CLIMATE CHANGE INDUCED LIVELIHOOD VULNERABILITY AND IT'S MANAGEMENT IN TRANS-BOUNDARY MANGROVE ECOSYSTEMS: A CASE STUDY OF SUNDARBANS

Dissertation submitted to Jawaharlal Nehru University in partial fulfillment of the requirements for award of the degree of

MASTER OF PHILOSOPHY

MALAY KUMAR PRAMANIK

Political Geography Division
Centre for International Politics, Organization & Disarmament
School of International Studies
Jawaharlal Nehru University
New Delhi 110067

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Centre for International Politics, Organization and Disarmament

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DECLARATION

I declare that the dissertation entitled, **"CLIMATE CHANGE INDUCED LIVELIHOOD VULNERABILITY AND IT'S MANAGEMENT IN TRANS-BOUNDARY MANGROVE ECOSYSTEMS: A CASE STUDY OF SUNDARBANS"** submitted by me, in partial fulfillment for the award of the degree of Master of Philosophy, of Jawaharlal Nehru University is my own work.

Malay Kumar Pramanik

CERTIFICATE

We recommend that this dissertation be placed before the examiners for evaluation.

27.7.15

Prof. Swaran Singh

Chairperson

CIPOD, SIS

Dr. Krishnendra Meena

Supervisor

...ol of International Studies, Jawaharlal Nehru University, New Delhi - 110067, India

Dedicated

to

my late maternal uncle

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List of Acronyms

ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
BOB	Bay of Bengal
CBMM	Community Based Mangrove Management
CEGIS	Center for Environmental and Geographic Information Services
DoF	Department of Fisheries
ETM+	Enhanced Thematic Mapper
EU	European Union
FAO	Food and Agricultural Organization
FRSS	Fisheries Resources Survey System
GIS	Geographic Information system
HTL	High Tide Level
IMD	Indian Meteorological Organization
IPCC	Intergovernmental Panel for Climate Change
IUCN	International Union for Conservation of Nature and Natural Resources
IWM	Institute of Water Modeling
LTL	Low Tide Level
LULC	Land Use and Land Cover
MCDA	Multi-Criteria Decision Analysis
MOEF	Ministry of Environment and Forest
MPO	Master Plan Organization, Dhaka
MSL	Mean Sea Level
MSS	Multi Spectral Scanner
NDVI	Normalized difference Vegetation Index
OLI	Operational Land Imager
SBR	Sundarban Biosphere Reserve

SRF	Sundarban Reserve Forest
SRTM	Shuttle Radar Topography Mission
TM	Thematic Mapper
TRMM	Tropical Rainfall Monitoring Mission
UNEP	United Nations Environment Program
UNESCO	United Nations Environmental and Scientific Cultural Organization
USGS	United States Geological Survey
WB	World Bank
WMO	World meteorological organization
WWF	Worldwide Life Fund

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Date

Malay Kumar Pramanik

Chapter-1

Introduction

Mangroves are the important primary resources of intertidal coastal areas along the tropical and subtropical regions of the world. The coastal ecosystems protect the shoreline with the role of attenuating wave energy, but now mangroves are mostly vulnerable due to climate change induced sea level oscillations (Alongi 2008, Gilman et al. 2008). The responses also effect the potential impact on mangrove distribution as well as displacement of all coastal ecosystem (Alongi 2008, Cahoon et al. 2006).

The components of climate change that affect mangroves significantly, include the changes in sea level, storminess, high water events, temperature, precipitation, ocean circulation patterns, atmospheric carbon-di-oxide concentration, status of functionally connected neighboring ecosystem and human responses to climatic variability. The relative sea level rise is the greatest threat to the changes in the alteration of land surfaces and atmospheric composition (Field 1995, Gilman et al. 2007, Lovelock and Ellison 2007), as well as health of mangrove and the reductions of mangroves (IUCN[1] 1989, Nichols et al. 1990, Cahoon et al. 2006, Gilman et al. 2006) High intensity water events, such as massive erosion, tidal surges and severe cyclones are now more frequent in Sundarban due to faster rising of sea level. The significant increase of the water level (Church et al. 2004) could affect mangrove diversity and health of the associated changes in the soil erosion, salinity, inundation and sediment deposition. The combined effects of all these adverse conditions can change the mangrove position from seaward to landward margins (Gilman et al. 2006). Storm surges and sea level rises combined decrease the productivity and the landward migration also (Ellison 2000) This vertical increase of water level and limitation of land may create the water logging situation, causing death of mangroves with associated flora (Jagtap et al. 2003).

[1] The International Union for Conservation of Nature, 1948

According to the Intergovernmental Panel on climate change (IPCC[2] 2001), predicted sea level of 21st century increases at 1-2 mm per year and also increase in peak wind intensities of tropical cyclone and mean intensities of tropical cyclone in some areas resulting from global climate change (Houghton et al. 2001, Church et al. 2001, Solomon et al. 2007). The report (IPCC 2007) warned that world largest Ganges-Brahmaputra delta[3] (West Bengal and Bangladesh) are now most vulnerable due to sea-level rise, climatic change and the intensification of coastal storms and Erosion is the common phenomenon of Sundarban forested Islands. Near about 100 sq. Km land has eroded during last 30 years (Hazra 2009). The report by UNESCO[4] in "case studies on climate change and world heritage" has stated 45 cm anthropogenic sea level rise (according to IPCC, the end could occur it of 21st century) and combined with other kind of anthropogenic stress, could lead the destruction of the Sundarban mangrove is about 75%. Therefore, the assessment of the impacts of climate change in mangrove belt as an additional risk that already is under significant stress (Haq 2010). Thus, the dynamics of the mangrove ecosystem in response to projected climate change sea level rise enable to take appropriate planning for reducing threats and human safety of the coastal area (Gilman et al. 2007).

Mangrove forest not only rich in biodiversity but also sustain the livelihood opportunities in worldwide of all coastal communities (Duke et al. 2007). The forest provides various ecosystem goods, such as, firewood, food, salt, timber as well as other essential ecosystem services likely the sediment trapping, shoreline protection from erosion and nutrient recycling (Snedakar 1995). However, mangrove wetlands also indirectly sustain artisanal and commercial fisheries to the important livelihood sustainability and create a strategic greenbelts for the protection of seaward habitats from coastal disaster (Dahdouh Guebas et al. 2006). They have Historical, cultural and aesthetic values and mostly important for tourism activity.

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[2] The Inter-governmental Panel on Climate Change is an intergovernmental (scientific) body under the United Nations, set up at the request of member governments, 1988

[3] The delta stretches from the Meghna River on the east to the Hooghly River on the west that is approximately 220 mile across at the Bay of Bengal

[4] The United Nations Educational, Scientific and Cultural Organization, 1945

The important livelihood of the Indian part of Sundarban mangrove are farming (60%), fishing (5%) activities (census, 2001) but Bangladeshi part of Sundarban have engaged in fishing (68%), crab catching (14%), honey collection (9%), Nypa palm collection (9%) activities as a prime livelihood (Islam 2011). The mangrove based livelihood activities (aquaculture and fishing, honey and wax collection, crab cultute and Nypa palm) and supportive services (habitats for animals and plants, nursery grounds for wildlife and fisheries) recently changing due to coastal erosion, rising sea levels, saltwater incursion, frequent storm activities and over exploitation of living resource in Sundarban (Uddin et al. 2013). Increasing pressure on shrimp farming and fishing was also the leading cause of the loss of mangrove habitat in the extensive way. It will be difficult for long-term sustainability of the Sundarban mangrove dependent livelihood community.

The expansion of forest cover area by increasing the regenerating or rehabilitating potential and planting of most threatened and valuable mangrove species in the estuarine and intertidal areas are some of the crucial management options. For addressing the forest restoration and the conservation priorities different nurseries has developed at Lothian Island, Bakkhali reserved forest and along the Bidya river etc. The afforestation program have made for the Sundari tree[5] (Heriteria fomes) as an endangered species in Red list (IUCN 1989). The plantation has helped in the conservation of threatened species such as Sundari, Goran, Gewa and Nypa habitat improvement and also employment generation for the adjacent population. The most threatened species in Sundarbans with less adapting capacity to climate change and associated effects should be promoted to regenerate or rehabilitee in new areas. The continuous monitoring of the sea level rise, as well as climate change effects on mangrove ecosystem, should be documented to get consistent inputs for crucial management strategies (Singh 2003). Also, Site productivity and temporal variability are an indicator of the potential mangrove ecosystem to deliver goods and ecosystem services (Islam 2011).

[5] The naming of Sundarbans mainly based of Sundari, the scientific name is Heritiera fomes, is the most threatened species according to IUCN red list

1.1 Study Area and It's Importance as a Coastal 'Biosphere Reserve[6]':

Sundarban mangroves is a unique and significant Trans-boundary ecosystem covering 10200 sq. Km of which about 4200 sq. Km are in India and remaining 6000 sq. Km in Bangladesh. It is located in the southeastern part of West Bengal and southwestern part

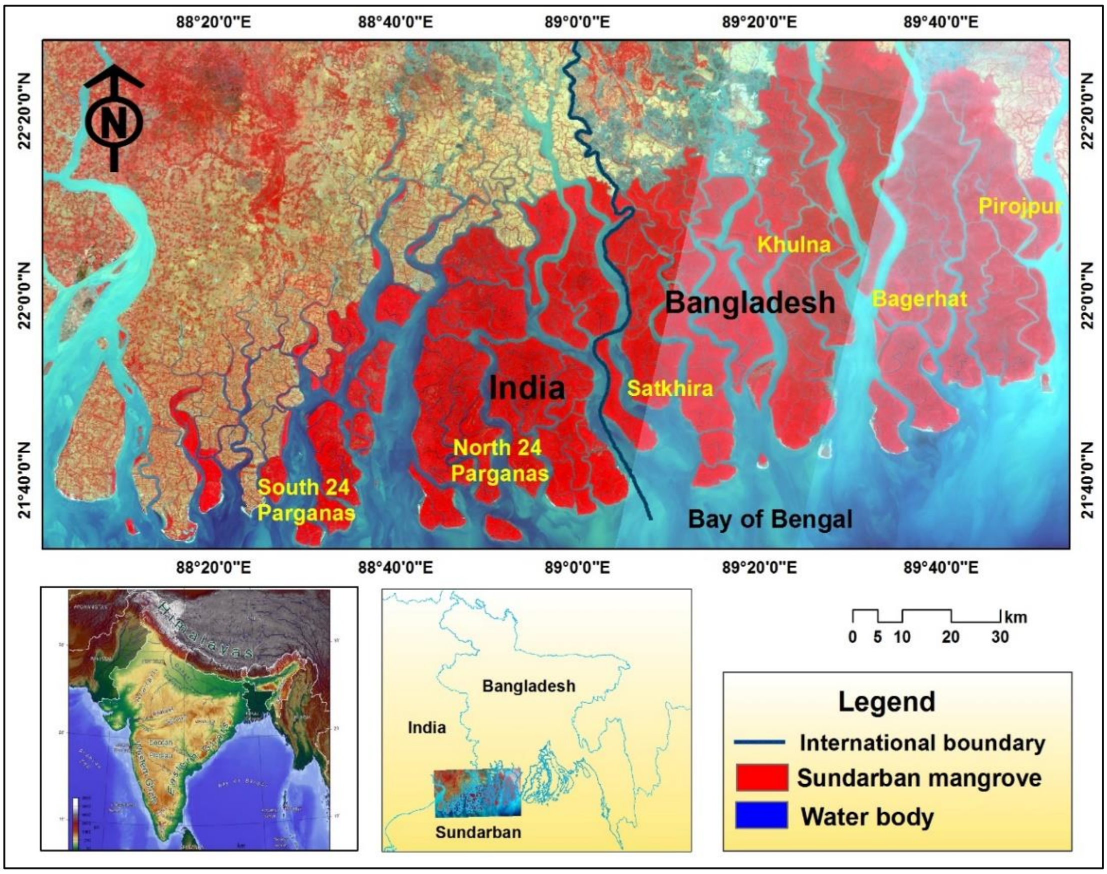

Fig. 1.1 The study area of trans-boundary Sundarbans mangrove (India and Bangladesh)

of Bangladesh. The forest lies between 21º30´N - 22º30´N latitudes and 89º00´E - 89º55´E longitudes (fig. 1.1). It is a home of a large human population of which 4.5 million in India and 7.5 million in Bangladesh (table 1.1). It is a deltaic ecosystem has formed by the estuarine region of Ganga-Brahmaputra and Meghna River. The mangroves have the 'Region of largest halophytic formation'[7] along the coastline. It

[6] The Sundarbans Biosphere, located in Bangladesh and India, is part of the world's largest active delta of Ganga, Brahmaputra and Meghna River. A delta is a complex set of channels, islands, creeks, rivers, mudflats, and sand dunes constantly changing due to recent climate change and tidal influence

[7] A halophyte is a plant or species that grows in waters with high salinity

has also declared a "world heritage site"[8] (IUCN, 1987) and "biosphere reserve" (UNESCO, 1999). The region is characterized by most of the innumerable rivers, tidal creeks and small channels. The biodiversity has been significant as an abandoned biodiversity of which have 87 plant species therein 37 are mangrove species.

