 to 2003 the observed thermal expansion rate of the ocean was $0.42 \pm 0.12$ mm per year but the projected thermal expansion is $1.3 \pm 0.12$ mm per year during 2000 to 2020. This projected thermal expansion rate is even much more during the year 2080 to 2100, which

[7] The **National Center for Atmospheric Research** (**NCAR**) conducts collaborative research in atmospheric and Earth system science, encompassing meteorology, climate science, atmospheric chemistry, solar-terrestrial interactions, environmental and societal impacts, and more. A nongovernmental institute, the center is based in Boulder, Colorado, USA at the Mesa Laboratory.

is 3.8 ± 1.3 mm per year (Figure 4). The increased climatic warming is responsible for this acceleration (IPCC, 2007).

Greenland and Antarctica contain major parts of the world´s glacier and ice sheets. Global warming is the primary reason that melts those glaciers and ice sheets and over the last few decades ice and snow have decreased significantly especially in the Northern Hemisphere (UNEP, 2009). Every year a large amount of additional fresh water is coming from melting glacier and ice sheets to the ocean. If there is no ice masses, i.e., all ice sheets and glaciers are melted, the sea level could eventually rise up to 65 meter which is not possible but a major change can happen even a minor melting of these ice masses. According to UNEP (2009), if the ice melts by 20 per cent in Greenland and 5 per cent in Antarctica at the same time, the sea level will rise by 4 to 5 meters. This will have not only major consequences for the small islands in the Pacific, Caribbean, and the Indian Ocean, but also for countries like the Netherlands and Bangladesh; and cities and coastal infrastructure in many other countries will be affected negatively.

IPCC (2007) addressed strong evidence about global sea level rise and currently the increased rate is higher than previous time (up to the $20^{th}$ century). Hydrographic observation, climatic models and satellite data show that sea level rise is not uniform across the world. In some parts the increasing rates are up while other regions are falling and this is due to non-uniform changes in temperature and salinity and related to changes in the ocean circulation.

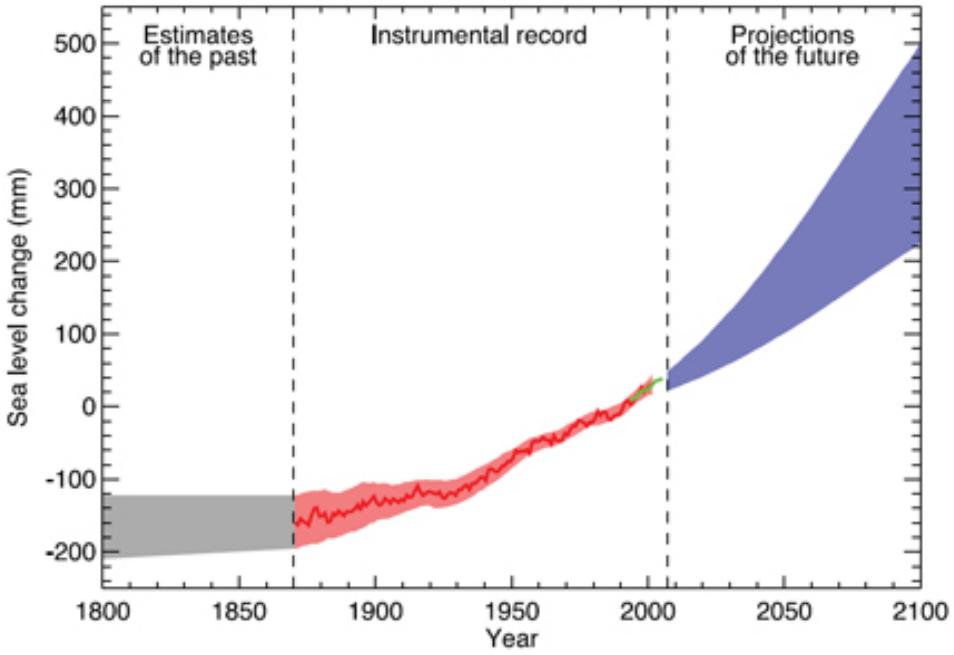


Figure 4: Past, present and predicted sea level trends (Source: IPCC, 2007)

Coastal zones around the world are especially vulnerable to climate change and sea level rise (Figure 5). Over the past few decades world´s coastlines reveal a relative sea-level rise recorded by tide gauges leads to coastal erosion which facilitates wave action to progressively higher levels and permits larger waves to reach the coast through deepening near-shore waters (Milliman, 1996). Saline water intrusion from sea into the adjacent coastal areas can paralyze permanently agricultural fields, fresh water wetlands and fisheries and forestry (EPA, 2009). Coastal wetland biodiversity such as marshes and mangroves can also be adversely affected by sea-level rise particularly in the area where they are constrained on their landward side. Rising sea-level may convert the world´s coastal wetlands to open water up to 33 percent where most densely populated areas are seen and millions of them are projected to be flooded or waterlogged by the year 2080 (IPCC, 2007). Recreational resorts on the coastal barriers, considered as economically important, are also vulnerable (EPA, 2009).

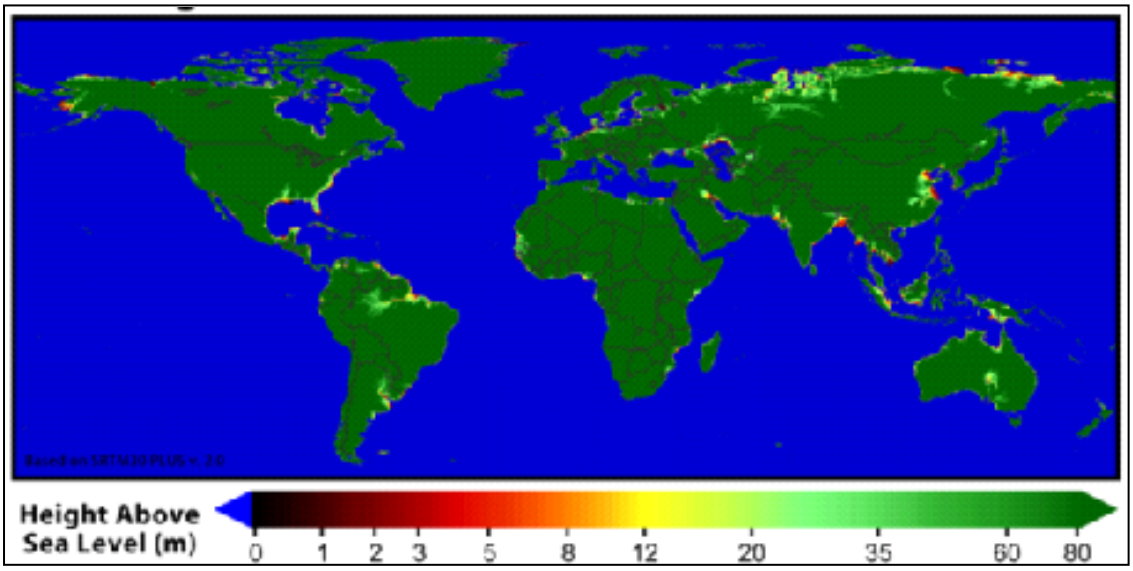


Figure 5: Regions vulnerable to sea level rise (Source: Global Warming Art, 2009)

Biodiversity and ecosystem services which are critically important for human well-being are already under threat to the land use changes. Climate change has added additional stress to these and it is likely to enhance habitat loss through, for example, deforestation, forest fires and desertification. Climate change is also likely to trigger species migration and certain ecosystem such as mountains and coasts including mangroves and coral reefs. The poor in developing world those who have contribute less or least to causing climate change are the people who have experienced more and more severely, the negative impacts are likely to be most seriously in the tropics and subtropics where the majority of developing countries are located and weather capacity to adapt to changes is most limited. (Lovejoy, 2006)

## 2.3 Impact of climate change in Bangladesh

Ganges delta, the largest river delta of the world, was formed by the confluence of the major three rivers of Bangladesh, *Ganges, Jamuna* and *Meghna* and hundreds of their tributaries (Rashid, 1991). The country´s population density is the highest in the world and almost half of the total people live below the poverty line. Bangladesh can be the example of several kinds of natural calamities such as flood, cyclone, draught, landslides and water logging in the present time (Climate Change Cell, 2007). Every year hundreds of villages and many cities are inundated by floods damaging agricultural fields. Many people, in some years even millions, die along the coastal areas due to devastating cyclones (Table 1) which are considered as negative impact of global climatic change (Banglapedia, 2006). SPARSO[8] of Bangladesh produced a map showing the cyclone affected areas of Bangladesh (Figure 6).

Table 1 : Major Cyclones affecting Bangladesh since 1960

| **Year** | **Death** | **Year** | **Death** |
|---|---|---|---|
| 1960 | 3,000 | 1970 | 300,000 |
| 1960 | 5,149 | 1985 | 11,069 |
| 1961 | 11,466 | 1988 | 2,000 |
| 1963 | 11,520 | 1981 | 138,000 |
| 1965 | 19,279 | | |

Source: European Community, 1998

[8] Space Research and Remote Sensing Organization (**SPARSO**), Bangladesh

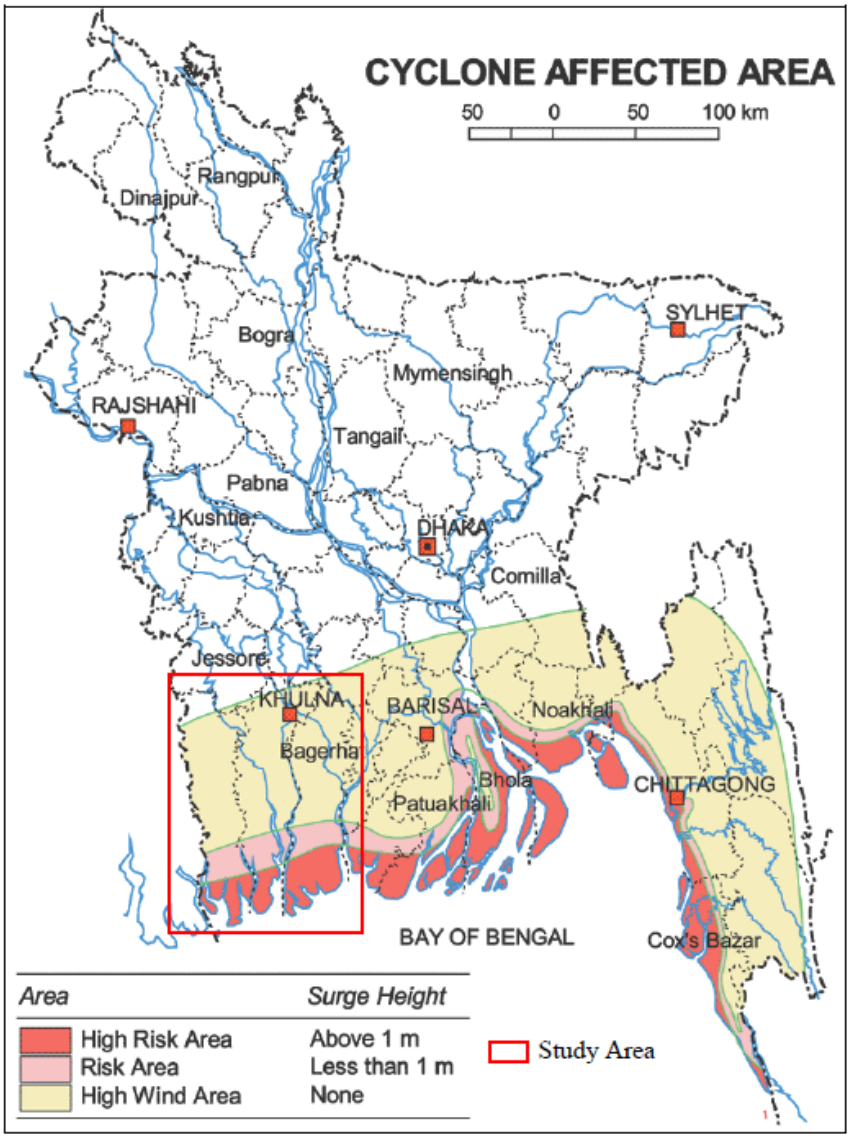


Figure 6: Cyclone affected area of Bangladesh
(Source: Dhakadailyphoto, 2007, adopted from SPARSO, Bangladesh)

Almost every five years Bangladesh is affected by droughts that affect crop life cycles and north western regions are particularly vulnerable to this affect. Although in monsoon period a substantial amount of rain occurs but some years in some parts the amount is not sufficient for agriculture. Moreover, land degradation, livestock population, employment

and health sectors are also affected considerably by this hazard. During the last fifty years, droughts happened in Bangladesh 19 times. Among all, droughts of 1951, 1961, 1975, 1979, 1981, 1982, 1984, 1989, 1994, 1995 and 2000 year were severe (FAO, 2007).

