

Chapter 21

Impact of Climate Change in Bangladesh: Water Logging at South-West Coast

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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, health and education in the south-western coastal areas of Bangladesh. A multi-temporal analysis method has been used with remote sensing (LandSat 1975 and LandSat 2010) data. SRTM data has been used to visualize the water logged areas attractively. 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 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.

Keywords Global warming • Sea level rise • Floodplain • Remote sensing

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Introduction

Global climate is a continuous changing phenomenon. The earth has long been subjected to sequential glacials, interglacials 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°C less and interglacial periods 1–2°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°C over the past century and eleven of the last twelve years rank among twelfth hottest years on record since 1850. And the second half of the twentieth century was the warmest fifty abbreviated in the last 1,300 years (IPCC 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 the surface of the planet, 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 Intergovernmental Panel on Climate Change (IPCC 2007) indicates that the average global surface temperature will likely rise from 1.1 to 6.4°C during the twenty-first century.

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 carbon dioxide (CO₂), methane, ozone, chlorofluorocarbon (CFC) and nitrous oxide (Mastrandrea and Schneider 2005). The biggest factor of present concern is the increase in the CO₂ levels (Fig. 1). The 2005 level was highest over the last 650,000 years and the same rise in the CO₂ concentration at the end of ice ages took over 5,000 years while even a bigger rise has happened only at industrial age. Fossil fuel burning has produced approximately three-quarters of the increase of CO₂ 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).

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

Fig. 1 CO₂ and global temperature. (Source: zFacts.com (2007))

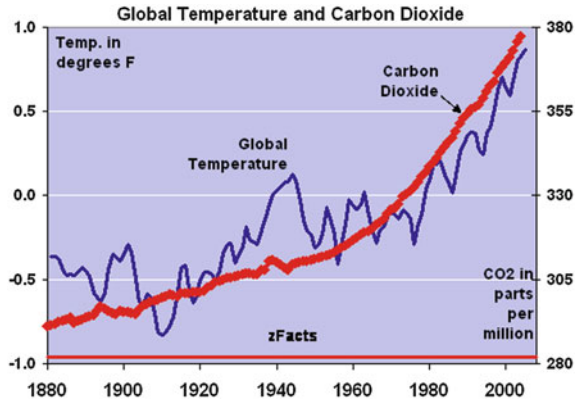


Table 1 Major cyclones affecting Bangladesh since 1960

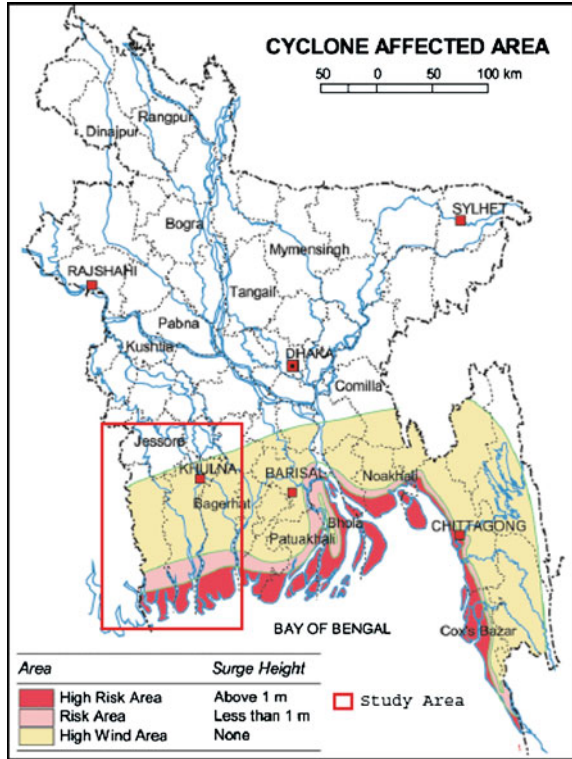
Year	Death	Year	Death
1960	3,000	1970	300,000
1960	5,149	1985	11,069
1961	11,466	1988	2,000
1963	11,520	1981	138,000
1965	19,279	2001	3,064

Source: European Community (1998)

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, earthquake, 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). Space Research and Remote Sensing Organization (SPARSO) of Bangladesh produced a map showing the cyclone affected areas of Bangladesh (Fig. 2).

Almost every five years Bangladesh is affected by droughts which shake 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 50 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).