Table 1.1 Description of the Trans-boundary Sundarbans

country	Area (Km^2)	Districts	Population	Total no of Islands
India	4200	North 24 Parganas and South 24 Parganas	4.5 million	48
Bangladesh	6000	Satkhira, Khulna, Bagerhat, Pirozpur	7.5 million	200

In the last century, the probabilities of flood and bank erosion have accelerated due to increased rate of siltation of river beds. The continuous rises of climate change and relative sea level are now a significant threat to the existence of this fragile ecosystem.

1.2 Literature Review:

Lots of works have done in the field of climate change components and their effects on mangrove dynamics and mangrove vulnerability, subsequent livelihood vulnerability of the local inhabitants. But in the context of climate change mangrove dependent livelihood vulnerability and their proper management strategies also is an important aspect in Sundarbans as a trans-boundary mangrove ecosystem of India and Bangladesh. A number of academicians and scholars has undertaken works for the sustainable forest management. This study mainly covers the topics climate change components, mangrove dynamics, mangrove vulnerability, livelihood changes and their vulnerability, technical guidance of mangrove conservation and management strategies related issues on Sundarbans.

1.2.1 Climate Change Effects on Mangrove Dynamics:

Alongi (2008) examine the degree of resilience to large-scale, infrequent disturbance (Tsunamis), the role of the events of chronic disturbances, importance in coastal

[8] A World Heritage Site is a site that is listed by the UNESCO as being of special physical or cultural significance. See https://en.wikipedia.org/wiki/World_Heritage_Site

protection and future potentiality to global climate change. The ultimate disturbance of climate change can lead to the global loss of 10-15% of mangrove habitat. The loss may depends on different climate change components like rising sea level, the rise in atmospheric $co_{2,\ the}$ rise in water and air temperature and the changes in frequency and intensity of storm and precipitation patterns. He especially emphasized chronic disaster like a tsunami[9] (26 December 2004). This desperate event may provide clues that how mangrove ecosystem will respond to the future disturbances. Limaye and Kumaran (2012) assesses how mangrove vegetation responses to Holocene Climate Change along the Konkan Coast in southwestern India. They also pointed out that these responses also causes for the coastal elevation, Climate change induced sea level rise and other climatic changes. Extends of mangrove vegetation is not uniformly distributed, and diversity of mangrove forest is much less due to sea level rise. They also signify that the mangrove responses also depend on the influences of salinity, sedimentation, geomorphology and another geomorphic factor. Li et al. (2012) explains that the mid-Holocene mangrove Succession and their responses to sea level change in the upper Mekong River delta of Cambodia Where vegetation responses primarily depends on the sedimentary environment. They also specify the changes of mangrove depend with their sedimentological characteristics. The succession of the mangrove Classified in five different units where all changes basically vary with the tidal level of the Mekong River. Ligia et al. (2012) analyzed the responses of two Caribbean mangroves to Sea Level rise in Guajira peninsula (Columbian Caribbean).They emphasized the local and regional factor for establishment and survival of mangrove communities along the coastal area. Moreover, also includes some parameter such as geomorphology, Precipitation rates and fluvial sediment input for the analysis of the establishment of coastal mangroves. According to him two main factors responsible for mangrove establishment in this region; i) Accelerated sea level rise from 6000 calendar year BP promoted to the originating coastal lagoons and wetlands that favored for mangrove establishment, and ii) High precipitation and marine still stand around 3000 calendar year BP leading to the second process of mangrove expansion. He also claimed that the coastal erosion is also responsible for mangrove expansion. Ellison &

[9] tsunami is a tidal wave or seismic sea wave originated from deep sea. See https://en.wikipedia.org/wiki/Tsunami

Stodart (1991) pointed out that the mangrove ecosystem collapsed due to sea level rise in Holocene period of South Florida, Grand Cayman, Queensland and northern territory, Fiji, Caroline Islands, Western Samoa, Tongatapu whose have broad regional implications. They signify mainly stratigraphic record and sediment accumulation of the study area. Other factors are the rate of forest's primary production, the intensity and frequency of tropical storms and shoreline erosion due to more and deeper turbulent water. Rogers, Saintilan, & Heijnis (2005) explains how sedimentation, subsidence, sea level rise effects to the declining of salt marsh in western Port Bay, Victoria, Australia. He found that the inverse relationship between increase of surface elevation and the degree of mangrove encroachment where, mangrove specifically replacing salt marsh by extension along the tidal creeks draining to the salt marsh and also extending into this salt marsh interior. Jagtap & Nagle (2007) studied about the adaptability and response of mangrove habitats of the Indian subcontinent in the context of changing climate. He also mentioned that the habitats would be a more vulnerable condition to the climate change and resulted in rising sea level (SLR) for their unique location at the near portion of the sea. Present global warming and resulted increasing atmospheric temperature may be influence evaporation and precipitation that ultimately affected to the salinity from the coastal and marine habitats. He also recommends that biodiversity and coastal regulations and global policies has strictly implemented for the conservation of marine habitats and the mitigation of greenhouse gas emissions.[10]

1.2.2 Climate Change and Mangrove Vulnerability:

Ellison and Zouh (2012) assesses how inter-tidal mangroves are less resilient or more vulnerable to recent climate change impacts and associated relative sea level rise. To analyze the mangrove vulnerability they had used ground survey method combined with spatial techniques. Paleo-biological reconstruction and stratigraphic coring were also used to investigate the net sedimentation rate and long term biological changes of the Doula estuaries (Cameroon) mangrove communities. The results signifies that the seaward margins of mangroves shoreline experienced by dieback at the rate of 3m per year over the last two or three decades. An offshore mangrove area had also suffered

[10] A greenhouse gas (GHGs) is a gas in an atmosphere that emits and absorbs radiation within the thermal infrared range. See https://en.wikipedia.org/wiki/Greenhouse_gas

by 89 degradation and loss. They also suggested that the limited intertidal elevation of all mangrove habitats and low net sedimentation ratio of the seaward edge margins. Lovelock and Ellison (2007) explains that how saltmarshes, salt flats and mangrove are vulnerable to climate change induced sea level rise. However, increases in relative sea level showed increases the mangrove area, migration of salt flats upslope, mangroves, and salt marshes. The conditions are occurs in the areas of Great Barrier Reef[11] where they found high tidal ranges, the areas with obstacles for landward migration, the precipitation is predicted to increase in a large scale, and the areas with low sediment inputs. Additionally, low humidity, more severe storms and high temperature could also lead to erosion and subsidence, reduced productivity of the mangrove area. Ellison (2013) pointed out that the valuable coastal resources are now vulnerable due to increasing negative impacts of wave and wind energy, rising temperature, increasing co2, changing precipitation, increasing relative sea level. The last 20 years, the mangrove areas having lost about 50% and also degraded and converted to other livelihood uses such as, agriculture, aquaculture and fishing, timber collection and other related activities. They emphasized on the inundation period of mangrove area which affects the productivity, recruitment and forest health which leads to the vulnerability of the mangrove area. The vulnerability assessment of the mangrove area under climate change can provide site specific responses and synthesis of various components, that needs some appropriate adaptation strategies to be prioritized. Ellison (2014) assessed a vulnerability of mangrove ecosystem to climate change and relative sea level rise impacts. He includes 3 dimensions of vulnerability assessment that are exposure components, sensitivity components and appropriate adoptive capacity to climate change at the sites in South Pacific and Africa. The approaches of his ranking techniques is that the vulnerability assessment integrates the abiotic and biotic factors along with anthropogenic management controls. These factors are forest health and density, adjacent ecosystem resilience, the effects and extend of anthropogenic impacts, and the various environmental conditions in different mangrove settings. This study is a comparative study between Tikina Wai (Fiji), Douala estuary (Cameroon) and Rufiji

[11] The Great Barrier Reef is the world's largest coral reef system comprising of over 2,900 individual reefs, is located in the Coral Sea, off the coast of Queensland, Australia.

See https://en.wikipedia.org/wiki/Great_Barrier_Reef delta (Tanzania) where Douala estuary marked as a highest vulnerability due to higher ranking of exposure components that signify that higher sediment supply and higher rate of relative sea level rise.

1.2.3 Mangrove Dynamics on Changing Livelihood:

Dutta and Deb (2012) analyze the coastal land use and land cover changes in the Indian Sundarban. They give out a structure about the changes of all land use and land cover in coastal Sundarban through GIS and remote sensing techniques. They referred that the changes of mangrove forest mainly depend on the sea level, policy and afforestation related issues where dense mangrove gradually increases but open mangrove gradually decreases and other land use category changes but at limited rates. They find that the changes, in the last two decades mainly depends on the growths of tourism activities and infrastructure, new settlements. In the effect of that local peoples are engaged in a different alternative occupation like coastal tourism, commercial fishing and shrimp culture, prawn seeds from subsistence farming and traditional forestry. Uddin, Shah, et al., (2013) assessed the impact of climate change in the mangrove ecosystem services and livelihoods in the Bangladesh Sundarbans. They emphasized that the mangroves was not only influenced by climate change, also much more influenced by anthropogenic activities. Gewa (Excoeceria agallocha) and Sundari (Heritiera fomes) may be decreased by 2100 due to 88 cm sea level rise in Sundarban about 2001.[12] The decreasing rate of this two species impact to the reduction of their timber stock. The other ecosystem (fishery, tourism, farming, biodiversity) may be affected by climate change. Consequently, forest-dependent livelihood and services were affected by their degraded nature. Ding & Nunes (2014) attempt to the modelling of the links between biodiversity, ecosystem services and climate change in European forest ecosystem. The relationship shows by composite biodiversity indicator that confirm that the role of biodiversity is a nature oriented policy solution to climate change mitigation. They mention that the flows of ecosystem goods and services and the biodiversity conservation have a role for the sustainability of human livelihoods. Paul & Vogl (2012) evaluate the role of organic shrimp aquaculture for the sustainability of

[12] See CEGIS (2006), "Coastal Land Use Zoning in the Southwest: Impact of Sea Level Rise on Land use Suitability and Adaptation Options", Center for Environmental and Geographic Information Services (CEGIS), Dhaka

household livelihood in southwestern Bangladesh of Sundarban. All farmers are mostly vulnerable due to the natural phenomena like floods, diseases, cyclones, untreated water sources, direct hindrance to the economic growth of the region. The data are collecting from the questionnaire, interviews, focus group discussions, transect walks and group discussion from 144 organic shrimp farmers for the analysis sustainable livelihood approach as an asset-based conceptual framework. The shrimp farming gradually has increased the farmer assets also mitigated the vulnerability that make a livelihood as a sustainable of the farmer. Emch & Peterson (2008) Use the remote sensing approach for the explanation of the mangrove forest cover change from 1989 to 2000 in Bangladesh Sundarban forest zone. They also explain the Sundarbans ecosystem changed dynamically due to anthropogenic causes that create a more complex situation of land use and land cover changes. This study represents the non-forest, and sparse forest area decreased significantly, but dense forest increased due to interference of anthropogenic influence. They mentioned that approximately six lakhs people are dependent on the forest belt for their livelihoods, but the formation of shrimp farming and the implementation of water development projects are the cause of ecological change in the adjacent area of Sundarban. Giri et al., (2007) referred about the mangrove dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000. They compare only of the canopy closure in the mangrove forest belt where 1997 to 1990 mangrove increases about 1970 to 2000. According to their explanation, the causes of these changing land use is affected by the earth's aggradation and soil erosion along the coastal belt. They referred that the forest is also a center of economic activities that mainly depend on fuel wood, fishing, timber and the collection of honey and other related forest products. The population density of Sundarban is also highest in the world where more than 2.5 million inhabitants depend for their subsistence from mangrove forest products. The livelihood of 300,000 people has also engaged with palm collectors, wood cutters, honey hunters and fisherman.

