Land cover change, population dynamics and climate change: Spatial and chronological transformation of Sundarbans and its adjacent areas, Bangladesh

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ID: 2013-02-97-002

A thesis submitted for the degree of Masters
In
Population, Reproductive Health, Gender and Development

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March, 2015

Declaration

I hereby declare that this work, now submitted as thesis for the degree of Masters of Population, Reproductive Health, Gender and Development of the East West University, is the product of my own research. To the best of my knowledge and belief, it contains no material previously published or written by another person, except where due acknowledgment has been made in the text. I certify that this thesis has not been presented to any other examination authority.

Md. Sanaul Haque Mondal

Signature:

Date: 22 March 2015

Dedication

This work is dedicated to my best teacher Dr. Rafiqul Huda Chaudhury. I am very grateful to him for his support and encouragement of MPRHGD program and encouraging my mission and dedication on working for population, environment and development.

Acknowledgement

During the development of my research work, several persons and institutions assisted me directly and indirectly to accomplish the study successfully. Without their support it would really be impossible for me to finish my work. It is my privileged to acknowledge their contribution.

My sincere gratitude goes to Dr. Rafiqul Huda Chaudhury for inspiring me to venture into the realm of population and development, and for his support and guidance throughout my research. I received motivation and encouragement from him throughout my Masters studies.

I am thankful to Dr. Lutfun Nahar for her valuable suggestions and well wishes throughout the Masters program. My heartfelt thanks go to all faculty and adjunct faculty members of MPRHGD- M. Ataharul Islam, Fouzia Mannan and Marzia Zaman Sultana- for their generous support during my study tenure in East West University. I would also like to thank to the Chairperson of Department of Social Relations for giving me the opportunity to do this research work. I am also thankful to all administrative staffs of Department of Social Relations and classmates of MPRHGD program for their strong support and encouragement all the way through my study tenure in East West University.

My specials thanks to the residents of Sundarbans Impact Zone (SIZ) who shared their valuable opinions, knowledge and experience with me when I was employed in Khulna as a development professional, without which this study would not have been possible. Truly speaking, they are the main architect of this research because they pushed me to grow my research interest on Sundarbans.

I wish to express my thanks BBS library team. It was not possible to collect the chronological socio-demographic data of SIZ without their coordinal assistance. In addition, my sincere thanks to all anonymous researchers who carried out researches on Sundarbans- their studies helped me a lot to organize and prepare this report.

I am indebted to Mr. Debnath who has supported me a lot to analyze the satellite images. Actually, I was not used to GIS and remote sensing. It is Debnath who has made this mission possible for me. He has taught me GIS and remote sensing. I am also grateful to my dearest teacher Dr. Serajul Islam and younger brother Mr. Kutub for their well wishes.

I am grateful to Mr. Mahmudun Nabi Khan, Mr. Palash Kanti Haldar and Mr. Sakil Ahmed who shared their knowledge with me on climate change in south western Bangladesh and Sundarbans mangrove.

I would like to express my deepest gratitude to my mother, mother in law, Anwar Bhai, Shipon Apa, Kanij Apa, Lian Apa, and nephew- Tahmid. Without their unstinting support, encouragement, prayer and blessing the completion of this research program would not have been possible.

I want to remember the departed soul of my father who always dreamt of me. I hope I will be receiving his blessings from heaven.

I am really grateful to my dearest Fatema-tuj-Zohora, who kept me free from many of my duties which allowed me to pursue the study. I express my deepest pleasure for her understanding during the preparation of the thesis. Finally, my sincere thank to Almighty Allah for blessing me at all stages.

Abstract

Sundarbans is the largest mangrove forest of the world. It covers an area of around 10,000 km^2 of which 62% lies in the districts of Bagerhat, Satkhira and Khulna of Bangladesh and the rest 38% shared by India. The Sundarbans mangrove forest of Bangladesh constitute around 50% of the country's protected area and around 2 million people of the Sundarbans Impact Zone (SIZ) are directly and indirectly depends on Sundarbans and its resources. The forest is under threats because of population pressure, human encroachment, shrimp farming, crab farming, frontier agriculture, pollution, natural disasters e.g. cyclones, coastal erosion, storms surges, floods, hydrological changes, sea level rise, and above all lack of awareness, etc. This paper examines the population dynamics of Sundarbans Impact Zone (SIZ) from 1974 to 2011; climate change impact on Sundarbans; and land cover changes of Sundarbans from 1973 to 2010. A strong relationship has found between population pressure and decrease of vegetated land cover from the Sundarbans Reserved Forest. The population size of SIZ increased by 20 percent (between 1981 and 1991) where as the number of trees per hectare in SRF has decreased by 25% (between 1983 and 1996). During 1973 to 2010, water bodies, barren land and vegetated land decreased by 7%, 50% and 16% respectively; whereas the grassland increased by 228% during the same period. This indicates that the density of evergreen vegetation and its canopy closure has decreased. Climate change put another set of impact on Sundarbans through increasing salinity regime of SRF and decreasing economically valuable species from the Sundarbans. Thus the vicious cycle of population growth and climate change impact on Sundarbans is playing an important role to the depletion of Sundarbans resources. The recommendations of this paper includes in-depth understanding of population dynamics of SIZ locality, develop GIS and remote sensing based real time monitoring system, comprehensive protection, implicit political commitment, environmental friendly development interventions, flow augmentation from Farakka barrage, creating alternative livelihoods for Sundarbans dependent communities, and above all, ensuring transparency, accountability and awareness of community people and forest managers to conserve the Sundarbans from human interventions.

Key words: Sundarbans Reserved Forest (SRF), Sundarbans Impact Zone (SIZ), population dynamics, climate change and land cover change.

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List of abbreviations

ADB	:	Asian Development Bank
BBS	:	Bangladesh Bureau of Statistics
BFD	:	Bangladesh Forest Department
BFRI	:	Bangladesh Forest Research Institute
CMC	:	Co-Management Committee
CEGIS	:	Centre for Environmental and Geographic Information Services
DBH	:	Diameter at Breast Height
DOE	:	Department of Environment
Edt.	:	Edited
et al.	:	And others
etc.	:	Etcetera
ETM+	:	Enhanced Thematic Plus
EU	:	European Union
FAO	:	UN Food and Agricultural Organization
FAP	:	Flood Action Plan
FD	:	Forest Department
FRMG	:	Forest Resources Management Project of FD
GDP	:	Gross Domestic Product
GEMI	:	Global Environmental Monitoring Index
GIS	:	Geographical Information System
GLCF	:	Global Land Cover Facility
Glovis	:	Global Visualization Viewer
GoB	:	Government of Bangladesh
Ha	:	Hectare
HCR	:	Head Count Ratio
HH	:	Household
i.e.	:	That is
IPAC	:	Integrated Protected Area Co-Management Project
IPCC	:	Intergovernmental Panel on Climate Change
IUCN	:	International Union for the Conservation of Nature
Km	:	Kilometer
MARC	:	Multidisciplinary Action Research Centre
MoEF	:	Ministry of Environment and Forests
MSS	:	Multi Spectral Scanner

NA	:	Not available
NAC	:	Not available in census
NBSAP	:	National Biodiversity Strategy & Action Plan for Bangladesh
NDVI	:	Normalized Difference Vegetation Index
NGO	:	Non-Governmental Organization
ODA	:	Overseas Development Administration
OSAVI	:	Optimized Soil Adjusted Vegetation Index
PA	:	Protected Area
pp.	:	Pages
RIMS	:	Resource Management Information System
RS	:	Remote Sensing
SIZ	:	Sundarbans Impact Zone
SPARRSO	:	Space Research and Remote sensing Organization
SRF	:	Sundarbans Reserved Forest
TDVI	:	Transformed Difference Vegetation Index
TM	:	Thematic Mapper
UNDP	:	United Nations development Program
UNEP	:	United Nations Environmental Programme
UNESCO	:	United Nationa Education, Scientific and Culture Organization
UNFCCC	:	United Nations Framework Convention on Climate Change
WB	:	World Bank
WGS	:	World Geodetic System

List of glossaries

Aila	:	A tropical cyclone that landfall on 25 May 2009 in southern coast of Bangladesh.
Bawalis	:	Wood cutter or *golpata* collector.
Charland	:	Land comprising of silt and sand deposited in the braided channels f the main rivers or in the coastal delta.
Gewa	:	*Excoecaria agallocha,* used as low-value firewood and for other general purposes.
Golpata	:	Leaves of *Nypa fruticans:* common English name, Nipa palm. The leaves are used for roof thatching.
Goran	:	*Ceriops decandra*, mangrove species which grows as a small tree or shrub, highly valued for firewood.
Hental	:	*Phoenix paludosa*, a slender, straight, small palm used for rafters, fences and house posts.
Mouals	:	Honey collectors.
Sidr	:	A tropical cyclone that landfall on 15 November 2007 in southern coast of Bangladesh.
Sundari	:	*Heritiera fomes.* Main tree species of the Sundarbans, the largest mangrove forest in the world.
Upazila	:	Sub-district, the local government administrative unit of Bangladesh.

Chapter- One: Introduction

1.1. Introduction:

The densely populated climate fragile country Bangladesh has shared the world's largest mangrove forest with India. Around 38% of the world's mangroves occur in Asia of which Indonesia alone accounts for 19% (FAO, 2007). While almost all mangroves occur in small patches that develop in deltaic habitats, the Sundarbans Mangroves Forest (SMF) is the only contiguous and largest coastal wetland system in the world. Exploration of the SMF dates back to the 16th century. Since 1947 the Sundarbans mangroves are divided between India and Bangladesh (erstwhile East Pakistan), as Sundarbans in Bangladesh (also known as Sundarbans Reserve Forest) and as Sundarbans National Park in India (Rahman, 2007). The SMF extends over the South-west part of Bangladesh (Bagerhat, Satkhira and Khulna district of Bangladesh) and the Southeastern part of the State of West Bengal in India. The SRF is located at the southern edge of the Gangetic delta bordering the Bay of Bengal and is bounded by the Baleswar River on the east and Harinbanga River (international boundary with India) on the West. The SRF covers an area of 6,017 sq. km which accounts for 4.07% of total area of Bangladesh and 40% of total area managed by the Forest Department (BBS, 2014). The Sundarbans Reserved Forest is both a Ramsar site, since 1992, and a World Heritage site of the United Nations Educational, Scientific and Cultural Organization (UNESCO) since 1997 (FAO, 2007). The Sundarbans is playing an important role in balancing and protecting the coastal wetland ecosystems in the Bengal basin. It also provides natural protection to the life and properties of the coastal population from cyclones and storm surges. It has been suggested that the large loss of life (300,000 to 500,000 lives) in Bangladesh during the 1970 typhoon was partly due to the fact that many of the mangrove swamps protecting those populated coastal regions had been removed and replaced by rice paddies (McKee, 1996. p. 6).

Mangroves include the provision of a large variety of wood and non-wood forest products; coastal protection against the effects of wind, waves and water currents; conservation of biological diversity, including a number of endangered mammals, reptiles, amphibians and birds; protection of coral reefs, sea-grass beds and shipping lanes against siltation; and provision of habitat, spawning grounds and nutrients for a variety of fish and shellfish, including many commercial species (FAO, 2007). According to FAO (2007) some 15.2

million hectares of mangroves are estimated to exist worldwide as of 2005, down from 18.8 million hectares in 1980. On an average, annually 0.114 million hectares of mangrove forest were converted for other uses. It is worthy to mention that high population pressure in coastal areas has led to the conversion of many mangrove areas to other uses (FAO, 2007).

In Bangladesh, government-owned forest area covers 2.19 million ha (GOB 2005). Of the government owned forest land, 1.49 million ha are national forests under the control of the Department of Forest, with the rest being under control of local governments (Zaman, 2011). The natural forests of Bangladesh are classified into three categories: 1) Tropical evergreen/semi-evergreen forest in the eastern districts of Sylhet, Chittagong, Chittagong Hill Tracts, and Cox's Bazaar: 2) Moist/dry deciduous forest also known as Sal forests in the central and the northwest region and 3) Tidal mangrove forest along the coast, known as the Sundarbans, the largest mangrove ecosystem in the world (GOB, 1995 cited in Zaman, 2011). Over 90% of the country's total forest is concentrated in the Eastern and South-Western region of the country.

According to 2011 Census, the total population of Bangladesh was 14,97,72,364 with a density of 1015 person per sq.km. The heavy population pressure is placing growing demand on natural resources, especially forest sector. Over one million people directly or indirectly depend on the forest for their livelihood and the forest contributes great amount of Gross Domestic Product (GDP) in Bangladesh (Giri et al. 2008). About 2% (two percent) of the total manpower of the country is engaged in the forestry sector, is contributing about 2% of the total GDP (Gross Domestic Product) of Bangladesh (BBS, 2014). At approximately 0.02 ha per person of forest, Bangladesh currently has one of the lowest per capita forest ratio in the world (Zaman, 2011).

The existing area of Sundarbans is approximately half the size of the area of mangrove that existed 200 years ago, the other half being cleared and converted to agricultural land. The SRF is surrounded by a very densely populated area and people are mostly depends on Sundarbans for their livelihoods, therefore human pressure is important. Numerous people are engaged in the commercial exploitation of Sundari and other tree species, while the local people depend on the forest for firewood, timber for boats, poles for house-posts and rafters, golpata leaf for roofing, grass for matting and fodder, reeds for fencing, and fish for their own consumption. It is evident the anthropogenic interventions on Sundarbans has increased rapidly over the past few decades. The forest is under threats because of human encroachment, shrimp farming, crab farming, frontier agriculture, pollution, natural disasters e.g. cyclones, coastal erosion, storms surges, floods, hydrological changes, sea level rise, and above all lack of awareness, etc. Apart from the human population pressure, two other major factors determine the future of the Sundarbans mangroves and its biological diversity-demand of freshwater for mangrove species and impact of climate change.

The Sundarbans mangrove forest is exceptional for its richness with high biodiversity featuring habitats for fish, shrimp, birds, and other wildlife, including the Bengal tiger. The forest is very important for its protection and productive functions. It serves as a natural protection for coastal communities from disasters. The SRF contributes about 41% of the total forest revenue (Islam, 2010, p. 2). The forest accounts for over half of all reserve forest area in Bangladesh and is the single largest source of forest products - supplying nearly half of all timber and fuel wood output, directly providing income and subsistence for at least half a million people, maintaining a similar number of households in the buffer area (Islam, 2010). Several industries are based on the raw material obtained from the Sundarbans ecosystem. Besides, thousands of poor coastal communities engage in generating their income through harvesting non-timber forest products such as honey, wax, medicinal plants, golpata and grass. It produces a large quantity of fish, shrimp and crabs. The SRF also represents the largest single carbon asset pool for the country to market in appropriate carbon markets (FD, 2010). The area serves a vital role in a variety of ecosystem functions including (1) trapping of sediment and land formation, (2) protection of human lives and habitation from regular cyclones, (3) acting as a nursery for fish and other aquatic life, (4) oxygen production, (5) waste recycling, (6) timber production, (7) supply of food and building materials, and (8) climate change mitigation and adaptation through carbon sequestration, storage and cycling. These functions are increasingly at risk from the effects associated with climate change and sea level rise (FD, 2010).

The Sundarbans mangrove forest is most likely to be changed directly or indirectly by human activities. Several efforts have been made to protect the Sundarbans. The area was mapped as early as 1764, soon after proprietary rights were obtained by the East India Company in 1757. The first Forest Management Division to have jurisdiction over the Sundarbans was established in 1869. The Sundarbans was declared a reserved forest in 1875-76, under the Forest Act, 1965 (Act VIII of 1965). The first management plan was written for the period 1893-98 (Rahman, 2000). In 1977, Bangladesh created three wildlife sanctuaries: the Sundarbans West (71,502 ha), Sundarbans East (31,226 ha); and Sundarbans South (36,970 ha), protecting about 23.5 % of the remaining Sundarbans under the Bangladesh Wildlife (Preservation) (Amendment) Act, 1974 (Wikipedia).

1.2. Some Concepts:

1.2.1. Household:

Persons, either related or unrelated, living together and taking food from the same kitchen constitute a household. A single person living and eating alone forms one-person household. The average size of households is calculated by knowing the number of people who live in households and the number of households (PRB). The average household size of Bangladesh is 4.4 (BBS, 2011).

1.2.2. Sex Ratio:

The sex ratio is the ratio of males to females in a given population, usually expressed as the number of males for every 100 females. The sex ratio at birth in most countries is about 105 males per 100 females. After birth, sex ratios vary because of different patterns of mortality and migration for males and females within the population (PRB, 2011). The current sex ratio of Bangladesh is 100.3 (BBS, 2011).

1.2.3. Population dynamics:

Population dynamics is the changes in the number of individuals in a population or the vital rates of a population over time. The size, growth rate and composition of the population are influenced by the three demographic phenomena, namely fertility (births), mortality (deaths) and migration. As people are born, die, or move, their total numbers in an area change.

1.2.4. Crude birth rate:

The crude birth rate indicates the number of live births per 1,000 populations in a given year. Births are only one component of population change (PRB). The crude birth rate of Bangladesh is 19.2 per thousands (SVRS, 2010).

1.2.5. Crude death rate:

The crude death rate is the number of deaths per 1,000 populations in a given year (PRB). The crude death rate of Bangladesh is 5.66 (SVRS, 2010).

1.2.6. Migration:

Migration is the geographic movement of people across a specified boundary for the purpose of establishing a new permanent or semi permanent residence. Along with fertility and mortality, migration is a component of population change (PRB).

1.2.7. Total fertility rate:

The total fertility rate (TFR) is the average number of children that would be born to a woman by the time she ended childbearing if she were to pass through all her childbearing years conforming to the age-specific fertility rates of a given year (PRB). The TFR of Bangladesh is 2.1 (BBS, 2011).

1.2.8. Growth rate:

The growth rate is the rate at which a population is increasing (or decreasing) in a given year due to natural increase and net migration, expressed as a percentage of the base population. The growth rate takes into account all components of population growth: births, deaths, and migration (PRB). The annual growth rate of Bangladesh is 1.47 percent (BBS, 2011).

1.2.9. Population Density:

Population density is a measurement of the number of people in an area. It is an average number. Population density is calculated by dividing the number of people by area. It is usually shown as the number of people per square kilometer. The density of Bangladesh is the highest (976 per sq km) in the world.

1.2.10. Age sex structure:

Age-sex structure is the composition of a population as determined by the number or proportion of males and females in each age category. It is the cumulative result of past trends in fertility, mortality, and migration. Information on age-sex composition is essential for the description and analysis of many other types of demographic data.

1.2.11. Population pyramid:

A population pyramid graphically displays a population's age and sex composition. Horizontal bars present the numbers or pro- portions of males and females in each age group. The sum of all the age-sex groups in the population pyramid equals 100 percent of the population (PRB).

1.2.12. Urbanization:

Urbanization is the increase in the proportion of the population living in urban areas—the process of people moving to cities or other densely settled areas (PRB). The urbanization rate of Bangladesh is 23.3 percent (BBS, 2011).

1.2.13. Reserved Forests (RF):

These are lands under the direct control of the FD. The Forest Act is applicable for their protection. According to FD records the total Reserved Forests in Bangladesh is 1.2 million hectares (Mha). Though these lands are declared as 'Reserved Forest' they do not carry good tree cover that can be designated as forests (Choudhury and Hossain, 2011). The Sundarbans, declared as Reserved Forest (RF) in the 1870's.

1.2.14. Mangrove forest:

Mangroves are coastal forests found in sheltered estuaries and along river banks and lagoons in the tropics and subtropics. According to Tomlinson (1986) the term mangrove describes both the ecosystem and the plant families that have developed specialized adaptations to live in this tidal environment. Mangroves are found along sheltered coastlines, shallow-water lagoons, estuaries, rivers or deltas in 124 tropical and subtropical countries and areas (FAO, 2007). In Bangladesh, mangrove forests are located in the Sundarbans and along the coast.

1.2.15. Coastal zone of Bangladesh:

Coastal zones refer to areas where land and sea meet. The three basic natural system processes and events that govern opportunities and vulnerabilities of coastal zone of Bangladesh are: tidal fluctuations; salinities (soil, surface water or groundwater); and cyclone and storm surge risk. The coastal zone of Bangladesh consists of 19 districts comprising 147 upazilas and Exclusive Economic Zone (EEZ) (Islam, 2004).

1.2.16. Sundarbans Impact Zone (SIZ):

The periphery of the SRF includes the legally declared "Ecologically Critical Area" assumed to be within a 20 km band surrounding the SRF. This is what can be called the Sundarbans Impact Zone (SIZ). The SIZ vis-à-vis the study area comprises 5 districts, 10 upazilas, 151 unions/wards and 1,302 villages, which are as follows.

Table 1.1: Districts and upazilas of Sundarbans Impact Zone

District	Upazila	No. of Unions	No. of villages
Bagerhat	Sadar, Mongla, Morrelganj, Sarankhola	65	486
Khulna	Dacope, Koyra, Paikgacha	37	440
Satkhira	Shymnagar	13	216
Pirojpur	Mathbaria	20	94
Barguna	Patharghata	16	66
5 Districts	10 Upazilas	151	1,302

Source: Islam, 2010

1.2.17. Land cover and land use:

Land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or artificial structures. Land cover may be observed directly in the field or by remote sensing. Land cover change plays a major role in climate change at global, regional and local scales.

Land use is the human use of land. Land use involves the management and modification of natural environment or wilderness into built environment such as settlements and semi-natural habitats such as arable field, pastures, and managed woods. According to FAO/ UNEP FAO (1999) Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (Wikipedia). These two terms are very interrelated as land cover is the type of features that exist on the earth and land use is the economic utilization of land (Lilles and Keifer, 1994 cited in Samanta and Hazra, 2012).

1.2.18. Deforestation:

Deforestation is the loss or continual degradation of forest habitat due to either natural or human related causes. Agriculture, urban sprawl, unsustainable forestry practices, mining, and petroleum exploration all contribute to human caused deforestation. Natural deforestation can be linked to tsunamis, forest fires, volcanic eruptions, glaciation and desertification. Deforestation can be defined broadly to include not only conversion to non-forest, but also degradation that reduces forest quality – the density and structure of the trees, the ecological services supplied, the biomass of plants and animals, the species diversity and the genetic diversity (Cited in Ahmed, 2008).

1.2.19. Forest degradation:

According to FAO (2006), *Forest Degradation* is the changes within the forest which negatively affect the structure or function of the stand or site, and thereby lower the capacity to supply products and/or services (FAO 2006, Cited in Ahmed, 2008). Forest degradation can take place mainly from human activities such as overgrazing, overexploitation (for fuel wood or timber), repeated fires, or due to attacks by insects, diseases, plant parasites or other natural sources such as cyclones. Unsustainable logging practices can contribute to degradation.

1.2.20. Climate change:

A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC).

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'.

1.2.21. Disaster:

A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources (UNISDR, 2009). Disaster impacts may include loss of life, injury, disease and other negative effects on human physical, mental and social well-being, together with damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation (UNISDR, 2009).

2.2.22. Sea level rise:

Sea level is the average height of the ocean's surface between high and low tide. A height averaged over a year is used often to describe sea level for that year. Sea level rise can be calculated using average-daily to average-yearly data. Sea level rise is caused by a complex suite factors. Climate change contributes to global sea level rise in two ways a) higher seawater temperatures cause the volume of seawater to increase and b) melting ice caps, glaciers and ice sheets increase the total amount of seawater.

1.2.23. Vulnerability:

Vulnerability is the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard (UNISDR, 2009). Vulnerability is a complex process that can arise from various physical, social, economic, and environmental factors.

1.3. Objective of the research:

Mangroves are heavily used traditionally and commercially worldwide. Local communities have always used mangroves as a source of wood for cooking and heating, and for building houses, huts, fences, matting and scaffolds. Moreover, commercial practices are being increasingly (Alongi, 2002).

The anthropogenic pressure on Sundarbans has been increasing in manifolds over the last few decades. Along with the anthropogenic stress another dimension of pressure has recently been imposed on Sundarbans in the form of climate change. These two factors are playing a crucial role in changing the forest cover of Sundarbans. It is true that Sundarbans is a highly fragile ecosystem and its delicate balance may be adversely affected if these pressures are not dealt with. On this background the major objectives of this study are:

- To understand the dynamics of population on land cover change.
- To understand the impact of climate change on Sundarbans in the lens of population dynamics.
- To understand the spatial and temporal changes in vegetation coverage of Sundarbans using remote sensing and GIS tools.
- To find out the linkage between population dynamics, land cover change and climate change

1.4. Methodology of the study:

The study combines three features- population dynamics in SIZ, climate change and land cover change in Sundarbans. Hence, the research involves multistage systematic methods of investigation. The research is generally based on secondary data and satellite images. The stages of methods of this study can be categorized into the following steps:

a. Selection of the study area.
b. Prepare a list of bibliographies on population and environment interaction in Sundarbans; impact of climate change on Sundarbans; and Sundarbans land cover change.
c. Collection of secondary data.
    I. Population dynamics data of SIZ.
    II. Impact of climate change and sea level on Sundarbans.
    III. Collections of land cover satellite images of Sundarbans.
d. Analysis of the population data of SIZ.
e. Analysis of satellite images.
f. Report drafting.