Fig. 2 Cyclone affected area of Bangladesh. (Source: Dhakadailyphoto 2007, adopted from SPARSO, Bangladesh)



The Coastal Zone of Bangladesh

Bangladesh is basically a riverine country and a few of the world’s major rivers 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 locates 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* [subdistrict which is also known as upazila (Fig. 3, Islam 2006)]. This coastal zone reserves 32% of the total area and 28% of total population of Bangladesh and covers an area from the shore of 37 to 195 km (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 (Fig. 3). The exposed coast zones are more vulnerable to climate change such as cyclone, sea level rise, tsunamis and water logging.

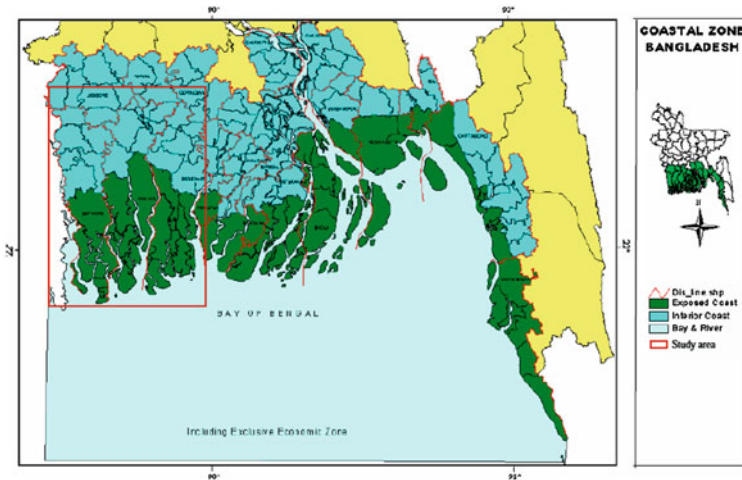


Fig. 3 Coastal zones of Bangladesh (Source: Islam 2006)

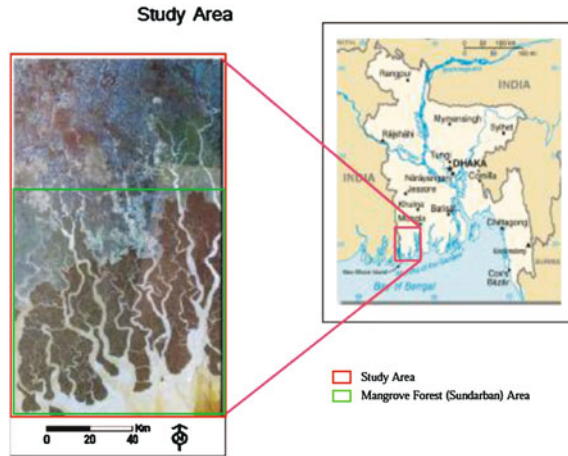
Remote Sensing and Water Logging

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 et al. 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.

Objectives

Keeping the aforementioned problems in mind the research has accomplished 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 2010;
- (b) to delineate different sectoral impacts of water logging such as agriculture, health, settlement and education.

Fig. 4 Study area

Study Area

The present study was conducted in the south-west coastal area of Bangladesh, Satkhira, Khulna, Bagerhat and Jessore Districts (Fig. 4), where a large number people are living. Total number of population is 2,520,961; 1,950,557; 2,586,771 and 1,620,216 in Khulna, Satkhira, Jessore and Bagerhat districts respectively (BBS 2007). Annual average temperature is maximum 35.5°C, minimum 12.5°C; annual rainfall 1,710 mm. The soil of this region is mainly alluvial floodplain. Main rivers are *Kobadak*, *Sonai*, *Kholpatua*, *Morischap*, *Raimangal*, *Hariabhanga*, *Ichamati*, *Betrabati* and *Kalindi-Jamuna* (Rashid 1991). The largest mangrove forest “*Sundarbans*” is also in this area. Sundori, Goran, Geoa etc. are the main trees of this forest.

Methodology

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 Thematic Mapper (TM) of 2010 which were taken from the USGS Global Visualization Viewer (GloVis). Band 1 and band 2 are visible bands and bands 3 and 4 are near infra-red (IR) of MSS scanner. For TM visible range is from band 1 to band 3, band 4 is near IR and band 5–7 are short wave IR (inforterra 2010). All information is summarized in Table 2.