1.2.4 Climate Change Adaptation for Trans-boundary Mangrove Ecosystem:

Datta , Chattopadhyay & Guhan (2012) gives the outline of the structure of Community-based mangrove management, their status and sustainability. This research advocates the wide-scale adaptation option of decentralized governance policies in the developing countries. They also signify the ecological, economic, social and institutional sustainability issues for the future development of mangroves. They referred academia and governed agencies are the alternative option for sustainably managing mangrove forest that are ecologically significant and disappearing rapidly worldwide. Higher no of community-based mangrove management initiatives were found from South Asia and also lesser from Africa and South America. The management option is mostly applicable to the highly stressed forests. Bado & Froehlich (1998) describe the community-based mangrove rehabilitation of East Sinai in Indonesia. The local people's rights and responsibility are the major property to manage the mangrove rehabilitation along the coastal habitat that also related to their socio-economic condition and ecological surroundings. Dev Roy, Alam, & Gow (2011) states that the role of property rights and forest policies to managing mangrove. They broadly explain the role of local user benefits from property rights and the property rights regime to sustainability analysis. This option helps different policy implementations as well as community-based environment sustainability. Iftekhar and Islam (2004) attempt to consider some appropriate management strategies for the degradation of the Sundarban mangrove in Bangladesh as a part of trans-boundary mangrove ecosystem. They found that the Sundarban suffers by poor implementation capacity and limited effectiveness of policy and planning to forest management. They also suggested to the broadening of management capacity, the establishment of financial responsibility etc. that gradually reduce some management problems of the Bangladesh Sundarbans.

1.2.5 Climate Change and Species Rehabilitation Planning:

Lua, Gua, Daid, & Weib (2012) assessed the habitat suitability modelling of the endangered Schisandra sphenanthera rehd et. wils wild herb plant in Qinling Mountain, China. The model have based on the collecting samples of Schisandra sphenanthera species by field work from Qinling Mountains. They also combined geographic information system (GIS), maximum entropy modelling and the fuzzy membership functions to obtain the suitable range of plant growth and spatial distribution of this modelling for the conservation and restoration of the ecosystem. The model has built for the application to besides habitats of this mountain used by validation. They also used the weighted method where each factor formulated by available temperature and light of growth period and organic carbon content ratio have played a major role of S. sphenanthera for the proper habitat suitability. The spatial distribution of the overall Qinling Mountains suggested that the suitable habitat ratio amounts are about 70.80%.

Store & Jokimaki (2003) developed a method for the produce of geo-referenced ecological information on the basis of habitat requirements of different habitat species. They define integrated habitat suitability approach includes the various steps of producing data, find target area on the basis of suitable factors, combining the various suitability indices and at last construct the habitat suitability model. They used the multi-criteria analysis methods[13] (MCEs) for connecting (weighting, standardizing, combining) the different habitat species and integrate with expert knowledge and empirical models. The method have also illustrated that the case study is an integrated the habitat suitability map for the group of old forest habitat species. Zohmanna, Pennerstorferb & Nopp-Mayra (2013) attempt to the restoration and maintenance of high-quality habitat for wildlife species are the key issues in Alpine ecosystem for the biological conservation. They developed a knowledge-oriented habitat suitability in the Eastern Alps, Austria. The model formulated by nine habitat variables such as patches, slope and different land cover classes (forest, scree, dwarf pine, dwarf shrubs, subnival/alpine grassland, rocks and rock vegetation intermixed). The habitat suitability model output is mainly based on present and absence of data, Nonparametric correlations and habitat suitability classification with contingency tables. The model used the object based image analysis of very high-resolution satellite images for the spatially explicit habitat suitability assessment that should be use full in regional planning, management and monitoring activities for ptarmigan. Estreguil, Rigo & Caudullo (2013) characterize the habitat pattern for the analysis of fragmentation and connectivity of the biodiversity policy agenda. They use a set of indices that organized into four categories: Habitat morphology, edge connectivity, edge interface and general landscape composition. The methodology have identified for the focal forest habitat from the European biodiversity conservation network that used 65 in situ habitat maps. Biswas et al. (2009) established a unified framework for the rehabilitation of Southeast Asian mangrove, particularly for the Chokoria mangrove forest belt of Sundarban in Bangladesh. Due to uncontrolled anthropogenic activities such as salt forms and shrimp cultivation in the forest has been degraded completely. To establishment some

[13] Method to assist decision-making in different situations involving multiple criteria. See Store, R. and Jokimaki, J. (2003), "A GIS-based multi-scale approach to habitat suitability modeling", Ecological Modelling, 169: 1-15.

restoration planning, they have addressed the economic, social and ecological issues simultaneously. Their argument is that ecological issues are the mostly important than the economic and social issues in the successful rehabilitation planning. They have also suggested to enhance the community participation for minimizing unwanted human disturbance.

1.3 Definition and Rational of the Study:

Sundarban is a dynamic and vibrating ecosystem along the boundary of India and Bangladesh, which formed by the interaction of land, water and dense vegetation. It has considered as the most productive wetlands in the world, but this important Transboundary ecosystem are now fragile condition due to climate change. The region has also considered as a magnificent Delta oriented climate change hotspot that influence the livelihoods and lives both of the local inhabitants. The area is the land of 12 million inhabitants likely depend on a natural resource in Sundarban. The IPCC report (4^{th} assessment, 2007) predicts that the changes of climatic variable will intensify extreme water events (salinity intrusion, sea level rise, temperature and high rainfall and land erosion) and storm surges along the Bay of Bengal. It will affect the livelihood activities like agriculture, fishery (aquaculture and fishing) and animal husbandry to a great extent. The rehabilitation and re-establishment of mangrove species must be necessary for their future sustainability of local livelihood.

1.4 Objectives of the Study:

The study will examine the relationship between climate change, changing livelihood and planning for forest conservation. The main goals of this study are,

- **a.** To highlight the impact of climate change effects on the dynamics of Transboundary mangrove ecosystem.
- **b.** To find the changes in natural resource-dependent livelihood patterns of the adjacent inhabitants.
- **c.** To identify the suitable zone for mangrove restoration and proposal for other management option.

1.5 Research Questions:

The research questions that the study will undertake are the following:

a. What is the effect of climate change on mangrove dynamics and mangrove vulnerability?

b. What is the livelihood pattern of people in mangrove regions?

c. How does climate change influence a Trans-boundary mangrove ecosystem?

e. What management strategies are suitable for coping with climate change in mangrove areas?

1.6 Hypothesis:

The main hypothesis is:

Climate change has an impact on mangrove dynamics that affect livelihood patterns.

1.7 Methodology:

The study basically emphasized on the changing climatic components and their effects on the mangrove ecosystem and subsequent effect on dependent livelihood in Sundarbans. The methodology of the present study have been divided into different sections (fig. 1.2). These are,

1.7.1 Analysis of the Climate Change Components:

To find the changing pattern of climatic components in Sundarbans, various primary and secondary data has been used in the present study. The study considers five climate change components that signify the region is a 'climate change hotspot' (Haq 2010) that may cause for the dynamics of mangrove ecosystem and make more vulnerable as a deltaic or coastal ecosystem. The study refers three climatic components (such as air and sea surface temperature, precipitation and monsoonal pattern) and three physio-chemical components (such as sea level rise, salinity regime, and ocean circulation pattern, storm and depression) has been studied.

Various statistical and cartographic techniques has been used to analyze the changing future trends of these climatic components. Therefore, used statistical techniques has listed in table 1.2.

Table 1.2 Used statistical techniques representing climate change components

Climate change components	Statistical techniques
Rising air and sea surface temperature	Moving average, correlation, and regression
Changing rainfall and monsoonal pattern	Regression, moving average
Sea level rise	Regression
Salinity regime	Correlation
Increased frequency of storm, frequency	Regression

1.7.2 Mangrove Dynamics Analysis:

In the context of climate change and subsequent sea level rise, Sundarbans mangrove ecosystems are now more vulnerable and less resilient. The dynamics of the mangrove areas has been analyzed by land use and land cover changes (by supervised classification), Normalized Difference Vegetation Index (NDVI= NIR band-Red band/ NIR band + Red band), prone to erosion and accretion (change detection), and vulnerability in embankments. The all analysis has been developed by using Arc-GIS and ERDAS Imagine software and satellite images. NDVI signifies the canopy closure, forest density and health of the mangrove.

1.7.3 Trans-boundary Vulnerability Analysis:

The vulnerability assessment methodology was devised to identify the fundamental components of the mangrove ecosystem that may be experiencing climate change and sea level rise impacts, and which were also most vulnerable to their related impacts.

Table 1.3 Vulnerability dimensions and their components

Vulnerability dimensions	Component
Exposure	Sea level rise trends
	Tidal range
	Type of sediment supply
	Precipitation change
Sensitivity	Mangrove health
	Retreat of seaward edge
	Mangrove area reduction
	Within the mangroves elevation
	Net accretion rates
	Adjacent ecosystem resilience
Adaptive capacity	Status of mangrove protection
	Stakeholder involvement
	Local management strategy
	Elevations above mangrove zones

However, the assessment are basically based on three dimensions. These are sensitivity, exposure and adaptive capacity dimensions. Also, this vulnerability dimensions also calculated by different components that provided in table 1.3. On the basis of these components criteria based rank has developed for each vulnerability extent. The ranks 4 is high vulnerability and 1 is low vulnerability and final results were averaged to present an overall vulnerability rank of trans-boundary mangrove ecosystem. The vulnerability analysis has been calculated by,

$$V_r = \frac{S_r}{N}$$

Where, V_r indicates the vulnerability rank, Sr refers the total rank score of the components, and N signifies the no of completed components.