1.4.1. Sources of data:

The availability of appropriate data is most important part of any research. The purpose of the study is to understand the impact of climate change, population pressure and deforestation on Sundarbans. Secondary data are the prime sources of data of this research. More specifically, researches and data sets from Bangladesh Bureau of Statistics (BBS), United Nations, UNDP, UNFPA, UNEP, World Bank, ADB, IPCC, UNFCCC, IPAC, NGO publications, newspaper, etc. and researches carried out by scholars (books, journals, newspaper articles, etc.).

1.4.2. Population data collection and analysis:

Population data were collected from BBS population censuses reports for 1974, 1981, 1991, 2001 and 2011. The same data were analyzed to establish changes in population size, age structure and sex composition through time. Changes in population of the actors in terms of size, age structure and sex composition for 1974, 1981, 1991, 2001 and 2011 were analyzed to determine trends and changes in population characteristics to compare such changes with changes in forest cover. Statistical tables and graphs were generated using Microsoft Excel package.

1.4.3. Land covers change analysis:

a. Raw satellite image collection: The study used Landsat images to derived chronological land cover maps. Landsat image spatial and spectral characteristics are suitable to derive land cover at local scale. These images are provided historical records at free of cost. The study period was chosen from 1973 to 2011.

b. Image processing: This stage involves the processing of raw satellite images including geometric correction, features extraction, geo-processing, and image filtering. Finally, images are classified to identify land cover change.

c. Mapping and analysis: In this stage vector maps were prepared by the ArcGIS 10.1 software. The ERDAS Imagine 2013 were used to perform digital images processing, accuracy assessments and data analysis.

1.4.4. Research Questions and Hypotheses:

In order to fulfill the aim of the research project following questions will be addressed during the research.

- What are the changes in population in Sundarbans reserve forest area?
- What are the possible impacts of climate change on Sundarbans?
- What is the present land cover in the study area?

- Which major land cover types have changed in the study area over last 37 years or more?
- Is there any linkage between population dynamics, climate change and land cover change?

1.4.5. Hypothesis of this research:

- Both population pressure and climate change has contributed to change of land cover of Sundarbans.

1.5. Rationale of the study:

The Sundarbans has a diverse unique ecosystem that provides important resources for the local and larger communities which serves immense opportunities for livelihoods through resources extraction. Although Sundarbans plays an important role in environmental and ecological processes, this forest has been degraded over the last couple of decades due to anthropogenic origin. Moreover, due to the changes in climate, the forest has been reducing day by day. Climate change is a big threat to this forest because Sundarbans is only 3m above from the sea levels in Bangladeshi side and 10m at almost in India side. The trend of land cover change of Sundarbans has been so alarming that could create serious ecological imbalances. Therefore, the study of land covers change of Sundarbans in the aspect of population and climate change is very urgent. Thus this study is an attempt to explore the role of population and climate change to the changes in forest cover of Sundarbans. The contribution of this research would be of interest to scholars in establishing the linkage through population, development and environmental dimension. Studies on population and development are the core areas of research in the field of environment, in the backdrop this study would be of interest to scholars and practitioners particularly who are engaged in development and management of Sundarbans.

1.6. Scope of this research:

The coastal area of Bangladesh comprises of 19 districts and represents 31% of country's total population. This research limits its boundary to analysis the population dynamics of SIZ only i.e. five districts of coastal zone- Khulna, Bagerhat, Satkhira, Pirojpur and Barguna.

Climate change is now a global threat. Climate change impacts on every sector adversely. This research limits its scope to review the existing literatures that are related to the impacts of climate change on Sundarbans, Bangladesh.

Land cover science deals with physical and biological cover on the earth's surface. There are lots of research gap on studying land cover change in Sundarbans. However, the present study analyzes some satellite images of Sundarbans in Bangladesh from 1973-2010 and detects the changes of Sundarbans land cover during that period. In addition, within the forest, tree cover changes data has been collected from several researches and incorporated into this research for further in depth analysis.

1.7. Limitations of the study:

The study has some limitations which should be addressed as a means of improvement for further study. Access to chronological data on population, in many cases, has remained as the major limitation. In 1974, present districts (Khulna, Bagerhat, Satkhira, Pirojpur and Barguna) were under the erstwhile greater Khulna and Bakergonj; and some upazila boundaries were changed in the early 1990s. This boundary delineation has made difficult to extract the data of 1974 census. Although I tried to get data from different agencies and sources, it is recognized that enough could not be done to secure data.

The study was prepared based on raw satellite images which were taken through remote sensing over the last 37 years. One of the objectives of this research is to see the changes of land cover during the census years of Bangladesh. But actual study interval period was compromised depending on the availability of cloud free images. The other limitation is the resolution difference. Landsat images of 1973 and 1978 have been acquired with the multi-spectral scanner (MSS) which has a spatial resolution of 79 meters, whilst the images of 1989 & 2010; and 2001 have been acquired with Thematic Mapper and Enhanced Thematic Mapper (ETM) respectively. The spatial resolution of MSS, TM and ETM are 79 meters, 30 meters and 30 meters respectively. Image thinning has applied to MSS images to overcome the barriers.

The impact of climate change on Sundarbans has discussed based on existing researches and personal observations. This is one of the limitations of this research not to carry out any scientific modeling on climate change impacts and sea level rise.

1.8. Structure of the Report:

The purpose of this research is to ascertain the linkages of climate change, population dynamics and land cover change of Sundarbans over three decades. This research is likely to be useful for policy makers, planners, environmentalists, conservationist, researchers, educators and general communities. Thus the report is structured in six chapters. Starting with the **Chapter 1** presenting the study background, objectives, methodology and literature review, **Chapter 2** presents brief notes on Sundarbans. **Chapter 3** introduces the analysis of population dynamics in SIZ. **Chapter 4** addresses the impact of climate change on Sundarbans through extensive reviewing literatures and personal observations. **Chapter 5** discusses with the changes in the land cover of Sundarbans using remotely sensing GIS. And **Chapter 6** presents linkages between population dynamics, climate change and land cover change with discussions and recommendations. And bibliographies and annexure are listed in the final part of the report.

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Chapter- Two
Study Area: The Sundarbans Mangrove Forest, Bangladesh

2.1. Introduction:

This chapter deals with the description of the study area where this research was conducted. The description includes the geographical settings and biodiversity of Sundarbans mangrove forest and socio-economic features of SIZ localities.

The Sundarbans is the largest productive mangrove forest in the world. It has a diverse unique ecosystem and has supported ample plant and animal species. Sundarbans is one of the world richest biodiversity store house which supports 300 species of birds, 50 species of mammals, 50 species of reptiles, 8 species of amphibians, 177 species of fishes, 24 species of shrimps, 7 species of crabs, 32 species of mollusks, 8 species of locust lobsters, 3 species of turtles etc. (IUCN, 2003)[1]. The most important faunas are world famous Royal Bengal Tiger, crocodile, spotted deer, lizards, dolphins, turtles etc. The estuaries and waterways hold a rich source of marine biodiversity, which are of great value both ecologically and economically. This forest has also rich floral diversity of around 330 plant species. The most notable mangrove floral species are Sundari, Gewa, Golpata, Passur etc. The role of Sundarbans in environmental process is also significant. It plays as a buffer in protecting the densely populated areas from the aggression of frequent cyclones, storm surges and tidal waves. The Sundarbans is the single largest source of forest resources in the country. It provides livelihoods for millions of fishermen, honey collectors, woodcutters, golpata collectors, fuel wood collectors, shell collectors, etc. The Sundarbans has been declared as a UNESCO World Heritage site (798th) for its unique ecosystem, and as a RAMSAR site (560th) for its importance as an internationally significant wetland (RAMSAR, 2007, UNESCO, 1997).

Sundarbans was declared "Reserve Forest" during 1875-76 under Act VII of 1865 and was placed under the Forest Department for management. Since then FD is managing this area as Sundarbans Reserved Forests (SRF). During the partition of greater India in 1947, the portion of Sundarbans that became the part the then East Pakistan, at present is the Bangladesh Sundarbans, a valuable natural resource of the country. It is the single largest chunk of productive mangrove forest in the world.[1]

[1] National Biodiversity Strategy and Action Plan for Bangladesh, 2005

2.2. Etymology of Sundarbans:

The meaning of the Sundarbans in Bengali language is 'beautiful forest', where '*Sundar*' means beautiful and *Ban* means 'forest' (Choudhury, 2001). It is difficult to determine the origin of the name of Sundarbans. One of the popular notions is that it was named after its major plant species 'Sundari' which in Bengali means beautiful. Alternatively, it has been proposed that the name is a corruption of *Samudraban*, *Shomudrobôn* (Sea Forest), or *Chandra-bandhe* (name of a primitive tribe) (Wikipedia)[2]. Later on the British adopted the present name Sundarbans for the mangrove forest (Choudhury et al. 2001; Siddiqi, 2002; Islam, 2003). However, the generally accepted view is the one associated with *Sundari* trees (Wikipedia).

2.3. Location of Sundarbans:

Historical records reveal that the northern boundary of Sundarbans during the Mughal Period (1203-1538) extended from Hatiagarh (south of Diamond harbor) to Bagerhat (in the southern part of Jessore) and to Haringhata along the southern portions of Sirkars, Satgaon and Khalifatabad. During the latter part of the 18th and the beginning of the 19th century the boundaries of the Sundarbans tracts extended inland to a distance of 60 miles and towards the Bay of Bengal about 170 miles expanding from the estuary of the Hoogly and Meghna. Regular repossession of the Sundarban started in the 1830s. Between 1830 and 1875 a large portion of the forest was cleaned out. In 1875 and 1876 under the Forest Act of 1876, certain tracts of the forest were declared as reserve forest. The boundary of the reserve forest of the greater Khulna district, comprising of Khulna, Bagerhat and Satkhira district, did not undergo any major change since 1876, except for some small scale deforestation in latter part of the 19th century and early of 20th century. This area today comprises the Bangladesh Sundarbans (Tabassum, 2000).

At present, the Sundarbans Reserve Forest in Bangladesh is located at the edge of the southwest of Bangladesh between the river Baleswar in the East and the Harinbanga in the west adjacent to the Bay of Bengal. Geographically, Sundarbans is located south of the Tropic of Cancer and lies between 21° 31′ N and 22° 30′N latitude and 89° 01′ E and 90° 18′E longitude (Katebi, 2001; Islam, 2003). The location of Sundarbans is given in the Figure 2.1.

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[2] http://en.wikipedia.org/wiki/Sundarbans

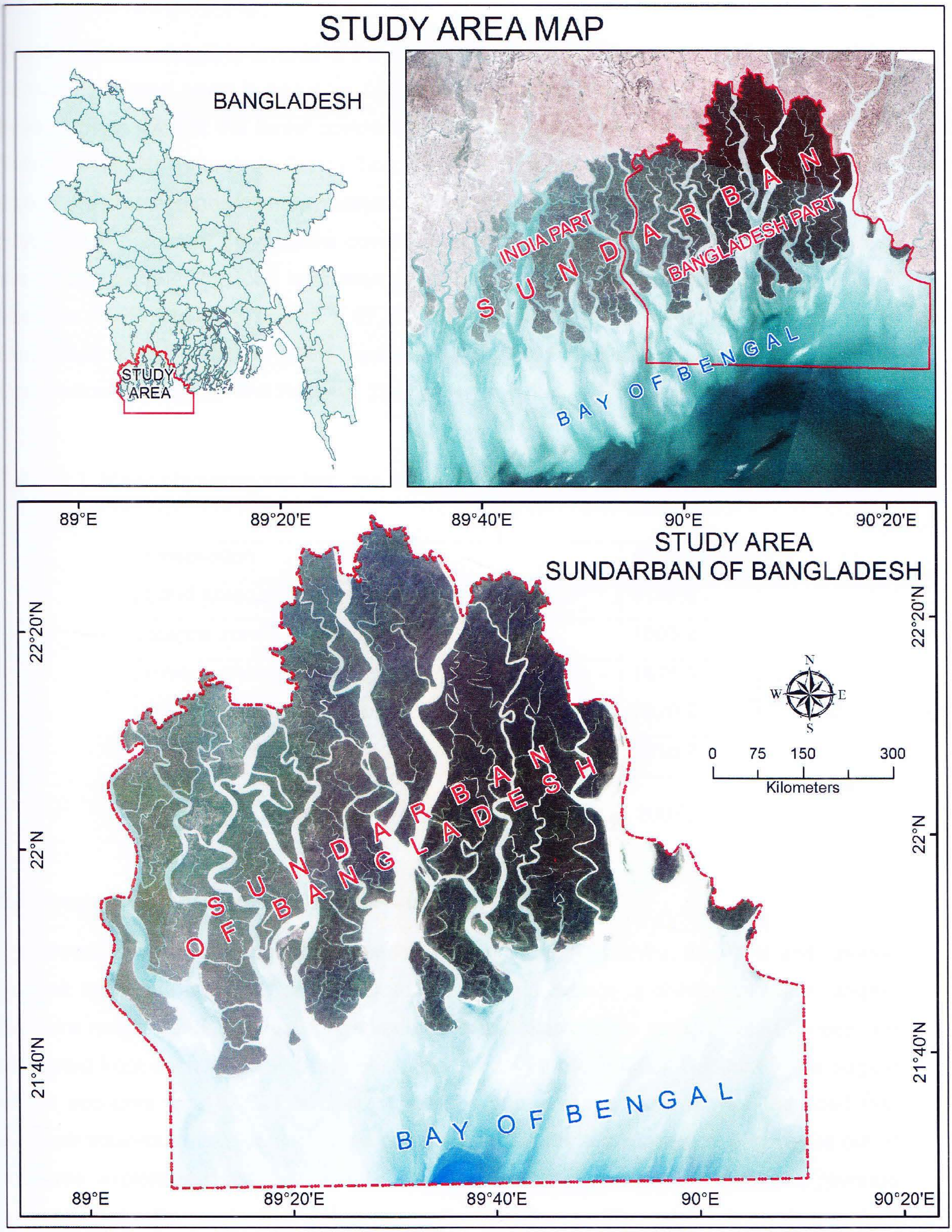

Figure 2.1: Map of study area

2.4. Area of Sundarbans:

The Sundarbans forest is located at the edge of the southern Ganges delta. The area of the Sundarbans forest cover is about 10, 000 km² in southwest Bangladesh and West Bengal of India. Around 62% of the forest covers lies in Bangladesh, while the remaining 38 % is in India (Siddiqi, 2001; Lacerda, 2001). This present Sundarbans area is approximately half the size of the area of mangrove that existed 200 years ago when the area was 17,000 km². The Bangladesh portion of Sundarbans covers an area of around 6017 km^2 (7620 km^2 including the marine zone). The total land area (including exposed sandbars) occupies 4, 14,259 hectares (70%) and water bodies 1, 87,413 hectares (30%). An area of 139,700 hectares of Sundarban forest land has been declared as a World Heritage Site under the Ramsar Convention (Choudhury and Hossain, 2011).

Table 2.1: Major physiographic features in Sundarbans

Description	Area (km^2)
Land area (including sandbars)	4142.6
Marine zone	1603.2
Rivers, channels, streams & canals	1874.1
Total area including marine zone	7620.0
Total area excluding marine zone	6016.7

Source: 1995 data BGD//84/056 GIS (cited in Dey, 2007)

2.5. Regional subdivisions of Sundarbans:

The Sundarbans is located in three districts of Bangladesh- Satkhira, Bagerhat and Khulna. For the better management of the resources, the Sundarbans is divided into four ranges- Satkhira range, Khulna range, Chandpai range and Sarankhola range. These ranges are dissected from each other by rivers or canals. Among these ranges, Satkhira is the largest which accounts for 182,664 hectors of forest. These ranges are again subdivided into revenue stations to take control on resource management and realization of revenue out of resource exploitation process directly. There are 48 patrol posts under these revenue stations that offer protection duties through surveillance. The regional subdivisions of Sundarbans forest is given in Table 2.2.

Table 2.2: Regional sub-divisions of Sundarbans

Name of range	Name of district	Area of range (in hectors)	Name of revenue station	No. of patrol post under each revenue station
Satkhira Range	Satkhira	182,664	Burigoalini	3
			Kobadak	1
			Kaikhali	1
			Kadamtala	2
Khulna Range	Khulna	161,352	Nalian	1
			Kalabogi	3
			Sutarkhali	2
			Baniakhali	1
			Kashiabad	5
Chandpai Range	Bagethat	100,022	Dhangmari	6
			Chandpai	3
			Jewdhara	3
			Dhansagar	4
Sarankhola Range	Bagethat	133,247	Sharankhola	4
			Bogi	4
			Supati	2
			Dubla	3
4 Ranges	3 districts	577,285	17 revenue station	48

Source: Bangladesh Forest Department

2.6. Physiography and physiographic settings of Sundarbans:

The deltaic swamp like Sundarbans is basically flat in nature with some micro-topographical features. To the north of the Sundarbans, between the towns of Khulna and Jessore, the land surface is inclined towards the sea at a slope equivalent to 0.03 m vertical distance per km of horizontal distance. From the sea face north there is an equally shallow, north-facing slope, resulting from tidal redeposition. Within the Sundarbans, the micro-topography is main the product of the action of the rivers and streams dissect the area and the twice-daily tidal incursions. Generally, the highest land is that immediately adjacent to the watercourses, where sediment is deposited when these overflow their banks. Low levees are formed, behind which are relatively low-lying areas, although the variations in heights is likely to be the only some tens of centimeters and discernable by eye. The low lying areas are drained by a network of small creeks which flow into the main watercourses on the ebb-flow of the tide. These are in some instances eroded by the tide to form saucer-shaped depressions in which there may be standing water. These micro-topographical features are more marked in the east than the west. In the western parts of the Sundarbans the levees are less pronounced and the interior depression more extensive (Chaffey et al., 1985, pp. 17). In general, the Sundarbans mangrove forest spreads over the Ganges delta with an average elevation of 0.9 to 2.1 meters above mean-sea level (Bird, 1969; adopted from Islam, 2008). The recent geomorphology of the Sundarbans is characterized by chronological geological and tectonic activities, along with past and existing drainage network systems of the Bay region. The present fluvial and tidal geomorphic features have been resulted by the deposition of weathered materials which were carried by the three mighty rivers the Ganges, the Brahmaputra and the Meghna. The composite drainage pattern of Sundarbans is regulated by seasonal rainfall, inflow of water and sediments. The sediment accumulation and the composite drainage network formed during the delta formation give rise to the different landforms within the Sundarbans supporting microhabitat for diversified species. Mudflats, backswamps or basins, ridges or levees and tidal creeks are the different types of landforms of the Sundarbans (Tabassum, 2000).

2.7. Climate:

The Sundarbans is located in the south of the Tropic of Cancer. Hence, the forest is characterized by humid tropical monsoon climate. Temperature is fairly equable because of the proximity to the sea. Highest temperature is found during the month of April and May and lowest in December and January. Variation of the characteristics of the air and the temporal variation and spatial mix characterize differentiation into four seasons: pre-monsoon (March-May), Monsoon (June- September), post- monsoon (October-November) and winter season (December- February).

a. Pre-monsoon (March-May): This season is characterized by southerly winds, high temperatures and evaporation with occasional heavy thunderstorm. The salinity of river water reaches a maximum in this season because of increasing maritime influence.

b. Monsoon (June- September): The monsoon is characterized by high rainfall, humidity and cloud cover. The water level of water increases due to the heavy rainfall in the upstream catchment. In general, 80% of the total rainfall is received from June to September. August and September are the wettest months.

c. Post-monsoon (October-November): The post monsoon is hot, humid and sunny with heavy condensation at night. During this season occasional thunderstorm, cyclones and storm surges are common. The salinity level of river water increases during this season because of high rates of evaporation.

d. Winter (December- February): Winter is the driest season and is characterized by cool with low precipitation. Western depression can lead to erratic rainfall during January to February.

2.8. Rainfall:

The rainfall is heavy in Sundarbans forest due to the proximity of the Bay of Bengal and the intensity of rainfall increases from west to east. The mean annual rainfall varies from about 2000 mm in the east to 1600 mm in the west. Around 80-85% of the rainfall occurs during May to September and the rest rain can fall before the monsoon (March, April and May) as part of the frequent short duration violent thunderstorms. However, the six months dry period is very crucial because during this period precipitation falls short of meeting evapotranspiration. During this scarcity, the only water available for transpiration is the surface water in the rivers and creeks. River flow from the upstream also reduces and as a result the salt concentration rises up.

2.9. Temperature:

Temperature in Sundarbans are consistent than the land areas. Temperature reaches its maximum from the middle of March and continues till middle of June. Winter begins from the beginning of December and by the end of February the weather gets warmer. The annual mean (over a period of ten years: 2000-2009) maximum and minimum temperatures of the Sundarbans were 28.44°C and 12.75°C respectively. The highest and lowest monthly temperatures were recorded as 36.6° in April 2009 and 11.9°C in January 2010 (Forest Department, 2010).

2.10. Humidity:

The Sundarbans region has relatively high humidity comparatively other area. The 10-year (2000-2009) annual average humidity was recorded as 81%. The highest and lowest humidity were recorded as 90% in April 2000 and as 65% in January 2005 respectively.

2.11. Soil and its texture:

The characteristic of soil is one of the determinant factors for the growth, composition and distribution of floral and faunal species in mangroves. Sundarbans has different vegetation zones and the different vegetation zones support different physical and chemical characteristics in soil.

The soil of Sundarbans forest is of recent origin consisting of alluvium washed down from the Himalayas. Several soil types occur in the Sundarbans. The soil of Sundarbans is medium textured, sandy loam, silt loam or clay loam. Silt loam is the dominant soil textural class and is present in greater quantities in eastern part of the forest than the western part. Besides, based on the chemical composition, the Sundarbans soils can be classified as saline soil, saline-alkaline soil, non-saline alkaline soil and degraded alkaline soil. The mangrove soil is slightly alkaline to neutral in nature. The pH value is ranging from 6.5 to 8, but throughout the SRF most of the soils fall on the alkaline pH range between 7.0 and 8.0.

2.12. River systems in Sundarbans:

The river network of Sundarbans is quite complex. These rivers receive large volumes of fresh water from inland rivers flowing from the north and of saline water from the tidal incursions from the sea. Generally the rivers flow from north to south and are connected with a large number of side channels. These side channels connect two rivers and facilitate exchange of water between them. Few decades ago, all rivers were connected with the Ganges. But now, only Baleswar and Gorai Rivers have the direct connection to the eastern part of Sundarbans which carries substantial amount of fresh water. A number of rivers namely Passur, Sibsa, Selagang, Arpongasia, Kobadak, and Malancha and to a lesser extent Jamuna and Raimangal have indirect connections and receive the overflow of the Ganges during the rainy season. Based on the hydrological regime, Sundarbans has been classified into three sub-systems (Islam, 2008):

a. Western sub-system:

The western sub-system represents the western part of Aura Sibsa and the east of the Raimangal River. This sub-subsystem is connected with the Kobadak- Betna River system.

b. Central sub-system:

The central sub-system is located east of Aura Sibsa and west of the Passur River. This sub-system is directly connected with the Ganges through the Gorai River. The connection between Passur and Gorai has blocked following after the construction of Farakka Barrage across the Ganges River by India.

C. Eastern sub-system:

The eastern sub-system is located east of the Passur River and west of the Baleswar River. This sub-system receives freshwater from the Ganges through the Gorai-Madumati River. The river systems in the Sundarbans can be divided into 5 estuaries. These are as follows:

i) Bangra estuary

ii) Kunga estuary

iii) Malancha estuary

iv) Raimangal estuary

v) Baleswar estuary

2.13. Tides:

Tides in Sundarbans are semi-diurnal with a little diurnal variation. In the eastern Sundarbans, the variation is minor and vice versa in the west. Moreover, there is a seasonal variation of tidal height ranging between 3.5 to 5.0 meters, while the mean tidal height is 4.0 meters. The maximum rise and fall occurs during the spring tides in March and April.

2.14. Hydrology:

The tidal inundation regulates the hydrology of Sundarbans. The hydrology is interrelated to the high seasonal rainfall and the duration of the tidal inundation. Based on the frequency of the tidal inundation during May to October, Seidnesticker and Hai (1983) divided the Sundarbans into four hydrological zones. These are as follows:

i. Areas inundated by all tides
ii. Areas inundated by normal high tides
iii. Areas inundated only by spring high tides
iv. Areas inundated by the monsoon high tides.

2.15. Wind:

Winds are generally light to moderate with exception during cyclonic storm. But winds are stronger in the southern Sundarbans (near the coast). Winds blow mostly from directions between the south-east and south-west during May to September but in October, winds vary in direction. During the winter, winds blow mainly from the north-west but in March and April they blow from the south and south-west.

2.16. Geology:

The Sundarbans mangrove is a tropical forest. The geology of the Sundarbans is of recent origin. It was formed by the gradual deposition of sediments carried by the Ganges from the Himalayas. The formation process has been accelerated by tides from the sea face. The substratum consists entirely of Quaternary Era sediments, sand and silt, mixed with marine salt deposits and clay. Several geomorphological and resultant hydrological changes have contributed to the present position and condition of the Sundarbans. The rising of the western part of the delta caused separation of the ancient branches of the Ganges from the area, which today is known as Indian Sundarbans.