Table 2 Image information

Sensor	Path/Row	Acquisition date	Spectral range (μm)	Bands	Pixel resolution (m)
MSS	148/44, 148/45	15 Dec., 1975	0.5–1.1	1, 2, 3, 4	60
TM	138/44, 138/45	10 Jan., 2010	0.450–2.35	1, 2, 3, 4, 5, 6, 7	30

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 the study area which can be mostly neglected.

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.

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 TM were not considered for spectral comparability of bands 1–4 of MSS and TM. And then carried out a supervised classification using parallelepiped non-parametric rule (Schanze et al. 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 and Jia 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 and Jia 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 and Jia 2006). The main advantage of the parallelepiped classification is that it is easy to leave areas unclassified. It might also be possible to set certain limits for classifying using nearest neighbour or maximum likelihood, but in the parallelepiped classification 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).

Three samples of 3×3 pixel size in both images were defined representing water bodies (Appendix, Tables A.1 and A.2) 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. 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 2010).

These two classified images are then subtracted, classified image of 1975 were subtracted with union operation from classified image of 2010 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° 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 (Fig. 5) shows the overall method mentioned above.

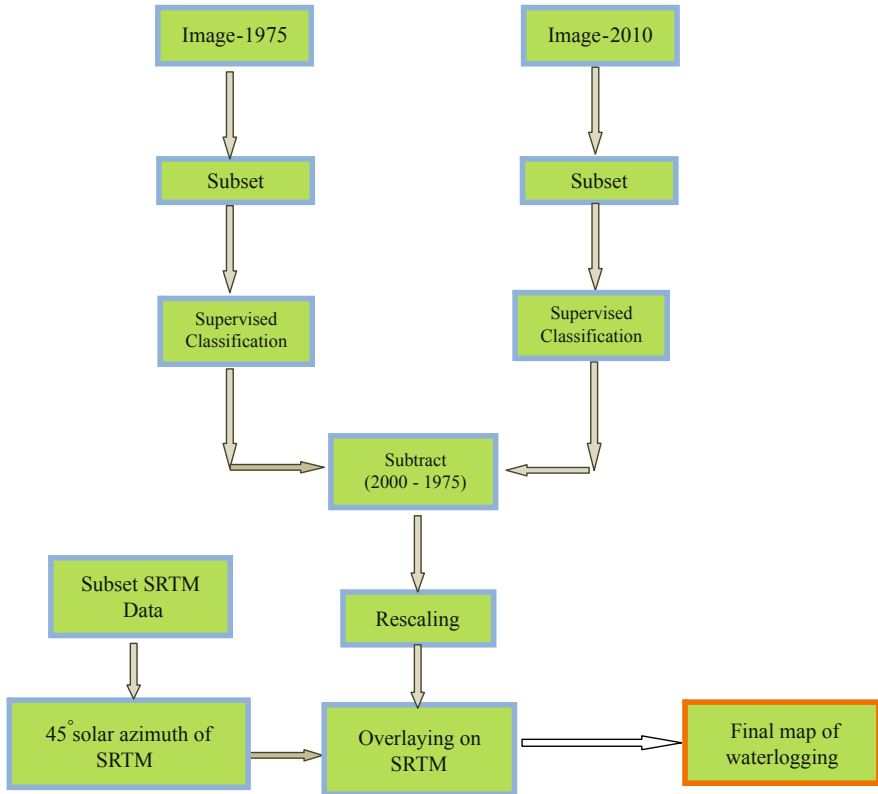


Fig. 5 Flow chart of the methodology

Results and Discussion

Water Logging Areas

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 that in 1975 total area of water bodies was about 310,341 ha including rivers, lakes and parts of Bay of Bengal. This had increased to 492,759 ha in 2010. Here additional 182,418 ha area of water bodies existed in 2010 (Fig. 6). 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.