### 2.4 The coastal zone of Bangladesh

Bangladesh is basically a riverine country and a few of the world´s major river passing through the country helped to form as a deltaic land (IUCN, 1994). The destination of all rivers is to meet to the Bay of Bengal which is located to the south of Bangladesh. The country´s big coastal area is 710 km long, which covers 19 districts out of 64 and 147 *thanas*[9] (Figure 7) (Islam, 2006). This coastal zone reserves 32 percent of the total area and 28 percent of total population of Bangladesh and covers an area from the shore of 37 to 195 kilometers (Islam, 2006).

According to the closer to the sea the zone is divided into exposed and interior coast. The *thanas* which are facing the southern sea coast or river estuaries are known as exposed coastal zone and the total number of such exposed zones is 48, whereas interior coast which are located behind the exposed coast do not face sea coast or riverine estuaries and they are 99 in numbers (Figure 7). The exposed coast zones are more vulnerable to climate change such as cyclone, sea level rise, tsunamis and water logging.

[9] **Subdistrict** which is also known as upazila.

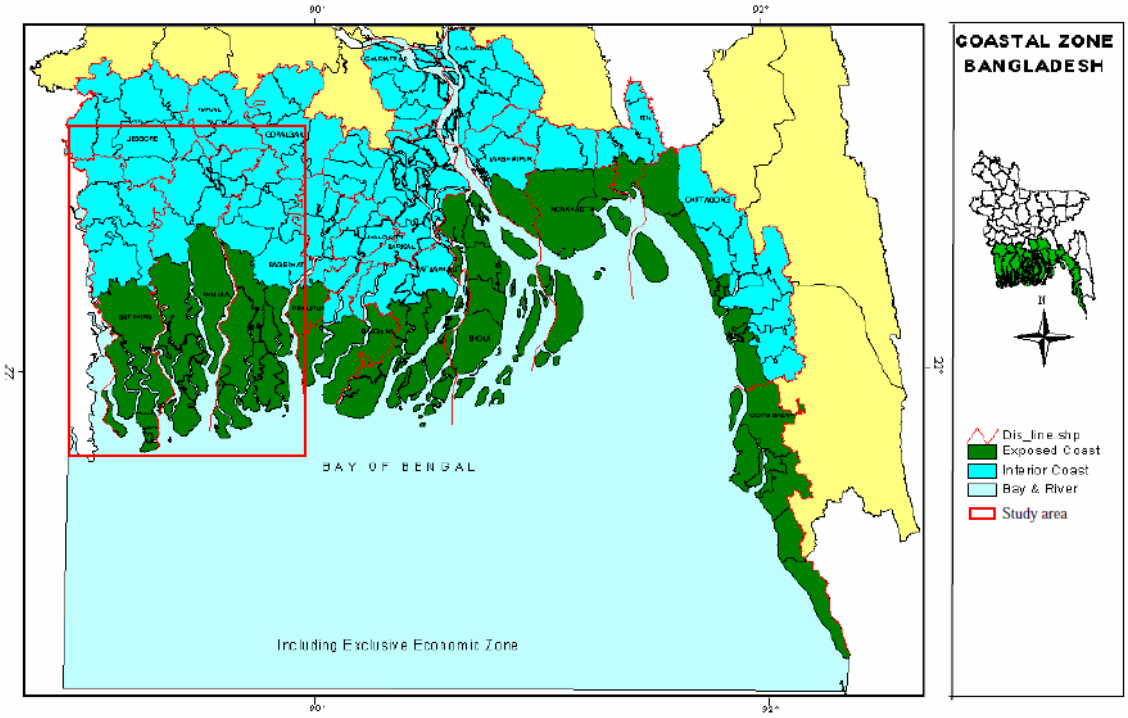


Figure 7: Coastal zones of Bangladesh (Source: Islam, 2006)

## 2.5 Remote sensing and water logging

Remote Sensing is an extremely useful tool to detect natural or human induced disasters among others such as floods, cyclone, water logging. This tool has been widely using for mapping and monitoring waterlog both in urban areas and coastal zones. Different images of satellites are different and complement each other with respect to spatial, temporal and spectral resolution (Lelkes, 2002). Choubey (1997) used IRS-IA LISS data of 1989 to delineate water logged areas in the Tawa command areas of India during pre and post-monsoon period and he obtained both water logging areas and areas are sensitive to water logging. This study also suggest that periodic assessment of water logging using remotely sensed data should be carried out at regular intervals. Landsat Multi-spectral Scanner data of different years have been used to detect water logging and salinization areas of India´s arable land (Dwivedi, 2006). The study shows a significant decrease of soil fertility due to salinity over 15 years.

## 2.6 The mangrove forest of Bangladesh

Sundarbans[10], the largest mangrove forest of the world, has been sharing its area within two neighboring countries India and Bangladesh. It covers an area of 16,700 sq. km of which India comprises one third of the original size and the major rest is remaining in the south west part of Bangladesh (Wikipedia, 2009). A large number of rivers and cannels are connected to the sea, Bay of Bengal, have also captured a significant volume of total area and have a decisive role for the environment. This tidal halophytic mangrove forest is the border between sea and land of the country was formed over the millennia through natural upstream sediment deposition and became a part of Ganges Delta (Rashid, 1991).

The *Sundarbans* has a rich biodiversity where a variety of vegetation including trees, grasses, herbs, accompanied by mangrove type forests mainly "*Sundori" are* dominating. There have been more than 200 fishes, 300 birds and numerous species of phytoplankton, fungi, bacteria, zooplankton, benthic invertebrates, molluscs, reptiles, amphibians and mammals are included. The Royal Bengal Tiger of Sundarbans is world famous. Compare to the other parts of the country a small number of people live in or around the mangrove forest who are *bawalis* (collectors of golpata), *mouals* (honey collectors) and woodcutters. Usually they have built their cottages or houses at the edge of the forest on platforms supported on 3-5 meter high poles of wood or bamboo. Some people who are called gypsy live on boats round the year (Banglapedia, 2006).

To the local or national economy, this mangrove forest has an important role. Every year a number of national and international tourists visit, raw materials for wood based industries are supplied. Thousands of fishermen live on fishing into the rivers and cannels passing throughout the forest. Sundarbans´ protective role is one of the main important values for the country. Cyclones become weak while passing over the largest coastal forest and save thousands of lives and wealth every year (FAO, 1995).

[10] The Local Name of south-west mangrove forest. ***Sundar*** means beautiful and ***ban*** means forest. So, the *Sundarban* is "beautiful forest".

## 2.6 Adaptation to climate change

As the dimension of climate change effect is capital and humans are not able to protect it readily, adaption has therefore become necessary in certain regions or environmental systems vulnerable to extreme events (EPA, 2009). According to the IPCC (2007) *Adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*. Leary et al (2008) has described nine general lessons about adaptation which are (1) adapt now, (2) create conditions to enable adaptation, (3) integrate adaptation with development, (4) increase awareness and knowledge, (5) strengthen institutions, (6) protect natural resources, (7) provide financial assistance, (8) involve those at risk, and (9) use place-specific strategies.

# Chapter 3
# Methodology

## 3.1 Data collection and software

In this study data were collected from different secondary sources. For identifying water logging areas two satellite images were used. One of them was Multi-spectral Scanner (MSS) in the year of 1975 and the other one was Enhanced Thematic Mapper Plus (ETM+) of 2000 which were taken from GLCF[11]. Band 1 and band 2 are visible bands and band 3 and 4 are near infra-red of MSS scanner. For ETM+ visible range is from band 1 to band 3, band 4 is near infra-red and band 5 and 7 are short wave infra-red (infoterra, 2010). All information is summarized in the following table.

Table 2: Image information

| Sensor | Path/Row | Acquisition Date | Spectral Range | Bands | Pixel Resolution |
|---|---|---|---|---|---|
| MSS | 148/44, 148/45 | 5 Dec., 1975 | 0.5 - 1.1 µm | 1, 2, 3, 4 | 60 meter |
| ETM+ | 138/44, 138/45 | 17 Nov., 2000 | 0.450 - 2.35 µm | 1, 2, 3, 4, 5, 7 | 30 meter |

The acquisition month generally has to be taken into account when comparing multi-temporal data, especially in areas of strong seasonal change of water bodies. In this study Landsat imagery of dry season in Bangladesh (from November to March) were considered to identify the actual water logged areas as additional water from rain can be found in the rest months of the year to ensure that those water logged areas were not flood. Moreover, seasonal effects on vegetation are not so strong in Bangladesh which can be mostly neglected.

[11] GLCF (Global Land Cover Facility) provides remotely sensed satellite data and products to better understand global environmental systems. Landsat imageries can be downloaded from the website http://www.landcover.org/data/landsat/.

SRTM data of 90 meter resolution were downloaded from the website of http://srtm.csi.cgiar.org/ and used for accurate visualization of water logging areas and to make a map of vulnerable places of the study area. Sectoral effect data have been used which were collected from government organizations, NGOs and different offices. ERDAS Imagine, ArcGIS and Global Mapper software were used to analysis and find out the results.

### 3.2 Methods of water logging analysis

To find out water logged areas in the south-west coast of Bangladesh both images were subset first according to the study area where band 1, band 2, band 3 and band 4 were considered. Band 5 and band 7 of ETM+ were not considered for spectral comparability of bands 1-4 of MSS and ETM+. And then carried out a supervised classification using parallelepiped non-parametric rule (Schanze, 2004). The image classification is a process of categorizing all pixels or regions of the image into classes intended to represent different physical objects or types. The output of such process is considered as a thematic map rather than image (Richards, 2006). Unsupervised and supervised are the main two methods of image classification. In the unsupervised classification method training samples or user´s previous knowledge on land cover of the study area is not necessary (CCRS, 2005), whereas supervised classification method refers users training classes and a-priori knowledge of the area. It rests upon using suitable algorithms to label the pixels in an image as representing particular ground cover types, or classes (Richards, 2006).

The parallelepiped classifier is known as box decision rules. This classification is based on the ranges of values within the training data to define the regions within a multidimensional data space (Campbell, 2002). Principally this classifier uses the class limits and stored in each class signature to determine if the class will receive the given pixel or not. The limits of class indicate the dimensions (in standard deviation units) of each part of a parallelepiped surrounding the mean of the class in feature space. The given pixel may fall or may not fall to the specified class and even some pixels are owned by more than one class (Richards, 2006). The main advantage of the parallelepiped

classificator is that it is easy to leave areas unclassified. It might also be possible to set certain limits for classifying using nearest neighbor or maximum likelihood, but in the parallelepiped classificator a box is defined based on statistical parameters, and only pixels within the box are assigned to the desired class.

However, the classification was accomplished to separate water bodies from the rest land cover areas, such as agricultural fields, forest and vegetation, roads and bare soils, urban areas, etc. Signatures, main hub of supervised classification, were collected from feature spectral images. Feature space layers help to explore spectral properties of image. ERDAS Imagine software allows user to create a scatterplot where the data file values of one band have been plotted against the data file values of another band. This can only be done in a two dimensional histogram, but theoretically data has multi-dimensions of spectral space (Spatial Analyst Laboratory, 2009).