2.17. Forest type:

Based on salinity distribution, the Sundarbans mangrove forest can be classified into three major categories (Islam, 2008, p. 37). These are as follows:

Table 2.3: Forest type of Sundarbans based on salinity distribution

Fresh water forest	North and the eastern portion of the Sundarbans
Moderate salt water forest	Area includes the forest area near the sea-face and less saline area that is available in the monsoon and in the lean period.
Salt water forest	Goran and Gewa dominated forest area of Malancha River

2.18. Ecological zones and habitats:

Sundarbans can be classified into three major ecological zones- slightly saline zone, moderately saline zone and strongly saline zone. These zones are recognized based salinity, freshwater flushing, physiography and their influence on the composition and characters of the species (Islam, 2004, p. 68).

Moreover, on the basis of biogeographical approach, Sundarbans can be classified into five habitat types (Islam, 2004, p. 68). The five habitats are as follows:

a. Shore habitat,
b. Low mangrove forest habitat,
c. High mangrove forest habitat,
d. Openland/ grassland habitat, and
e. Estuarine/ riverine habitat.

2.19. The Sundarbans floral and faunal composition:

a. Floral diversity:

The Sundarbans mangrove forest is characterized by high floral diversity. A total of 245 genera and 334 plant species are recorded by IFMP in 1998. Major tree species of Sundarbans include Sundari, Gewa, Keora, Goran, Singra, Dhundal, Amur, Passur, Kankra, Golpata, Hental and few other tree species. Golpata palm is commonly used as thatching material and Hental is used for construction of small huts as roof rafter and frame of walls. The common undergrowth species are Goran, Hantal, Shingra, Khalsi and Bhola.

Sundari is the most important species of the Sundarbans. As pure crop and in mixture with Gewa, Sundari occupies about 18.2% and 62.4% of the forest area respectively (IUCN-Bangladesh, 2001). But the dominance of Sundari tree in the forest has been decreasing because of 'Top-dying disease'. Around 20.18 million Sundari trees are seriously affected by this disease (Rahman, 1998).

b. Faunal composition:

The Sundarbans is rich with terrestrial, aquatic and avian faunal species. There are 120 species of fishes, 290 species of birds, 42 species of mammals, 35 reptiles and 8 amphibian species found in Sundarbans. The Sundarbans is the single habitat of Bengal Tiger. The forest also provides habitat to the Otter, Squirrels, Rhesus Macaque, Spotted Deer, Barking Deer, Wild Boar, and in rivers and sea, a number of Dolphin species (Islam, 2004).

2.20. Wildlife sanctuaries:

Wildlife Sanctuaries are the area maintained as an undisturbed breeding ground for wild fauna and where the habitat is protected for the continued well-being of the resident or migratory fauna. There are three wildlife sanctuaries in SRF established in 1977 under the Bangladesh wildlife (preservation) (amendment) act, 1974. These sanctuaries are the Sundarbans East (Bagerhat), Sundarbans South (Khulna) and Sundarbans West (Satkhira).

2.21. Socio-economic profile of Sundarbans:

The Sundarbans is the most economically valuable and the richest natural forests of Bangladesh. Over 0.1 million people work as primary collectors of forest products in Sundarbans (Choudhury, and Hossain, 2011). It constitutes about 51% of the total reserved forest and contributes about 41% of the total forest revenue (Shah, 2010). The Sundarbans constitute about 45% of all the timber and firewood supplied from the country's reserved forests. About 50 to 60 thousand people work inside the Sundarbans for at least six months. And around 3.5 million people are entering into the forest in each year (BFD). Approximately 2.5 million people live in the small villages surrounding the Sundarbans, while the number of people within 20 km of the Sundarbans boundary is 3.14 million (MARC, 1995 cited in BFD). The forest dependency rate in higher within the 10 km of the forest boundary. Around 0.1 to 0.2 million people depend on Sundarbans for their livelihoods by collecting non- wood forest products. Fishery is the most important non-wood component of the Sundarbans. Total stock of fish in the areas of SRF has been estimated at 2.9-3.7 tons/km^2, which contributes 5% of the total fish harvest of Bangladesh (cited in Shah, 2010). Sundarbans is also the most attractive place for viewing wildlife. Moreover, some major industries are either partly or totally dependent upon the Sundarbans for their raw materials.

2.21.1. Land tenure:

Sundarbans is a reserved forest. It is managed and controlled by the Bangladesh Forest Department. However, the exception cases are the waterways through which local and international shipping has the right of passage and the naval and Port Authority stations at Hiron Point.

2.21.2. Land use:

In Sundarbans, forestry is the only land use pattern. Timber, pulpwood, fuelwood and range of minor produce are the forestry product of Sundarbans. However, some exceptions are found in encampment- south eastern Sundarbans are being used encampments and markets by fisherman; and small portion of agricultural land in the northwest corner of Sundarbans.

2.21.3. People in Sundarbans:

Sundarbans is blessed with vast natural resources. These natural resources always attracted people for diverse interests. The Sundarbans is free from any encroachment and permanent human habitation except few hundreds of Forest Department personnel on official duty. However, people like Bawalis, Mouals, fishermen, grass cutters and mollusk shell collectors converged into the area for exploration of forest resources. The livelihoods of these people depend on the collection of Sundarbans resources. In addition, there are pirates, poaches and plunders looting the scare resources of Sundarbans.

2.22. Degradation of Sundarbans:

Sundarbans have been losing its coverage, density, composition, and overall productivity. Forest cover has decreased between 1983 and 1995 at an average annual rate of 0.12%, and average stand density of the forest has been reduced by 87% between 1933 and 1995 (Sen, 2010). Besides, the productivity of the mangrove system had already declined by 25% in the two decades leading up 1985, and the rate is estimated to be higher for the two decades since (Millat-e-Mustafa, 2002 cited in Sen, 2010).

2.23. Summary:

The SRF was selected as study area for this research. The physical, geographical and socio-economic importance of Sundarbans has been discussed in this chapter. In summary, Sundarbans is very important for the local economy and livelihoods of millions of poor people living around and outside the landscape area.

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Chapter- Three: Socio-demographic dynamics of SIZ

3.1. Introduction:

With 11% forest area[3], Bangladesh is the 8th most populous county[4] of the world. The country is the highest densely populated country (except city state) of the world. And the density of population in 2011 has almost doubled since 1974. Conversely, forest cover has decreased between 1983 and 1995 at an average annual rate of 0.12%, and average stand density of the forest has been reduced by 87% between 1933 and 1995 (Sen, 2010, p. 6). Thus, per capita forest land has been decreasing at an alarming rate. Most of the forest cover has distributed sparsely over the country. The Sundarbans mangrove forest constitute around 50% of the country's protected area and around 2 million people of the Sundarbans Impact Zone (SIZ) are directly and indirectly depends on Sundarbans and its resources. Among them several thousands of frontier populations are directly engaged in Sundarbans resource extracting for their livelihoods. These people enter into the forest to catch fish fry, collect honey, wood resources and other economic purposes. Consequently, demographic variables are very important for population- environment study.

3.2. Area and population size of Sundarbans Impact Zone (SIZ):

Sundarbans impact zone covers an area of around 6% land of the country. More than half of the total impact zone is shared by Shyamnagar, Koyra and Dacope Upazila. About 58% area of five districts is occupied by the SIZ Upazila. SIZ districts have an area of about 15280 sq km which represents 10.4 percent of the country's total area. Khulna has the highest area to lie in SIZ, followed by Bagerhat, Satkhira, Barguna and the lowest Pirojpur. The Sundarbans reserve forest is located in Bagerhat, Satkhira and Khulna district.

Table 3.1: Area shared by each SIZ upazila

District	SIZ Upazila	Total area (sq. km)	% share of total SIZ Upazila's area
Bagerhat	Bagerhat Sadar	272.73	3.09
	Sarankhola	756.6	8.57
	Mongla	1461.2	16.55
	Morrelganj	460.9	5.22
Satkhira	Shyamnagar	1968.23	22.29
Khulna	Koyra	1775.4	20.11
	Dacope	991.56	11.23
	Paikgachha	411.19	4.66
Pirojpur	Mathbaria	344.23	3.90
Barguna	Patharghata	387.36	4.39

Source: BBS, 2011

[3] http://data.worldbank.org/indicator/AG.LND.FRST.ZS?order=wbapi_data_value_2012%20wbapi_data_value%20wbapi_data_value-last&sort=asc
[4] http://www.prb.org/pdf14/2014-world-population-data-sheet_eng.pdf

SIZ districts have a population of 7.8 million which constitute about 5.4 percent of the total Bangladesh population. According to 2011 census, almost 28 percent of five-district total population belongs to the SIZ. Among the SIZ districts, the highest percentage of population lives in Bagerhat SIZ (53.3%), followed by Khulna (25.6%), Pirojpur (23.6%), Barguna (18.36%) and the lowest in Satkhira SIZ (16.0%). The 2011 census estimated that 2.2 million populations are inhabited in the SIZ Upazila which is around 1.5% of the country's total population and around 32% of the SIZ districts.

Table 3.2: Population size of SIZ upazilas and districts (1974-2011)

Name of District	Name of Upazila	Census Year				
		1974	1981	1991	2001	2011
Bagerhat	Sadar	192530	208143	235848	257273	266389
	Sarankhola	71177	92734	107856	114083	119084
	Mongla	57825	97399	137947	149030	136588
	Morrelganj	232647	272112	321153	349551	294576
Bagerhat district		1027160	1203551	1431332	1549031	1476090
Satkhira	Shyamnagar	196221	234164	265004	313781	318254
Satkhira district		1143953	1354662	1597178	1864704	1985959
Khulna	Koyra	91335	125090	165473	192534	193931
	Dacope	89381	116455	143141	157489	152316
	Paikgachha	258080	175715	225085	248112	247983
Khulna district		1386347	1771101	2010643	2378971	2318527
Pirojpur	Mathbaria	188567	221476	254000	263527	262841
Pirojpur district		823787	947420	1063185	1111068	1113257
Barguna	Patharghata	NA	122000	135000	162025	163927
Barguna district		589147	677771	775693	848554	892781
Bangladesh		76400000	90000000	106314992	124355000	144043697

Source: Compile from different censuses of BBS (1974, 1981, 1991, 2001 and 2011)

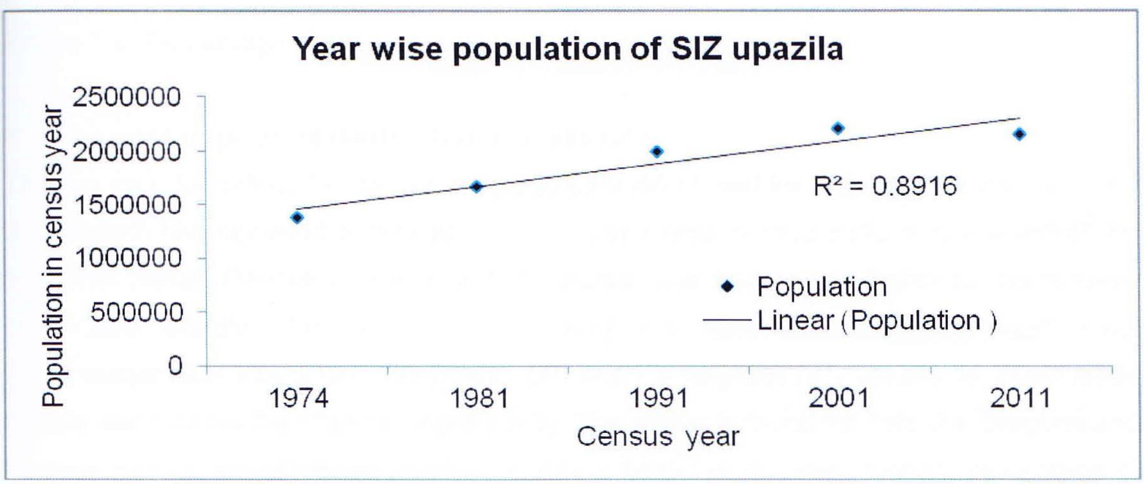

Figure 3.1: Year wise population SIZ upazila with linear trend line

The demographic trends for Bangladesh reveal that the population grew almost doubled between 1974 and 2011. The data also demonstrate that at nationally the population increased by about 60 percent in the period of 1981 to 2011, while at the same period by 28 percent in Bagerhat and Sarankhola, 40 percent in Mongla, 8 percent in Morrelganj, 36 percent in Shyamnagar, 55 percent in Koyra, 31 percent in Dacope and 41 percent in Paikgachha. This analysis reveals that the population growth of SIZ upazilas has not crossed the national growth.

According to the Table 3.2, the actual number of population for each upazila has increased. But while analyzing the data in terms of percentage to country's total population shared by these upazilas, it is found that the shared population by each upazila has been decreasing since 1974 with little fluctuations. However, the actual size of population has decreased in 2011 compare to 2001 census. The figure 3.2 illustrates the changes of population in percentage for different censuses.

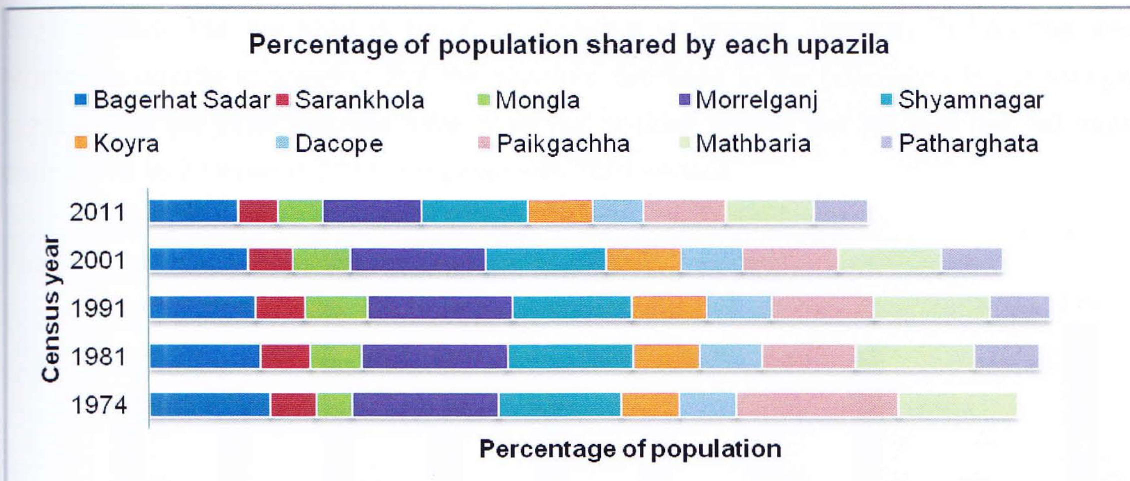

Figure 3.2: Percentage of population shared by each upazila

3.3. Sex wise population distribution and sex ratio:

The sex ratio for different censuses is sporadically distributed for SIZ upazilas. By 2011, the Bangladesh has achieved almost equal (100.3) sex ratio. Similar pattern has observed for Bagerhat Sadar, Dacope and Paikgachha upazila. The sex ratio is higher for Sarankhola (110) and Mongla (110) upazila. The exceptions have found for Morrelganj (95), Shyamnagar (93), Koyra (97), Mathbaria (96) and Patharghata (97) upazila. In these areas female sex crosses the male sex significantly. The similar is found for Satkhira, Barguna and Pirojpur district. Among these districts, Satkhira district is occupied highest percentage of Sundarbans reserve forest.

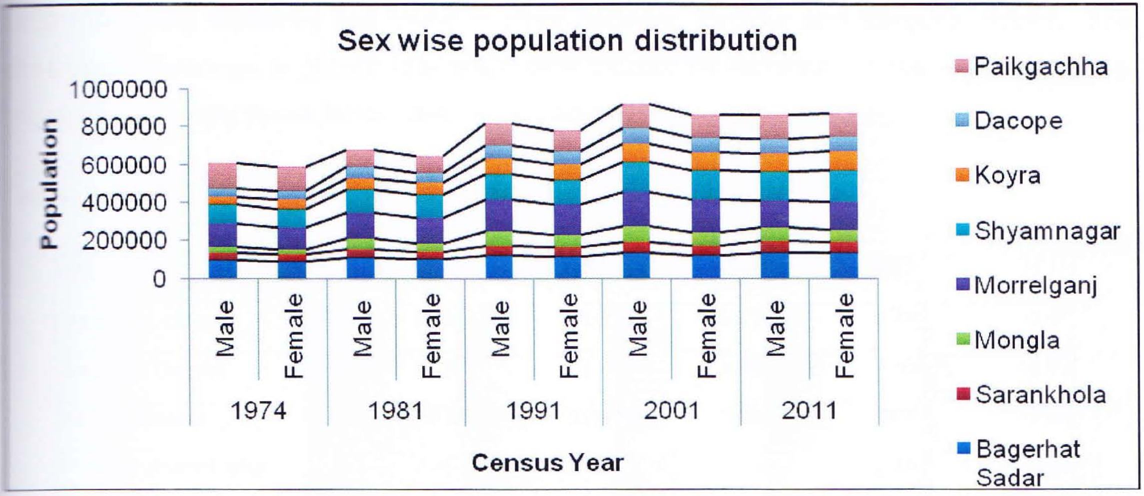

Figure 3.3: Sex wise population distribution of SIZ upazilas

3.4. Annual population growth rate:

Although at national level a positive decline in growth rate has been recorded in 2001 and 2011 census, but the level is found as negative in Mongla, Dacope, Paikgachha and Mathbaria upazila suggesting that the absolute decrease in the population is surprisingly great. While the other upazilas have observed positive growth, but the rate has fall more than 1 time to 23 times in 2011 compared with 2001 census.

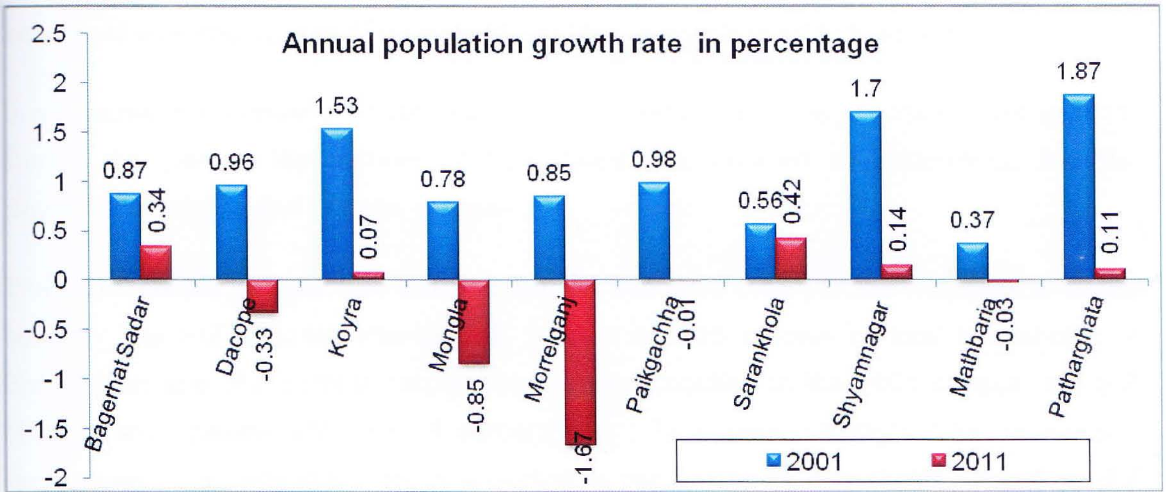

Figure 3.4: Annual population growth rate of SIZ upazila

The SIZ districts also observe a dramatic decline in growth rate. The highest growth rate (5.12) was found in Khulna district in 1974, while this district has observed negative growth rate (-0.25) in 2011. Approximately, similar growth observed by Bangladesh (2.48) as a whole and Bagerhat (2.62), but after four decades Bagerhat has negative growth rate. The similar declining tendency has found in other Satkhira, Pirojpur and Barguna district. The observed differences in growth rate are mainly caused by variations in the rates of internal migration. Probably these factors are influenced by climatic abnormalities.

Table: 3.3. SIZ district wise population growth rate from 1974- 2011

SIZ district	1974	1981	1991	2001	2011
Bagerhat district	2.62	1.6	1.75	0.79	-0.47
Satkhira District	3.45	1.7	1.66	1.56	0.62
Khulna district	5.12	2.48	1.28	1.7	-0.25
Pirojpur district total	2.35	1.41	1.16	0.44	0.02
Barguna district total	2.53	1.89	1.36	0.9	0.5
Bangladesh	2.48	2.35	2.01	1.58	1.47

Source: Compile from different censuses of BBS (1974, 1981, 1991, 2001 and 2011)

3.5. Household and household size:

For forested areas, households are an important demographic variable in determining the dependency on forest resources. In the frontier forest area, most of the households have a profession which is related to forest. The extent of forest resource dependency depends on household size, the number of households and the materials used to build homes.

In all upazila, the number of households has increased between the periods of 1974 to 2011. During this period, the number of households has doubled in Sarankhola, Mongla, Shyamnagar, Koyra and Dacope upazila.

The 2011 census reveals that the SIZ districts comprise 5.73 percent households of the country. The SIZ upazilas shares 1.62 percent and 28 percent of total households of Bangladesh and SIZ districts respectively. While according to the 2001 census, the SIZ districts and upazilas shared 6.38 percent and 1.78 percent country's total households respectively. This indicates there is a decline in percentage of households shared by SIZ districts and upazilas in 2011 compare to 2001.

The number of people per household was between 3.8- 4.24 in 2011 in SIZ upazila, down from around 6 in 1981. Currently, the average household size of SIZ upazila is below the national average (4.44) size.

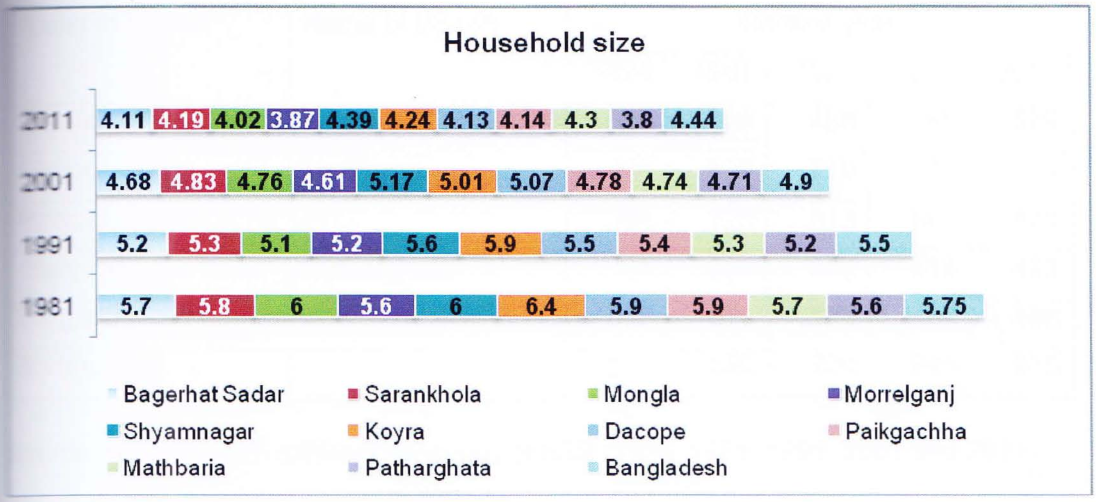

Figure 3.5: Household size of SIZ upazila

3.6. Population density:

The density of population in SIZ districts (556 sq km) and SIZ upazilas (425.5 sq km) are far below the national average (976), nearly 43 percent and 56 percent less respectively. The national population density increased from around 530 persons per square kilometer in 1974 to 625, 720, 843 and 976 persons per square kilometer in 1981, 1991, 2001 and 2011, respectively. These density figures give an impression that Bangladesh has become a densely populated country over the last five decades. However, variations exist between SIZ districts, and even upazila levels. Table 3.4 demonstrates the regional variations in population density for the period of 1974 to 2011 censuses.

Table 3.4: Population density of SIZ locality (in sq. km)

Name of District	Name of Upazila	Census year				
		1974	1981	1991	2001	2011
Bagerhat	Bagerhat Sadar	NA	763	865	812	977
	Sarankhola	NA	123	143	151	157
	Mongla	NA	67	94	102	93
	Morrelganj	NA	590	697	758	639
Bagerhat district		259	304	362	391	373
Satkhira	Shyamnagar	NA	119	135	159	162
Satkhira district		296	351	414	483	520
Khulna	Koyra	NA	70	93	281	283
	Dacope	NA	117	144	159	154
	Paikgachha	NA	427	547	603	603

Name of District	Name of Upazila	Census year				
		1974	1981	1991	2001	2011
Khulna district		315	403	458	541	528
Pirojpur	Mathbaria	NA	627	719	746	764
Pirojpur district		NA	725	813	850	871
Barguna	Patharghata	NA	304	348	418	423
Barguna district		306	370	424	463	488
Bangladesh		518	590	720	843	976

Source: Compile from different censuses of BBS (1974, 1981, 1991, 2001 and 2011)

While the population density at the national level increased by about 84 percent in 2011 from 1974, some SIZ districts like Bagerhat (44 percent) recorded the lowest increase in population densities followed by Khulna (68 percent) and Satkhira (76 percent). In almost all regions the population density increased between 1981 and 2011 suggesting that there were significant increases in the regional populations in absolute numbers. The highest absolute change in population density was observed in Bagerhat Sadar upazila (from 763 in 1981 to 977 in 2011). Conversely, the population densities have decreased remarkably in some SIZ upazilas like Mongla (8.8 percent), Morrelganj (15.7 percent) and Dacope (3.1 percent) during 2001 to 2011 period. Such decrease in population densities also observed for Bagerhat (4.6 percent) and Khulna (2.4 percent) districts. One of the critical arguments for decreasing the densities was due to the landfall of two devastating cyclones Sidr (2007) and Ayla (2009) during this period.