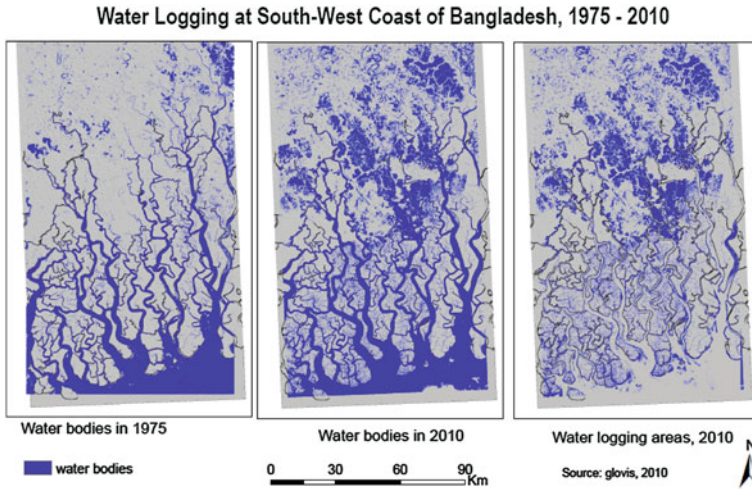


Fig. 6 Water logging in 2010

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 km 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.

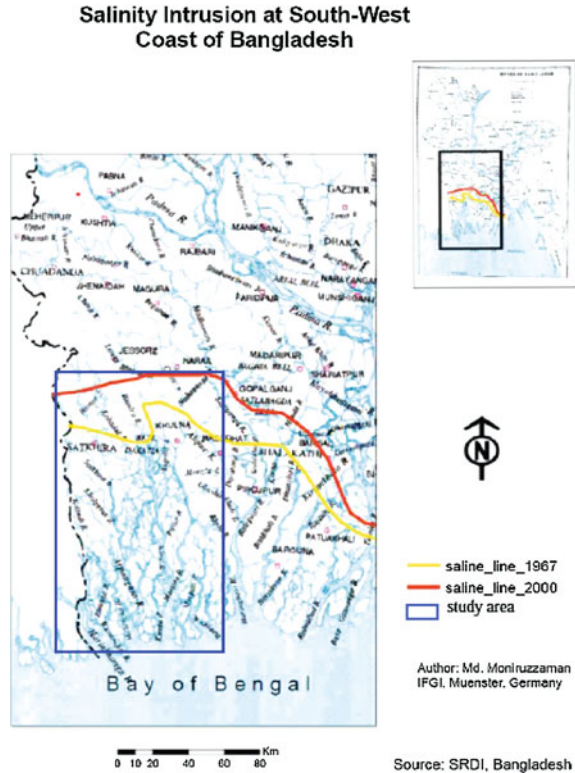
Sectoral Impact

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 rate of saline water intrusion into this area has increased. Saline line has entered up to 20 to 35 km into the mainland since 1967 (Fig. 7). It is estimated that every year, on average, about 1 km area is covered with saline water (SRDI 1998a, b, c). *Monirampur, Keshabpur, Jhikorgacha* of *Jessore* District and *Tala, Kalaroa* and *Ashashuna thanas* of *Satkhira* districts are mostly affected by this sea salt water.

With the moving of salinity line northward soil in that area is becoming salty. From the map (Fig. 8) we can see that the area covered by salty soil in 1997 is

Fig. 7 Salinity line at south-west coast



considerably bigger than that in 1967 in the south-west part of Bangladesh. Both dimension and intensity have increased substantially (SRDI 1998a, b, c).

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% 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 3, Fig. 9).

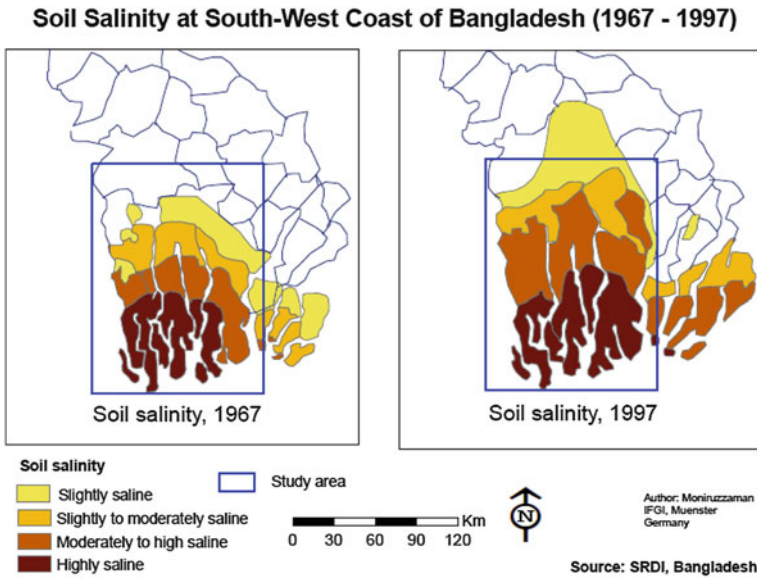


Fig. 8 Soil salinity at south-west coast

Table 3 Agricultural impact of different years

	1988 Total arable land (ha)	1998 Total arable land (ha)	2008 Total arable land (ha)
Jhikorgacha	28,230	26,909	23,370
Monirampur	41,343	38,465	34,478
Keshabpur	29,509	26,512	20,543
Tala	25,807	25,021	24,608
Kalaroa	21,258	20,387	17,710