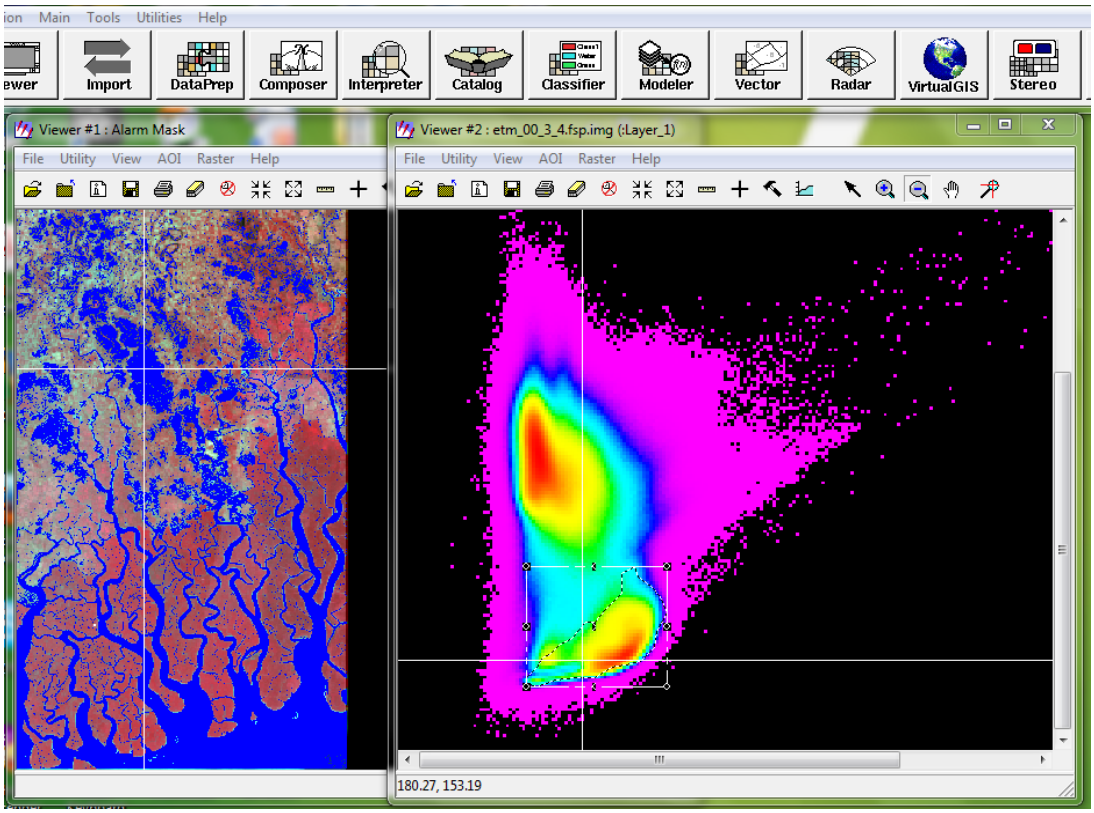


Figure 8: Polygon of Water bodies in scattergram of ETM+ image and image alarm mark.

Three samples of 3 x 3 pixel size in both images were defined representing water bodies (Appendix, Table A and Table B) and then scattergrams were checked to examine if these three samples were located in spectral space. A polygon was defined in the scattergram that include all the three samples. This polygon therefore defines the spectral range of desired class "water bodies". The selected polygons were checked in the images with image alarm (Figure 8). Image alarm shows the pre-classification of the image data. Signature file with the defined colour can be checked on the image to be classified with this operation. This process can be done repeatedly to get a better classification result (LLU – ESSE21).

These two classified images are then subtracted, classified MSS image of 1975 was subtracted with union operation from classified ETM+ image of 2000 with an aim to find out the changes in water logging situation in the study area. Image Subtraction is the extraction of information of differences between two images of a particular location. This difference can be increased or decreased in the average intensity level (CCRS, 2005). The resultant image was then rescaled where water bodies were layered as 1 and rest is 0. Rescaling of image converts one data type to another such as from 16 bit to 8 bit or so on. It decreases the file size changing the image contrast (Campbell, 2002). This rescaling, however, is very much useful for detecting particular object and to overlay on other phenomena. To create the final water logging map opacity were used for non water bodies to make transparent so that water bodies can be overlaid. However, it was then overlaid on SRTM image which was made as $45^0$ solar azimuth for proper visualization. ERDAS Imagine 9.1 was used for the above all operations. But for taking layout or final map ArcGIS 9.3 was used. The following flow chart (Figure 9) shows the overall method mentioned above.

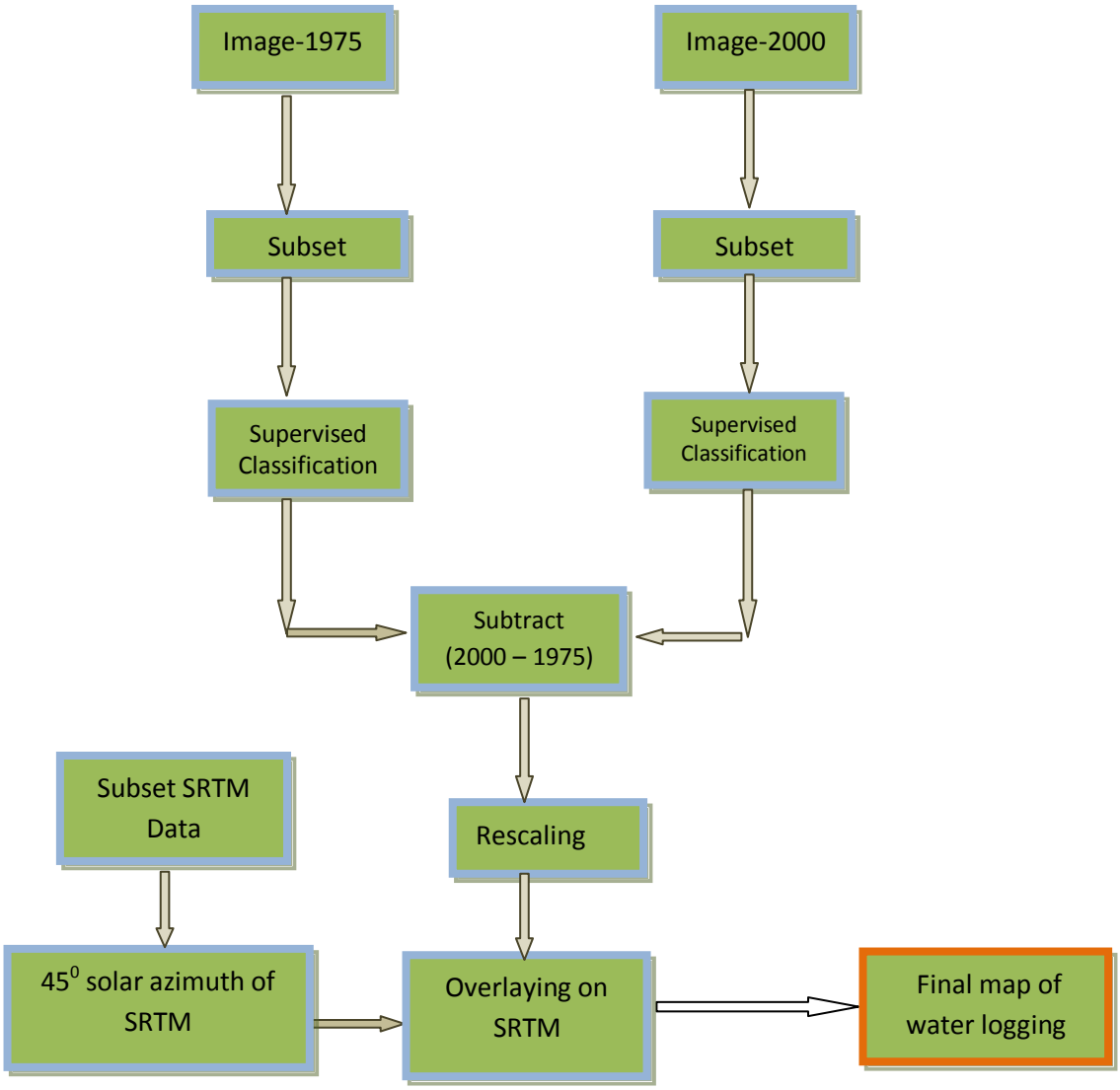


Figure 9: Flow chart of the methodology

### 3.3 Methods for risk mapping

Digital Elevation Model (DEM) of 90 meter resolution data was used to calculate the probable vulnerability to water logging due to sea level rise (SLR) or other factors involved to increase water level in the south west coast of Bangladesh. According to the study area SRTM was subset first using Erdas Imagine 9.1 software. The geographic coordinate system of the SRTM data was GCS WGS 1984. The geographic coordinate system of the original SRTM data was projected according to the coordinate system of the available in the study area and Universal Transverse Mercator Projection system. The vulnerable areas were calculated using reclassify function of ArcGIS (Figure 10). As one meter sea level rise would inundate almost the whole south-west of Bangladesh which is 17 percent of the country (Ali, 1989), the SRTM data has been classified according to 1 meter, 2 meter and 3 meter elevation to make compare with the present water logged scenario. These elevation layers were defined as different vulnerable areas such as 1 meter is high risk areas, 2 meter is medium and 3 meter is low risk areas as there is high possibility to enter water easily into those areas with 1 meter elevation than the areas with 2 meter elevation or then 3 meter elevation.

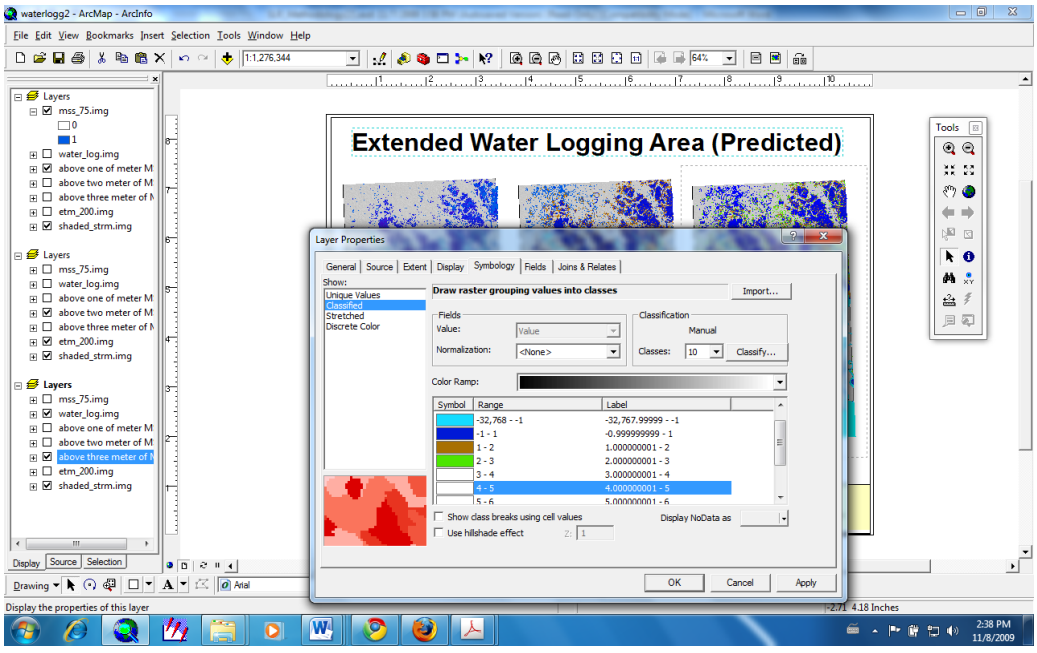


Figure 10: Classification of SRTM data

### 3.4 Deforestation analysis method

The principal objective of this part was to carryout change detection on the *Sundarban* vegetation between 1975 and 2000. For this, ERDAS Imagine 9.1 software was used and below is a sequential description of the methodology that was followed to achieve the results. First, a tasseled cap transformation was performed on the both images, i.e., MSS of 1975 and ETM+ of 2000. A tasseled cap transformation is a linear transformation of Landsat data that project soil and vegetation information into a single space in multispectral data space – a plane in which the major spectral components of an agricultural or forest scene are displayed in two dimensions (Campbell, 2002). The tasseled cap transformation for the Landsat MSS data can be performed using the following formula:

The soil vegetation Index (SBI)=0.332MSS1+0.603MSS2+0.675MSS3+0.262MSS4
The green vegetation index (GVI)=-0.283MSS1-0.660MSS2+0.577MSS3+0.388MSS4
The yellow stuff index (YVI)=-0.899MSS1+0.428MSS2+0.076MSS3-0.041MSS4
A non-such index (NSI)[12]=-0.016MSS1+0.131MSS2-0.452MSS3+0.882MSS4
(Source: Liu, 2006)

For TM images this transformation is calculated with the following coefficients:

*Brightness = 0.3037(TM1) + 0.2793(TM2) + .4743(TM3)*
*+ 0.5585(TM4) + 0.5082(TM5) + 0.1863(TM7)*

*Greenness = -0.2848(TM1) - 0.2435(TM2) - 0.5436(TM3)*
*+ 0.7243(TM4) + 0.0840(TM5) - 0.1800(TM7)*

*Wetness = 0.1509(TM1) + 0.1973(TM2) + 0.3279(TM3)*
*+ 0.3406(TM4) - 0.7112(TM5) - 0.4572(TM7)*

(Source: Center for Advanced Spatial Technologies)

[12] a non-such index (NSI) is associated with atmospheric effects and image noise

For ETM+ images this transformation is calculated with the following coefficients

Table 3: Tasseled cap coefficients for Landsat 7 ETM+ at-satellite reflectance

| Index | Band 1 | Band 2 | Band 3 | Band 4 | Band 5 | Band 7 |
|---|---|---|---|---|---|---|
| Brightness | 0.3561 | 0.3972 | 0.3904 | 0.6966 | 0.2286 | 0.1596 |
| Greenness | -0.3344 | -0.3544 | -0.4556 | 0.6966 | -0.0242 | -0.2630 |
| Wetness | 0.2626 | 0.2141 | 0.0926 | 0.0656 | 0.7629 | -0.5388 |
| Fourth | 0.0805 | -0.0498 | 0.1950 | -0.1327 | 0.5752 | -0.7775 |
| Fifth | -0.7252 | -0.0202 | 0.6683 | 0.0631 | -0.1494 | -0.0274 |
| Sixth | 0.4000 | -0.8172 | 0.3832 | 0.0602 | -0.1095 | 0.0985 |

Source: U.S. Geological Survey**,** 2003

The resultant images were brighter compared to the original images. Then a subtraction operation was carried out on the enhanced tasseled cap images using bands 1 of both images; that is, subtracting band 1 of the tasseled cap image of 2000 from band 1 of the tasseled cap image of 1975. The reason for using band 1 of both images was due to capability of band 1 of Landsat images to strongly differentiate areas where there is no vegetation from vegetation. In other words, band 1 distinguishes bare soil such as places where deforestation has taken place respectively. The resultant image from this subtraction highlighted deforested areas as black polygonal patches (Figure 11) that was found at the northern edges of the mangrove forest.

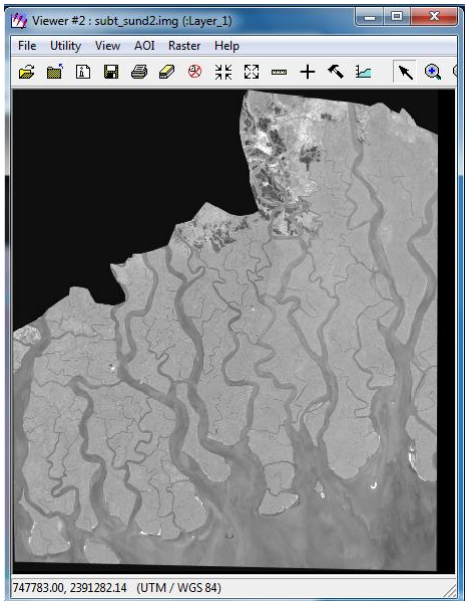


Figure 11: Subtraction from tasseled cap images

This image was composed from the subtraction of single band, in this case band 1; a layer stack was done. Bands 1 and 2 of the MSS of 1975 were stacked to the resultant image of the subtraction. This combination was preferable since band 1 could be used to distinguish between no vegetation and vegetation.

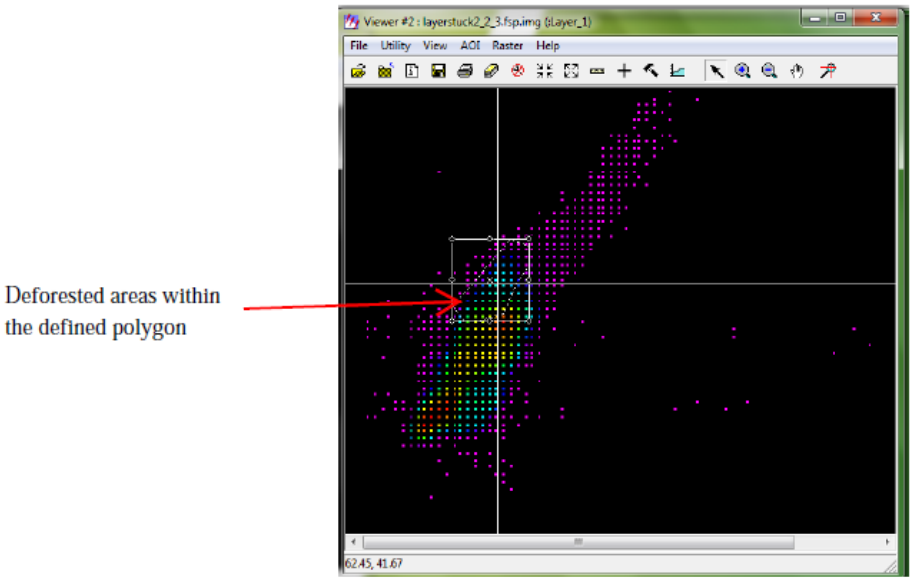


Figure 12: Deforestation areas in Spectral Diagram

Like before, three samples of 3 x 3 pixel size in the stacked image was defined representing deforestation (Appendix, Table C) and then scattergrams were checked to examine if these three samples were located in spectral space. A polygon was defined in the scattergram that include all the three samples (Figure 12). This polygon therefore defines the spectral range of desired class "deforestation". The selected polygons were checked in the images with image alarm. The overall methods have figured out in the following work flow.

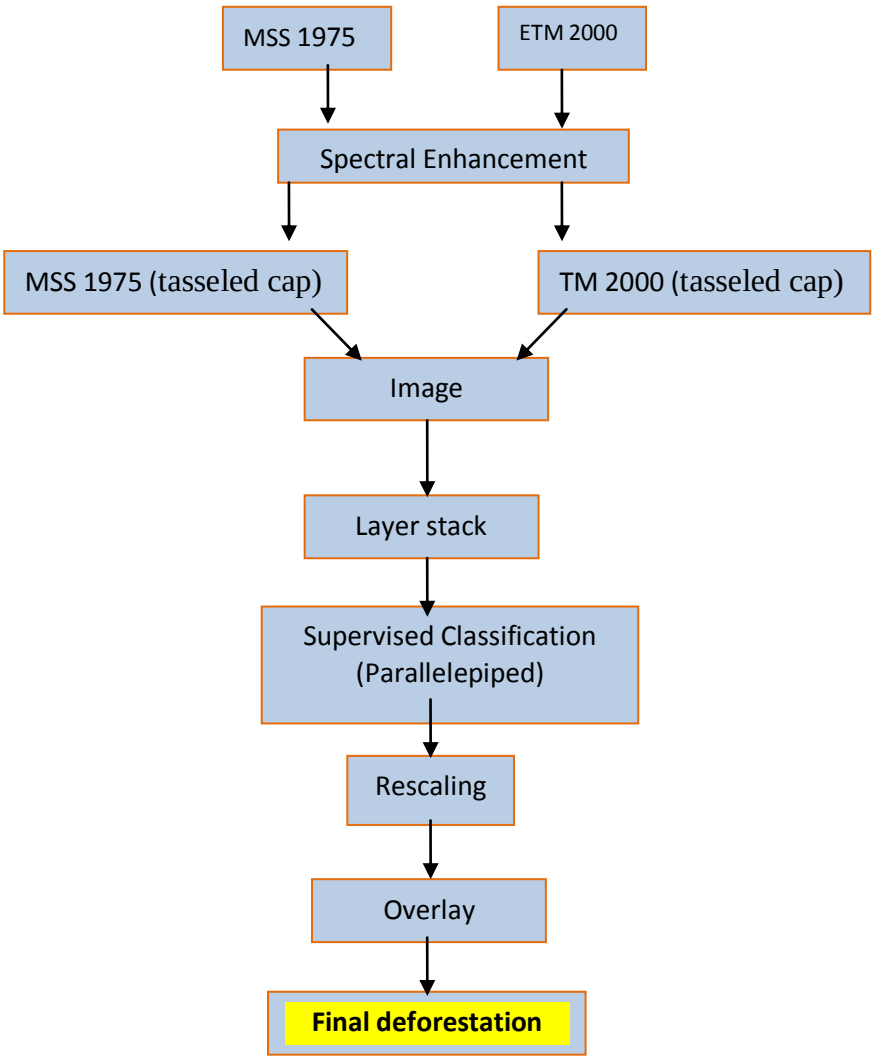


Figure 13: Workflow diagram of deforestation

### 3.5 Water logging checking with Google Earth

The water logged areas were checked with Google Earth[13] whether the identification of water logging areas were correct or not. Figure 14 shows that water bodies in the Google Earth and water logging map calculated from Landsat images are same.

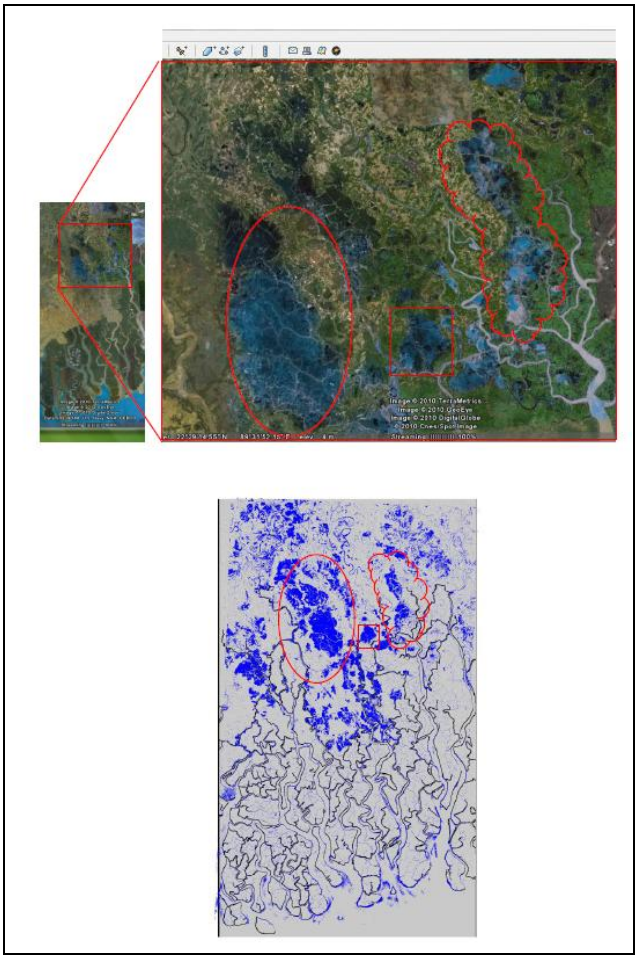

Figure 14: Google Erath and water logging

[13] ***Google Earth*** *is a virtual globe, map and geographic information program that was originally called EarthViewer 3D, and was created by Keyhole, Inc, a company acquired by Google in 2004. Most land areas are covered in satellite imagery with a resolution of about 15 m per pixel. This base imagery is 30m multispectral Landsat which is pansharpened with the 15m [panchromatic] Landsat imagery. However, Google is actively replacing this base imagery with 2.5m SPOT Image imagery and several higher resolution datasets* (Wikipedia, 2010).