3.7. Urbanization:

Bangladesh has been experiencing a rapid growth in urbanization since 1974. The proportion of urban population increased gradually from 7 % in 1974 to 23.30% in 2011. SIZ upazilas showed a very little progress in urban growth. Most of the upazilas hardly crossed double digit of urbanization rate in 2011. Cyclone Sidr and Ayla affected upazilas recorded negative urban growth in 2011 compare to 2001. The upazilas are Shyamnagar (5.42 percent), Koyra (5.89 percent) and Dacope (9.31 percent). The detail analysis of urbanization versus population growth has presented in the figure 3.6.

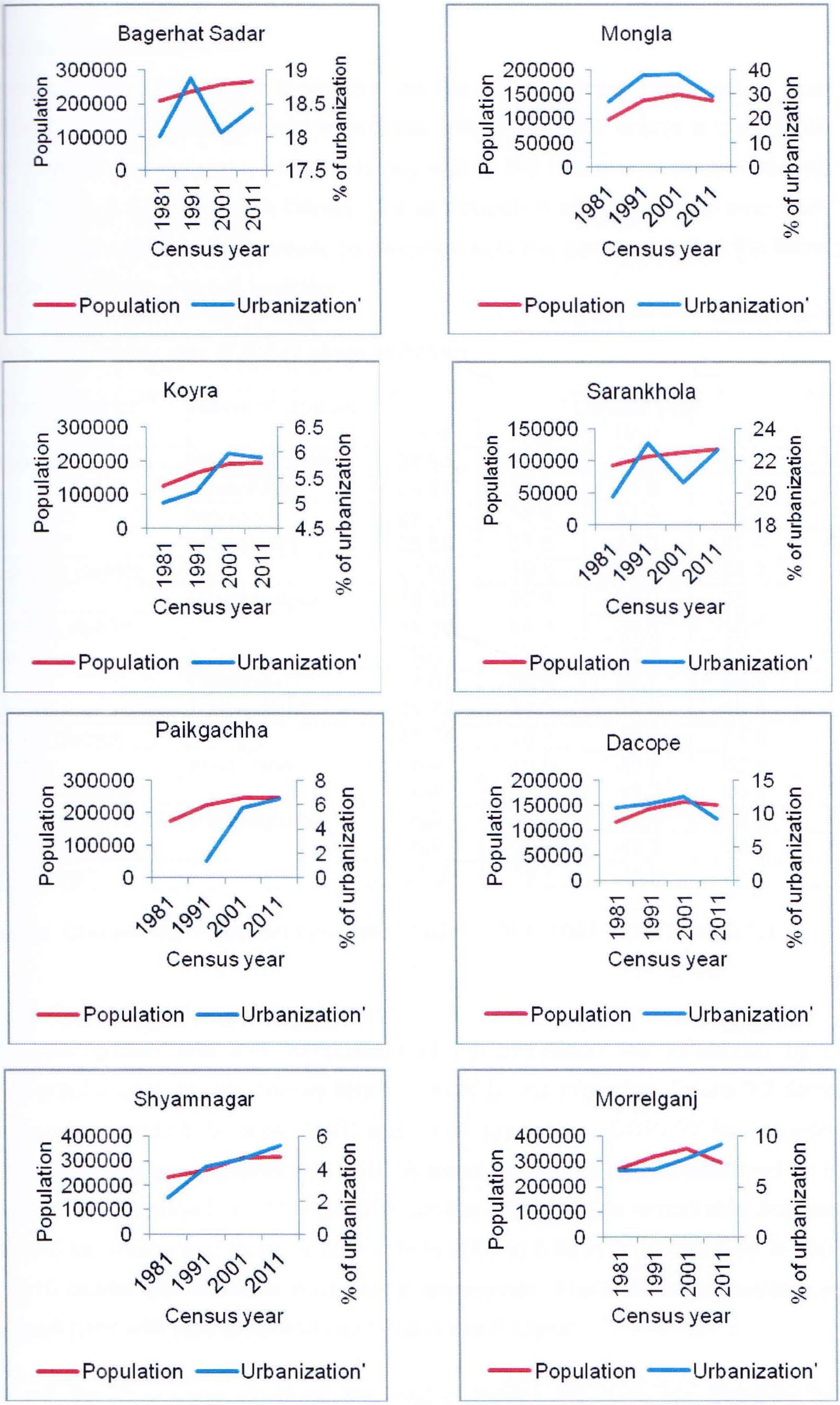

Figure: 3.6. Population and urbanization rate of selected SIZ upazila

3.8. Literacy:

Education has a significant implication on the frontier forest conservation. Low literacy sometime hinders environmental awareness. Historically, SIZ enjoys a quite better literacy rate than the country, as a whole. Literacy rate in SIZ has almost doubled during 1974 to 2011. Table 3.5 illustrate the literacy rate of population of 7 years and over from 1974 to 2011 for SIZ upazilas. It can easily be assumed from the below table that the literacy rate is gradually increasing in SIZ localities.

Table 3.5: Literacy rate of SIZ (7 years and over)

Name of District	Name of Upazila	Census year				
		1974	1981	1991	2001	2011
Bagerhat	Bagerhat Sadar	32.37	44.5	49.9	60.9	63.6
	Sarankhola	24.92	31.3	41.8	56	58.9
	Mongla	28.31	38.9	42.8	56.1	57.2
	Morrelganj	26.58	27.8	49.5	62.4	60.7
Bagerhat district		27.65	39.1	44.3	58.7	59
Satkhira	Shyamnagar	16.96	22.9	28.2	39.7	48.6
Satkhira district		19.39	24.7	30.5	45.5	52.1
Khulna	Koyra	NA	27.1	32.4	44.5	50.4
	Dacope	22.05	30.8	37.7	49.3	56.00
	Paikgachha	19.72	24.3	32.6	45.8	52.8
Khulna district		31.74	26.3	43.9	57.8	60.1
Pirojpur	Mathbaria	NA	49.8	45.9	62.8	61.7
Pirojpur district		NA	41.1	48.2	64.3	64.9
Barguna	Patharghata	NA	43	46.4	63.2	60.5
Barguna district		NA	35.2	42.3	55.3	57.6
Bangladesh		20.2	19.7	24.9	37.7	51.8

Source: Compile from different censuses of BBS (1981, 1991, 2001 and 2011)

3.9. Components of population growth:

The size, growth rate and composition of the population are influenced by the three demographic components namely fertility, mortality and migration. Figure 3.7 demonstrates the trends in crude birth rates (CBR) and crude death rates (CDR) for Bangladesh and SIZ districts for the period of 2003 and 2010. A steady decline in CDR is observed for Bagerhat, Pirojpur and Barguna from 2003 to 2010. On the other hand, a remarkable increase in CDR is found for Khulna and Satkhira from 4.69 in 2003 to 6.64 in 2010 and 5.93 in 2003 to 6.06 in 2010 deaths per thousand populations respectively. The trend also illustrates an almost sluggish CBR with little exceptions for Khulna and Pirojpur.

Overall, the young age structure, the level of fertility, the huge gap between fertility and mortality rate and the declining trend in the mortality conditions of the country as a whole and SIZ districts indicate the tendency of the population to continue growing in the next few decades.

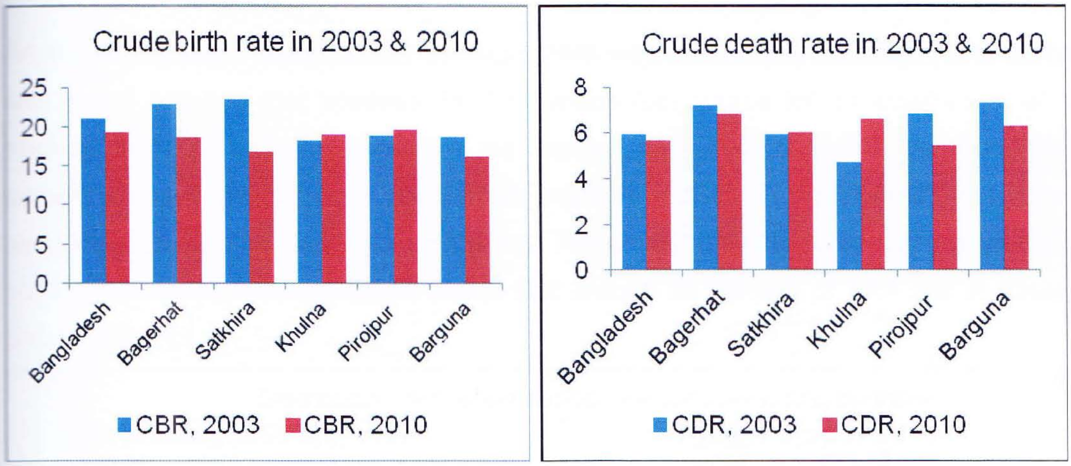

Figure 3.7: CBR and CDR of SIZ districts in 2003 and 2010

BBS calculated lifetime migration pattern for the divisions and found that net migration value was negative for Barisal and Khulna divisions. The percentage of immigrants in the total population of Khulna is 33.18 in 1991, 6.48 percent for Bagerhat, 6.04 for Barguna, 4.07 percent for Pirojpur and 6.54 for Satkhira district. The 1991 census also identified rural to urban migration (more than 85 percent) as a dominant form of migration among the migrants.

'A temporary migration takes place every year during October through March: Transitory populations of about 600,000 people migrate in and out of the southern Sundarbans temporary fishing camps. They come from different places; majority from the districts of Chittagong (fisherman, traders) and Khulna (laborers). They make use of the dry season for fisheries activities in the Bay of Bengal, the majority of the catch is dried on mats and racks made from Sundarbans wood and reed resources. All houses, jetties and other infrastructure are left behind at the onset of monsoons, and rebuilds in the next season' (Islam, 2004).

3.10. Distribution of household sources of fuel:

Most of the wood energy is used for domestic cooking (Choudhury and Hossain, 2011). Figure 3.8 shows the percentage distribution of the sources of fuel consumed by households in 2003 and 2010. There was an increase in the consumption of straw (except Pirojpur and Barguna) and bran/ husk (except Khulna) at national and SRF districts level. Conversely, a downward tendency was observed of using other sources of energy (Kerosene, Gas, electricity) at all levels. Moreover, the pattern of using wood/ bamboo as fuel wood was mixed nature with increasing tendency for Khulna and Pirojpur; and decreasing pattern for

Bagerhat, Satkhira and Barguna. A dramatic decline of using wood/ bamboo was observed in Barguna from 66.4 percent in 2003 to 42.6 percent in 2010.

An interesting observation is that although there was a decrease in using wood/ bamboo, it was wood/ bamboo that possess the top ranked fuel source for all localities in all times. Khulna, Satkhira and Pirojpur were the highest consumer of wood/ bamboo. More 65 percent of these districts were using wood/ bamboo in 2010. This indicates that fuel-wood is used most in Khulna and Pirojpur district. These two districts have comparatively easier access to forests. It is relevant to notice that around 85 percent of SRF lies in Khulna and Satkhira district.

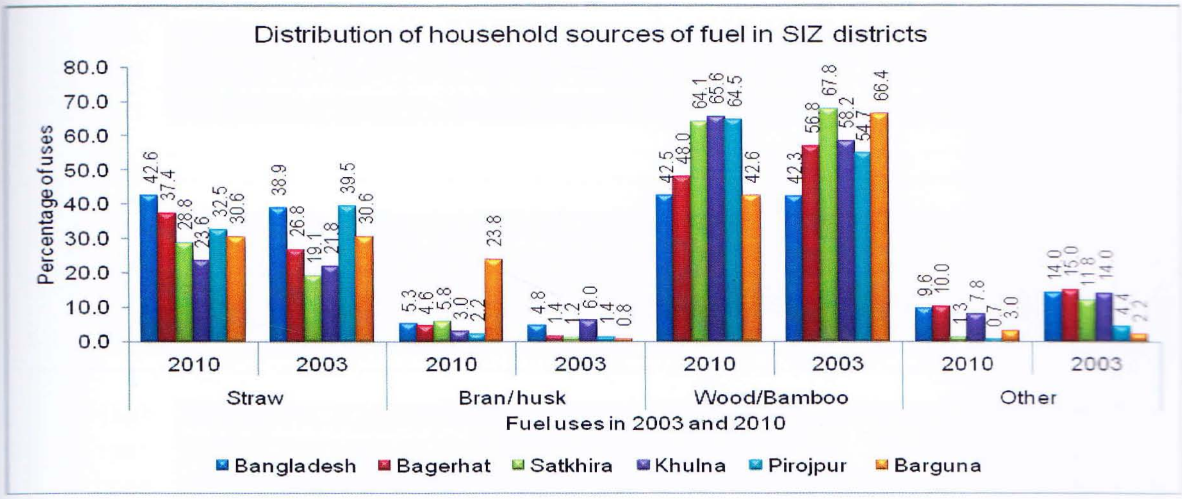

Figure: 3.8: Distribution of household sources of fuel in SIZ districts

3.11. Age sex distribution:

Age-sex composition has environmental implications because different population subgroups behave differently. The population under age 15 and those at ages 65 and over are economically dependent age groups that must be supported by the population in the working age group (15-64).

According to the 2011 census, the total male population in the SIZ upazila is 1.07 million and female 1.09 million. The sex ratio female overtops compared to male which is 99.9 for SIZ upazila, it ranges between 93 and 110 (BBS, 2011). The female population has increased more compared to male population during the last decades. This has decreased the male: female ration from around 105.1 in 1991 to 99.9 in 2011. The greater number of female population may be a reflection of male out migration, which seems to be higher in number in SIZ upazila and coastal zone than the rest of the country. Within the SIZ upazila, the female population is larger (sex ration below 100) in the upazilas of Morrelganj (95), Shyamnagar (93), Koyra (97), Mathbaria (96) and Patharghata (97).

The age structure of SIZ upazila is quite interesting. The population within the age group of 0-15 years is quite similar to country which was decreased from average of around 46 in 1981 to its present ratio of around 39.9. The proportion of aged population (65+ years) was almost doubled in SIZ area compared to national age structure. However, economically active population was always below the national proportions. This indicates that the dependency ratio (0-14 years and 65+ years) is higher in SIZ area.

Figure 3.9: Broad age group wise population in SIZ districts and Bangladesh

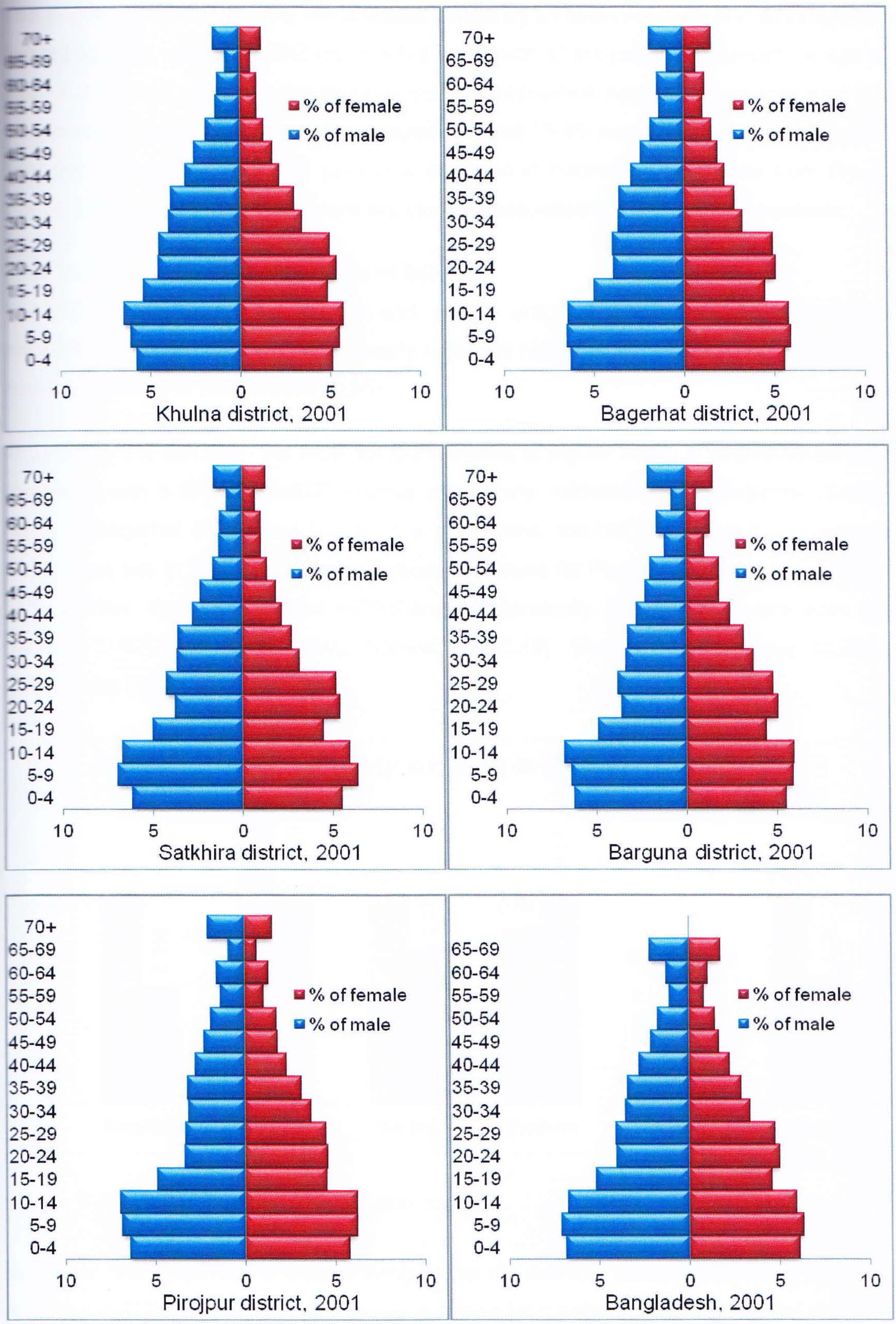

Figure 3.10: Age-sex structure of SIZ districts

The population of SIZ districts are is characterized by an extreme youth and adult age group. According 2001 census, in SIZ districts the proportion of the population under the age of 15 was 36.8 percent, whereas the proportion of the population aged 50 years and over is only 13.0 percent. The proportion of the population aged 15-49 accounts for 50.1 percent of the total population. This group of people is engaged in harvesting resources from the SRF. Hence, the changes in age structure are closely associated with resource extractions.

3.12. Income and poverty Situation in SIZ

The SIZ is relatively income poor and people are suffering from marginalization and inequality in income. The extreme poverty rates are higher in SIZ upazila (0.42) compared to non-SIZ upazilas in Bangladesh (0.26).

Among the SIZ upazilas, the HCR for SIZ Satkhira is higher which is estimated as 0.65 as compared with 0.45 for non-SIZ upazilas of Satkhira, followed by SIZ Bagerhat (0.43) and non-SIZ Bagerhat (0.24) and SIZ Khulna (0.41) and non-SIZ Khulna (0.32). These three districts are lies in SRF area. The exceptions are found for Pirojpur and Barguna. Among the SIZ upazilas, the guesstimated HCRs are comparatively higher for Shyamnagar (0.65), Dacope (0.60) Morrelganj (0.50), Sarankhola (0.49), Mongla (0.42), Koyra (0.35) and Paikgachha (0.34)

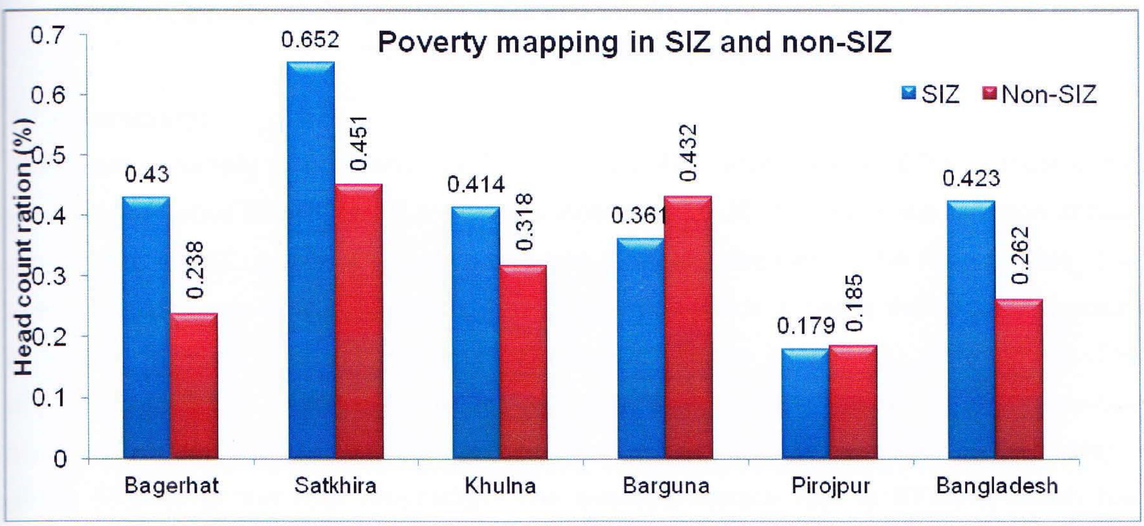

Figure: 3.11. Poverty mapping of SIZ and non-SIZ

Moreover, the proportion of people living below the extreme poverty and upper poverty line is higher in SIZ upazila. Table 3.6 shows a comparison between of poverty level of 2005 and 2010. Although, the percentage of people living below the extreme poverty line has decreased significantly, but the percentage of people living below the upper poverty line has increased radically from 2005 to 2010 in Koyra, Paikgachha and Mathbaria. Among the SIZ districts and upazilas, Sarankhola has the highest percentage of extreme poor people (28.2) which is also characterized by 48 percent of people living below the upper poverty line. Shyamnagar is the highest poverty stricken area where the poverty level below the upper poverty line is 50.2 in 2010.

Table 3.6: Percentage of poor and extreme poor people in SIZ

District/ country	Upazila	2005		2010	
		% Extreme poor (lower poverty line)	% Poor (Upper poverty line)	% Extreme poor (lower poverty line)	% Poor (Upper poverty line)
Bagerhat	Sadar	42.7	31.6	18.6	35.9
	Sarankhola	62.8	48.7	28.2	48.0
	Mongla	56.4	41.5	22.7	41.9
	Morrelganj	64.0	50.3	27.0	46.5
Satkhira	Shyamnagar	75.7	65.2	33.8	50.2
Khulna	Koyra	50.0	34.8	29.1	49.1
	Dacope	73.3	60.4	24.9	44.5
	Paikgachha	49.6	34.4	23.3	42.4
Pirojpur	Mathbaria	38.1	17.9	25.6	38.0
Barguna	Patharghata	56.3	36.1	6.10	12.9
Bangladesh		25.1	40.0	17.6	31.5

Source: Poverty maps of Bangladesh, 2005 and 2010.

3.13. Summary:

The average density of population of SIZ upazila is 426, which is one of the highest in the world in mangrove forest impact zone area. According to 2011 census, the average annual growth rate in SIZ upazila is negative and has gradually declined in the recent years. The average fertility rate of SIZ districts is 1.89 per woman which is below the national average (2.12 per woman). The average sex ratio in SIZ upazila is 99: 100 male/female. The population structure is pyramidal where the under-aged groups (below 15 years) occupy about 36.9% of the total population, and the economically active population (15-59 years) is about 55.89% of the total population. The average literacy rate is 57.04%, which has increased from 34.04% in 1981. Poverty is also a dominant phenomenon in SIZ locality. Thus this is quite interesting to analyze the population and environment relationship in SIZ.

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Chapter- Four: Climate change and Sundarbans

4.1. Introduction:

Climate change is one of the greatest challenges for the present world. The intensity, severity and frequency of climate-induced disasters have been increased in recent years. The Inter-governmental Panel on Climate Change (IPCC) defines climate change as: 'a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use'. Climate variability is the results of deviations from the long-term meteorological averages of different parameters (precipitation, temperature, humidity, etc.) over a certain period of time like a specific month, season or year. Climate change can alter the disaster risk through increased weather related risks, sea-level rise (SLR) and temperature and rainfall variability. The mean global temperature of the earth has increased by on the average 0.5°C during the last about 100 years triggering a prolonged debate on climate change over the last 20 years.