Source: Agricultural Extension Office (2009a, b)

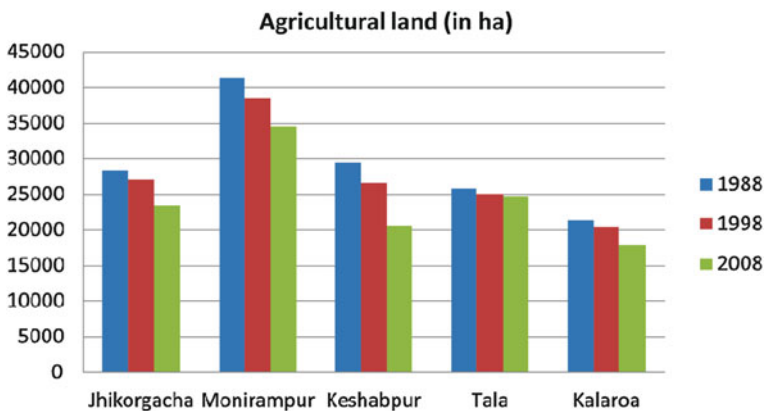


Fig. 9 Agricultural impact of different years

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 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 4) we can see that 12,855 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 (Figs. 10, 11).

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 polythene 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 2006, total 121 primary and secondary schools were fully inundated and 80 schools were partially inundated (Fig. 12, Table 5).

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 5). 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 diarrhoea 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 (Figs. 13, 14).

Table 4 Affected families in Jessore and Satkhira District

Jessore and Satkhira District			
Upazila	Affected families	No. of shelter	No. of families took shelter
Jhikorghacha	988	5	261
Monirampur	1,428	6	323
Keshabpur	3,176	9	571
Tala	3,842	15	511
Kalaroa	3,421	7	742

Source: Disaster Forum (2008)

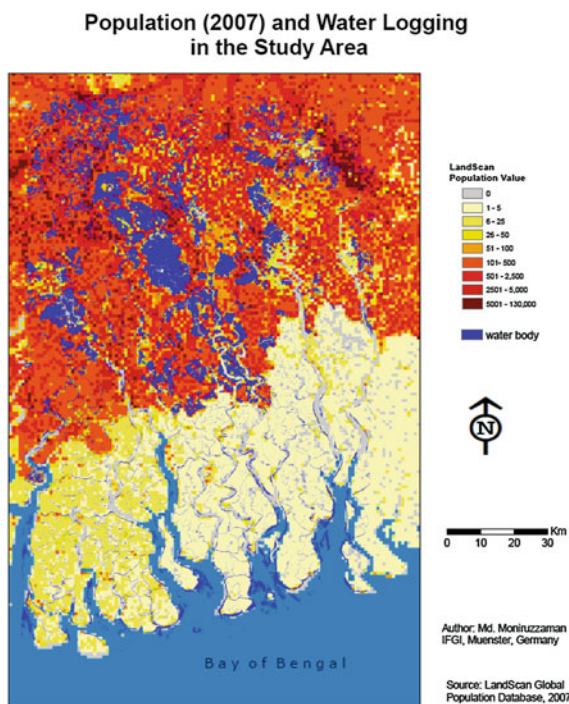
**Fig. 10** Population and water logging**Fig. 11** Families affected by water logging in Satkhira District. Source: ClimateWire (2009)



Fig. 12 An affected primary school in *Keshabpur Upazilla*. Source: Khan (2008)

Table 5 Affected schools, tube wells and health care centers

	Fully inundated	Partially inundated	At the risk of inundation
Primary schools	81	55	28
Secondary schools	33	25	14
Tube wells and other sources of drinking water	13,838	9,443	4,665
Mother and child health care facilities	13	11	–

Source: LCG Bangladesh (2006)



Fig. 13 An affected secondary school in *Keshabpur Upazilla*. Source: (Khan 2008)



Fig. 14 Women are busy for collecting drinking water in *Kalaroa upazila*. Source: The Daily Star (2008)

Conclusions

The current study has shown water logging areas 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 monitoring.