# CHAPTER FOUR
# Water logging and sectoral impact

## 4.1 Remote sensing analysis of water logging

Considering the methods mentioned above, the two images were classified with particular view to see the actual changes in water bodies of the coastal area. However, after supervised classification of MSS and ETM+ images it can be seen (Figure 15) that in 1975

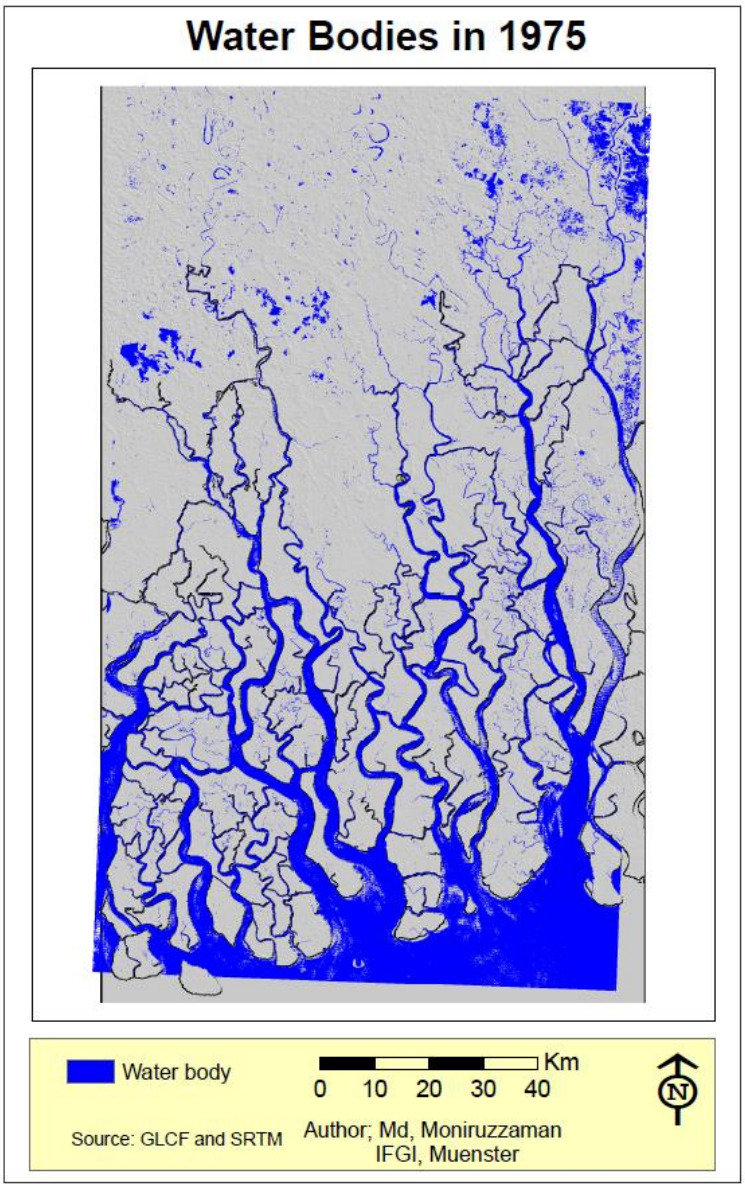


Figure: 15: Water bodies in 1975

total area of water bodies was about 310,341 hectares including rivers, lakes and parts of Bay of Bengal. This had increased to 492,759 hectares in 2000 (Figure 16). Here additional 182,418 hectares area of water bodies existed in 2000 (Figure 17 and Figure 18). This can be identified as water logged areas influenced by sea level rise. In 1975, there was no impact of sea level rise and no stagnant water was found in the study area. Only some regular water bodies such as rivers, canals, ponds, lakes and wetlands existed.