The funnel like geographical shape of Bangladesh has made it one of the most vulnerable countries of the world to the impact of climate induced disasters. The coast of Bangladesh is a global hotspot for tropical cyclones. The coastal area represents around 32% of Bangladesh's total geographical area and about 10% of the country's total land lies 1 m above the mean sea level. The coast of Bangladesh can be divided into three distinct geo-morphological regions - western, central, and eastern coastal zones (Islam, 2004). The western part is known as Ganges tidal plain that lies below 1.5 m mean sea level. The southwestern portion is covered by the world's largest mangrove forest where erosion is comparatively small but suffers from salinity and tidal flooding. The central region is the most active region where erosion and accretion are very much active. This chapter aims at organizing the literatures on impacts of climate change and sea level rise on Sundarbans under several projection scenarios.

4.2. Climate change and sea level rise scenario in Bangladesh:

Impacts of climate change in Bangladesh have been observed in the form of temperature extremes, irregular or excessive rainfall and increased number of extreme floods, cyclones, droughts, salinity intrusion.

Habib (2011) showed an increasing trend of annual maximum and minimum temperature for 60 years (1950-2010). Basak et al (2013) studied on variation of temperature and rainfall of 34 stations of Bangladesh over the 33-years period (1976 to 2008). They observed that the yearly average maximum temperature has been increasing at a rate of 0.018 °C per year. A positive trend of average rainfall during 1950-2010 was also observed by Habib (2011). He confirmed that during this period the frequency of heavy rainfall has been considerable increasing trend during pre-monsoon (+0.00258/year) and during monsoon (+0.0053/year). Moreover, the numbers of cyclone formation and landfall are increasing in Bangladesh, although the causalities of human beings have been decreased than earlier due to the awareness of coastal communities. During 1876 – 1964 there was only one intense cyclone (wind speed more than 200 Km/h) over North Bay of Bengal but in next 45 years (1965 – 2010) it was 9. From 1950 to 1990 intense cyclones were only two but during next 20 years (1991-2010) it was 7 (Habib, 2011).

IPCC projected that the temperature of Bangladesh will increase by 0.7°C in monsoon and 1.3°C in winter by 2030. Increase in temperature by 4°C can decline the Boro rice production by 32 percent and wheat production by 31 percent (World Bank, 2010). Climate change will also hamper the precipitation pattern. Some models illustrate the likelihood of increasing monsoon precipitation (May to September), and decreasing dry season precipitation (December to February).

The sea level along the Bangladesh coast is rising at about 3 millimeters a year, and the sea surface temperature is showing a rising trend (World Bank, 2010). Generally, cyclones are formed in the deep sea when sea surface temperature reaches the threshold value of about 27°C. Thus, the frequency of occurrence of cyclones and increasing the temperature of sea surface are correlated.

Table 4.1: Climatic Change Scenarios

Year	Sea Level Rise (cm)	Temperature increase (°C)	Precipitation Fluctuation Compared to 1990 (%)
2030	30	+0.7 in monsoon; +1.3 in winter	-3 in winter; +11 in monsoon
2050	50	+1.1 in monsoon; +1.8 in winter	-37 in winter; +28 in monsoon

Source: World Bank, 2000.

IPCC estimates rising in sea level would be in the range of 15 cm to 95 cm by 2100. Interpolations suggest that 10 cm rise in sea level would inundate 2500 sq. km, about 2% of the total land area. With the high end estimates, sea level rise in Bangladesh would inundate

18% of the country by 2100 (World Bank, 2010). UNEP (1989) showed 1.5 m sea level rise in Bangladesh coast by 2030 affecting 22,000 Sq. km (16% of total landmass) area with a population of 17 million (15% of total population) affected. The SAARC Meteorological Research Centre (SMRC) analyzed sea level changes of 22 years historical tide data at three tide gauge locations in the coast of Bangladesh and based on this trend SMRC projected the rise of sea level of 18 cm, 30cm and 60 cm for the years 2020, 2050 and 2100, respectively (SMRC, 2000 cited in Hussain, 2013).

4.3. Observed climate change impact on Sundarbans:

Sundarbans, the largest mangrove forest of the world lies in the extreme southern part of the country that serves as a barrier to the furiousness of tropical cyclones and storm surges formed in the Bay of Bengal. Sundarbans is the immediate path of cyclonic storms generated over the sea or down from the Himalayas. During the last 135 years, more than 45 cyclones have crossed the coastal belt of Bangladesh, of which 13 are trekked through the Sundarbans (IPAC, 2010). Cyclone Protection Project II mentioned the role of the Sundarbans in dampening tidal surges and pointed out that 100m to 200m wide strips of dense mangrove vegetation can reduce wave energies by 20-25% (cited in IPAC, 2010).

In the last decade, several cyclones have landfall through the Sundarbans. Cyclone Sidr is the most devastating one that landfall on 15 November 2007 with an average wind speed of 223 km per hour, causing more than 3000 casualties. It caused serious disruption to Sundarbans, tress were uprooted and broken down, thousands of animals died, saline water flushed into the forest causing fresh water scarcity for biotic species. The other notable cyclone is Aila. Cyclone Aila stuck on 25 May 2009 that endangered lives and livelihoods of thousands of people. After these two consecutive cyclones, the impact of climate change has become more pronounced in the southern coastal area of Bangladesh.

The IPCC projected that climate change will probably deteriorate the state of tropical forest ecosystems. As a tropical country, Bangladesh is going to face several physical effects of climate change including increased temperature and salinity, irregular precipitation, increased extreme weather events such as floods, cyclones and droughts that have profound negative impacts on its forests.

Several researches revealed that Sundarbans is the innocent victims of climate change impacts in many ways. The notable impacts would be sea level rise, increases in the frequency and intensity of cyclonic storm, irregular rainfall, salinity ingression, etc. These changes will have definite adverse impact on Sundarbans and the lives and livelihoods of frontier population.

The Sundarbans has already affected by increasing salinity and extreme weather events. Several researches revealed the correlation between the top dying of Sundari trees and the consequence of slow increase of salinity over a long period of time. Rahman (2013) studied on the time-series data (1973-2010) of coastal erosion in the Sundarbans mangrove and found 233 km^2 total forest loss due to coastal erosion over the studied period.

The freshwater flow in Sundarbans depends on upstream river flow. Gorai River was the largest perennial distributary of the Ganges River and is one of the waterways that carry freshwater through the south western region into the Bay of Bengal. Gorai River carries freshwater for Sundarbans. But the water flow of Gorai has been influenced after the construction of Farakka barrage by India in 1975 about 190 km upstream of the Gorai mouth to divert the Ganges water through the Hoogly River to the Kolkata port. Since then the dry season flow in the Ganges or the Padma River has dropped alarmingly. Due to a drastic fall in the flow of the Gorai River, at least seven of the 15 rivers dependent on it, are now nearly dead while eight others are flowing timidly (Haq, 2010). The Gorai River has been completely disconnected from the Ganges flow during the dry season (November to April) since 1988. The creeks and rivulets of Sundarbans play a vital role to keep a balance between saline and fresh water. Freshwater flow through the rivers helps to flush the salinity off from the forest floor. Thus chronic disturbance to freshwater flow can alter the salinity regime. Decrease in water flow encourages sedimentation that may block the channels and further periodic/ permanent inundation around the forest could be observed.

The Sundarbans forest has been divided into 3 zones on the basis of salinity: less saline zone (5-15 ppt), moderately saline Zone (15-25 ppt) and strong saline zone (25-30 ppt) based on degree of salinity (CEGIS, 2006). The salinity of the Sundarbans increases from east to west and, hence, the density of vegetation growth and canopy closure decreases from east to west. Height and growth of different mangrove species in the Sundarbans are correlated with the salinity level. For example, Sundari trees grows in low saline zone (5~10 ppt), Gewa in moderate saline zone (10-25 ppt) and Goran in high saline zone (over 25 ppt). Siddique et al. (2001) showed significant decrease in regeneration and growth with an increase in the level of salinity in the Sundarbans (cited in Hussain, 2013). While the ecological successions following the degree of salinity had greatly influenced the distribution of species and stand-height from 10m to more than 15m in the eastern part of the

Sundarbans, following cyclone Sidr, the stand-height has drastically reduced in severely damaged areas (Islam, 2007).

Sundari trees are being destroyed by the outbreak of top-dying disease. Studies on top-dying Sundari have detected some indications which relate to the ecological conditions of the affected area, and were predominant in areas with high sedimentation rate where the numbers of pneumatophores (breathing roots) were significantly less (Islam, 2007). Top-dying was already endemic among Sundari trees, but the disease has intensified and spread faster since the recent hit by cyclone Sidr. Flood Action Plan 4 (FAP, 1993) concluded that top-dying of Sundari tress may be a synergic effect of a number of factors including salinity, sedimentation, water logging, cyclone damage, and accumulation of toxic elements from agricultural wastes and port discharge (Haq, 2010).

4.4. Projected impact of climate change and sea level rise on Sundarbans:

Sundarbans is not continuing as it was, rather appears to have entered a premature transitional stage seemingly induced by human interventions, particularly emanating from hydrological change in the upstream. These impacts would be exacerbated by climate change and sea level rise estimated at 60cm over 50 years (MoEF, 2005, p. 13). The National Biodiversity Strategy and Action Plan for Bangladesh (2005) have clearly predicted that by 2050 the following may happen to Sundarbans:

- Freshwater mangroves are totally replaced by saline water mangroves
- Decrease in total area under true mangroves
- Increase of the area with mesophytic vegetation
- Major loss of biodiversity through changes in communities
- Major decline in timber production
- Increase of use of non-timber forest products (NTFPs).

Sea level rise poses a severe threat to the Sundarbans. Inundation and salinity intrusion due to sea level rise may create adverse impacts on Sundarbans and its ecosystem services. Sundarbans will be submerged in relation to growing rise of sea level. Around 15% of the forest will go under water as long as the sea level rise by 10 cm and will be lost forever under 100 cm sea level rise (World Bank, 2000).

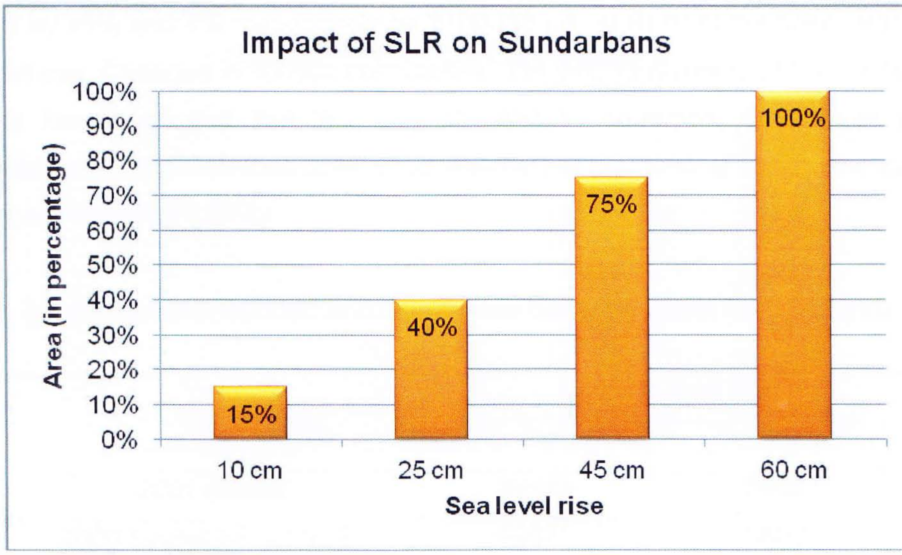

Figure: 4.1: Impact of SLR on Sundrabans Source: World Bank, 2000, PP. 42

Table 4.2: Projected sea level rise situation

Year	2020	2050	2100
Sea level rise	10 cm	25 cm	1 m (high end estimate)
Land below SLR	2 % of land (2,500 km^2)	4 % of land (6,300 km^2)	17.5% of land (25,000 km^2)
Ecosystem	Inundates 15% of the Sundarbans	Inundates 40% of the Sundarbans	The Sundarbans would be lost.
Salinity	Increase	Increase	Increase

Source: Karim, 2012

World Bank (2000) also mentioned that due to the impact of climate change species like Sundari would be replaced by less valuable Goran and Gewa. Loss of the Sundarbans and other coastal wetlands would reduce breeding ground for many estuarine fish, which could reduce their population. Sea level rise would result in saline waters moving farther into the delta. This would reduce the habitat for freshwater fish, although it could increase the habitat for estuarine fish (World Bank, 2000).

The CEGIS (2006) study projected the availability of suitable area for two major timber tree species- Sundari and Gewa under 32 cm sea level rise by 2050 and 88 cm sea level rise by 2100 scenarios. The study revealed that the suitable area for Sundari and Gewa tree will be decreased by 45% and 7% respectively by 2100 (88 cm SLR) from the base year 2001 due to sea level rise. Changes in floristic composition, the wildlife diversity of Sundarbans will be particularly hampered and that will lead to gradual extinction. Chaffey et al. (1985) demonstrated that, total merchantable wood volume per unit area of forest land decline with increasing soil and river salinity.

Table 4.3: Suitable area of Sundari and Gewa trees under sea level rise scenarios

Year	Suitable area (ha)	
	For Sundri	For Gewa
2001 (Base)	80489	59027
2050 (under 32 cm SLR)	69571 (-14%)	58992 (-0.06%)
2010 (Under 88 cm SLR)	43884 (-45%)	55021 (-7%)

Source: CEGIS, 2006

It is assumed that mean sea surface temperature will be increased due to climate change and as a result frequency and intensity of tropical cyclone formation in the Bay will be increased. Cyclonic storms can cause severe damages to the forest, its inhabitants and resources.

The effects of climate change on the Sundarbans would be more pronounced during the dry season. Hussain, et al, (2013) studied on changes of the seasonal salinity distribution at the Sundarbans coast due to impact of climate change and found maximum increase of salinity during the monsoon season (average 4 psu), followed by the winter (average 2.4 psu), the post-monsoon (average 1.8 psu) and the pre-monsoon (average 1.7 psu) for 2080s time slice compared to base condition (1991-2010). Climate change induces higher evapo-transpiration and low flow in winter would increase salinity. As a result, growth of fresh water loving species would be impaired (World Bank, 2000). Moreover, decrease in the precipitation reduces the freshwater flow into the Sundarbans which also directly affect the evapotranspiration systems. These combine effects will further contribute to salinity ingression into the forest regime and its adjacent land boundary. The existence of current mangrove depends on the quality of forest environment. If the quality of the forest degraded, the biodiversity of Sundarbans would also be degraded in a parallel way.

4.5. Conclusion:

Climate change is not now assumption, it is already happen in the earth. The impact of climate change on Sundarbans is really a great concern for the communities and the policy makers. Climate change will appear in Sundarbans as rise in salinity level, loss of biodiversity, shrinking of reserve forest area due to the sea level rise. These impacts are closely looped back with the sustainable resource harvesting from the Sundarbans. Millions people are directly engaged in livelihoods dependent on the Sundarbans. The SRF depended livelihoods may be endangered because of shrinking the livelihoods opportunities. Alteration of livelihoods is looped with the searching of new livelihoods opportunities. The SRF dependent people will be migrated from their forefather's land. This will be one of the mass migrations due to the impact of climate change on single forest.

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Chapter- Five: Temporal change detection of Sundarbans land cover using GIS and remote sensing tools

5.1. Introduction:

Every parcel of land on the Earth's surface is unique in the cover it possesses (Meyer, 1995). Land use and land cover are distinct yet closely linked characteristics of the Earth's surface. The term land cover originally referred to the kind and state of vegetation, such as forest or grass cover but it has broadened in subsequent usage to include other things such as human structures, soil type, biodiversity, surface and ground water (Meyer, 1995). Thus, land cover data documents how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types. Water types include wetlands or open water. Land cover can be determined by analyzing satellite and aerial imagery.[5] Land cover maps help to understand the current landscape and associated alteration over time. Land cover change is increasingly affecting the biophysics, biogeochemistry, and biogeography of the Earth's surface and atmosphere. Anthropogenic interventions are the prominent forces of land cover changes: by agriculture and livestock raising, forest harvesting and management and urban and suburban construction and development. Moreover, natural events like weather, flooding, climate fluctuations, fire, or ecosystem dynamics may also initiate modifications upon land cover.

Mangroves are the important land cover found in the tropics and subtropics regions. Mangroves may grow as trees or shrubs according to the climate, salinity of the water, topography and edaphic features of the area in which they exist (FAO, 2007). These forests are very important for coastal ecosystems in terms of primary production and coastal environment protection. However, all over the world mangrove ecosystems are threatened with destruction through various forms of human pressure, in particular extraction, pollution and reclamation (Farnsworth and Ellison, 1997 cited in Akhter, 2006). The mangrove areas worldwide have dropped to some 15.2 million hectares in 2005, down from 18.8 million hectares in 1980. Hence, it is important to assess the changes of mangrove forest cover for improved understanding on the gradual altering characteristics. Sundarbans is the largest mangrove chunk of the world, has been gradually decreasing due to the human interventions. Around 200 years ago, Sundarbans was around 16,700 square kilometers. Now it has dwindled into about 1/3 of the original size (Wikipedia). Thus the study of land cover change of Sundarbans is very important to conserve its ecosystems. This chapter

[5] http://oceanservice.noaa.gov/facts/lclu.html

analyses the temporal changes in land cover (forest cover area) of Sundarbans using GIS and remote sensing tools.

5.2. Use of remote sensing and GIS to identify land cover change:

Land cover is a way of portraying the surface of the earth. The use of satellite imagery has made the mapping of land cover much more practical (GLCF). It has made possible to look at land cover from global to local scales.

The study of land cover change using remote sensing has started after the launch of the first Landsat-1 in 1972. Remote sensing provides an efficient and reliable means of collecting spatial information required for assessing forest cover. According to Macleod and Congalton (1998), in general, remote sensing considers following four aspects of change detection (a) detect the changes, (b) identify the nature of change, (c) measure the aerial extent of change and (d) assess the spatial pattern of change (cited in Rahman, 2013).

5.3. Normalized Difference Vegetation Index (NDVI):

To determine the density of green on a patch of land, researchers must observe the distinct colors (wavelengths) of visible and near-infrared sunlight reflected by the plants. When sunlight strikes objects, certain wavelengths of this spectrum are absorbed and other wavelengths are reflected. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 μm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 μm). The more leaves a plant has, the more these wavelengths of light are affected, respectively.[6]

Satellite maps of vegetation show the density of plant growth over the entire globe. Although there are several vegetation indices (NDVI, GEMI, TDVI, OSAVI), Normalized Difference Vegetation Index (NDVI) is the most widely used vegetation index (VI) for vegetation cover and biophysical parameter analysis. By transforming raw satellite data into NDVI values, researchers can create images and other products that give a rough measure of vegetation type, amount, and condition on land surfaces around the world[7].

NDVI is calculated from the visible and near-infrared light reflected by vegetation. Healthy vegetation absorbs most of the visible light that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation (right) reflects more visible light and less near-infrared light.[6]

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[6] http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php
[7] http://phenology.cr.usgs.gov/ndvi_foundation.php

NDVI is thus calculated -near-infrared radiation (R_{NIR}) minus visible radiation (R_{RED}) divided by near-infrared radiation (R_{NIR}) plus visible radiation (R_{RED}). Mathematically, the formula is:

$$NDVI= (R_{NIR} - R_{RED})/ (R_{NIR}+R_{RED})$$

NDVI values ranges from minus one (-1) to plus one (+1); however, no green leaves gives a value close to zero. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves.[6]

Areas of barren rock, sand, or snow usually show very low NDVI values (for example, 0.1 or less). Sparse vegetation such as shrubs and grasslands or senescing crops may result in moderate NDVI values (approximately 0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such as that found in temperate and tropical forests or crops at their peak growth stage.[7]

5.4. Methods of satellite image processing to detect Sundarbans land cover change:

The RS and GIS methods have been used to detect the vegetation coverage change of Sundarbans during 1973 to 2010. The GIS functions are used for combining vector layers into raster layer to overlay the maps for identifying the vegetation cover area. To conduct the study, a great deal of mechanism and information was needed which was fulfilled this research.

a. Literature review of the study area.
b. Landsat satellite images of Jan-1973, Jan-1978, Jan-1989, Jan-2001 and Jan-2010 were obtained from USGS, Global Visualization Viewer (Glovis).
c. Vector data were collected from LGED
d. Data were processed in ERDAS Imagine 2013 and ArcGIS 10.1 software.
e. Find out statistics, histogram and output maps.

5.4.1. Collection of Landsat Images of study area:

This study is conducted applying UTM projected Landsat imagery from the Glovis. Images have acquired in the months of January and February considering vegetation phenology, and less cloudy time periods of the year. Cloud free quality images are very important for analyzing land cover, hence the actual study interval period has to compromise. The spatial resolution of Landsat images is large enough to monitor vegetation coverage in large scale. Fig 5.1 shows the images of Landsat satellite from 1973 to 2010. Table 5.1 provides the actual acquisition dates of the images, spatial resolution and associated sensors that have been used in the study. Data from three sensors of Landsat- Multi Spectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Plus (ETM+) have used to derive land cover maps in satellite image.

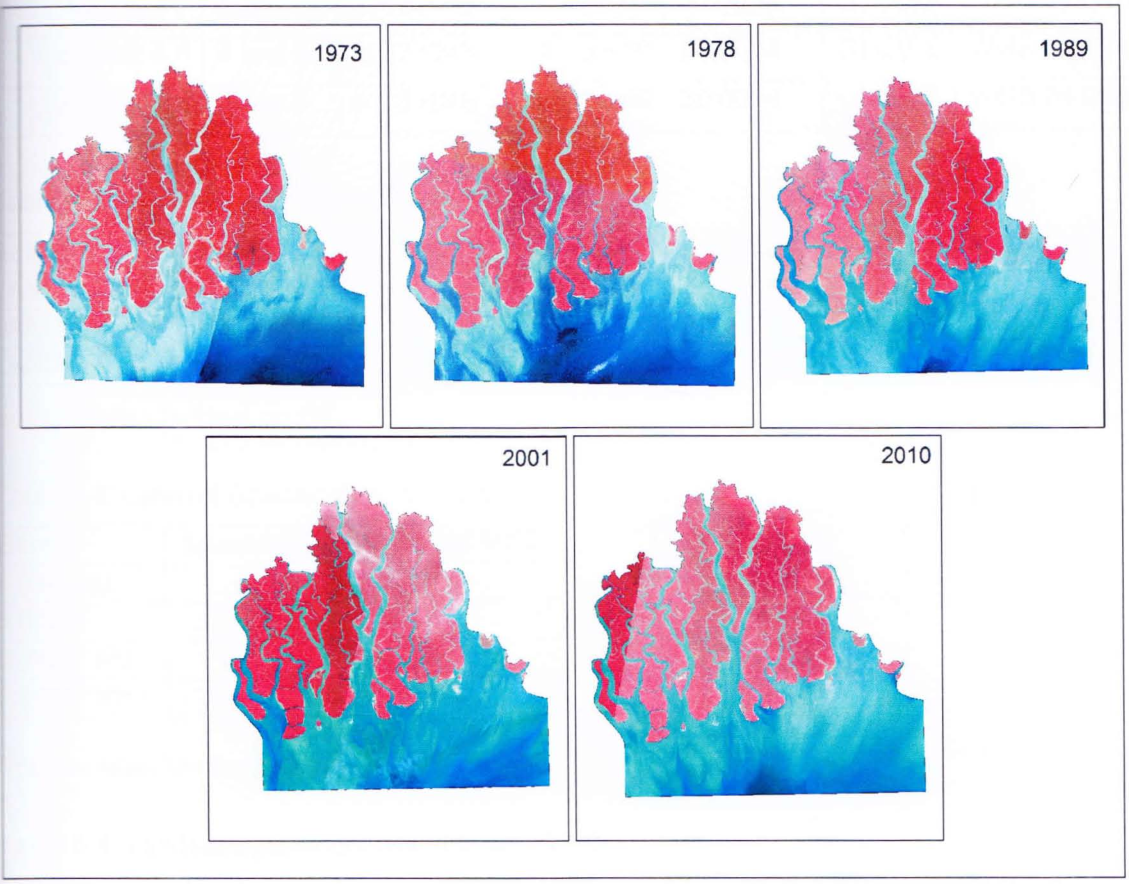

Figure 5.1: Landsat images of Sundarbans from 1973 to 2010 (Source: Glovis)

Table 5.1: Properties of Landsat images used in this study

Sensor type	Platform	Band	Path/Row	Acquisition date	Spatial Resolution	Source	Projection
MSS	Landsat 1-3	5 and 6	p147 r045	2-Feb-73	79.00 M	GLOVIS	WGS 84 UTM 46
MSS	Landsat 1-3	5 and 6	p148 r044	21-Feb-73	79.00 M	GLOVIS	WGS 84 UTM 46
MSS	Landsat 1-3	5 and 6	p148 r045	21-Feb-73	79.00 M	GLOVIS	WGS 84 UTM 46
MSS	Landsat 1-3	5 and 6	p147 r045	24-Dec-78	79.00 M	GLOVIS	WGS 84 UTM 46
MSS	Landsat 1-3	5 and 6	p148 r044	25-Dec-78	79.00 M	GLOVIS	WGS 84 UTM 46
MSS	Landsat 1-3	5 and 6	p148 r045	25-Dec-78	79.00 M	GLOVIS	WGS 84 UTM 46
TM	Landsat 4-5	4 and 5	p137 r045	12-Jan-89	30.00 M	GLOVIS	WGS 84 UTM 45
TM	Landsat 4-5	4 and 5	p138 r045	19-Jan-89	30.00 M	GLOVIS	WGS 84 UTM 45
ETM	Landsat 7	4 and 5	p137 r045	29-Jan-01	30.00 M	GLOVIS	WGS 84 UTM 45

Sensor type	Platform	Band	Path/Row	Acquisition date	Spatial Resolution	Source	Projection
ETM	Landsat 7	4 and 5	p138 r045	4-Jan-01	30.00 M	GLOVIS	WGS 84 UTM 45
TM	Landsat 4-5	4 and 5	p137 r045	30-Jan-10	30.00 M	GLOVIS	WGS 84 UTM 45
TM	Landsat 4-5	4 and 5	p138 r045	21-Jan-10	30.00 M	GLOVIS	WGS 84 UTM 45

Table 5.2: Orbit and Acquisition Characteristics

Satellite	**Sensor**	**Swath (km)**	**Scene Size (km)**	**Altitude (km)**	**Revisit (days)**
LANDSAT 1-5	MSS	180	180 x 170	917	18
LANDSAT 4-5	TM	185	170 x 183	705	18
LANDSAT 7	ETM+	185	170 x 183	705	16

Source: http://landsat.co.za/

Table 5.3: Landsat Specification for MSS

Band	**Spectral Resolution of MSS**
4 (Green)	0.50 - 0.60
5 (Red)	0.60 - 0.70
6 (Near IR)	0.70 - 0.80
7 (Near IR)	0.80 - 1.10

Source: http://landsat.co.za/

Table 5.4: Landsat Specification for TM and ETM

Band	Spectral Resolution	
	TM	ETM
1 (Blue)	0.45-0.52 μm	0.45-0.52 μm
2 (Green)	0.52-0.60 μm	0.53-0.61 μm
3 (Red)	0.63-0.69 μm	0.63-0.69 μm
4 (Near IR)	0.76-0.90 μm	0.78-0.90 μm
5 (Middle IR)	1.55-1.75 μm	1.55-1.75 μm
6 (Thermal IR)	10.4-12.5 μm	10.4-12.5 μm
7 (Middle IR)	2.08-2.35 μm	2.09-2.35 μm
8 (Panchromatic)		0.52-0.90 μm

Source: http://landsat.co.za/

Near Infrared (NIR) (0.7-0.8 μm for MSS and 0.76- 0.90 μm for TM and ETM+) and Red (0.6-0.7 μm for MSS and 0.63-0.69 μm for TM and ETM+) bands are used to detect the forest cover change in this study.