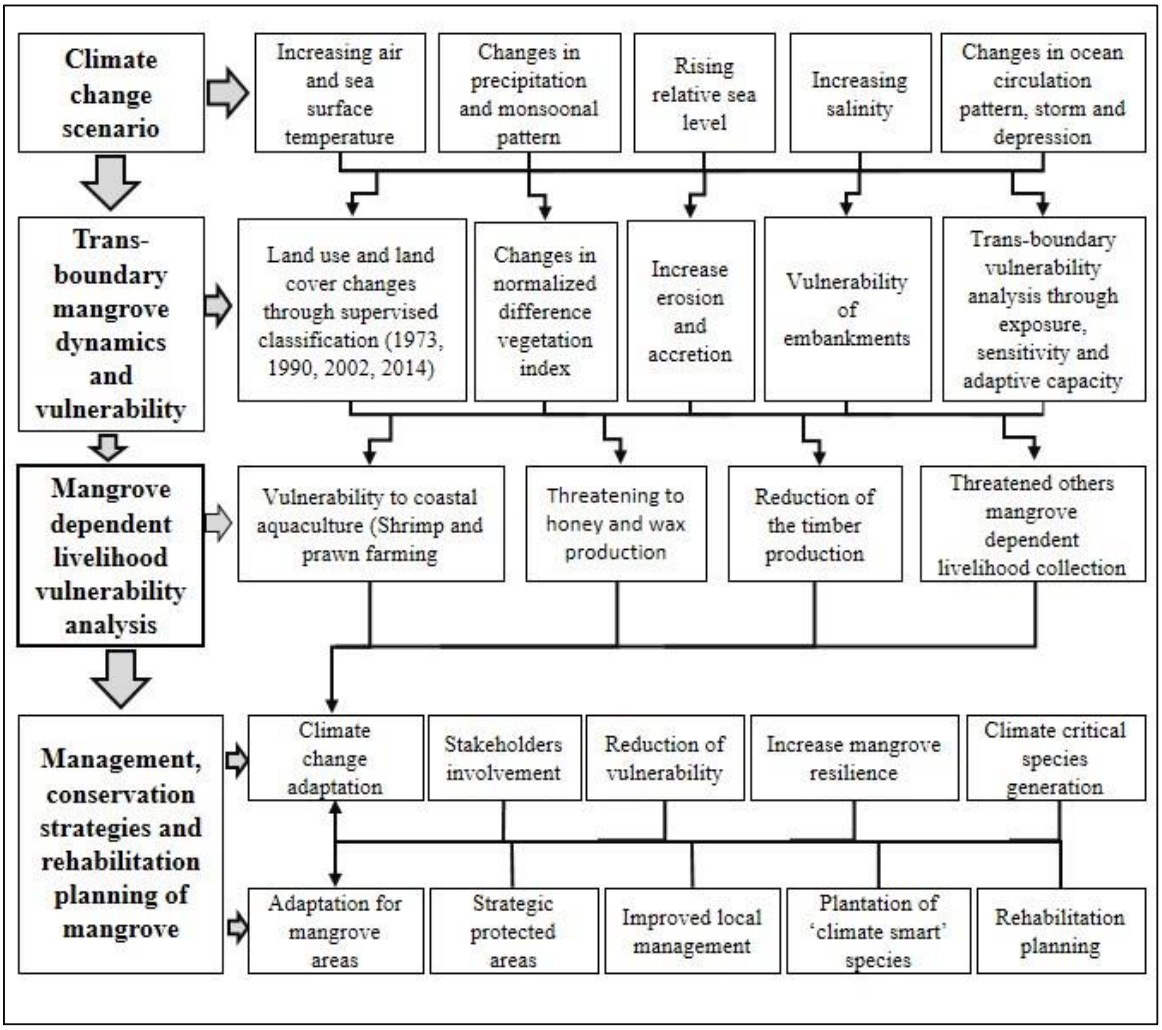

Fig. 1.2 Framework of the methodology in the present study.

1.7.4 Analysis of Changing Livelihood Pattern:

The objective can be analysed by the collecting of household sample survey through questionnaires schedule and literature search about the mangrove dependent livelihood pattern in Sundarbans. Apart from the sample survey, in-depth interview and different informal discussion were held with NGOs, social worker, panchayat and offices. After the collection of these data represent the temporal trends of livelihood collection and changing livelihood pattern that may help to find the appropriate causes of changing livelihood pattern.

1.7.5 Species Rehabitation Modelling:

To find the suitable location for the establishment of threatened mangrove species, habitat suitability modelling has been developed. The suitable location was developed for three

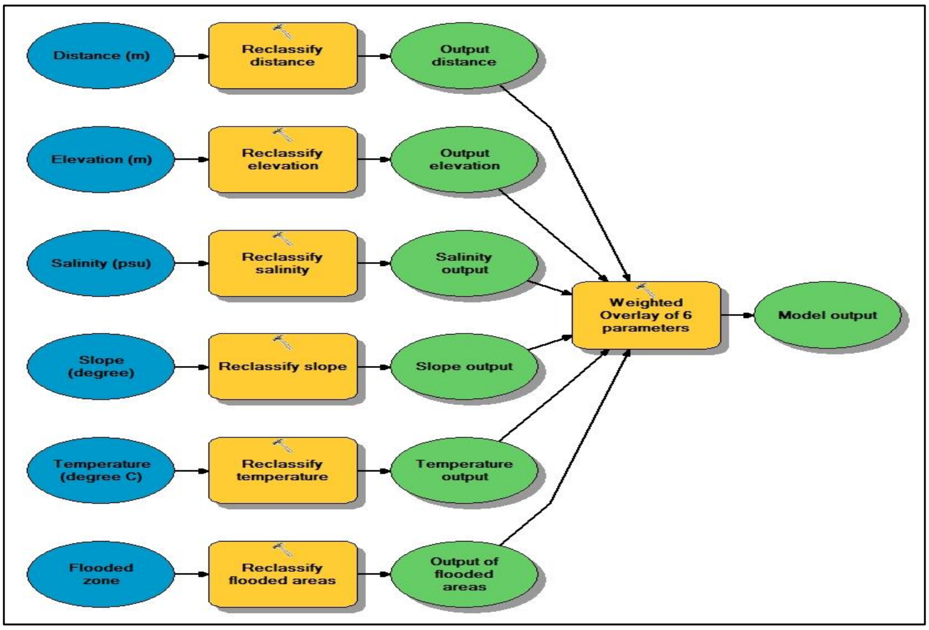

Fig. 1.3 Methodological flow diagram of Habitat suitability modelling in Arc GIS model builder toolbox

threatened mangrove species such as Heritiera fomes (Sundari), Excoecaria agallocha (Gewa), Ceriops decandra (Goran) etc. The suitable index calculated and mapped by model builder toolbox in Arc-GIS software (fig. 1.3). Several thematic maps such as salinity, temperature (using satellite images), slope, elevation, flooded areas, and drainage buffer (using DEM data) map has used for the fulfillment of this model. Different categories of this thematic layers were ranked or rated into habitat (mangrove species) values by assessing HQR (habitat quality rating) based on their suitability and preferences (table provided in details in chapter 5, section 5.4) on a scale 1-4 in increasing order of suitability (value 4 assigned to highly suitable location for mangrove species while 1 to least suitable location). The drainage buffer map were prepared on the basis of the measurement of Euclidian distance. Then reclassify all thematic layers and give them a weightage. After rating all criteria based thematic layers classified into three suitability classes, a suitability modelling was run to find the district wise suitable location for three threatened mangrove species.

1.8 Data Sources:

The data for the establishments of the above mentioned objectives collected from different primary and secondary sources. Different types of data sources are as follows (table 1.4):

Table 1.4 data sources in the present study

Data type	Dataset	Source	Year
Satellite image	Landsat MSS, TM, ETM, ELM	USGS Earth explorer	1973, 1990,2002, 2014
DEM data	ASTER[14], SRTM[15] data	USGS[16] Earth explorer	2014
Climatic data	rainfall, storms and other events	Indian Meteorological Department, Indian Institute of Tropical Meteorology, literature survey	1955-2014
Climatic data	Salinity and temperature	Extracted by Arc-GIS (provided by USGS manual)	2014
Sea level data	Tidal gauge	Permanent Service for Mean Sea Level (PSMSL)	1955-2014
Socio-economic	Population, economic activities, livelihood problems	Census of India(2011), Questionnaire sample survey	2014
Livelihood and forest data	Dependent livelihood, livelihood problems	Sundarban forest department (West Bengal and Bangladesh)	2000-2014
Drainage characteristics	Digital Elevation Model (DEM)	USGS Earth explorer	2014

[14] Advanced Space borne Thermal Emission and Reflection Radiometer
[15] Shuttle Radar Topography Mission
[16] United States Geological Survey

Chapter-2

Climate Change Impacts on Mangrove Ecosystem

Recently, climate change resulting in natural disaster like tsunami, increase susceptibility to sea-level rise, heat waves, cyclones, salinity intrusion, increasing atmospheric and sea surface temperature, changes in rainfall, continuous reduction of flora and fauna impact on the biodiversity is the global issue from the perspective of wildlife conservation and management along the coastal region (Ding and Nunes 2013). Of all the climate change results, the relative sea level acceleration, and atmosphere's composition has the most significant threat to mangrove ecosystem, and also other related tidal wetlands (Ellison and Stoddart 1991, Field 1995, Duke et al. 2007). Although, anthropogenic activities (such as, filling, and conversion of aquaculture) has a greater role, than climate change components (IUCN 1989, Ellison and Stoddart 1991, Field 1995, Primavera 1997, Alongi 2002). Therefore, relative sea level rise is now a substantial cause for the reduction of mangrove area, and forest health with other tidal wetland ecosystems (IUCN 1989, Primavera 1997, Ellison 2000, Mc Leod and Salm 2006, Cahoon and Hensel 2006, Gilman et al. 2007).

Mangrove areas have established in the subtropical and tropical low gradient coastlines and intertidal lowlands of Delta and estuaries (Parida et al. 2005). Mangrove perform valued site-specific and regional functions (Lewis 1992). Reduced mangrove area, and their health will effects to the shoreline development from coastal hazards (such as, flooding, erosion, storm surge and waves, and most recently occurred 2004 Tsunami of Indian Ocean) and the threat to human safety (Dahdouh-Guebas et al. 2005, Kathiresan and Rajendran 2005, Danielsen et al. 2005). Mangrove reduction will also deteriorate the coastal water quality, eliminate Crustacean nursery and fish habitat, reduce biodiversity, adversely influence adjacent coastal habitat, and reduce mangrove oriented services and products for human communities (Ewel et al. 1998, Nichols et al. 1999, Mumby et al. 2004, Walters et al. 2008). Mangrove loss may also exacerbate global warming and climate change trends, release extra quantities of carbon quantities to the atmosphere.

The relative sea level acceleration is not at a uniform rate throughout the world. The rate depends on regional configuration and local influences (Solomon et al. 2007). India and Bangladesh have been identified most vulnerable among selected 27 countries that are vulnerable to climate change induced sea level acceleration (UNEP 1989). The higher vulnerability of the India and Bangladesh coastal lands can be attributed to high population density, extensive low-lying coastal slope, high rate of coastal degradation, and pollution, and frequent occurrence of storm and cyclonic activity (Mitra et al. 2013). High water events and storm surge is the major contributing factor of climate change that has significant adverse effect on the coastal ecosystem (Church et al. 2004). Projected increase in high water events, and cyclonic activity (Church et al. 2001) could effects mangrove composition and health due to changes in inundation level, salinity and wetland sediment budget (Church et al. 2001, Gilman et al. 2006). Precipitation, sea level rise, and storm induced flooding can reduce the photosynthesis activity, productivity and survival strength (Ellison 2000). Inundation is also decreased the strength of mangrove leaves to photosynthesize and to conduct water (Naidoo 1983). Inundation of lenticels may decrease the oxygen concentration, resulting in death destruction of mangrove trees (Ellison 2004). Global climate change, more specifically changes in co_2, precipitation and monsoonal pattern, temperature, sea level, hurricane and cyclonic storms, and combined with anthropogenic causes, will affects the resilience of coastal mangrove (fig. 2.1). In the context of climate change, the response of mangrove does not occur in isolation, it is the net result of all climate change effect acting synergistically.

2.1 Effects of Changing Climatic Factors:

2.1.1 Impacts of Ambient Temperature Change:

2.1.1.1 Temperature Change Scenario:

Global mean atmospheric temperature has increased which is about 0.74° C (±0.18° C) in between 1906 and 2005 (Solomon et al. 2007). In the last fifty years, the average warming trend is nearly twice (0.13° C/decade) in respect to the last 100 years.