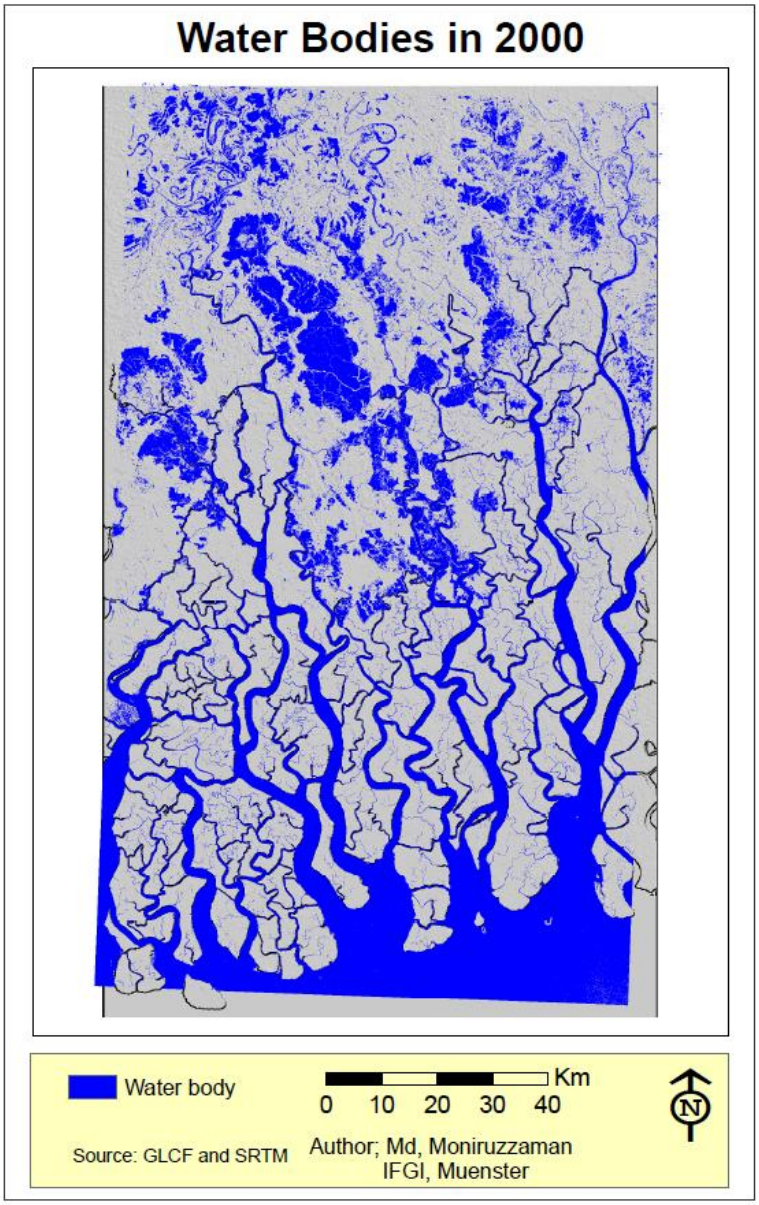


Figure: 16: Water bodies in 2000

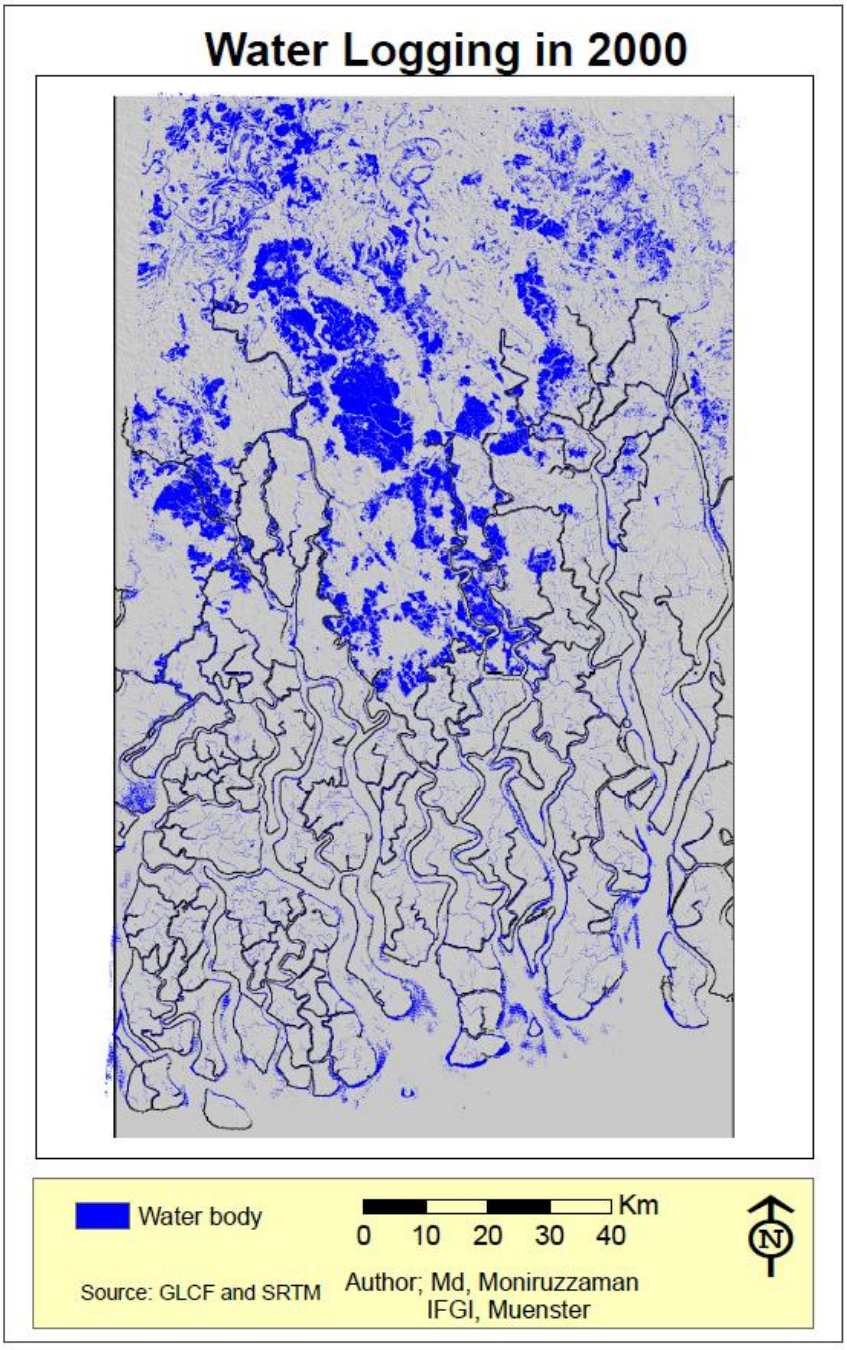


Figure: 17: Water logging areas

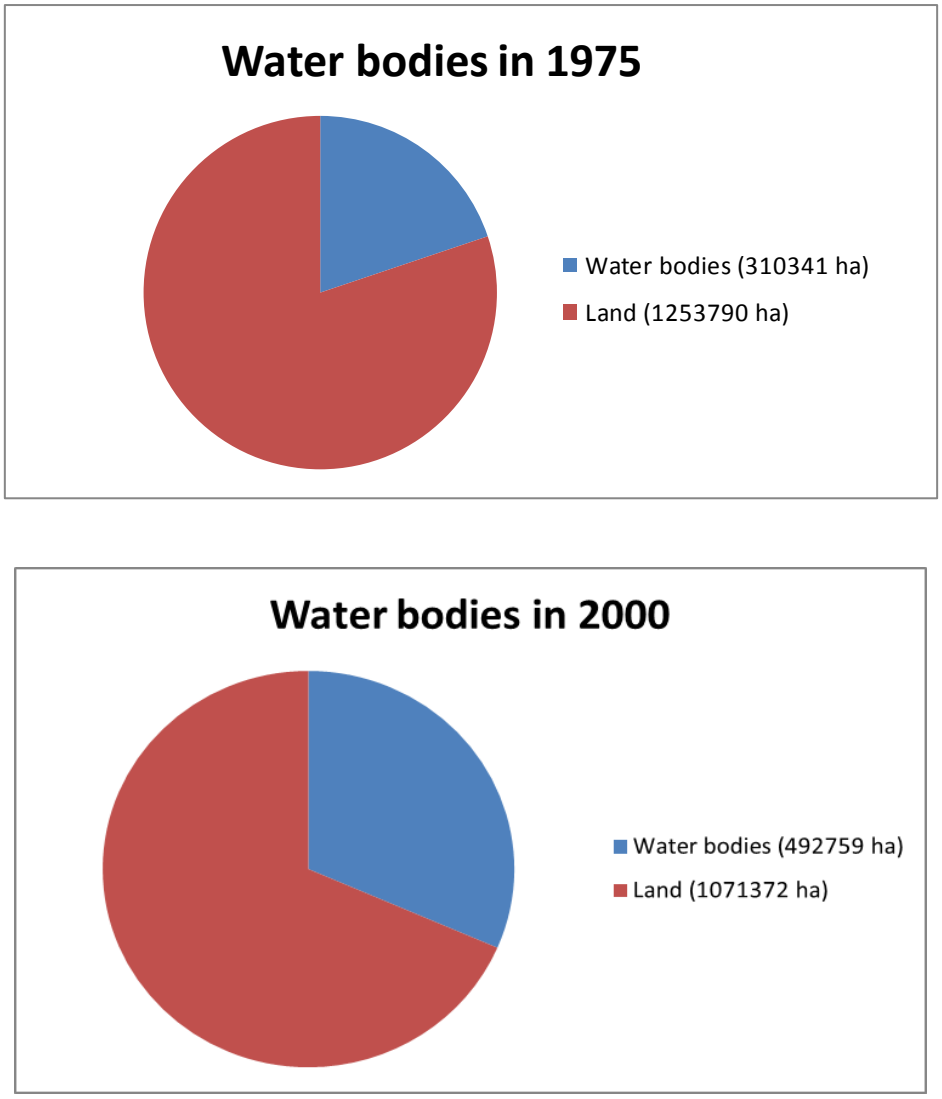


Figure: 18: Water bodies in 1975 and 2000

### 4.2 Estimating vulnerable areas

Using SRTM 90 meter resolution data, three vulnerable areas have been identified. High vulnerable areas are those with elevation less than 1 meter above mean sea level. Similarly, medium vulnerable and low vulnerable areas are calculated according to 1 to 2 meter and 2 to 3 meter higher than mean sea level respectively (Figure 19).

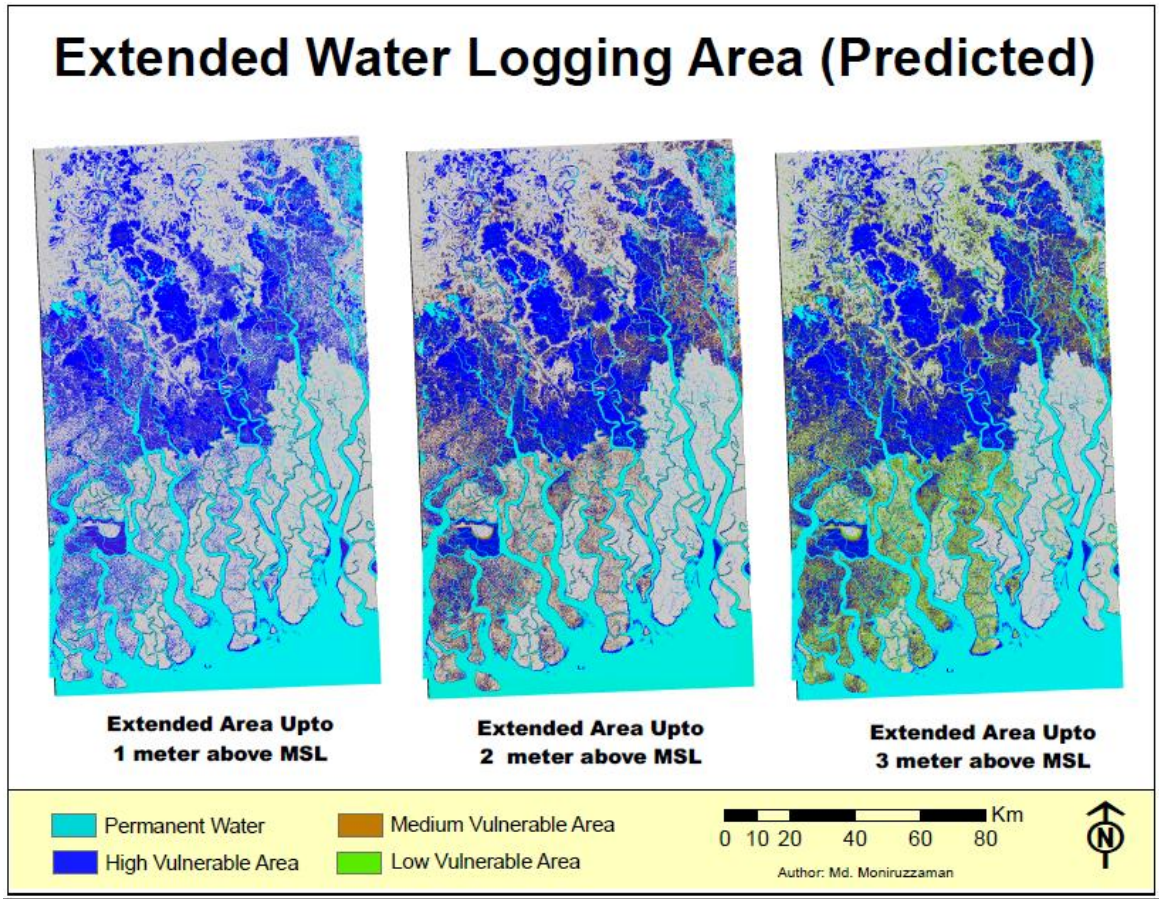


Figure 19: Vulnerable areas of different scale

The above maps express that almost 50 percent of the study area is classified having high vulnerability. Medium vulnerable areas account for 20 percent and low vulnerable and other areas are 30 percent. Usually, low lands and wetlands are connected with rivers and canals and there are no hills or big highlands in this area. Thus, a 1 meter rise in mean sea level would lead to a much worse situation for the people in the study area. All settlements and agricultural fields would be inundated and roads and transportation systems destroyed with 1 meter sea level rise. The difference of this prediction with other (IPCC and other) is that exposed coastal areas are less vulnerable than interior coastal areas and what is happening in the reality.

### 4.3 Results and discussion

Bangladesh is characterized by a tropical monsoon climate with wide seasonal variations in rainfall. In the monsoon period, when every year lot of rain occurs, water levels become higher and rivers play a very important role to flow this rain water out to sea. Over the last 40 years normal flow of rivers in Bangladesh, especially in the south west area, has become hindered by the high water level in the lower reaches caused by sea level rise. Water now stagnates in the area of 35 kilometer north of the Bay of Bengal. As sea level is continuously rising, sea water is also adding to the rain water and the logging process is becoming faster and wider spread.

#### 4.3.1 Salinity intrusion

The south-west coastal area, formed with fertile land by deltaic actions, is an important part of the country where a large number of people are living. Due to sea level rises the

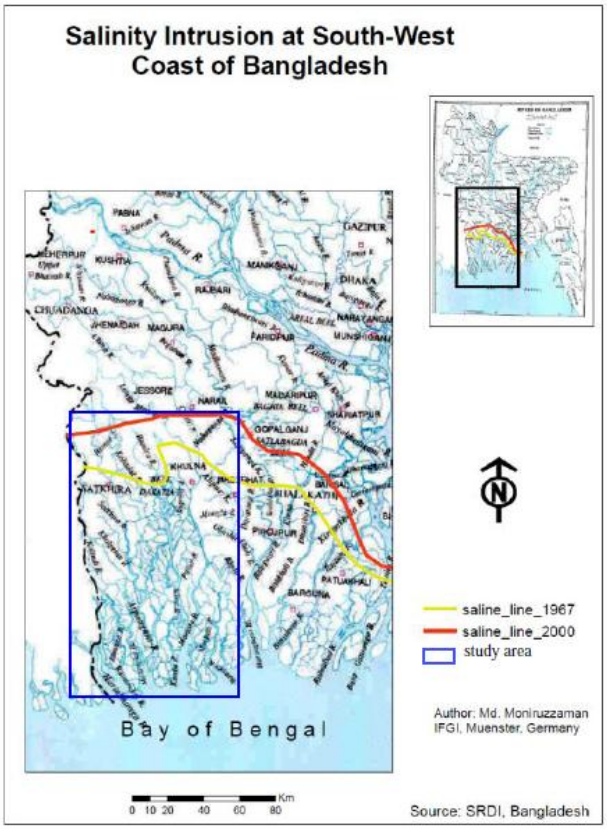


Figure 20: Salinity line at south-west coast

rate of saline water intrusion into this area has increased. Saline line has entered upto 20 to 35 km into the mainland since 1967. It is estimated that every year, on average, about 1 km area is coved with saline water (SRDI, 1997). *Monirampur, Keshabpur, Jhikorgacha* of *Jessore* District and *Tala, Kalaroa* and *Ashashuna thanas* of *Satkhira* districts are mostly affected by this sea salt water.

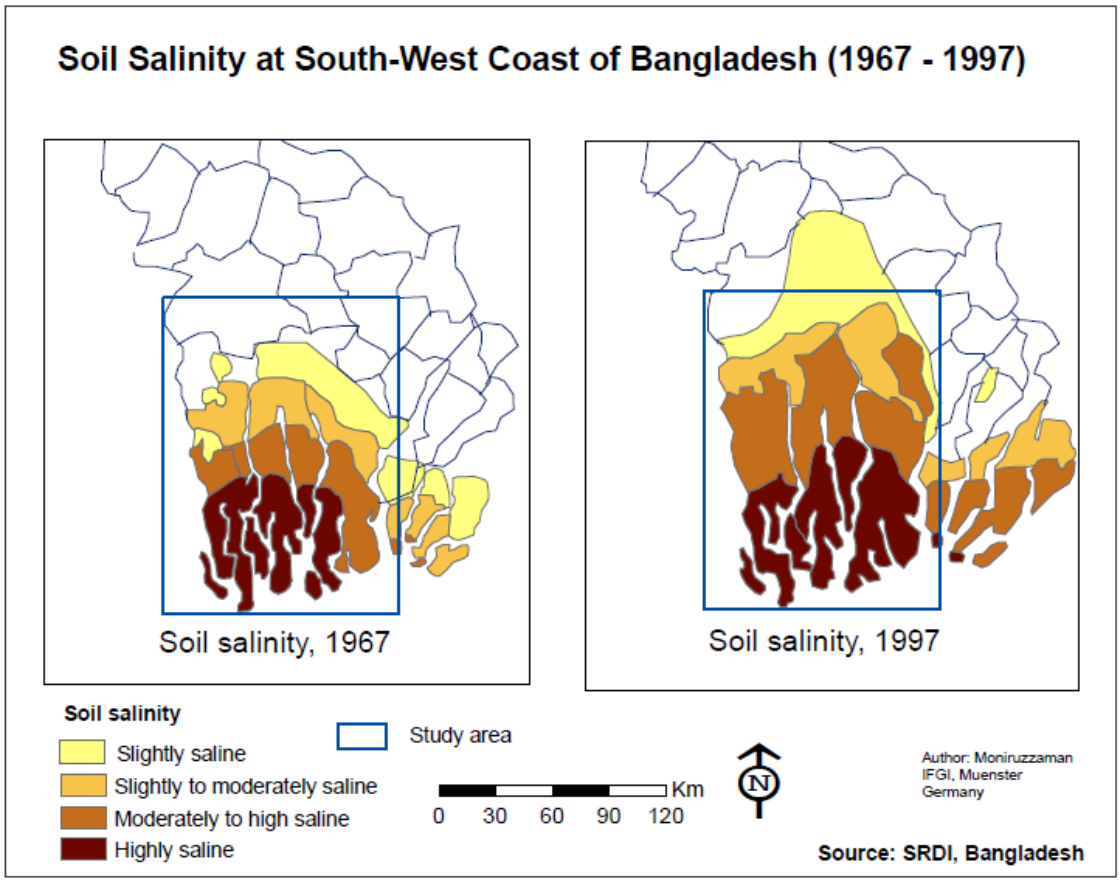


Figure 21: Soil salinity at south-west coast

With the moving of salinity line northward soil in that area is becoming salty. From the map (Figure 21) we can see that the area covered by salty soil in 1997 is considerably bigger than that in 1967 in the south west part of Bangladesh. Both dimension and intensity have increased substantially (SRDI, 1997).