5.4.2. Image processing:

- Stacking the layers: Stacking is the process by which the different bands (or layers) of information are overlaid in one file. It allows displaying true and false color images by assigning Red, Green and Blue display colors to 3 different layers. The two images of each year downloaded in two different times. Hence, layers stacking have been applied.

- Mosaicing (joining images) and image subsetting: Mosaicing is the seamless joining or stitching of adjacent imagery. Joining Landsat imagery that was collected along the same satellite path (one image taken after the other) is straightforward: with very little time elapsing between imagery collection, the atmosphere and sensor properties do not change (that much). However, when joining adjacent imagery from different paths, several days to a couple of weeks can pass. As such, there is a need to adjust the radiometric differences between the images in an effort to make the join appear seamless. In this study, after layer stacking mosaicing have been done for all Landsat images that were collected in different years. Then the images were cropped (subsetting) to show only study area.

- Geometric and Radiometric correction: Geometric corrections include correcting for geometric distortions due to sensor-Earth geometry variations, and conversion of the data to real world coordinates (e.g. latitude and longitude) on the Earth's surface.

  Radiometric corrections include correcting the data for Sensor Irregularities and Unwanted Sensor or Atmospheric Noise, and converting the data so they accurately represent the reflected or emitted radiation measured by the sensor.

  The area of Sundarbans is not covered by these images separately. Therefore the images are required to merge together. Moreover, the acquisition of those pairs of images was same. It influences the variation of reflectance due to satellite sensor calibration, change in illumination and observation angels, atmospheric effects and difference in target reflectance over time which has further effect on NDVI (cited in Islam, 2014). Therefore relative radiometric normalization has performed.

- Haze reduction and noise reduction: Most of the images were noise prone which requires removing No Data region. The noised areas (with No Data region) were separated as a subset using a mask.

5.4.3. Image classification using conditional logic:

After careful visual interpretation, four categories of land cover class scheme have developed. The classes along with their descriptions are provided in Table 5.5.

Table 5.5: Classification scheme:

Change Classes	Value Intensity
Water body	value<=0
Barren land	value>0 and value<=0.2
Grassland	value>0.2 and value<=0.3
Vegetated land	value>0.3 and value<=0.4
	value>0.4

5.4.4. Calculation of NDVI and analysis of land cover images:

Using the conditional logic the NDVI of the Landsat images were calculated and accordingly the area covered by each category was calculated. The NDVI raster layer is classified as 0-0.2 to barren land, 0.2-0.3 to grass land and 0.3-1.0 to vegetated land. The NDVI less and equal to 0 is kept out as water body.

5.4.5. Presentation land cover change map using Arc GIS 10.1:

Finally, the land cover maps of 1973, 1978, 1989, 2001 and 2011 were prepared using Arc GIS 10.1.

5.5. Sundarbans Land Cover Change: Trend, Rate and Magnitude:

NDVI spectral indices were calculated using Sundarbans study area subsets of the 1973, 1978, 1989, 2001 and 2010 Landsat images and are presented as Table 5.6. The images were limited to the mangrove forest area and thus only four basic thematic classes were created: vegetated land, grassland and water body. The barren land and water classes were not clearly distinguishable because in mangrove forest many of the barren land are tidal flats, very wet, or entirely under water; therefore, the water body represents areas that are both shallow and deep.

Table 5.6: Area of different land cover calculated from NDVI value

Land Cover Types	Area in hectors				
	1973	1978	1989	2001	2010
Water body	548804	545685	534120	521819	508492
Barren land	82012	30871.4	15488	73328	41369
Grassland	52616.85	113298	151314.5	112640	172657
Vegetated land	250105	242986	230836	223813.3	210293.9
Total area	933537.9	932840.4	931758.5	931600.3	932811.9

Source: Calculated from NDVI value

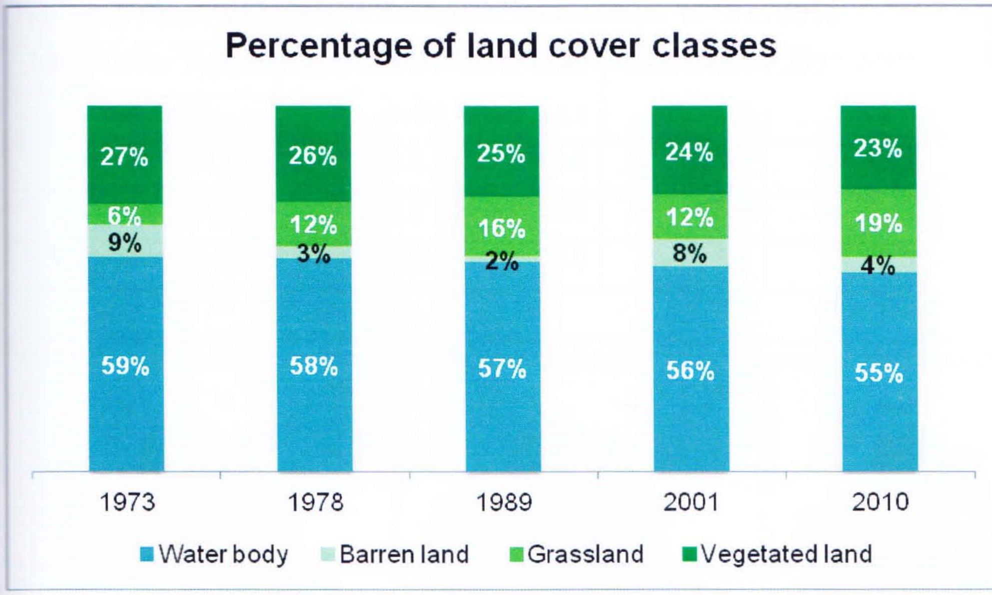

Figure 5.2: Percentage of land cover claseses to total land area

5.5.1. Changes in land cover classes:

After the image analysis, classifying and the processing, it has been identified the types of changes in the last 37 years. The water body, barren land and vegetated land had increased and grassland had increased significantly. The trend and changes in land cover classes has shown in picture 5. The rate of changes of different land cover classes has shown in Table 5.7. The types of changes can be easily identified by the observation of classified image maps of study areas' in 1973, 1978, 1989, 2001 and 2010 years respectively.

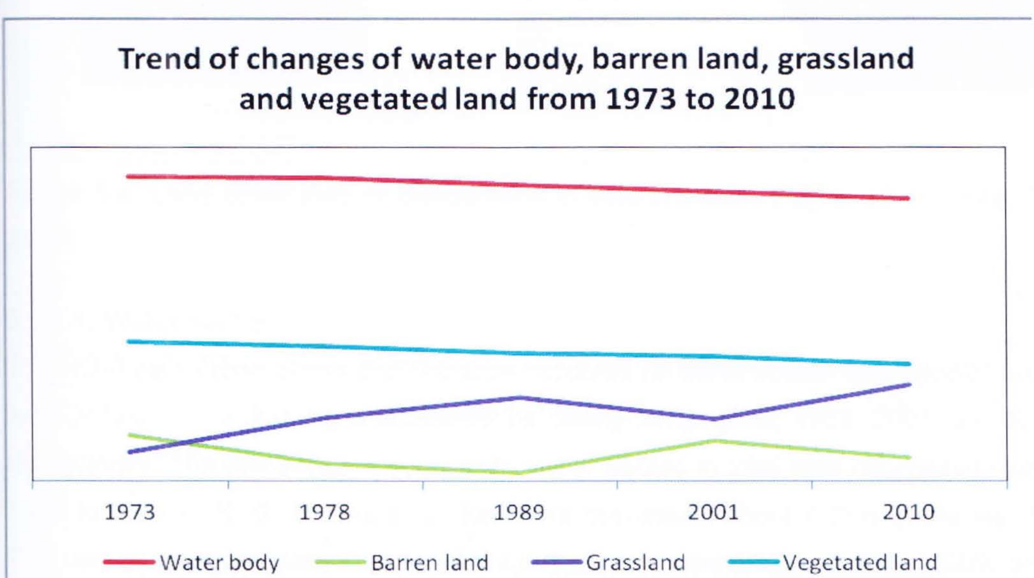

Figure 5.3: Trend of changes of different land cover classes

Table 5.7: Rate of changes in land cover classes from 1973 to 2010

Land Cover Types	1973-1978	1978-1989	1989-2001	2001-2010
Water body	-0.6	-2.1	-2.3	-2.6
Barren land	-62.4	-49.8	373.5	-43.6
Grassland	115.3	33.6	-25.6	53.3
Vegetated land	-2.8	-5.0	-3.0	-6.0

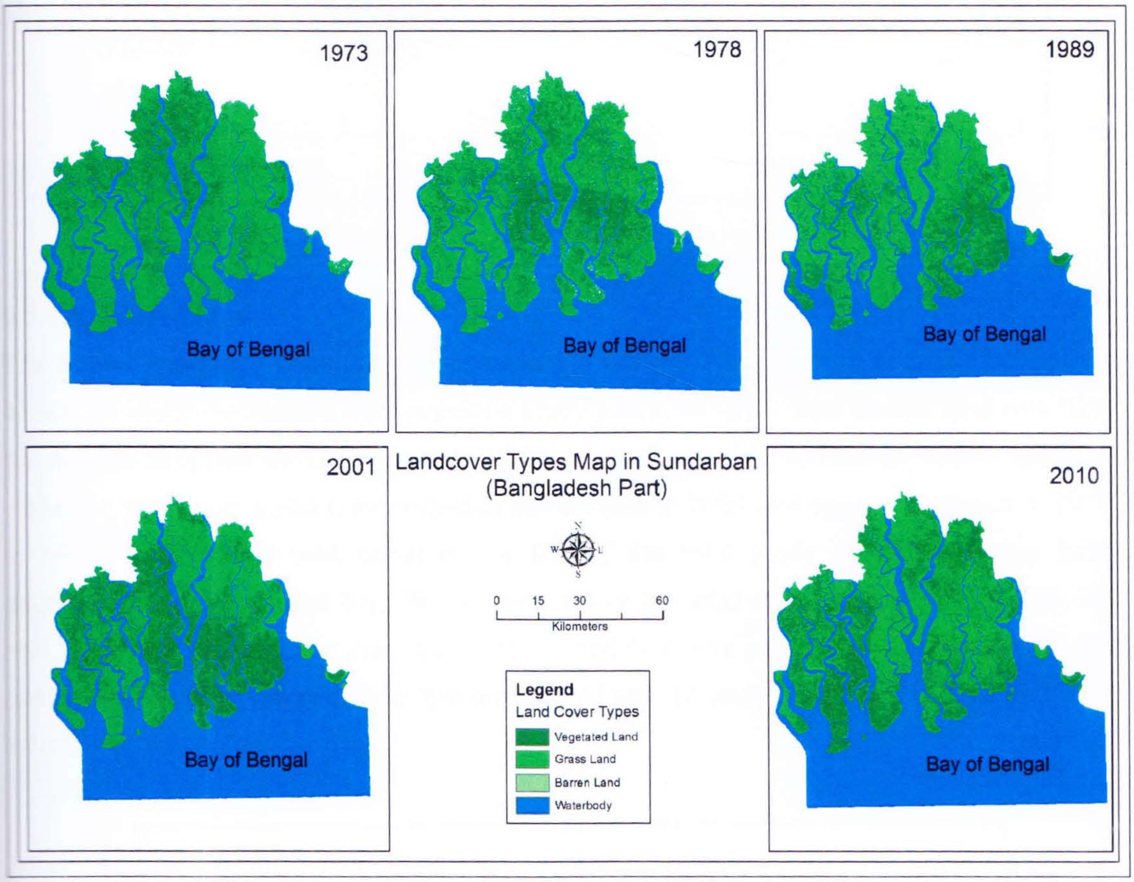

Figure 5.4: Land cover map of Sundarbans in different years (1973, 1978, 1989, 2001 and 2010)

5.5.1.1. Water bodies:

The NDVI calculation shows that the area occupied by water bodies was 548804 ha, 545685 ha, 534120 ha, 521819 ha and 508492 ha during 1973, 1978, 1989, 2001 and 2010 years respectively. The percentage occupied by water bodies to total area decreased from 59% in 1973 to 55% in 2010. The water bodies were decreased about 7.35% in the last 37 years. The rate of decrease between the inter-study periods was 0.57%, 2.12%, 2.30% and 2.55% during the period of 1973-1978, 1978-1989, 1989-2001, and 2001-2010 respectively.

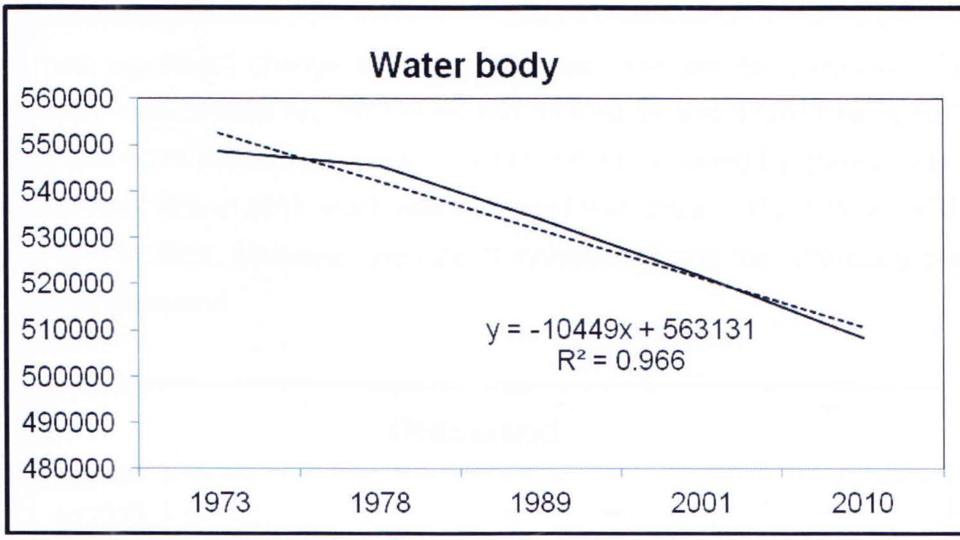

Figure 5.5: Areas occupies by water bodies from 1973 to 2010

5.5.1.2. Barren land

The most remarkable changed was observed in barren. Total amount of fallow in 2010 was 41369 ha which decreased from previous study years. In 1973, total barren land was 82012 ha. It was dropped in 1978, about 30871 ha and dropped further in 1789, 15588 ha. However, there was sudden increased of barren land in 2001 and again decreased in 2010.

In 1973, barren land was occupied by 9% of the total study area which was further decreased and constituted 3%, 2%, 8% and 4% of the total study area in 1978, 1989, 2001 and 2011 respectively. The inter-study decreased rate was also higher than the other three categories. So that, according to the analysis of last 37 years results, it is clear that fallow land is decreasing day by day.

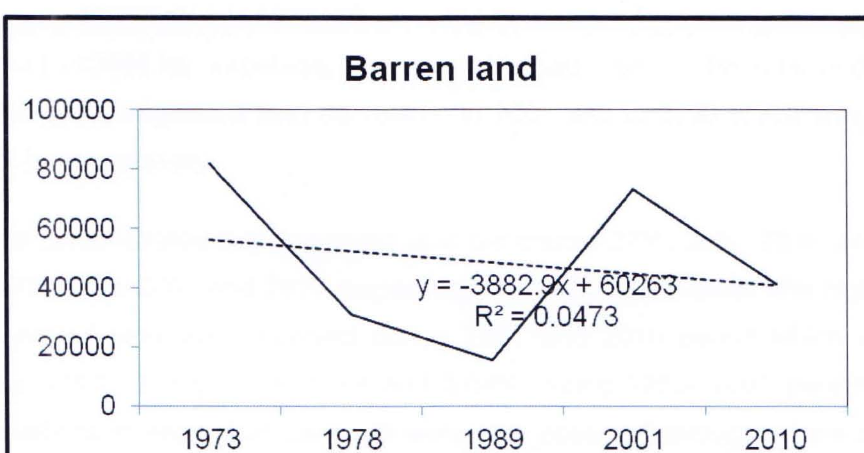

Figure 5.6: Areas occupies by barren land from 1973 to 2010

5.5.1.3. Grassland

Another most significant change of land cover was observed for grassland. Grassland occupied 52617 ha, 113298 ha, 151315 ha and 112640 ha and 172657 ha in 1973, 1978, 1989, 2001 and 2010 years respectively. The percentage occupied by grassland to the total study was around 19% in 2010 which was increased from 6% in 1973, 12% in 1978, 16% in 1989 and 12% in 2001. Moreover, the rate of increased during the inter-study period was also higher for grassland.

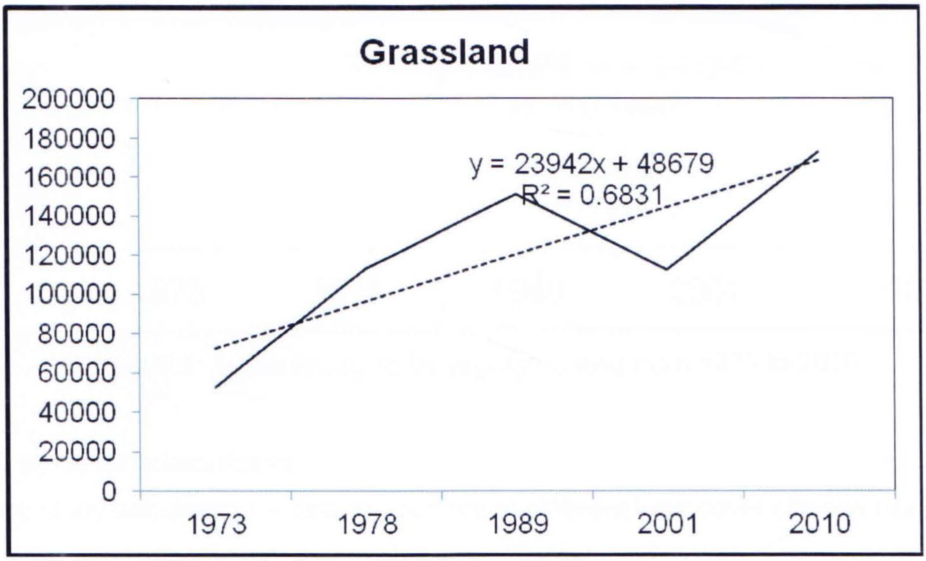

Figure 5.7: Areas occupies by grassland from 1973 to 2010

5.5.1.4. Vegetated land:

The dense vegetation forest area has been decreasing at a steady rate throughout the study period. Vegetated area covered 250105 ha in the time of 1973. It was quite dropped during 1978, covered 242986 ha. Vegetable land again dropped, about 230836 ha at the period of 1989. Furthermore, vegetated land decreased in 2001 and in 2010 which was 223813 ha and 210294 ha respectively.

The analysis demonstrated that vegetated land constituted 27%, 26%, 25%, 24% and 23% in 1973, 1978, 1989, 2001 and 2010 respectively to the total land area. The highest decline rate of vegetated land was observed during 2001 and 2010 period which was 6.04%. Followed by 5.00% during 1978- 1989 and 3.04% during 1989- 2001 period. Moreover, regional variations in vegetation coverage were also observed throughout the study years. Dense vegetation was apparently distributed uniformly in the forest except 2010. In 2010, the vegetated lands were agglomerated in the western part than the eastern part.

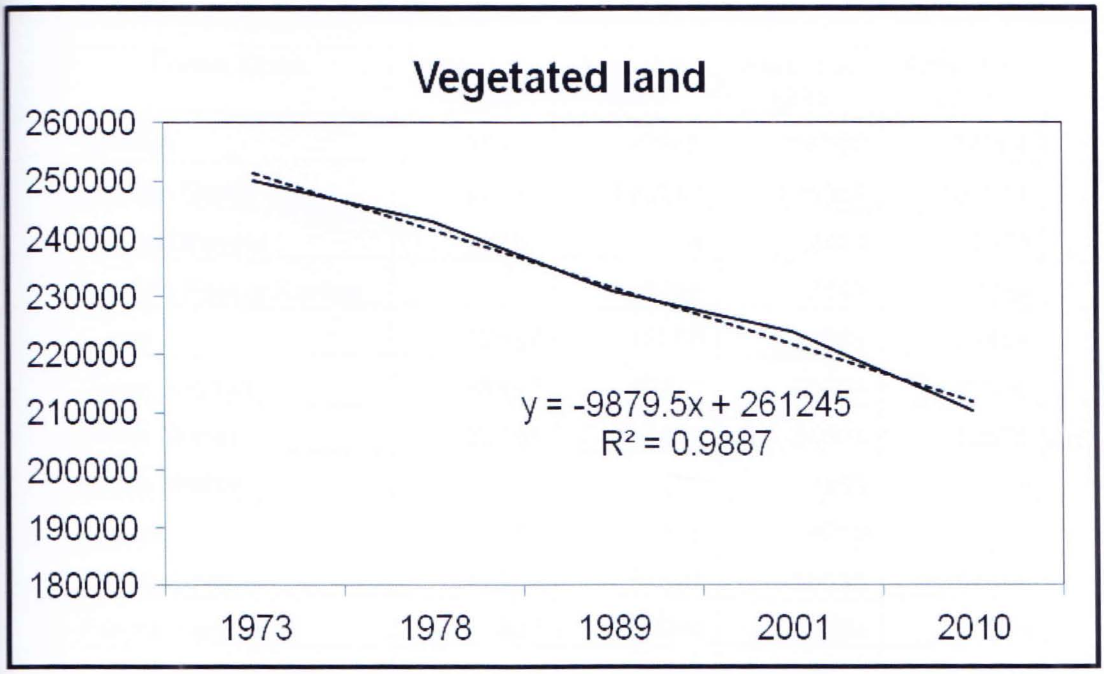

Figure 5.8: Areas occupies by vegetated land from 1973 to 2010

5.6. Tree cover of Sundarbans:

The above study calculated the rate of changes of different land cover classes using remote sensing and GIS tools. It is apparent that the different land cover classes have changed significantly during 1973 to 2010. Moreover, this study has also tried to link the tree cover changes apart from the above land cover classes. Analysis of changes in areas covered by different trees requires more advanced level remote sensing and GIS knowledge and data. Hence, different forest type categories data were collected from secondary sources such as RIMS unit of Forest Department and forest inventories. In this section attempt has been made to support the above analysis.