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 rivers mouths. 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 new destinations. 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 suffer the most. It is well established that the industrialized countries of the world are emerging huge amount of CO₂ 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% of the total fund built by the developed nations as 15% of the total affected population of the world live in the country.

Appendix

See Tables [A.1](#) and [A.2](#)

Table A.1 Digital number of water bodies in TM image

<i>Sample- 1</i>									
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
<i>Sample- 2</i>									
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
<i>Sample- 3</i>									
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 A.2 Digital number of water bodies in ETM+ Image

<i>Sample- 1</i>									
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
<i>Sample- 2</i>									
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
<i>Sample- 3</i>									
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

References

- Agricultural Extension Office (2009a) Jessore, Bangladesh
- Agricultural Extension Office (2009b) Satkhira, Bangladesh
- BBS (Bangladesh Bureau of Statistics) (2007) District population of Bangladesh, Bangladesh
- Bhatti J, Lal R, Apps MJ, Price MA (2005) Climate change and managed ecosystems. CRC press, Boca Raton
- Campbell JB (2002) Introduction to remote sensing. The Guilford Press, New York
- Choubey VK (1997) Detection and delineation of waterlogging by remote sensing techniques. J Indian Soc Remote Sens 25(2):123–139
- Climate Change Cell (2007) Climate change and Bangladesh, Department of Environment, Government of the People's Republic of Bangladesh
- Disaster Forum (2008) New flood in Kobadak basin villages, Mohammadpur, Dhaka
- Dwivedi RS (2006) Study of salinity and waterlogging in Uttar Pradesh (India) using remote sensing data, National Remote Sensing Agency, Hyderabad
- EU (European Community) (1998) Cyclone shelter preparatory study (CPSP) stage I: feasibility study, Draft Final Report; Supp. Vol. 3, Community Development Studies—Part A, supp vol 8; environmental analysis, field visits and other notes. EC/Sener Ingenieria Sistemas SA., 1996
- Harris F (2004) Global environmental issues. Wiley, Chichester
- IPCC (Intergovernmental Panel on Climate Change) (2007) Climate change 2007—impacts, adaptation and vulnerability: contribution of working group II to the fourth assessment report of the IPCC. Cambridge University Press, Cambridge
- Islam MR (2006) ICZM initiatives and practices in Bangladesh. In: Krishnamurthy R et al (eds) Integrated coastal zone management (ICZM)—the global challenge, New Delhi
- IUCN (1994) Mangroves of the Sundarbans: Bangladesh, vol 2. The IUCN Wetlands Programme, IUCN, Gland, Switzerland
- Khan SA (2008) Water logging and primary and secondary education at Keshabpur Upazilla. An unpublished dissertation for the degree of master in disaster management, BRAC University, Bangladesh

- Lelkes M, Csornai G, Wirthardt C (2002) Natural disaster monitoring by remote sensing in Hungary: water logging and floods in the 1998–2001 period. In: *Observing our environment from space: new solutions for a new millennium*. Swets and Zeitlinger, The Netherlands
- Rashid H (1991) *Geography of Bangladesh*. University Press, Dhaka
- Richards JA, Jia X (2006) *Remote sensing digital image analysis*. Springer, Berlin
- Schanze J, Zeman E, Marsalek J (2004) *Flood risk management: hazards, vulnerability and mitigation measures*. Springer, The Netherlands
- Skidmore A (2002) *Environmental modelling with GIS and remote sensing*. Taylor and Francis, New York
- SRDI (1998a) Coastal area and water salinity map of Bangladesh (1967 and 1997). Soil Resources Development Institute (SRDI), Dhaka
- SRDI (1998b) Soil salinity map of Bangladesh (1973), Soil Resources Development Institute (SRDI), Dhaka
- SRDI (1998c) Soil salinity map of Bangladesh (1997), Soil Resources Development Institute (SRDI), Dhaka