### 4.3.2 Impact on agriculture

Agriculture is the main hub of Bangladesh economy where more than 60% of the total population depends on agriculture and the south-west agricultural zones are about one sixth of the total area of the country. The total agricultural production in the study area is decreasing due to either water logging or salinity intrusion. In *Keshabpur* thana of *Jessore* district, the area most affected by water logging, agricultural lands decreased by 30%

Table 4: Agricultural impact of different years

| | 1988 Total arable land (in hector) | 1998 Total arable land (in hector) | 2008 Total arable land (in hector) |
|---|---|---|---|
| Jhikorgacha | 28230 | 26909 | 23370 |
| Monirampur | 41343 | 38465 | 34478 |
| Keshabpur | 29509 | 26512 | 20543 |
| Tala | 25807 | 25021 | 24608 |
| Kalaroa | 21258 | 20387 | 17710 |

Source: Agricultural Extention Office, Jessore and Satkhira, 2009

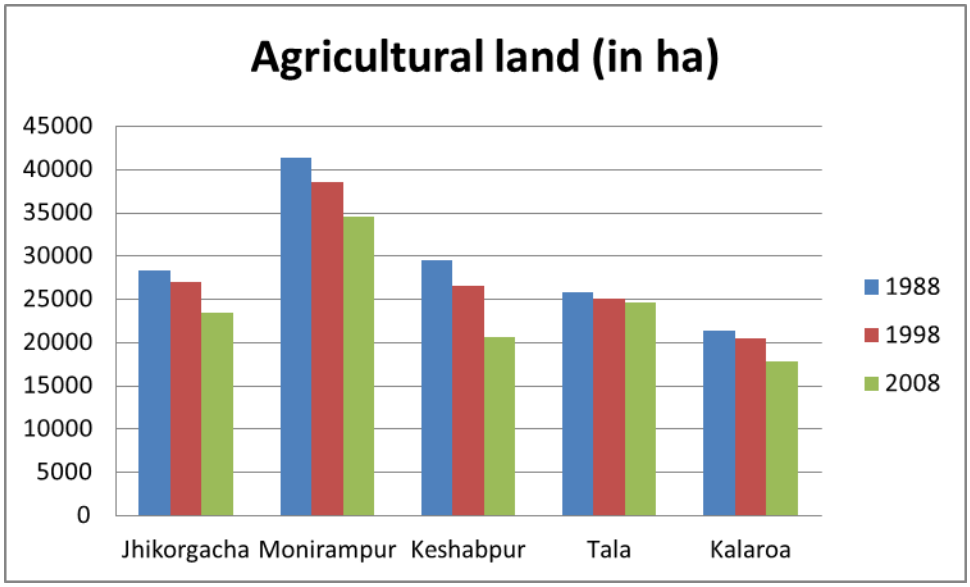


Figure 22: Agricultural impact of different years

in the 20 years until 2008, in *Monirampur* thana the rate of decrease is 16%, *Tala* and *Kalaroa* thanas are comparatively less affected but currently, the degree of water logging is increasing with the potential to cause serious agricultural damage (Table 4, Figure 22).

### 4.3.3 Impact on population and settlement

Bangladesh is one of the most densely populated countries in the world. Inhabitants are distributed throughout the country's rural and urban areas. There are no big cities in the

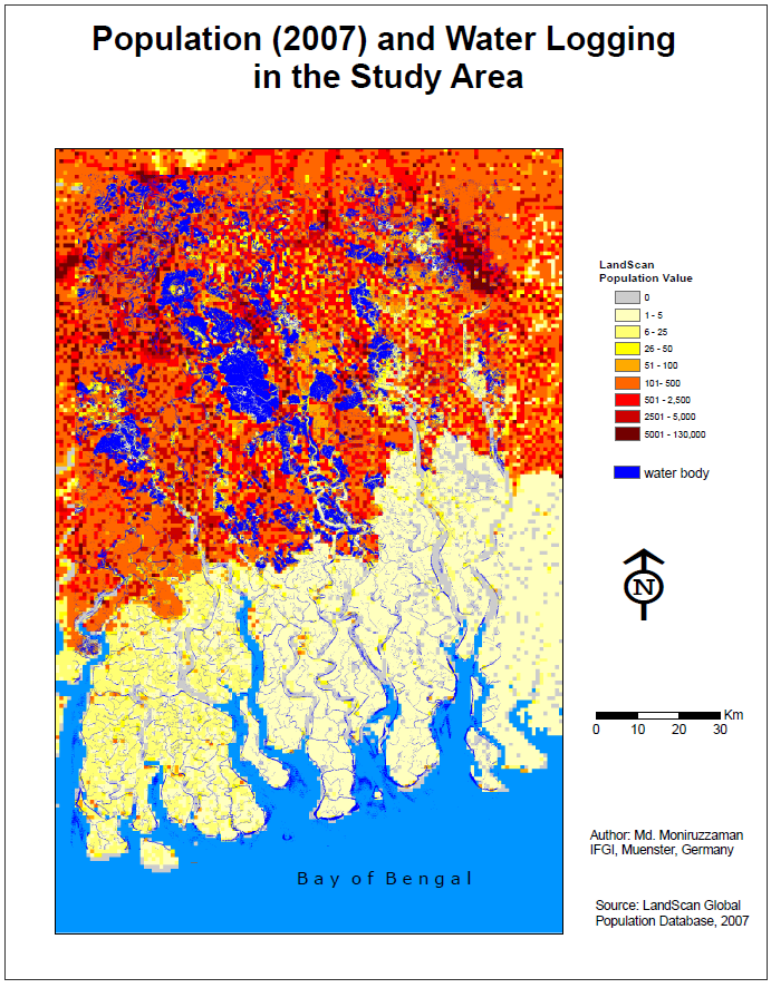


Figure 23: Population and water logging

south-west coastal areas of the country except Khulna Metropolitan Area. People generally live in the villages beside their agricultural fields. During the last four decades some settlement areas have disappeared due to severe water logging. From the following

two tables (Table 5 and Table 6) we can see that 12855 families were affected in 2008. Some of them have totally lost their houses while some are only partially affected. People are forced to live inhumanly with their remaining domestic animals, such as cows and goats, on the streets, high lands, in schools or shelters.

Figure 24: Families affected by water logging in Satkhira district (Source: ClimateWire, 2009)

Table 5: Affected families in Jessore District

| Jessore District | | | | | |
|---|---|---|---|---|---|
| **Upazila** | **Union** | **Affected Villages** | **Affected Families** | **No. of Shelter** | **No. of Families took Shelter** |
| Jhikorghacha | Bakura | Total Village 16 | 988 | 5 | 261 |
| | Panishara | | | | |
| | Muinicipality | | | | |
| | Nibashkhola | | | | |
| Monirampur | Horoharnagar | Panchpota,Dumurkhali, Goalbari, Mohadevpur | 1428 | 6 | 323 |
| | Jhapa | Jhapa | | | |
| | Moshninagar | Chakola, Parkhajura, Noali, Bharatpur,Kathaltala, Laxmikantapur, | | | |
| Keshabpur | Trimohoni | Chandra, Mirjanagar, Barandali, Sarashkathi | 3176 | 9 | 571 |
| | Sagardhari | Bishnupur, Mirjapur, Gopshana, Meherpur, Dharmapur, Bashbaria, Sripur, Chingra, Shekhpur, Komorpur, Sagardhari | | | |
| | Biddhanandakhathi | Aulaghathi, Boga, Rejakhathi, Nehalpur | | | |

Source: Disaster Forum, 2008

Table 6: Affected families in Satkhira District

| Satkhira DIstrict | | | | | |
|---|---|---|---|---|---|
| **Upazila** | **Union** | **Affected Villages** | **Affected Families** | **No. of Shelter** | **No. of Families took Shelter** |
| **Tala** | Dhandia | Uttar Shrasha, Dashkhin Sharasha | 3842 | 15 | 511 |
| | Sarulia | Borakashipur, Putiakhali, Perkumira, Patkelghata, Achimtala, Jucekhola | | | |
| | Kumira | Achimtala, Kumira, Raribari, Goripur, Senpur, Mirjapur, Kesha | | | |
| | Tentulia | Deoanipara, Dhalbaria, Noapara, Aarongpara, Kalapota, Kalia, Terachi. | | | |
| | Islamkathi | Islamkathi, Baokhola, paranpur, Chandpur, Uthali, Gopalpur, Kharail, Bhabanipur, Kazidanga, Barat, Denshakhola, Naranpur, Ghona. | | | |
| | Khalishkhali | Katakhali, | | | |
| | Magura | Chandkathi, Poaela, Chargram, | | | |
| | Jalalpur | Charcanidia, Jethua, | | | |
| | Tala | Kharerdanga, Majhiara, Shibpur, Khanpur,Murakulia, Kishmatghona, | | | |
| **Kalaroa** | Deara | Pakuria, Deara, Kashidanga | 3421 | 7 | 742 |
| | Joyanagar | Gajna, Khatrapara, Khordh, Batra, Ramkrishnaspur, Maniknagar, Joyanagar, Nilkanthapur | | | |
| | Jalalabad | Bodhanathpur, Shinghalal, Batra, | | | |

Source: Disaster Forum, 2008

### 4.3.4 Education and health

The education system in this area has totally collapsed due to factors related directly to water logging. First, as schools are being used as a shelter, teachers cannot take classes for teaching. Although it has been seen that some immediate make-shift schools are made on the street formed by polythenes and paper which are vulnerable to the medium to strong wind. Secondly, transportation systems have broken down. Children and teachers from outer parts can no longer go to their schools or colleges. In some cases students use local small boats, but those are few in number and they have to spend much time and energy to arrive there. Thirdly, some children are busy collecting diets for themselves and

even for their family members. Parents like to send their children to receive breads, rice, biscuits, and water from different shelters or aid centers. In 2008, total 121 primary and secondary schools were fully inundated and 85 schools were partially inundated (Table 7).

Figure 25: An affected primary school in Keshabpur upazilla

Source: Khan, 2008

Table 7: Affected schools by water logging

| | **Fully Inundated** | **Partially Inundated** | **At the Risk of Inundation** |
|---|---|---|---|
| **Primary Schools** | 86 | 58 | 29 |
| **Secondary Schools** | 35 | 27 | 17 |

Source: District Information Office, Jessore and Satkhira, 2008

Figure 26: An affected secondary school in Keshabpur upazilla (Source: Khan, 2008)

Along with education, overall health condition is also concerned. People are living in unhygienic environments where there is no drinking water or sanitary latrine. In some areas all tube wells, the only source of drinking water, have gone under water, some partially inundated tube wells are even supplying salty water (Table 8). Some ponds where people used to collect their water for drinking purpose and other domestic uses have also become salty. People from those areas are suffering from water borne diseases like diarrhea and cholera. Some NGOs opened mother and child care centers in few places, but most of them are either being used as shelter or are inundated wholly by the water logging. At the moment one severe problem has arisen, salty stagnant waters are getting more and more dirty day by day and people are suffering several skin diseases.