However, this globally averaged rising temperature is considered due to the observed increasing anthropogenic greenhouse gas concentration since the mid-20th century (Solomon et al. 2007). Projected global averaged atmospheric temperatures 1.1° C to 6.4° C in between 1980 and 2099 (Solomon et al. 2007). The rise of air temperature also is not uniform around Asia. The expected rise of temperatures are 3.3° C in the Southern part of Asia, 2.5° C in the Southeastern part of Asia and 3.7° C in the central part of Asia. According to different climate models, the projection of temperatures over the Asia-pacific regions are high rising rate in the 21st century, were estimated temperature in tropical South Asia will be 2.1° C in 2070 (Preston et al. 2006).

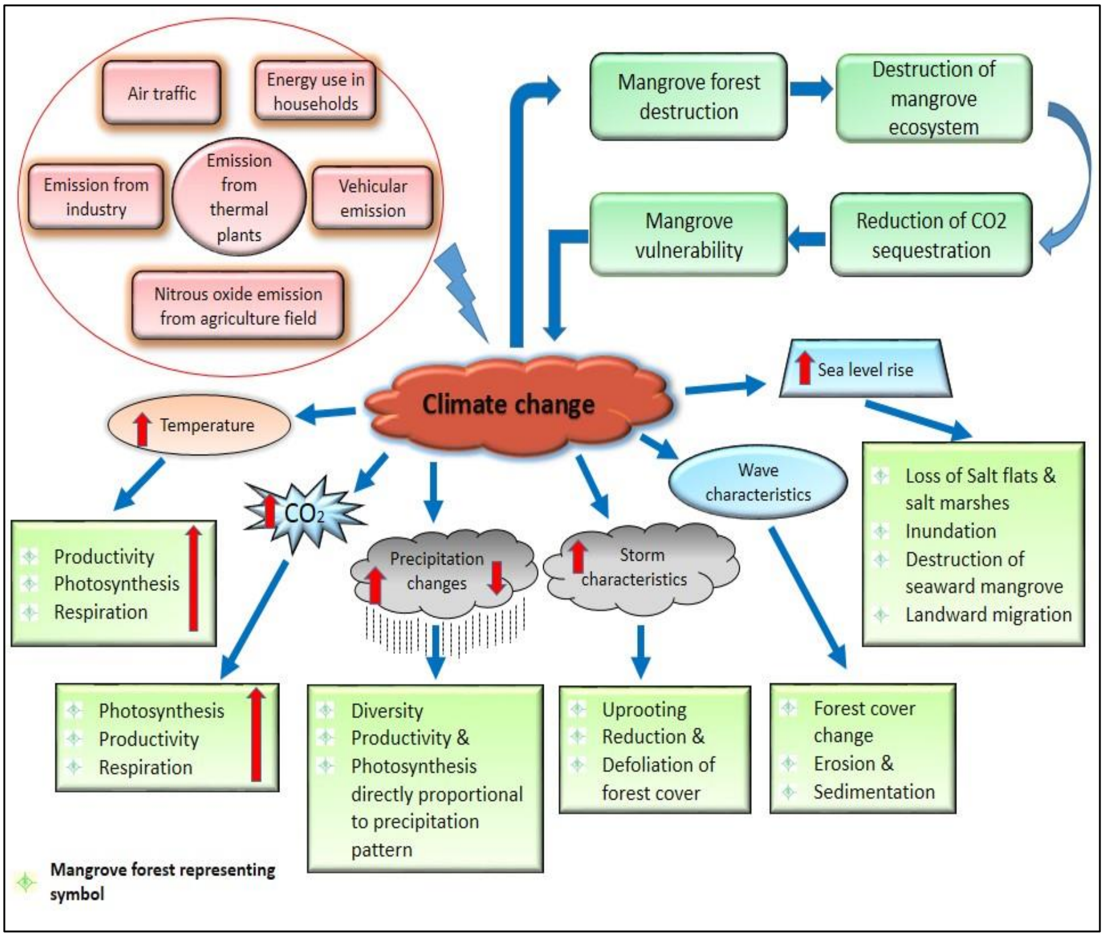

Fig. 2.1 Schematic representation of climate change effects and predicted impacts on intertidal mangrove ecosystem. The downward and upward arrows respectively represented the decrease and increase in various physiological, physiographic and climatic factors (Source: Parida et al. 2014.

Sundarban Ecosystem is experiencing extreme and extended summer season and relatively shorter winter over a long period. The study of 1990 to 2000 reveals that the changes of temperature has found from 1965 to 2000 that clearly indicates, there is a gradual and clear rise in ambient air temperature in the total area of Sundarbans. The observable rise of surface temperature may affect the overall socio-economic structure as well as different kind of physical process. A study over Sagar Island (as a part of Sundarbans, India) from 1891 to 1970. The average daily minimum temperature and daily average temperature has increased by 0.6°C and 0.1°C respectively. The growing trend of daily minimum temperature is faster than the daily maximum temperature that indicates the gradual decrease in diurnal temperature range (Mishra 2010). The trend of temperature change has well demarcated in 1970 it has been more prominently marked after 2000 (table 2.1 and fig. 2.2a, 2.2b, 2.2c).

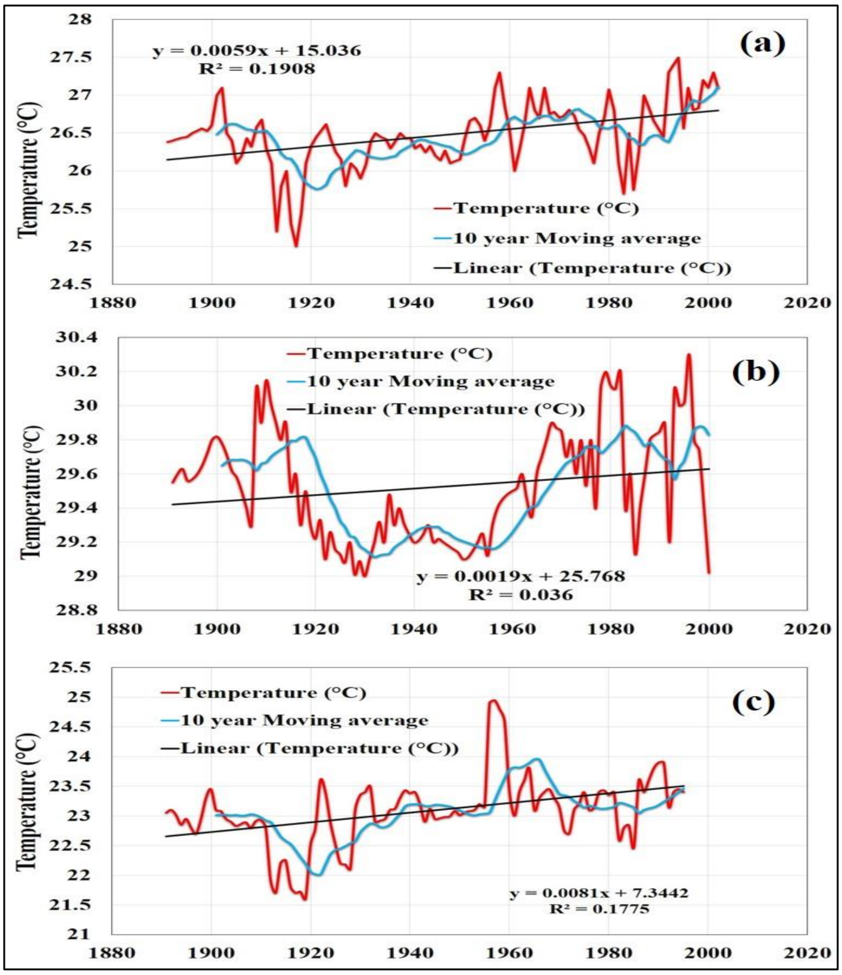

Fig. 2.2 (a) Mean daily average (1891-1987), (b) mean daily maximum (1891-2003), and (c) mean daily minimum (1891-1992) air temperature of Sagar Island in Indian Sundarbans (Source: Mishra 2010).

Air temperature in the Bay of Bengal comprise a significant increasing rate is about 0.019° C per year (fig. 2.3a). This similar type of trend have also observed in the total area of Sundarbans. If the changing trends holds continues the air temperature will arrive is expected to 1° C by 2050 in this study area (Hazra et al. 2002). The annual average atmospheric temperature has investigated from 2002 to 2009 at the Haldia station (India). The average temperature calculated from the daily minimum and maximum temperature recorded by the IMD (Indian Meteorological Department). The calculated annual mean temperature changes significantly, where the temperature varied from 27.093° C (2004) to 28.145° C (2009), and the increasing trend is 0.106° C per year (fig. 2.3b). However, the growing trend of temperature is depicted at an alarming rate of one-degree centigrade in a decade. The anomaly of temperature found due to the presence of industrial hub that forms a local heat pool in the adjacent atmosphere.

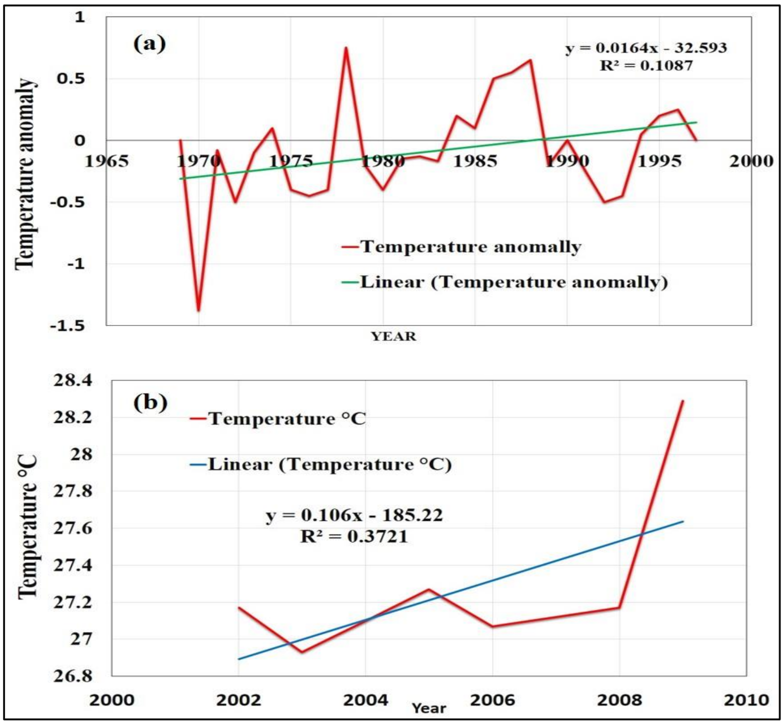

Fig. 2.3 Anomaly of air temperature over 85°E - 90°E and 20°N - 25°N reveals an increase of air temperature 0.019° C per year (a), Annual mean atmospheric temperature of Haldia (2002-2009) near Sundarbans (b) (Source: Hazra et al. 2010).

Table 2.1 Recorded air temperature of Sagar Island (Indian Sundarbans)

Period	Average daily minimum (°C)	Average daily maximum (°C)	Average daily (°C)	Diurnal range (°C)
1891-1930	22.935	29.658	26.296	6.723
1931-1970	23.510	29.249	26.379	5.739
1971-2002	23.660	29.471	26.545	5.811

(Source: Mishra 2010)

2.1.2 Impact on Mangroves:

The optimum temperature for photosynthesis of mangrove species is 28° C to 32° C (Clough et al. 1982). Mangrove seedling, and root structures are affected by higher than 35° C atmospheric temperature (UNESCO 1995) and the temperature higher than 25° C reduced the leaf formation for some mangrove species (Saenger and Moverly 1985). The photosynthesis of all mangrove species is ceased when the leaf temperature exceeds 38° C (Andrews et al. 1984, Clough et al. 1982). However, the mangrove may tolerate a high temperature where it has located near the power station effluents (Canoy 1975, Banus 1983). However, increased atmospheric temperature affects the mangrove by change of;

1. Species composition changes,
2. Phonological[17] pattern changes (e. g, finishing of fruiting and flowering)
3. Increases the mangrove productivity where find the optimum temperature but exceeding an upper threshold limit signify the low mangrove production.
4. Areal expansion and suitable physiographic condition of mangrove is also depended on the temperature where other factors are less important (Ellison 2000).