Internet Resources

- Banglapedia (2006) Global warming. Available at http://www.banglapedia.org/httpdocs/HT/G_0137.HTM. Accessed on 12 Nov 2009
- CCRS (Canada Centre for Remote Sensing) (2005) Glossary of remote sensing terms. Available at http://www.ccrs.nrcan.gc.ca/glossary/index_e.php?id=650. Accessed on 12 Jan 2010
- CAST (Center for Advanced Spatial Technologies) (2010) Landcover classification and mapping. Available at <http://www.cast.uark.edu/gap/chap2.htm>. Accessed on 13 Jan 2010
- ClimateWire (2009) Facing the specter of the globe's biggest and harshest mass journeys. Available at http://www.eenews.net/special_reports/bangladesh/. Accessed on 12 Oct 2009
- Dhakadailyphoto (2007) Cyclone affected area. Available at http://2.bp.blogspot.com/_ZPFIHUBNpK4/R9KAM08GLkI/AAAAAAAAAHHI/8EEEnE_hS90g/s1600-h/Cyclone.jpg. Accessed on 2 Dec 2009
- Environmental Protection Agency (2009) Coastal zones and sea level rise. Available at <http://www.epa.gov/climatechange/effects/coastal/index.html>. Accessed on 25 Nov 2009
- FAO (Food and Agriculture Organization) (2007) Climate variability and change: adaptation to drought in Bangladesh. Available at <http://www.fao.org/docrep/010/a1247e/a1247e00.htm>. Accessed on 29 Nov 2009
- Global Warming Art (2009) Global sea level rise risks. Available at http://www.global-warmingart.com/wiki/File:Global_Sea_Level_Rise_Risks_png. Accessed on 2 Dec 2009
- infoterra (2010) Satellite band designations and principal applications. Available at http://www.infoterra.co.uk/data_sat_bandedesc.php. Accessed on 11 Feb 2010
- Jones P, Salmon M (2008) Climate research unit: data, temperature. Available at <http://www.cru.uea.ac.uk/cru/data/temperature/>. Accessed on 3 Dec 2009
- LandScan (2008) LandScan population data 2007. Available at www.ornl.gov/landscan/ registration for population data collection in November 2008
- LCG Bangladesh (2006) Children vulnerability in waterlogging 2006. Available at www.lcgbangladesh.org/.../2006%20Report_SCF%20UK_Children%20Vulnerability%20in%20Water_logg%202006.pdf. Accessed on Oct 2009
- Liu H (2006) Image band transformations. Available at http://geog.tamu.edu/~liu/courses/g661/spectral_trans.pdf. Accessed on 3 Feb 2010
- LLU—ESSE21 (2010) Land use/land cover classification module. Available at http://resweb.llu.edu/rford/courses/ESSC5xx/docs/ESSE21_clsfn.pdf. Accessed on 12 Feb 2010
- Mastrandrea MD, Schneider SH (2005) Global warming. In: *World book online reference center*. World Book, USA. Available at http://www.nasa.gov/worldbook/global_warming_worldbook.html. Accessed on 20 Nov 2009

- National Climatic Data Center (2008) Global warming. Available at <http://www.ncdc.noaa.gov/oa/climate/globalwarming.html>. Accessed on 21 Nov 2009
- Southwest Climate Change Network (2009) Science daily. Available at <http://www.southwestclimatechange.org/news/feed/sciencedaily>. Accessed on 20 Nov 2009
- Spatial Analyst Laboratory (2009) Software. Available at <http://sal.ocean.washington.edu/tutorials/erdas/qtips.html>. Accessed on 13 Jan 2010
- The Daily Star (2008) Food, water crisis in 85 Kobadak basin villages. Available at <http://www.thedailystar.net/story.php?nid=57700>. Last accessed 17 Nov 2009
- US Geological Survey (2003) Using the landsat 7 enhanced thematic mapper tasseled cap transformation to extract shoreline. Available at <http://egsc.usgs.gov/isb/pubs/ofrs/03-272/OFR03-272.pdf>. Accessed on 12 Feb 2010
- United Nation Environment Programme (2009) Climate change science compendium 2009. Available at <http://www.unep.org/compendium2009/>. Accessed on 15 Nov 2009
- Wikipedia (2009) Sundarbans. Available at <http://en.wikipedia.org/wiki/Sundarbans>. Accessed on 10 Nov 2009
- zFacts.com (2007) Evidence that CO₂ is cause. Available at <http://zfacts.com/p/226.html>. Accessed on 02 Dec 2009