Table 8: Affected tube wells and health care centers

| **Affected by Waterlogging** | **Fully Inundated** | **Partially Inundated** | **At the Risk of Inundation** |
|---|---|---|---|
| Tube wells & other sources of drinking water | 14232 | 9452 | 4762 |
| Mother & child health care facilities | 11 | 10 | -- |

Source: District Information Office, Jessore and Satkhira, 2008

Figure 27: Women are busy for collecting drinking water in Kalaroa upazila (Source: The Daily Star, 2008)

### 4.3.5 Impact on Sundarbans

Water logging what is created by climate change i.e., sea level rise has already had a negative impact on Sundarbans too. Although Sundarbans is very close to the Bay of Bengal but from SRTM data we can see that its elevation is higher than the adjacent northern area where a large volume of water has already been logged. Therefore, up to a certain area from south to north topography is gradually down and this low area is connected to the sea by a number of rivers through the mangrove forest. As a result of sea level rise, water goes towards the northern (comparatively low) lands through rivers and water is stagnating. When the level of this water is mounting up it is extending towards southern mangrove forest.

In the Sundarbans area as rivers are meeting places of freshwater and salt water, due to sea level rise, the pressure of salt water has increased which leads to advance saline water towards land and Sundarbans as well. Salinity intrusion has also increased in the water that comes from regular tide in the coastal area. Saline water reduces the fertility of soil, destroys tree seeds and organisms in the soil. From the map (Figure 28) it is clear that deforestation has begun at the northern edge of the forest which will be affected further with the increase of saline water level. Although, in the central area of Sundarbans deforestation has yet to begin.

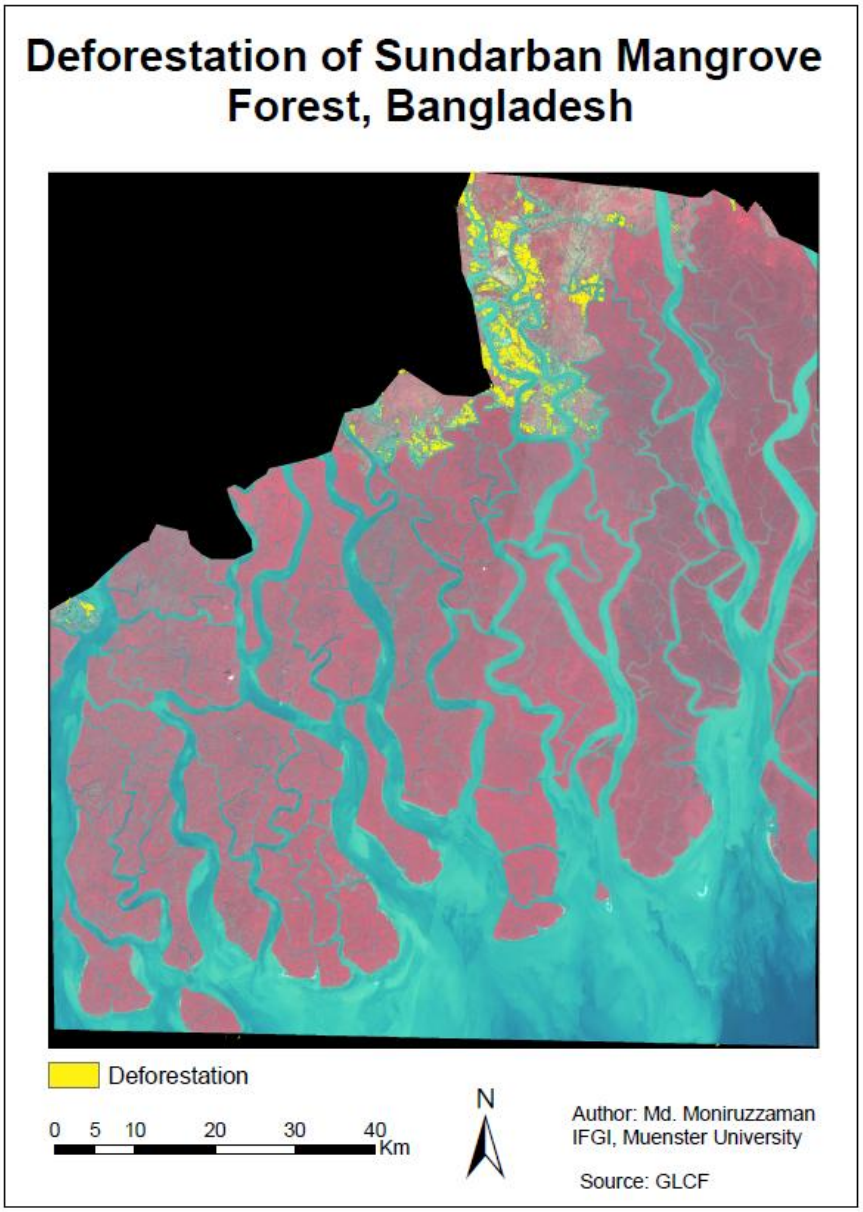


Figure 28: Deforestation of Sundarban forest

Like saline water, permanent water logging is also harmful for the forest. Permanent water logging damages seeds, grasses, young and mature plants, as a consequence forest in that coastal area can be destroyed within a few years. This can lead to a loss of biodiversity and of livelihood of over 6 million people who depended on mangroves. Other possible causes of deforestation are clearing forests by humans to build their settlement, cutting forests and selling woods by the poor people and river bank erosion.

# Chapter 5
# Conclusion

Remote Sensing is a revolutionary new tool that has tremendous applications in a number of fields across the world. It helps us for sustainable management of our healthy environment and to protect natural or human induced calamities perfectly especially in the coastal areas as coastal zones have great importance for any country and a large number of people of the world are living in these areas (Narayan, 2001). The current study has shown water logging areas and the damages in the largest mangrove forest of the world due to climate changes with remote sensing analysis which could be useful for the proper management in the affected areas. Land use pattern and land use modeling of the study area could be shown by remote sensing analysis (Skidmore, 2002) but further research is necessary in this regard. Although salinity impact on soil and water what is considered a big sectoral impact for both environment and economy, has shown here using GIS application rather than remote sensing.

Mitigation and adaptation are two major steps which are necessary to face this problem in Bangladesh. Since, the country is so poor, it does not have enough money, technology and resources to take actions for mitigation. A big barrage across the coastal belt can be effective to protect excessive water coming from the sea level rise and salinity water intrusion as well into the land but since the deltaic land is connected to the southern sea by a number of rivers, it is totally impossible to manage all the big revers´ mouth. Moreover, it is also necessary to drainage out huge rainwater occurred in the monsoon period into the sea. So, coastal barrage can make another prolonged problem.

People are thinking to leave their ancestors´ home and migrate into another places, very few of them have already found their places. But the whole Bangladesh is full of people; it is difficult to find out places where they can be accommodated. International migration policy, particularly to the developed countries, is also a big hindrance for them unless a new international agreement for climate refugee is going to make. Economic powerful

countries with huge land resources like USA, Germany, Australia, and Canada can consider taking refugee people made by climate change for rehabilitation.

Climate change is not only environmental problem but also social and economical crisis. The question is why the people who have very less contribution to create such a big problem but they supper the most. It is well established that the industrialized countries of the world are emerging huge amount of carbon dioxide ($CO_2$) into the atmosphere and making the globe warmer. So, to resolve this worldwide problem they should cut down their fuel consumption, decrease the uses of natural resources and other high ambitious life style.

Last and but not least way for the people who are affected to the stagnant water is adaptation. They need a large amount of money to cope with the climate change impact. A poor country like Bangladesh has a few capacities to build fund for this hazardous people. International community should enlarge their helping hand with big budget and also technology and resources. In 2009, the climate conference held in Copenhagen, Denmark, Bangladesh claimed as the most vulnerable countries of the world due to climate change and demanded 15 percent of the total fund built by the developed nations as 15 percent of the total affected population of the world live in the country.

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# Appendix

Table A: **Digital Number of Water Bodies in TM Image**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample- 1** | | | | | | | | | |
| Blue Green | 21 | 21 | 21 | 20 | 21 | 21 | 20 | 20 | 20 |
| Green | 24 | 23 | 20 | 21 | 20 | 20 | 22 | 21 | 21 |
| Red | 18 | 14 | 14 | 15 | 13 | 12 | 15 | 13 | 14 |
| Near-IR | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 4 |
| **Sample- 2** | | | | | | | | | |
| Blue Green | 13 | 13 | 14 | 12 | 12 | 13 | 13 | 13 | 12 |
| Green | 14 | 14 | 15 | 14 | 13 | 15 | 13 | 12 | 14 |
| Red | 8 | 9 | 10 | 9 | 10 | 10 | 8 | 8 | 9 |
| Near-IR | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Sample- 3** | | | | | | | | | |
| Blue Green | 12 | 12 | 11 | 13 | 13 | 12 | 12 | 12 | 13 |
| Green | 14 | 13 | 12 | 13 | 14 | 12 | 12 | 14 | 11 |
| Red | 10 | 10 | 7 | 9 | 9 | 9 | 10 | 10 | 11 |
| Near-IR | 2 | 3 | 4 | 3 | 3 | 3 | 2 | 2 | 5 |

Table B: **Digital Number of Water Bodies in ETM+ Image**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample- 1** | | | | | | | | | |
| Blue Green | 75 | 77 | 79 | 76 | 76 | 77 | 76 | 78 | 77 |
| Green | 62 | 61 | 60 | 59 | 62 | 61 | 61 | 61 | 62 |
| Red | 50 | 50 | 51 | 51 | 48 | 50 | 51 | 50 | 50 |
| Near-IR | 26 | 25 | 26 | 27 | 26 | 26 | 27 | 27 | 27 |
| **Sample- 2** | | | | | | | | | |
| Blue Green | 74 | 76 | 75 | 76 | 74 | 76 | 74 | 74 | 74 |
| Green | 59 | 61 | 62 | 61 | 61 | 62 | 58 | 61 | 61 |
| Red | 51 | 51 | 51 | 53 | 52 | 50 | 53 | 50 | 53 |
| Near-IR | 28 | 29 | 27 | 28 | 27 | 28 | 27 | 30 | 27 |
| **Sample- 3** | | | | | | | | | |
| Blue Green | 87 | 85 | 83 | 87 | 84 | 85 | 88 | 87 | 84 |
| Green | 70 | 69 | 73 | 69 | 72 | 71 | 70 | 72 | 72 |
| Red | 69 | 70 | 71 | 70 | 73 | 70 | 68 | 68 | 70 |
| Near-IR | 31 | 31 | 31 | 30 | 30 | 31 | 30 | 30 | 30 |

Table C: **Digital Number of Deforestation**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample- 1** | | | | | | | | | |
| Subtraction Tasseled cap Layer | 32.7 | 33.5 | 42.7 | 31.11 | 29 | 32 | 38 | 31 | 31 |
| Blue Green | 20 | 18 | 20 | 21 | 20 | 21 | 21 | 21 | 21 |
| Green | 27 | 27 | 25 | 26 | 27 | 27 | 29 | 29 | 27 |
| **Sample- 2** | | | | | | | | | |
| Subtraction Tasseled cap Layer | 37 | 39 | 39 | 35 | 39 | 39 | 37 | 39 | 40.5 |
| Blue Green | 16 | 17 | 16 | 18 | 19 | 16 | 18 | 19 | 17 |
| Green | 21 | 21 | 19 | 22 | 22 | 21 | 21 | 21 | 22 |
| **Sample- 3** | | | | | | | | | |
| Subtraction Tasseled cap Layer | 50 | 43 | 33 | 46 | 42 | 36 | 43.55 | 40 | 40 |
| Blue Green | 16 | 16 | 19 | 17 | 17 | 18 | 18 | 18 | 18 |
| Green | 22 | 23 | 28 | 25 | 25 | 28 | 23 | 24 | 27 |