The intensity, duration and frequency of extreme cold events may explain the latitudinal limits of tropical mangrove distribution (Snedakar 1995). Biogeochemical process in soils and plants has changed due to increasing temperature of air and water, with both photosynthetic and respiration carbon gain being affected (Andrews and Muller 1985, Lovelock and Ellison 2007). However, increasing atmospheric temperature may change significantly in net primary productivity of mangroves. However, increased sediment temperature may be caused by multiplication of bacteria and increase growth rate, resulting in the increase of nutrient regeneration and recycling (UNEP 1994) of mangrove (through microbial decomposition). Rainfall along with decreased humidity, when combined with increased temperatures, may reduce photosynthetic activity and productivity at the time of the higher temperature of a day in lower latitudes (Lovelock and Ellison 2007). Thus, it is confirmed that the increasing air temperature will change and adversely affect the intertidal mangrove ecosystem.

[17] Phenology is the study of animal life and periodic plant cycle events, how these are influenced by inter annual and seasonal variations in climate

2.1.2 Impact of Precipitation and Monsoonal Pattern:

2.1.2.1 Precipitation and Monsoonal Pattern:

Globally, the total amount of precipitation is predicted to the increase will be 25% by 2050 in response to present climate change. Also, the regional distribution of precipitation more specifically rainfall pattern will be uneven and changes dynamically (Houghton et al., 2001). In the assessment of IPCC, southern, northern and central Asia is mostly affected due to significant increases in Rainfall.

In the Sundarban, maximum rainfall occurs mainly during monsoon season (south-west monsoon) in the month of mid-June, and it withdraws during mid-October. Within monsoon season, August receives the highest rainfall that is about 21-22% of the total annual precipitation. There is a significant change at the time of recession of monsoon and onset in south Bengal with specifically in Sundarban region. The average annual rainfall in this region is very high is about 1625 mm but at the time of high rainfall years the average amount may exceed 2000 mm and low rainfall years may exceptionally drop to 13 mm. (fig. 2.4a). The analysis of the rainfall data over a period of the last decade of the 20^{th} century (1990-1999) have received increasing trend of monsoon rainfall especially post monsoon (retreating monsoon) season. The study of WMO recommended method where mean 30 years successive rainfall from 1891 to 2000 shows that the trend of

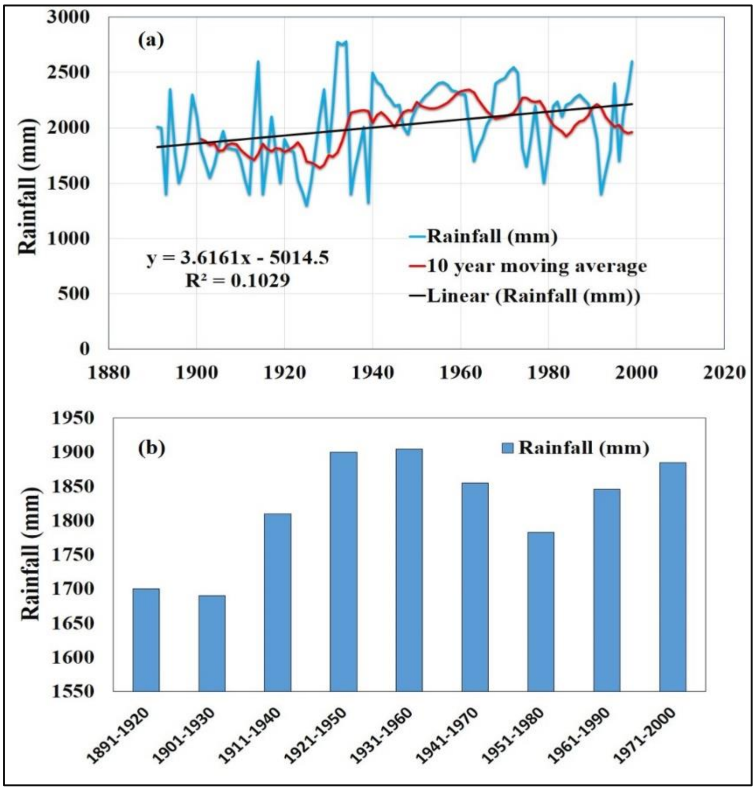

Fig. 2.4 Rainfall trend from 1891 to 1991 in Indian Sundarbans (a), mean rainfall of 30 successive years in Sundarbans (b) (Source: Mishra 2002).

rainfall is increasing during the last three successive mean periods (fig. 2.4b). In Sundarban, rainfall in the most significant aspect to the distribution and development of aquaculture, fishing and agriculture as well as other economic activities. Another observation of Hazra et al (2010) analyzes the trend of monsoon rainfall, and the rainfall of Bay of Bengal area over 2003 to 2009 time period by using TRMM (Tropical Rainfall Measuring Mission) satellite data. The analysis of annual data has been noticed that the annual rainfall over the Bay of Bengal has been increased during the study time (fig. 2.5a). The study is evident that the monsoonal rainfall also has increased significantly at the rate of 0.0041 mm per hour in the Sundarban region (fig. 2.5b).

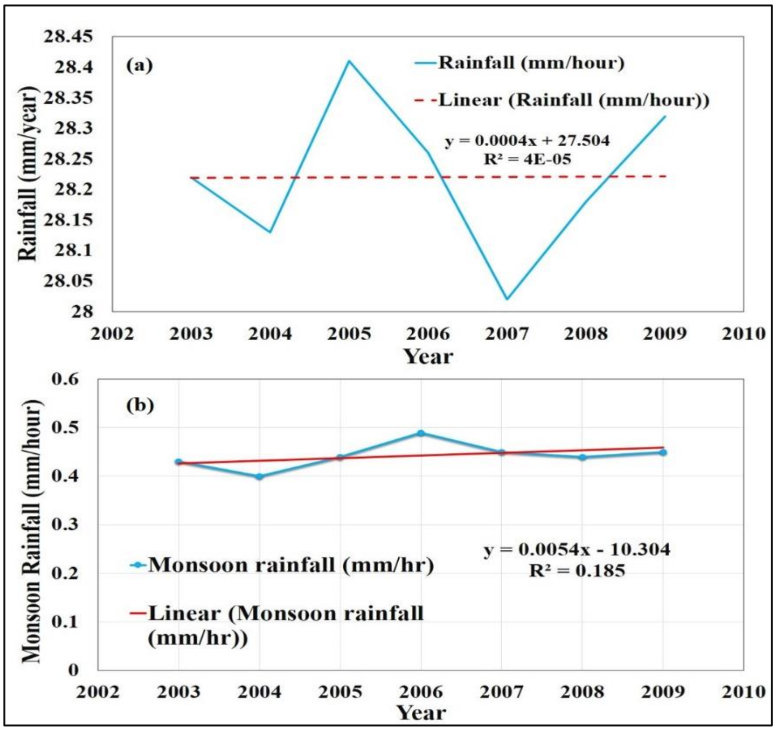

Fig. 2.5 Increasing rainfall (a), Increasing Monsoonal rainfall (b) over Bay of Bengal at the period of 2003 to 2009 (Source: Hazra et al. 2010).

b. Impact on Mangroves:

Changes in rainfall patterns are mostly expected to affect spatial distribution and growth of mangrove (Ellison, 2000). Increasing evaporation and decreasing rainfall will decrease the growth, net primary productivity and seedling survival of mangrove due to increasing salinity. The increasing salinity also can influence to the altering completion between different mangrove species, reduction of a mangrove area by the conversion of tidal zones to halophytic mud flats as well as decrease the diversity of mangrove habitat. Field (1995) observed that the link between rainfall trends, and habitat condition where signifies that increasing soil salinity will have increase the salt level of mangrove tissue, finally reduces the productivity of that habitat (Field, 1995).

Decreasing precipitation can affect in the mangrove encroachment into freshwater wetlands and salt marsh (Rogers et al., 2005). On the other hand, increasing rainfall will influence the increased biodiversity and growth rates, increased diversified mangrove zones and increased the mangrove areas (Duke et al., 1998). Areas with intense rainfall have a greater degree of mangrove productivity and diversity due to a huge supply of fluvial nutrients and sediments, reduced exposure to low salinity and sulfate (McKee 1993, Ellison 2000).

2.1.3 Impact of Increasing Surface Water Temperature on Mangroves:

2.1.3.1 Surface Water Temperature:

The water temperature in the eastern and western part of Sundarban has increased significantly for both during Monsoon and pre-monsoon seasons (fig. 2.6a). The rate of surface water temperature in the western part of Sundarban (Indian part of mangrove ecosystem) have risen 6.14%, and eastern part (Bangladesh part of this ecosystem) is about 6.12% from 1978 to 2008 (over past 30 years). This rising trend indicates the change approximately is about 0.5° C per decade (Mitra et al. 2009).

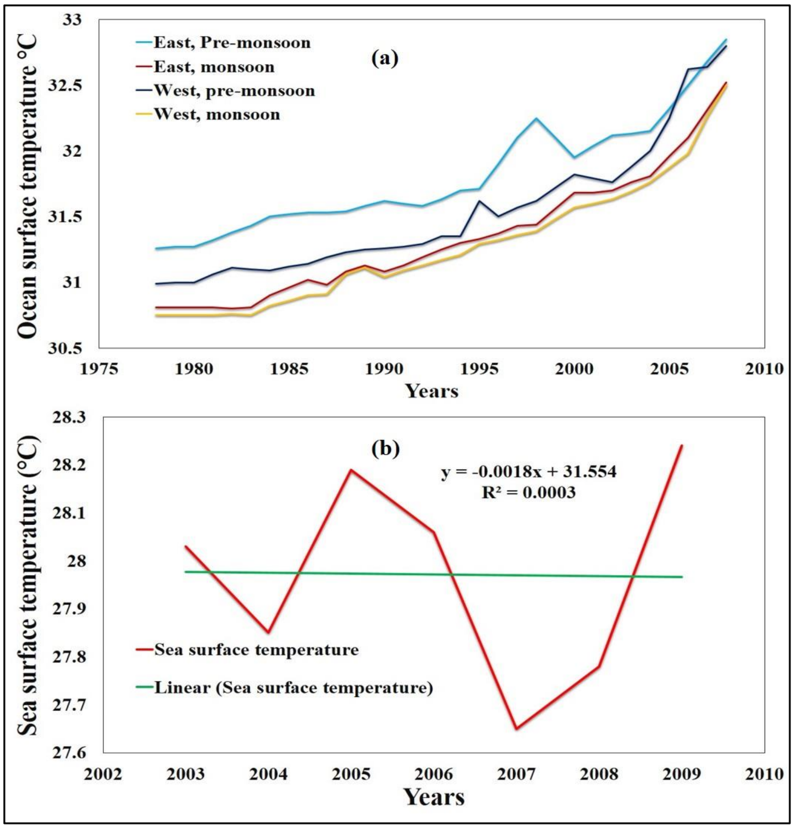

Fig. 2.6 Trend of Sea surface temperature in Eastern and Western part of Indian Sundarban (Mitra et al. 2009) during monsoon and pre-monsoon season (a), Annual composite Sea surface temperature of Bay of Bengal (Hazra et al. 2010) From 2003 to 2009 (b).