5.6.1. Areas covered by forest types:

A study conducted by Ministry of Environment and Forest on 'Assessment of Sundarbans Reserved Forest in 1960, 1985, 1995 and 2013'. This research described the occupancy of different mangrove species in different years. Table 5.8 shows the areas covered by forest types of Sundarbans Reserved Forest in 1960, 1985, 1995 and 2013.

Table 5.8: Areas covered by forest types of Sundarbans Reserved Forest in 1960, 1985, 1995 and 2013

Forest types	Area (ha) 1960	Area (ha) 1985	Area (ha) 1995	Area (ha) 2013
Sundari	98551	82845	74992	74264
Sundari Gewa	92139	123247	105967	102274
Sundari Passur	29752	2214	2413	2368
Sundari Passur Kankra	-	6799	7143	7084
Gewa	12557	18556	19909	21454
Gewa Sundari	58897	59973	75704	73505
Gewa Goran	32196	37593	34604	32575
Gewa Mathal	-	836	1611	-
Goran	2910	8706	8269	-
Goran Gewa	42115	57597	56536	54655
Passur Kankra	947	940	284	275
Passur Kankra Baen	-	1614	2516	2525
Baen	-	828	1230	-
Keora	8854	3509	8287	10603
Tree plantation	-	351	217	-
Non Forest	28032	-	-	-
Grass and bare ground	-	4614	6931	4856
Sandbar	-	4024	4614	1218
Non Mangrove	-	-	-	362

Source: RIMS Unit, Forest Department, Bangladesh.

The study found that the areas covered by different forest types had been decreasing at an alarming rate. The area occupied with Sundari tree was decreased by 24% in 2013 compared with 1960. The rate destruction was higher in 1970s to 1990s. Most of the degradation held between 1960 and 1985. During this period around 16% of Sundari forest cover was destroyed. However, around 1% of Sundari forest cover was lost in the latter part of the study (between 1995 and 2013).

The occupancy of Sundari Gewa decreased from 123247 ha in 1985 to 102274 ha in 2013. The immense lost occurred between 1985 and 1995. In this period, around 14% Sundari-Gewa forest cover was lost.

In 1960, Sundari Passur occupied around 29752 ha forest cover. But, in 1985, this forest class reduced by 93%. Since then this Sundari Passur tree cover was remained more or less same with no further damage. Moreover, similar pattern was also observed for Sundari Passur Kankra. Sundari Passur Kankra forest type was increased by 5% during 1985 to 1995 and decreased by 0.83% during 1985 to 2013.

In contrast, the area of Gewa forest type was increased by 70.85% in 2013 compared to 1960. Similarly, an increasing trend during 1960-1995 was found for Gewa Sundari with meager decreased in 2013.

The areas covered by Gewa Goran increased by 17% in 1985 and being decreasing continuously as observed in 1995 and 2013. Likewise, the area covered by Keora was almost tripled in 2013 compared to 1985. Furthermore, area covered by Goran, Baen and Passur Kankra Baen was also increased, as found in the study.

5.6.2. Inventory of the Sundarbans Reserved Forests (1984-85 and 1996-97):

The Sundarbans natural forests are characterized by the abundance of Sundari, Gewa, Goran and Keora. According to the 1958-60 inventories of Sundarbans, about 99% of the forest area is accounted for by 9 forest types. Among these major forest types Sundari-Gewa covered 29.45% followed by Sundari (21%). Gewa- Sundari type forest covered about 14.79% of the total area and Goran- Gewa community groups occurred 14.46% of the total area. Table 5.9 shows the percentage and area covered by each of the dominant species as reported by Chaffey et al in 1985 and IMFP in 1998.

Table 5.9: Major forest types according to the predominant species

Forest type	Area (Chaffey et al, 1985)	Area (ha) IFMP, 1998
Sundari	83100	74992
Sundari- Gewa	116500	105973
Sundari- Passur	2200	-
Sundari-Passur-Kankra	6500	9556
Gewa	19600	21,520
Gewa- Sundari	58500	75,703
Gewa- Goran	36200	34,604
Goran- Gewa	57200	64,807
Passur-Kankra-Baen	-	4,030
Goran	9300	-
Keora	3300	8,286
Others	3200	0

Source: Sundarbans Forest Inventory of 1985 and 1998

These two inventories also found the same result that the area covered by Sundari tree; Sundari- Gewa; and Gewa- Goran had been decreasing.

5.6.3. Growing stock of the Sundarbans as found in different inventories:

The 1959, 1983 and 1996 forest inventories provided an opportunity to analyze the trend of growing stock of Sundarbans species. The Sundari growing stock (DBH 15 cm and above) has declined by 50% in 37 years (between 1959 and 1996). At the same time the growing stock of Gewa has gone down by 67% during between 1959 and 1996. Above all, between 1959 and 1996, the growing stock of all tree species of Sundarbans has declined by 51%.

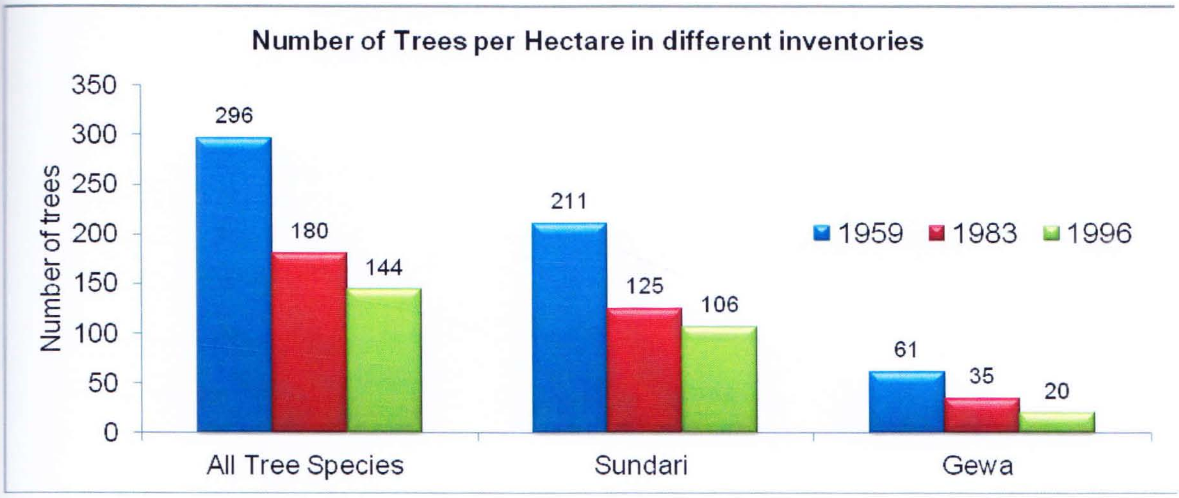

Figure: 5.9: Number of tress per hectare (Source: Forest Inventories of 1959, 1983 and 1996)

The growing stock of Sundarbans has been continuously decreasing at a rate of 1% per year (Hasan, 2013). If the Sundarbans decline at such rate (1% per year), by 2020, the growing stock (number of trees per hectare) of all tree species of Sundarbans would be 109 fell down from 180 in 1983; Sundari, Gewa and other species would be 80, 7 and 22 respectively. Population growth and climate change is correlated to the depletion of Sundarbans forest cover. However, other factors –like over exploitation, salinity increase, diversion of fresh water sources, lack of awareness, policy implication and poverty- will also synergistically affect in changing the Sundarbans forest cover.

5.7. Summary:

The Sundarbans Reserved Forest is the single largest contiguous mangrove forest ecosystem in the world. The process for the institution of the Reserve began in 1875. The physical boundary of the reserve has changed several times over the years, and the creation of the protected area ended in 1932/1933. The limit of the Reserve has not changed since then. Thereafter, the Sundarbans Reserved Forest appears to have been relatively well protected and the area has been kept relatively intact[8]. But the major threats are decreasing the total stock of timber trees like Sundari. The economic value of Sundari is also higher than other species. Several studies observed the same finding of decreasing the stock of that Sundari trees in the Sundarbans. Survey of the Forest Department of Bangladesh from 1994 to 1996 showed that on an average about 34287 cum of Sundari trees die of the disease every year. Top-dying was already endemic among Sundari trees, but the disease has intensified and spread faster since the recent hit by cyclone Sidr (Haq, 2010).

[8] http://www.fao.org/docrep/007/j1533e/j1533e41.htm

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Chapter- Six:
Major findings, recommendations and conclusions

6.1. Introduction:

The linkage between environment and population trends is a less documented phenomenon for SIZ. This chapter discusses the linkages between population growth and climate change to the degradation of Sundarbans forest over the 37 years duration. The major environmental threats to Sundarbans due to climate change; demographics characteristics of SIZ; and land cover changes of Sundarbans are discussed in the preceding chapters. These discussions are intended to provide an empirical base for analyzing the impact of population growth and climate change to the forest degradation.

The natural forest of Bangladesh has been depleted at an alarming rate. The annual loss of forest in Bangladesh is estimated around 0.015 Mha (Choudhury and Hossain, 2011). The area under mangrove was 3.12% of the total area of Bangladesh in 1976. BFD (2011) estimated mangrove forest including water was 4.07% of the country's total land mass. This increase of mangrove forest may be due to mangrove plantation to 132000 ha of land along the shore land of coastal districts up to 2000 as reported by BFD (2011).

The total area of Sundarbans is 601,700 hectares of which 411,234 hectares are land and 190,466 hectares are water. Out of these 411,234 hectares of land, 399,471 hectares have tree cover (RIMS, FD, GOB 1995, cited in Choudhury and Hossain, 2011). In general, the more people in the frontier forest, the greater is the impact on forest and environment even when a population and its growth are relatively small. The high rates of the population growth in SIZ locality during 1980s and 1990s had significant environmental implications on Sundarbans. Increase in population in SIZ localities also caused increased demand for food and arable land. Moreover, agricultural expansion in the form of shrimp farming encourages deforestation and encroachment of coastal land, which in turn contributes to micro climatic change. Population growth is also associated with increased demand for energy, especially fuel wood from the forest, which provides energy to virtually all rural frontier population of SIZ.

6.2. Population and environment linkage:

There is reciprocal relationship between population factors (size, distribution and composition) and the environment factors (air, water and land). This relationship (Population-

Environment relationship) is affected by mediating factors which include technological, political and cultural factors. MacKellar et al. (1998) and Hunter, (2001) proposed a framework for population and environment linkage. This research described the critical linkages of population dynamics, climate change and land cover change using the below framework.

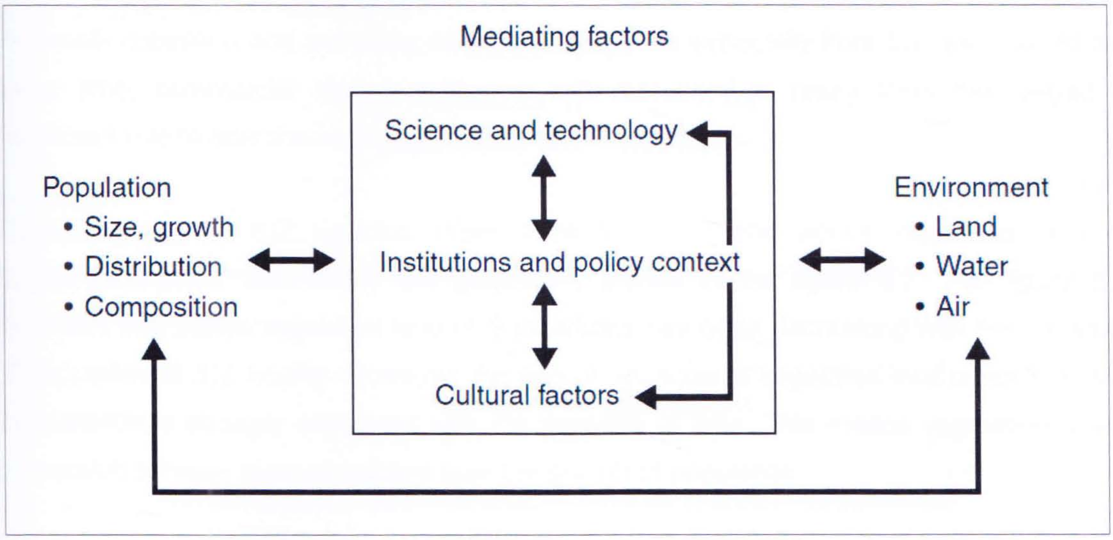

Figure 6.1: Framework for population and environment linkage, proposes by MacKellar et al. (1998) and Hunter, (2001)

6.3. Critical links: Population dynamics, climate change and land cover change:

According to FAO (2007), the Sundarbans Reserved Forest is well protected, and no major changes have been found during 1980 to 2005. The same finding is also observed in this study. Yet, unsustainable and illegal harvesting of forest resources is the major contributory factor for spatial and temporal changes in the tree cover of SRF. The resource extraction has been aggravated by population pressure around the interface localities of SRF. In addition climate induced disasters and outbreak of diseases also play important role to decline the forest cover.

Population size, composition, structure, urbanization, and household shrinking are positively correlated with resource extraction from the forest. The annual population growth rate in SIZ districts decreased dramatically, but the sheer number of population increased significantly which has contributed to increase the overall population size. Over the period 1981-1991, population size of SIZ increased by 20 percent where as the number of trees per hectare in SRF has decreased by 25% (as per forest inventory of 1983 and 1996). Population size is associated with the harvesting of wood for fuel, is an important factor contributing to deforestation. Around 57% (SVRS, 2010) population of SIZ districts used wood as fuel for cooking purposes. This figure is definitely much higher for rural settings. In SIZ upazila, the urbanization rate is much lower than the than the country. And this rate has been very slowly. Thus, most of the people are basically depends on primary economic activities especially collection and gathering of natural resources especially from Sundarbans. At the same time, commercial shrimp cultivation has increased in many folds has played a significant role to alter the climatic variability of SIZ localities.

The population of SIZ upazilas (from 1974 to 2011) and dense vegetated land of Sundarbans (from 1973-2010) are graphically plotted in the figure 6.2. The figure 6.2 illustrates that dense vegetated land of Sundarbans has been decreasing with the increase of population in SIZ locality. However, the rate of decrease of vegetated land cover from the Sundarbans is strongly correlated with the passage of time. This means vegetation cover conversion is much more prominent than the growth of population.

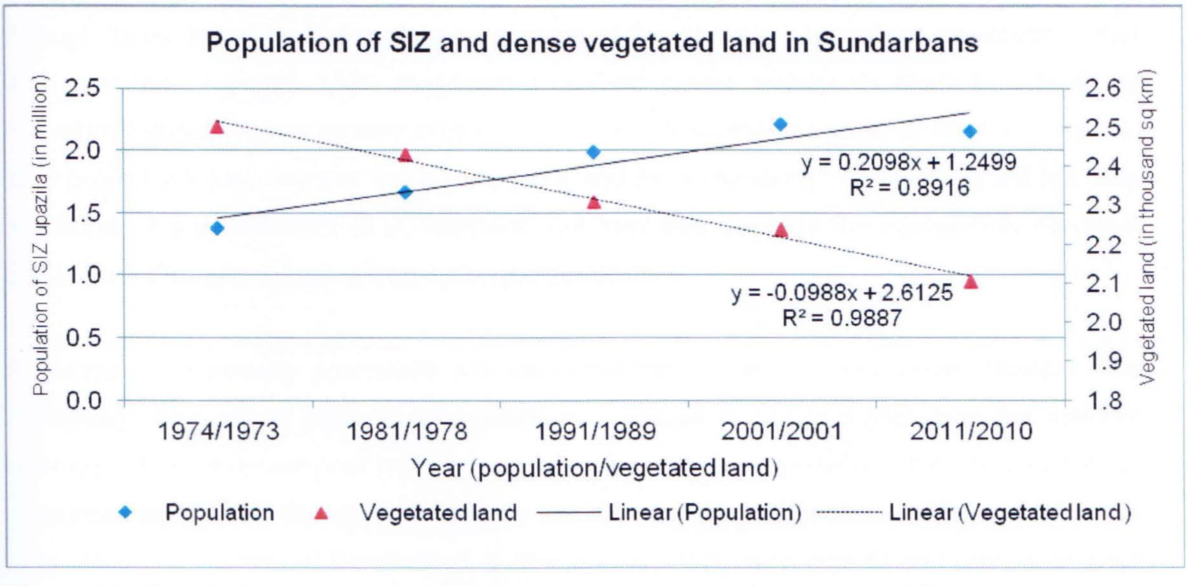

Figure 6.2: Trend of population in SIZ upazila and vegetated land cover of Sundarbans

It has found that the population composition in SIZ locality changed significantly. A smooth increased was observed for 15-59 years age group during 1974-2001. Most of the people of this age group are directly or indirectly involved in Sundarbans resource collection and gathering.

National and international policies and legislations have been playing an important role to conserve as well as destruct the Sundarbans. The legal forest cover of Sundarbans has not changed since last three decades and theoretically, it is now well conserved. Yet, it has difficult to conserve the Sundarbans from least flow of Gorai River that abruptly impacted on Sundarbans. India contracted Farakka barrage to divert Ganges river water. And as a result, the southern part of Sundarbans has been facing serious salinity problems. Several researches revealed the decreasing trend of Sundari tree from the southern part of Sundarbans, Bangladesh.

Institutional response represents a significant mechanism through which humans react to environmental change. In particular, policy plays a key role in determining the ultimate effect of humans on the environment. Hypothetically, if government of Bangladesh takes effective and efficient legal measures to conserve Sundarbans from illegal harvesting and if there is no climate change impact, even Sundarbans will further be degraded because of lack of policy integrations. The recent oil spills (9 December, 2014) at the Shela river threatened trees, plankton, and vast populations of small fish and dolphins of Sundarbans. Even after such a disaster government do not show any attempt to restrict the vessels movement through Shela River and other linked channels of Sundarbans. In addition government has also planned to install 1320 megawatt coal-fired power station at Rampal Upazila of Bagerhat District. The proposed project is situated 14 kilometers north of the Sundarbans. This project will also hamper the Sundarbans and its ecosystems. This project will not only ameliorate the ecosystems of Sundarbans, but may also degrade the ecologically sensitive SIZ locality through changing micro-climatic variabilities.

Population and poverty processes are also intimately linked to forest cover change. The percentage of extreme poor (lower poverty line) people in SIZ is higher than the national average. These extreme poor people are generally engaged themselves in extracting natural resources either from Sundarbans or from common property. The impact of climate change in south-western coast of Bangladesh is now visible. Population growth and climate change may speed up the poverty trap in SIZ locality. This vicious effect can increase the dependency on Sundarbans which further amplify the forest resource extraction.

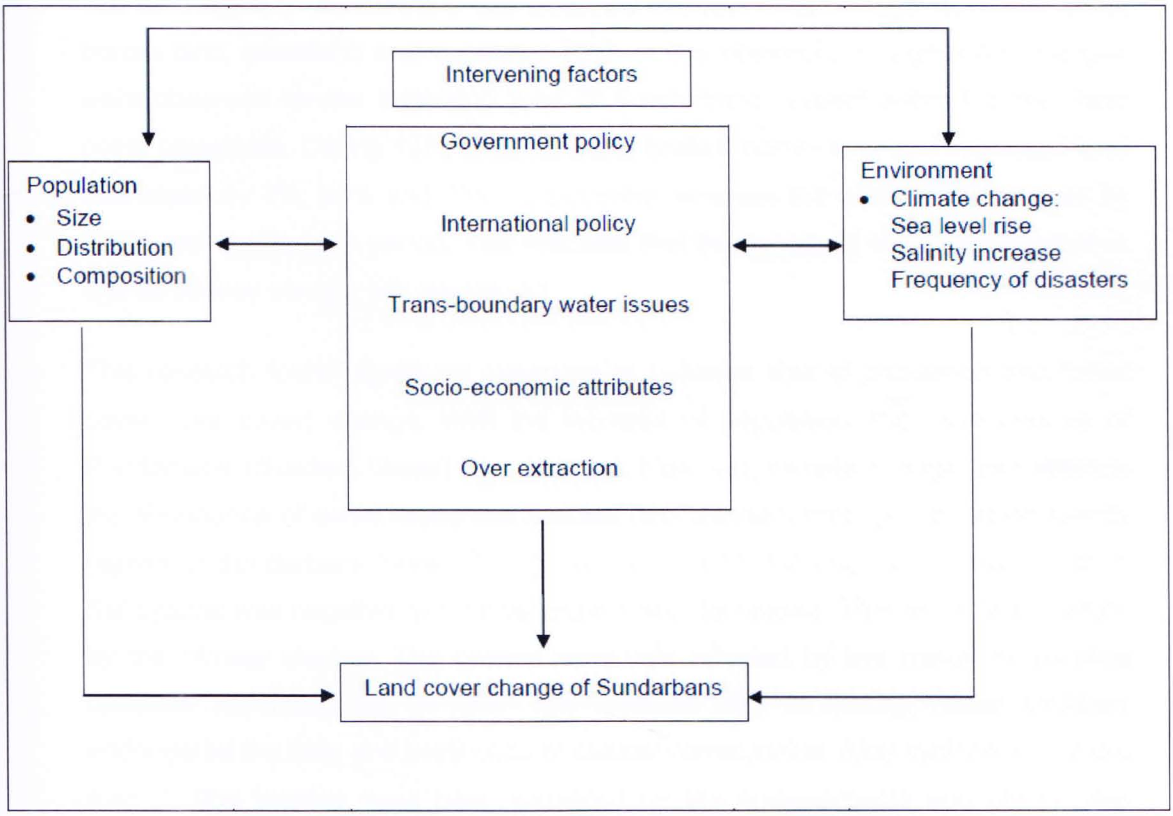

Figure 6.3: Population and environment relation in Sundarbans

6.4. Major findings:

- The size of SIZ population has increased by around 56% in 2011 compared with 1974. In reality, the population size of 2011 has slightly declined from 2001. The other important parameter-sex ratio- was also changed significantly, female sex ratio crossed the male sex ratio. The annual population growth rate was found negative in five SIZ upazila - Dacope, Mongla, Morrelganj, Paikgachha and Mathbaria. The size of households was decreased; and the number of households, density of population, urbanization and literacy rate increased significantly.

- The impact of climate change on Sundarbans was understood through extensive literature reviews and personal observations. The frequency and severity of landfalls of cyclonic storms in coastal zones and Sundarbans increased over the last couple of decades. Moreover, several researches revealed the shifting of saline regime of Sundarbans which is associated with the existence of several mangrove species like Sundari tree that cannot tolerate high salinity.

- The land cover of Sundarbans was classified into four major categories- water body, barren land, grassland and vegetated land. In this research, no significant changes were observed for the total land area of Sundarbans, expect within the four land cover categories. During 1973 to 2010, water bodies, barren land and vegetated land decreased by 7%, 50% and 16% respectively; whereas the grassland increased by 228% during the same period. This indicates that the density of evergreen vegetation and its canopy closure has decreased.

- This research found significant relationships between size of population and forest cover (tree cover) change. With the increase of population, the main species of Sundarbans (Sundari, Gewa) has declined. However, climate change also restricts the abundance of some mangrove species (like Sundari) through increasing salinity regime of Sundarbans forest. During 2001 and 2011, the population growth rate of SIZ upazila was negative, yet the vegetated land decreased. This could be explained by the climate change. The coastal zone was affected by two major consecutive cyclones (Cyclone Sidr in 2007 and Cyclone Aila in 2009). These cyclones endangered the lives and livelihoods of coastal communities. After cyclone Aila, more than 20,000 families have been displaced on the embankments and others near roads and collective centers from Koyra and Dacope (IOM Displacement Tracking Matrix, February 2010). Many people seasonally migrated from the SIZ for their livelihoods. And to some extend the dependency of some people on Sundarbans increased. Thus the vicious cycle of population growth and climate change impact on Sundarbans is playing an important role to the depletion of Sundarbans resources.

6.5. Recommendation:

Considering the abovementioned findings, several measures could be taken to conserve Sundarbans, these are:

- The Sundarbans mangrove ecosystems have remarkable value for south-west coastal communities and for the country as a whole. But the forest resources are being destroyed at alarming rates, although the total land cover has not changed significantly. The size of population of SIZ upazilas increased; amid there was a slight decline of population in 2011. However, the human threats to SRF like overexploitation of forest resources and conversion of impact zones into large scale development are notably contributing the resource extractions. This suggests that there is necessary to consider the demographic behavior of local population to undertake conservation efforts.

- To stop and reverse the current trend of resource depletion from the SRF, it is required to take urgent, effective, time fitting and efficient steps by Forest Department. It is also necessary to improve the institutional and management capacity of Forest Department. GIS and RS based regular monitoring system can easily identify the temporal and spatial change of forest cover. To stop the illicit resource extraction by mighty people and local communities, patrolling systems need to increased and modernized. The delegation and integration of works among the FD and coast guards is also indispensable.

- Many people of the SIZ are actively involved in SRF resource collection. Creation of alternative livelihoods for the Sundarbans dependent communities can reduce the burden from Sundarbans. Outcome oriented planning for alternative livelihood generation is highly recommended. In addition, temporal ban of Sundarbans resource extraction like shrimp fry collection, leaves collection, timber collection, fish collection, honey collection etc. can significantly play to conserve the Sundarbans.