According to Hazra et al. (2010) the annual composite ocean temperature on the western side (near Sagar Island) of Bay of Bengal in between 2003-2009 varies significantly by using MODIS sea surface temperature data. The amount of sea surface temperature is about 28.02° C in 2004 and 29.381° C in 2009 where the rate is 0.0453° C per year (fig. 6b). This observed rate also is similar to the Singh (2002) study that estimates previously is about 0.4° C to 0.5° C in a decade over Bay of Bengal which is seven times greater than the recent global warming rate of 0.006° C per year .

2.1.3.2 Impact on mangroves:

The gradual increase of ocean surface temperature has directly related to severity and increased the frequency of cyclonic depression and storms in the Bay of Bengal. The increasing trend of sea surface temperature may results in the decreased the dissolved oxygen level, leading to ocean acidification and the changes in the chemical composition of ocean water. This alarming temperature change in the Sundarban region makes one of the "worst climate change hotspot"[18] in the world (Haq 2010) which makes a significant challenge for fauna and flora survival in this ecosystem.

2.2 Effect of Changing Physio-Chemical Variables:

2.2.1 Impact of Sea Level Rise on Mangroves:

2.2.1.1 Sea Level Rise Scenario:

Sea level rise is one of the most certain outcomes of climate change. The changes in sea level have influenced by isostatic and tectonic adjustments like land subsidence, emergence and ocean basin deformation (Kennish 2002). Basically sea level change has been estimated by tidal gauges at various locations around the world, which are not evenly distributed and does not provide a precise and accurate information about the world pattern of sea level rise (Cabanes et al. 2001). The rate of sea level changes on different Coasts may be significantly varied from global average sea level trends due to regional and global subsidence/ uplift. Regional sea level fluctuation is affected by tectonic activities and movements that can cause for the upliftment and subsidence of land. Human induced and naturally occurring sediment compaction may also accelerate the impacts of rising sea level. Also, global projected, and recent rising sea level mainly

[18] See Haq, S.A. (2010), "Impact of climate change on "Sundarbans", the largest mangrove forest: ways forward", 18th Commonwealth Forestry Conference 2010, Edinburgh

caused by ice melt is adding and expanding oceans. However, the estimated global average sea level rising trends are 1.0 – 2.0 mm per year during the 20th century (Houghton 2001), but in the 21st century, global average sea level prediction varies between 0.09 and 0.28 m (Houghton 2001, Kennish 2002).

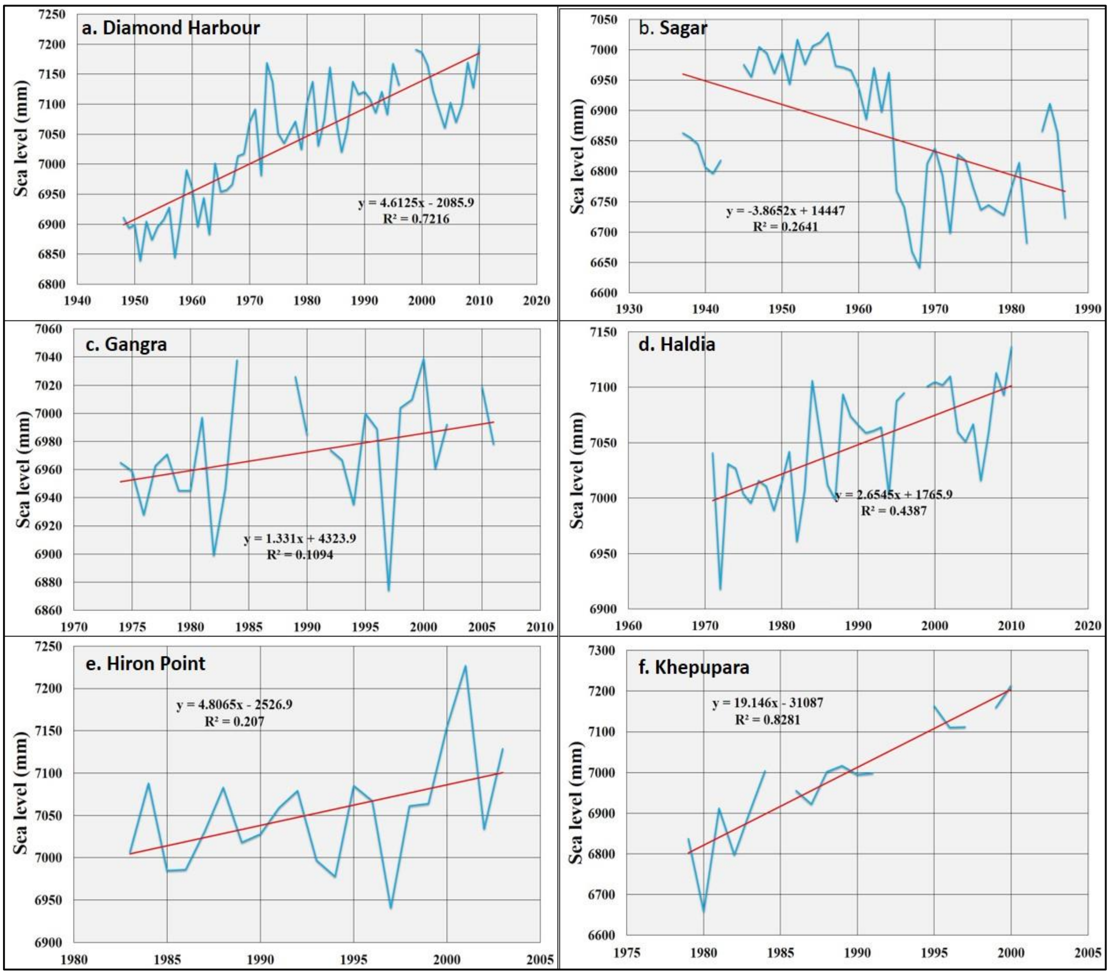

Fig. 2.7 Annual mean sea level rise scenario of (a) Diamond Harbour, (b) Sagar, (c) Gangra, (d) Haldia tide gauge stations in Indian Sundarbans and (e) Hiron Point, and (f) Khepupara tidal gauge stations in Bangladesh Sundarbans.

In the Sundarbans and its surroundings, total six tidal stations have been found with complete or near complete tide records to the analysis of sea level rise trends. These stations are Diamond Harbour, Sagar, Gangra, and Haldia in the Indian part of Sundarbans, and Hiron Point and Khepupara in the Bangladesh part of Sundarbans. Fig. 2.7 and Table 2.2 shows the overall trends, and the interannual variation of the selected tide gauge stations and these variations found of all stations due to the force of onshore winds during the monsoon season, water salinity and the inflow of fresh water of all the main rivers all over the Sundarbans. Sarkar and Unnikrishnan (2007) attributed that the difference between the adjusted rate of 5.74 mm/year at Diamond Harbour and the average rate of Indian Ocean land subsidence is about 1.29 mm/year. Therefore, PSMSL (Permanent service of mean sea level) data of the selected six tide stations in Sundarbans were examined, where the average sea level rise ranges from 17.90 (Khepupara, Bangladesh) mm to 0.40 (Gangra, India) mm per year. Except Sagar, all of the sea level fluctuations are positive, where the Khepupara tidal station of the eastern Sundarbans (Bangladesh part) recorded higher sea level rise that is about 17.90 mm per year during the study period of 1979 to 2000. If the rising rate continues to increase, most of the areas are inundated within the present century. The rising rate also high at the Hiron Point tidal station of Bangladesh, which is about 6.10 mm per year during the study period of 1983 to 2003 (table 2.2). The Diamond Harbour tidal station also marked as a higher sea level rise and the fluctuation rate is increased from the

Table 2.2 Details about the sea level data used and results

Sl. no.	Stations	No of years of data used	Range of the years Used	Data gap within the collected data	Trend in mm/year	Value of R^2
1.	Diamond Harbour	62	1948-2010	1997,98	4.65	0.72
2.	Sagar	50	1937-1987	1943,44, 83	-2.80	0.26
3.	Gangra	32	1974-2006	1985,86,88,91, 2003,04	0.40	0.11
4.	Haldia	39	1971-2010	1997, 98	2.46	0.44
5.	Hiron Point	20	1983-2003	-	6.10	0.21
6.	Khepupara	21	1979-2000	1985,92,94,98	17.90	0.83

period of around 1975. In fact, the mean sea level fluctuation of Diamond Hourbar at this time have been increased due to the diversion of water into the Hooghly River from Farakka barrage.[19]

[19] Farakka Barrage located across the Ganges River, in the West Bengal (India), roughly 16.5 km from the Bangladesh border near Nawabganj Chapai District

Also, the trend (R^2) of sea level rise are most significant at Khepupara (0.83), Diamond Harbour (0.72) and Haldia (0.44) tidal gauge stations. However, the higher sea level rise, and lower surface elevation signifies that the areas of Sundarbans ecosystem are more vulnerable.

2.2.1.2 Impact of Sea Level Rise on Mangroves:

Mangrove ecosystem occurs between high tide elevations and mean sea levels (Fig. 2.8), making vulnerable condition through the changes of mangrove habitat with rising sea level. Mangrove species are preferred micro elevation which controlled by sensitivity and frequency of inundation along the intertidal low lying land. However, presently, the combination of local impacts (Human and natural) and global sea level rise that associated to land subsidence and erosion threaten to the mangrove existence across the world. The predicted effects of climate change induced sea level rise can be the utmost threat and more vulnerable to the mangrove ecosystem (Gilman et al. 2008). Mangrove ecosystem can exist with a rising sea level up to 0.9 – 1.0 cm per decade (Singh 2003), and more than 1 cm rate of sea level rise in a decade may be devastating impact on the species composition and distribution of mangroves (Singh 2003).

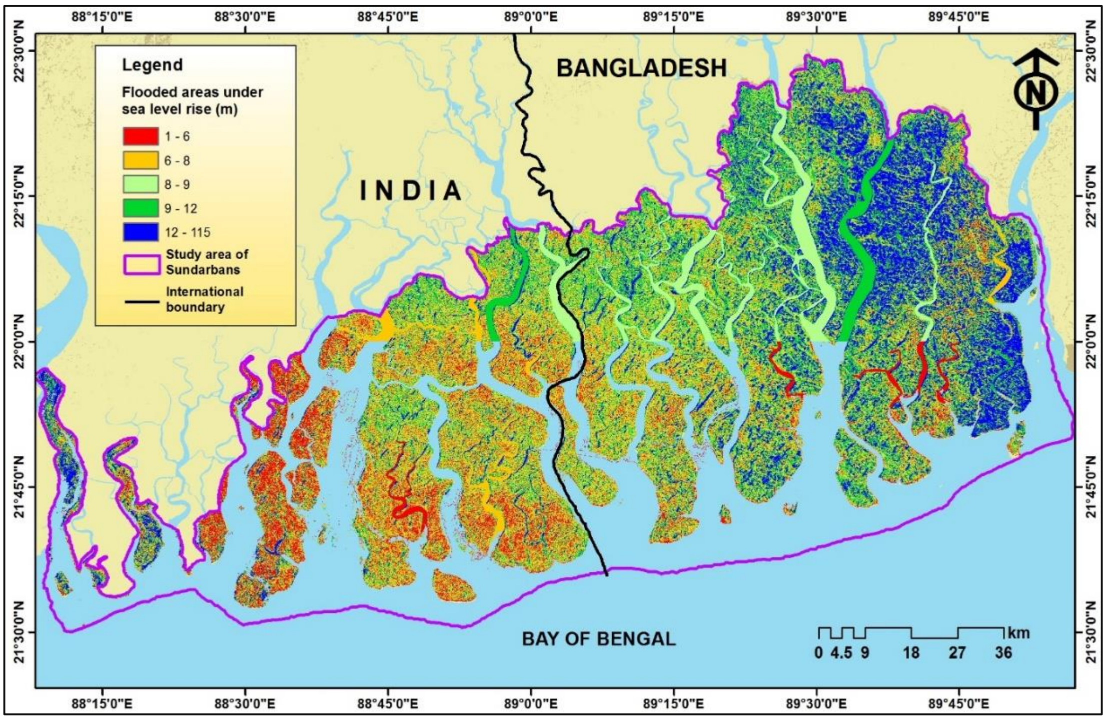

Fig. 2.8 Inundation areas under 6m, 6-8m, 8-9m, 9-12m and more than 12m sea level rise scenario over the sundarbans.