- Comprehensive protection measures should be taken at national and international level to conserve the Sundarbans. Political commitment and willingness on trans-boundary river management is strongly suggested to protect Sundarbans from human induced climate change impacts. The Joint River Commission need to be more proactive to ensure agreed water flow from Farakka Barrage.

- The role of frontier communities to conserve the Sundarbans is very important. IPAC formed three co-management committees – Burigoalini CMC, Nalian CMC and Sarankhola CMC and Chandpai CMC- with the involvement of 29 members from FD and other government representatives, local elected bodies and communities. It is the local communities who can play as a vigilant watchdog of the forest. But their involvement in the CMCs is low (6 person out of 23 members). Hence, it is highly recommended to increase the community's participation in CMCs.

- Finally, population growth and the associated human activities generate pressures on Sundarbans. Human beings are the prime destructor of Sundarbans. Although several environmental protection strategies have been adopted to preserve SRF, it is however still a challenge to protect the forest from the climate change impacts and the lowest level of transparency, accountability and awareness of community people and forest managers. So, it is required to ensure transparency, accountability and awareness of community people and forest managers to conserve the Sundarbans from human interventions.

6.6. Scope for further study:

Sundarbans plays an important role for the people of south-western coast of Bangladesh. With the advent of time this forest is being degrading day by day due to population pressure, anthropogenic interventions, climate change and national and international policy regulations. Considering the socio-economic and environmental significance of Sundarbans mangrove forest, a number of researches can be done for establishing effective population-environment relationships. These are:

- This research found no significant changes of SMF area during the study period. But different inventories clearly identified the declining trend of tree cover and growing stocks of trees. This is really alarming with the growing number of population. In-depth study on population dynamics and tree cover change can reveal the inter-relationship of population-environment of Sundarbans mangrove forest.

- Population pressure and climate change considerably alter the forest cover of Sundarbans. Apart from these two threats, other human interventions, political agenda, policies and legislations need to be researched comprehensively.
- This study is based on the secondary literatures. The impact of climate change on the livelihoods of Sundarbans dependent people and other social dynamism can be revealed through primary data collection which could be addressed through further study.

- The role of multiple factors to determining environmental degradation can be understood by the IPAT equation (where P= population, A= affluence, T= technology and I= environmental impact). Further research on IPAT model can give better understanding on population dynamics of SIZ and environmental degradation of Sundarbans.

- Population pressure and natural resources depletion is closely associated. Depletion of natural resources from Sundarbans can be plotted against the population pressure of SIZ. This analysis could reveal more apparent relationships between population pressure of SIZ and resources depletion of Sundarbans. This research would particularly be helpful for policy makers for sustainable resource management of Sundarbans.

- The effect of migration due to changes in climate variability was not taken into the consideration in this research. In this research, I found that the population was declined in 2011 from 2001. This parameter could reveal another dimension of research interest on Sundarbans.

- This study attempted to combine population dynamics, climate change and land cover change of Sundarbans. Several other factors like illegal entry and resource extraction from Sundarbans were not addressed in this research. Further research on illegal resource extraction with population dynamics and climate change can explore other causes of Sundarbans resource degradation.

6.7. Conclusion:

The population dynamics of SIZ locality provide a unique setting for examining population-environment linkages. The population-environment linkages must be considered in the context of the people and available natural resources. It is evident that high population density contributes to the intense use of forests, fisheries, and water resources. The various demographics parameters of SIZ and evidence of the impact of climate change on Sundarbans have been given to provide empirical evidences to the hypothesis given. The population size of SIZ upazila increased significantly as identified by different censuses (except 2011 census). It is true that the size and growth of population in SIZ locality has showed a decreasing tendency in 2011 census. The critical argument behind this population dynamism are the increased frequency of climate induced disasters like cyclones, (Cyclone Sidr in 2007 and Cyclone Ayla in 2009), increased level of salinity both in farmland and water bodies offers less livelihoods opportunities for the people and internal migration took place. Iftekhar and Islam (2004) concluded that in Sundarbans mangrove forest, plantations are gradually increasing in area but are losing growing stock level. In summary, this research demonstrates that high population growth and climate change contribute significantly to the changes of forest cover of Sundarbans mangrove forest.

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Annexure

Table 1: Year wise Population of SIZ

Name of District	Name of Upazila	Census Year				
		1974	1981	1991	2001	2011
Bagerhat	Sadar	192530	208143	235848	257273	266389
	Sarankhola	71177	92734	107856	114083	119084
	Mongla	57825	97399	137947	149030	136588
	Morrelganj	232647	272112	321153	349551	294576
Bagerhat district		1027160	1203551	1431332	1549031	1476090
Satkhira	Shyamnagar	196221	234164	265004	313781	318254
Satkhira district		1143953	1354662	1597178	1864704	1985959
Khulna	Koyra	91335	125090	165473	192534	193931
	Dacope	89381	116455	143141	157489	152316
	Paikgachha	258080	175715	225085	248112	247983
Khulna district		1386347	1771101	2010643	2378971	2318527
Pirojpur	Mathbaria	188567	221476	254000	263527	262841
Pirojpur district		823787	947420	1063185	1111068	1113257
Barguna	Patharghata	NA	122000	135000	162025	163927
Barguna district		589147	677771	775693	848554	892781
Bangladesh		76400000	90000000	106314992	124355000	144043697

Source: Compile from different censuses of BBS (1974, 1981, 1991, 2001 and 2011)

Table 2: Sex wise population of SIZ

Name of District	Name of Upazila	Census Year									
		1974		1981		1991		2001		2011	
		Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Bagerhat	Sadar	99395	93135	107010	101133	120805	115043	133514	123759	133690	132699
	Sarankhola	36386	34791	50290	42444	55304	52552	61,799	52,284	62,400	56,684
	Mongla	32846	24979	54040	43359	75496	62451	80,819	68,211	71,492	65,096
	Morrelganj	118626	114021	136273	135839	162122	159031	178676	170875	143251	151325
Bagerhat district		528833	498327	618920	584631	732710	698622	804143	744888	740138	735952
Satkhira	Shyamnagar	100367	95854	118099	116065	133721	131283	160294	153487	153441	164813
Satkhira district		585555	558398	684994	669668	812214	784964	955199	909507	982778	1003183
Khulna	Koyra	37970	53365	60796	64294	82199	83274	95,993	96,541	95,393	98,538
	Dacope	45757	43624	62205	54250	74783	68348	83,193	74,296	76,291	76,025
	Paikgachha	132948	125132	88358	87357	115104	109981	127579	120533	123900	124083
Khulna district		739856	646491	947398	823703	1054633	956010	1244226	1134745	1175686	1142841
Pirojpur	Mathbaria	95689	92878	112130	109346	127277	126638	131940	131587	128845	133996
Pirojpur district		417911	405976	476421	470999	535418	527762	561972	549096	548228	565029
Barguna	Patharghata	NA	NA	60471	57126	68067	66568	82,687	79,338	80,544	83,383
Barguna district		284808	277173	343277	334494	390803	384890	430322	418232	437413	455368
Bangladesh		37071000	34407000	44920000	42200000	54728350	51586642	64091508	60263755	72109796	71933901

Source: Compile from different censuses of BBS (1974, 1981, 1991, 2001 and 2011)

Table 3: Sex ratio of SIZ

Name of District	Name of Upazila	Census Year				
		1974	1981	1991	2001	2011
Bagerhat	Sadar	-	106	105	108	101
	Sarankhola	-	118	105	118	110
	Mongla	-	125	121	119	110
	Morrelganj	-	100	102	105	95
Bagerhat district		106	106	105	108	101
Satkhira	Shyamnagar	-	102	102	104	93
Satkhira district		105	102	103	105	98
Khulna	Koyra	-	95	99	99	97
	Dacope	-	115	109	112	100
	Paikgachha	-	101	105	106	100
Khulna district		114	115	110	110	103
Pirojpur	Mathbaria	103	103	101	100	96
Pirojpur district		103	101	101	102	97
Barguna	Patharghata	-	106	102	104	97
Barguna district		103	103	102	103	96
Bangladesh		107.7	106.4	106.4	106.1	100.3

Source: Compile from different censuses of BBS (1974, 1981, 1991, 2001 and 2011)

Table 4: Annual growth rate of SIZ upazila

Name of District	Name of Upazila	Census Year	
		2001	2011
Bagerhat	Sadar	0.87	0.34
	Sarankhola	0.56	0.42
	Mongla	0.78	-0.85
	Morrelganj	0.85	-1.67
Satkhira	Shyamnagar	1.7	0.14
Khulna	Koyra	1.53	0.07
	Dacope	0.96	-0.33
	Paikgachha	0.98	-0.01
Pirojpur	Mathbaria	0.37	-0.03
Barguna	Patharghata	1.87	0.11

Source: Compile from different censuses of BBS (1974, 1981, 1991, 2001 and 2011)

Table 5: Annual growth rate of SIZ districts

SIZ district	Census year				
	1974	1981	1991	2001	2011
Bagerhat	2.62	1.6	1.75	0.79	-0.47
Satkhira	3.45	1.7	1.66	1.56	0.62
Khulna	5.12	2.48	1.28	1.7	-0.25
Pirojpur	2.35	1.41	1.16	0.44	0.02
Barguna	2.53	1.89	1.36	0.9	0.5
Bangladesh	2.48	2.35	2.01	1.58	1.47

Source: Compile from different censuses of BBS (1974, 1981, 1991, 2001 and 2011)

Table 6: Household size in SIZ upazila

Name of District	Name of Upazila	Census year				
		1974	1981	1991	2001	2011
Bagerhat	Sadar	35287	36247	45527	54,465	64,022
	Sarankhola	12680	14653	19588	21,960	28,581
	Mongla	11058	15707	31015	31,015	32,383
	Morrelganj	44232	48336	61210	75,472	75,968
Bagerhat district		190596	209566	275246	323505	354223
Satkhira	Shyamnagar	33209	38342	46592	59,885	72,279
Satkhira district		193362	224894	290921	390745	469890
Khulna	Koyra	NA	19524	28061	38,394	45,750
	Dacope	16846	18649	25377	30,130	36,597
	Paikgachha	44056	29447	41194	51,757	59,873
Khulna district		242083	305947	374848	499324	547347
Pirojpur	Mathbaria	NA	38952	48139	55,617	61,187
Pirojpur district		NA	172900	204418	232962	256002
Barguna	Patharghata	NA	20505	25610	34,477	43,085
Barguna district		109897	115476	145211	179968	215842
Bangladesh			15075887	19397992	25490822	32173630

Source: Compile from different censuses of BBS (1974, 1981, 1991, 2001 and 2011)

Table 7: Area of SIZ locality

Name of District	Name of Upazila	Area in Sq. km.
Bagerhat	Sadar	272.73
	Sarankhola	756.6
	Mongla	1461.2
	Morrelganj	460.9
Bagerhat district		3959.11
Satkhira	Shyamnagar	1968.23
Satkhira District		3817.29
Khulna	Koyra	1775.4
	Dacope	991.56
	Paikgachha	411.19
Khulna district		4394.45
Pirojpur	Mathbaria	344.23
Pirojpur district		1277.8
Barguna	Patharghata	387.36
Barguna district		1831.31
Bangladesh		147569.06

Source: BBS, 2011

Table 8: Density of population in SIZ

Name of District	Name of Upazila	Census year				
		1974	1981	1991	2001	2011
Bagerhat	Bagerhat Sadar	NA	763	865	812	977
	Sarankhola	NA	123	143	151	157
	Mongla	NA	67	94	102	93
	Morrelganj	NA	590	697	758	639
Bagerhat district		259	304	362	391	373
Satkhira	Shyamnagar	NA	119	135	159	162
Satkhira district		296	351	414	483	520
Khulna	Koyra	NA	70	93	281	283
	Dacope	NA	117	144	159	154
	Paikgachha	NA	427	547	603	603
Khulna district		315	403	458	541	528
Pirojpur	Mathbaria	NA	627	719	746	764
Pirojpur district		NA	725	813	850	871
Barguna	Patharghata	NA	304	348	418	423
Barguna district		306	370	424	463	488
Bangladesh		518	590	720	843	976

Source: Compile from different censuses of BBS (1974, 1981, 1991, 2001 and 2011)

Table 9: Urbanization rate of SIZ

Name of District	Name of Upazila	Census year			
		1981	1991	2001	2011
Bagerhat	Sadar	18	18.87	18.06	18.42
	Sarankhola	19.81	23.09	20.64	22.65
	Mongla	26.98	37.96	38.08	29.17
	Morrelganj	6.61	6.73	7.82	9.21
Bagerhat district		11.18	13.23	13.33	13.23
Satkhira	Shyamnagar	2.2	4.16	4.62	5.42
Satkhira district		6.42	8.26	9.2	9.95
Khulna	Koyra	5.01	5.22	5.98	5.89
	Dacope	10.85	11.56	12.57	9.31
	Paikgachha	NAC	1.37	5.73	6.46
Khulna district		42.27	50.1	53.98	33.54
Pirojpur	Mathbaria	7.36	8.33	9.79	10.98
Pirojpur district		11.16	12.2	15.03	16.41
Barguna	Patharghata	10.2	11.91	15.11	17.4
Barguna district		7.6	8.66	10.32	11.55
Bangladesh		12	19.6	23.5	23.3

Source: Compile from different censuses of BBS (1981, 1991, 2001 and 2011)

Table 10: Literacy rate of SIZ

Name of District	Name of Upazila	Census year				
		1974	1981	1991	2001	2011
Bagerhat	Bagerhat Sadar	32.37	44.5	49.9	60.9	63.6
	Sarankhola	24.92	31.3	41.8	56	58.9
	Mongla	28.31	38.9	42.8	56.1	57.2
	Morrelganj	26.58	27.8	49.5	62.4	60.7
Bagerhat district		27.65	39.1	44.3	58.7	59
Satkhira	Shyamnagar	16.96	22.9	28.2	39.7	48.6
Satkhira district		19.39	24.7	30.5	45.5	52.1
Khulna	Koyra	NA	27.1	32.4	44.5	50.4
	Dacope	22.05	30.8	37.7	49.3	56.00
	Paikgachha	19.72	24.3	32.6	45.8	52.8
Khulna district		31.74	26.3	43.9	57.8	60.1
Pirojpur	Mathbaria	NA	49.8	45.9	62.8	61.7
Pirojpur district		NA	41.1	48.2	64.3	64.9
Barguna	Patharghata	NA	43	46.4	63.2	60.5
Barguna district		NA	35.2	42.3	55.3	57.6
Bangladesh		20.2	19.7	24.9	37.7	51.8

Source: Compile from different censuses of BBS (1981, 1991, 2001 and 2011)

Table 11: Adjusted population by sex and broad age group in SIZ district in 2001

Age group	Khulna District		Bagerhat district		Satkhira district		Borguna district		Pirojpur district	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
0-4	145636	129229	102140	89919	119541	107590	55214	49193	74586	67245
5-9	153614	139256	105900	95912	135960	124221	56873	52570	79370	72189
10-14	163079	145026	104996	93477	130556	116633	60406	52687	80436	72625
15-19	135974	123281	81054	72358	97179	87773	43509	39207	56975	52881
20-24	114533	135173	63541	82339	73293	105424	31885	45058	39061	53363
25-29	112766	125696	64128	79271	82205	101395	33531	42904	38259	52205
30-34	100049	87623	58507	52554	70461	62149	29737	33071	36721	42317
35-39	96866	75608	57749	45082	70001	53892	28572	27959	37394	36536
40-44	76619	55936	47074	36576	54033	42963	24354	21341	31776	26717
45-49	64042	46049	38866	30505	44881	36247	19900	16047	26581	21274
50-54	46862	33438	29998	25255	31957	27062	17558	16026	21834	20584
55-59	33680	23643	21789	16645	24604	20390	10644	8729	15407	12298
60-64	31040	24285	23858	18833	23607	21075	14199	11828	17987	15193
65-69	19552	15046	14913	11203	16323	13773	7189	5196	10491	7629
70+	36686	30675	30525	25249	29955	25413	18823	13166	23637	17976

Age group	Bangladesh	
	Male	Female
0-4	8913	7967
5-9	9270	8268
10-14	8783	7805
15-19	6720	6026
20-24	5246	6546
25-29	5307	6233
30-34	4576	4464
35-39	4456	3769
40-44	3629	2910
45-49	2742	2131
50-54	2275	1884
55-59	1383	1106
60-64	1602	1372
65+	2829	2309

Source: BBS, 2001

Table 12: Population by broad age group in SIZ districts

		2001			1991		
Bagerhat	Age group	Both	Male	Female	Both	Male	Female
	0-14	36.51	36.88	36.1	41.8	41.71	41.98
	15-59	55.8	54.74	56.95	51.88	51.34	52.45
	60+	7.69	8.38	6.95	6.28	6.95	5.57

		2001			1991			1981		
Satkhira	Age group	Both	Male	Female	Both	Male	Female	Both	Male	Female
	0-14	37.6	38.28	36.9	44.04	44.53	43.54	47.7	47.8	47.1
	15-59	55.72	54.65	56.87	50.35	49.35	51.37	46.9	46.4	48
	60+	6.67	6.23	6.23	5.61	6.12	5.09	5.4	5.8	4.9

Khulna	Age group	Both	Male	Female	Both	Male	Female	Both	Male	Female
	0-14	34.72	34.7	34.75	41.03	40.22	41.91	44.05	41.8	46.3
	15-59	59.04	58.65	59.46	53.64	54.04	53.2	50.8	52.7	48.9
	60+	6.24	6.65	5.79	5.33	5.74	4.89	5.15	5.5	4.8

		2001			1991			1981		
Borguna	Age group	Both	Male	Female	Both	Male	Female	Both	Male	Female
	0-14	36.79	37.98	35.57	44.12	44.76	43.37	47.82	48.02	47.59
	15-59	55.28	52.99	57.64	49.74	48.02	51.49	45.57	46.64	47.75
	60+	7.93	9.03	6.79	6.14	7.22	5.04	5.54	6.39	4.66

		2001			1991			1981		
Pirojpur	Age group	Both	Male	Female	Both	Male	Female	Both	Male	Female
	0-14	39.37	39.52	37.19	42.94	43.37	43.35	46.31	46.34	46.28
	15-59	53.63	51.49	55.82	50.44	49.16	50.77	47.03	47.05	47.02
	60+	8	8.99	6.99	6.62	7.47	5.88	6.66	6.61	6.7

Source: BBS, 1981, 1991 and 2001

Table: 13: Crude Birth Rate (CBR) in SIZ districts

Year	Bangladesh	Bagerhat	Satkhira	Khulna	Pirojpur	Barguna
2003	20.94	22.91	23.45	18.14	18.78	18.67
2010	19.2	18.7	16.84	19.03	19.52	16.16

Source: SRVS, 2003 and 2010

Table: 14: Crude Death Rate (CDR) in SIZ districts

Year	Bangladesh	Bagerhat	Satkhira	Khulna	Pirojpur	Barguna
2010	5.66	6.86	6.06	6.64	5.44	6.3
2003	5.93	7.21	5.93	4.69	6.82	7.33

Source: SRVS, 2003 and 2010

Table 15: Poverty situation of SIZ

Name of district	Name of upazila	2005		2010	
		% Extreme poor (lower poverty line)	% Poor (Upper poverty line)	% Extreme poor (lower poverty line)	% Poor (Upper poverty line)
Bagerhat	Sadar	42.7	31.6	18.6	35.9
	Sarankhola	62.8	48.7	28.2	48
	Mongla	56.4	41.5	22.7	41.9
	Morrelganj	64	50.3	27	46.5
Bagerhat district				24	42.8
Satkhira	Shyamnagar	75.7	65.2	33.8	50.2
Satkhira District				29.7	46.3
Khulna	Koyra	50	34.8	29.1	49.1
	Dacope	73.3	60.4	24.9	44.5
	Paikgachha	49.6	34.4	23.3	42.4
Khulna district				21.2	38.8
Pirojpur	Mathbaria	38.1	17.9	25.6	38
Pirojpur district				30.9	44.1
Barguna	Patharghata	56.3	36.1	6.1	12.9
Barguna district				9.8	19
Bangladesh		25.1	40	17.6	31.5

Source: BBS poverty mapping, 2005 and 2010

Table 16: Distribution of household sources of fuel

	Straw		Bran/ husk		Wood/Bamboo		Other	
	2010	2003	2010	2003	2010	2003	2010	2003
Bangladesh	42.6	38.9	5.3	4.8	42.5	42.3	9.6	14.0
Bagerhat	37.4	26.8	4.6	1.4	48.0	56.8	10.0	15.0
Satkhira	28.8	19.1	5.8	1.2	64.1	67.8	1.3	11.8
Khulna	23.6	21.8	3.0	6.0	65.6	58.2	7.8	14.0
Pirojpur	32.5	39.5	2.2	1.4	64.5	54.7	0.7	4.4
Barguna	30.6	30.6	23.8	0.8	42.6	66.4	3.0	2.2

Source: Sample Vital Registration System 2003 and 2010

Table 17: Areas covered by forest types of Sundarbans Reserved Forest in 1960, 1985, 1995 and 2013

Forest types	Area (ha) 1960	Area (ha) 1985	Area (ha) 1995	Area (ha) 2013
Sundri	98551	82845	74992	74264
Sundri Gewa	92139	123247	105967	102274
Sundari Passur	29752	2214	2413	2368
Sundari Passur Kankra		6799	7143	7084
Gewa	12557	18556	19909	21454
Gewa Sundri	58897	59973	75704	73505
Gewa Goran	32196	37593	34604	32575
Gewa Mathal		836	1611	
Goran	2910	8706	8269	
Goran Gewa	42115	57597	56536	54655
Passur Kankra	947	940	284	275
Passur Kankra Baen		1614	2516	2525
Baen		828	1230	
Keora	8854	3509	8287	10603
Tree plantation		351	217	
Non Forest	28032			
Grass and bare ground		4614	6931	4856
Sandbar		4024	4614	1218
Non Mangrove				362

Source: RIMS unit, Forest Department

Table 18: Growing stock of the Sundarbans according to different inventories

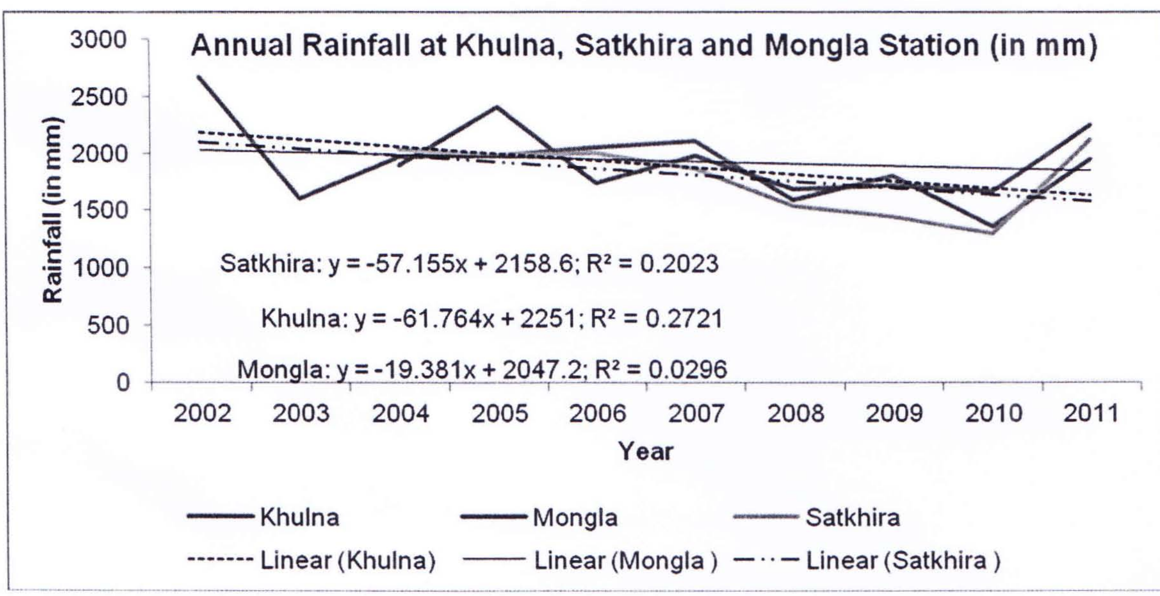
Year of publication of Inventory Results	Sundri (Number of Trees per Hectare, having DBH 15 cm and above)	Gewa (Number of Trees per Hectare)	All Tree Species (Number of Trees per Hectare)
1959	211	61	296
1983	125	35	180
1996	106	20	144

Source: Forest Department (cited in Choudhury, and Hossain, 2011)

Table 19: List of tropical cyclones that landfall in SIZ and Sundarbans since 1971

Sl	Date
1.	28–30 November 1971
2.	6–9 December 1973
3.	13–15 August 1974
4.	9–12 May 1975:
5.	9–12 May 1977
6.	24–30 November 1988
7.	29–30 April 1991
8.	19–22 November 1998
9.	15 November, 2007 (Cyclone Sidr)
10.	25 May 2009 (cyclone Aila)

Figure 1: Annual rainfall at Khulna, Satkhira and Mongla (in mm)



Source: Bangladesh Meteorological Department (adapted from BBS, 2011).