The increasing sea level also causes a serious threat to the mangroves and other coastal ecosystem due to erosion, excess flooding, and gracious exchange and nutrient cycling. The sea level rise will effect (the vertical increase of water level) to the limitations of landward margins, and the vertical increase of water column may create a water logging condition and causing death of mangroves (Jagtap et al. 2003). The WWF (world wildlife fund for nature conservation) has estimated that about 75 sq. Km area in the Bangladesh part of Sundarban mangrove are at risk or highly vulnerable due to the submergence in the future (Arefin 2011). During the last 25 years, 35 to 86 % of the mangrove area has been destroyed due to human activities (Gilman et al. 2008, Valiela et al. 2001). The anthropogenic activities are the major components of the global mangrove loss that is estimated likely 10 to 20 % per decade (Gilman et al. 2008). So far the anthropogenic stresses pose a significant threat to mangrove habitat as compared to the global sea level rise. However, the global mean sea level rise may predicted a significant loss of mangrove area in the future.

In the present study, shows the areas of inundation under sea level rise over Sundarbans where Indian part of Sundarbans mangrove are mostly affected due to a lower elevation where the maximum elevation varies between 0 and 6 m. On the other hand, the eastern part of Bangladesh Sundarbans are less affected due to their moderate slope and the elevation of many areas of that region have more than 12 m. The central portion of the study areas are moderately affected due to their moderate elevation but the coastal areas highly affected in the context of sea level rise (fig. 2.8).

2.2.1.3 Mangrove Responses to Sea Level Rise:

Mangrove ecosystem basically exists in active coastal areas which more influenced by wave action, tidal movements and catchment runoff including storm action and floods. In the last few decades, the area of mangrove changed significantly, and the mangrove destroy from the seaward side, which signify the impacts of sea level rise (Gilman et al. 2008).

In conditions where the net sediment accretion trends are lower than relative sea level rise, leads mangrove retreat landward side and the mangrove areas are more resilient when the sedimentation rates is higher in rising sea levels. In the context of sea level rise, mangrove ecosystems responses three different ways (table 2.3),

1. Stable relative sea level: Unchanged sea degree about the mangrove surface signify that the positions of mangroves is remained stable.
2. Falling relative sea level: falling sea degree about the mangrove surface may influence the seaward and lateral migration of mangrove margins if these areas are favorable for mangrove establishment.
3. Rising relative sea level: Rising sea degree about the mangrove sediment surface elevation may effect to the mangroves landward and seaward margins that retreat landward due to maintaining their suitable hydroperiod of all mangrove species.

Table 2.3 Mangrove shifting in the context of changing sea level.

Sea level rise conditions	Impact	Affected areas
Unchanged sea level about mangrove surface	Stable mangrove position	The areas that are located far from sea northern portion of Sundarbans
Sea level falls about the mangrove surface	Seaward migration of mangrove margins, expansion of land area	Near the sea margins and river estuaries, southern portion of Sundarbans
Sea level rises about the mangrove surface	Mangroves landward retreat from seaward margins, declining land area, soil erosion increase, and conversion of land use.	Near the oceans that also have a lower elevation and deltaic surface

The mangrove areas may also migrate and expand laterally from lower elevation areas to higher elevation areas. Environmental conditions for the establishment, and recruitment of mangrove species in new sectors which become available with rising sea level, include sediment composition and suitable hydrology, waterborne seeding availability and the composition with non-mangrove species (Krauss et al. 2008). The migration of mangrove from seaward margin to landward through the dieback of mangrove tree due to sea level rise induces stresses such as, increased salinity, very high depth, duration and frequency of inundation, and erosion resulting in falling of trees, and weakened root structures (Naidoo 1983, Lewis 2005, Ellison 2006). Mangrove migrated from seaward to landward via vegetative reproduction and seedling recruitment as new habitat through a concomitant change in salinity, erosion and inundation (Semeniuk, 1994). Some mangrove area is gradually reduced due to the presence of landward obstacles (e.g. roads, sea walls) and the slope of the adjacent area. Changes in mangrove margin also depend on a numerous condition other than sea level changes that are health and structure of mangrove. To predict mangrove responses, in the context of rising sea level, it is more important to determine that sea level is a predominant factor, or other factors are predominant to mangrove health and position. An observation of the relation between positive mangrove margin and changing sea level, sea level is the predominant factor in determining the migration of mangrove (Saintilal and Wilton 2001, Gilman et al. 2007).

In the context of rising sea level, sediment surface, and elevation of the mangrove is the predominant controlling factor to mangrove position, which has been shown by paleoenvironmental reconstruction[20] to past sea level acceleration (Ellison and Stoddart 1991, Ellison 2000, 2008; Berdin et al. 2003).

Mangrove resilience and resistance to sea level rise are the result of four combining components (fig. A2.2):

1) The trends of sea level change about the mangroves regional sediment surface effects on mangrove vulnerability.
2) Mangrove responses with the variation of species composition because species wise mangrove zones have different changing rate in sediment elevation (Rogers et al. 2005); some zones have more resilience and resistance to sea level rise. The changes have found due to their differential time required to colonize as a new habitat with changing sea level, and quick colonizer species may become a most dominant species (Lovelock and Ellison 2007).
3) The relative slope, and other physiographic setting of land that has currently occupied by mangrove and the presence of obstacles effects landward migration as well as resistance capacity of mangroves (Gilman et al. 2007).
4) The cumulative impacts of all stress factor that influence the mangrove resilience and resistance (Komar 1998).

[20] Paleo environmental reconstruction refers to the investigations of the undertaken environments to reconstruct the vegetation and climate of a specific place and time. See Berdin et al. 2003

However, the migration of mangrove towards sea (to fragile environment) often affects mortality, due to stresses induced by sea level rise such as depth and frequency of inundation, increasing salinity and erosion resulting in root structures are weekend and subsequently falling of mangrove trees (Naidoo 1983, Lewis 2005). The landward migration of mangrove via vegetative reproduction and seedling recruitment as a new habitat through salinity changes, inundation and erosion (Semeniuk 1994).

The Sundarban as a mangrove dominated deltaic region is affected by intense erosion and tidal inundation all over the islands. Therefore, mangrove afforestation[21] planning and programs are undertaken by the government on regular interventions to stabilize the erosion and mudflats encircling all of these islands. In the context of necessity space for mangrove planning, narrow width mudflats, and tidal creeks are basically avoided as less chance for mangrove expansion due to heavy erosion caused by the river and tidal waters along the delta or adjacent estuaries.

2.2.2 Effect of Salinity Regime:

2.2.2.1 Patterns Salinity Regime:

The polar and high altitudinal ice are melting as a result of recent climate change that effects in the intrusion of ocean water in the upstream area of connecting bays and estuaries. This condition can improve the physiological characteristics of fauna and flora inhabiting in the estuarine region. The increasing salinity may threaten the net primary productivity, seedling survival and growth of mangrove and change competition between inhabiting mangrove species (Snedakar 1995, Ellison 2000, 2004). The salinity changing pattern in the estuaries and the river mouths is a combining function of various factors like precipitation, sea level rise, evaporation, continental runoff and the volume of discharge freshwater from the barrage. The changing pattern of precipitation may alter the salinity level that can affect the spatial distribution and growth of mangrove (Field 1995, Snedaker 1995, Ellison 2000). The trend of decreasing rainfall, and increasing evaporation will increased the salinity level, which can decrease the growth, seedling survival, net primary productivity and the diversity of mangrove zones (Duke et al. 1998, Ellison 2004). The increasing salinity level also affects the conversion of upper tidal areas to hypersaline mud flats. The area with

[21] Mangrove forest restoration and the conservation planning has developed at Lothian Island, Bakkhali reserved forest and along the Bidya River (Dutta et al. 2013)

decreasing precipitation pattern also affect to a lesser amount of fresh water flow in the mangroves and a smaller amount of groundwater inputs in the mangrove area (Field 1995). The increasing soil salinity gradually increases the salt level of mangrove tissue and confined the water availability that reduced the mangrove productivity (Field 1995). Anthropogenic causes are also responsible for the alteration of subsurface soil salinity and groundwater salinity in the coastal regions (Subramanian 2000). However, climate change induced increased salinity reduces the mangrove area and species diversity with productivity along the coastal region. High salinity also increase the amount of sulfate in tidal water, and sea water may increase the anaerobic decomposition of peat (Snedakar 1995) and subsequently increase the vulnerability of mangrove with rising in relative sea level (Ellison and Stoddart 1991). The consequence of climate change induced increased groundwater salinity and the subsequent impact on mangrove diversity and productivity is represented schematically in fig. 2.9.

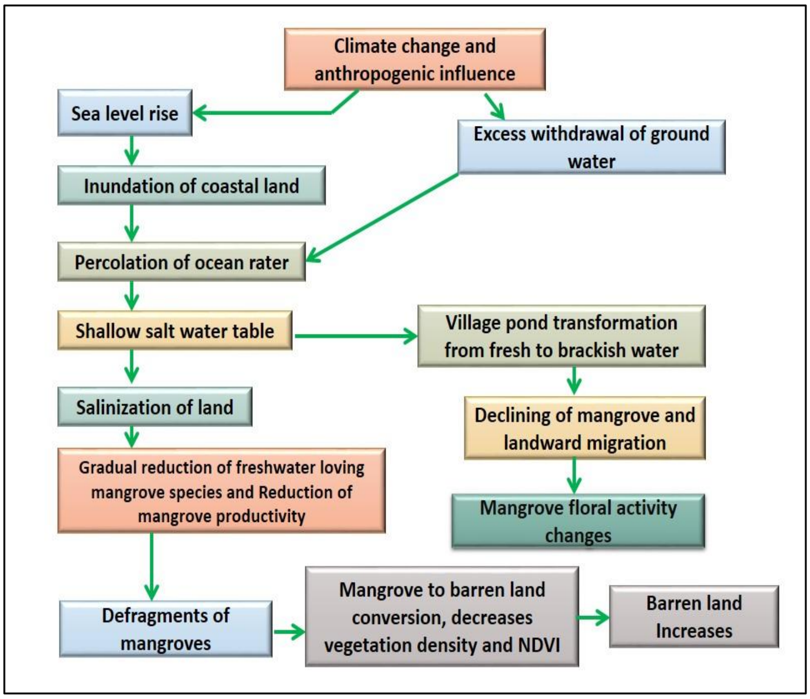

Fig. 2.9 Sea level rise impacts on mangrove ecosystem via ground water with salinity increases (Source: modified from Avijit Mitra)

The Sundarban region is the lowest landmass of the “Himalayan River Basin ecosystem”, so the aquatic salinity in the total region is highly dependent on the volume of ice melting, and freshwater flow coming from the upstream Ganges and Brahmaputra River. The volume of freshwater and subsequently annual salinity, changes with the nature of tide along the Ganga Brahmaputra delta. Salinity in the total Sundarban region, is influenced by the 6 river (Muriganga, Saptamukhi, Thakuran, Matla, Gosaba and Harinbhanga River) in West Bengal, India and the 7 river (Raimangal, Jamuna, Malancha, Arpangachia, Sibsa, Pasur and Baleswar River) in Bangladesh (Fig. 2.10).

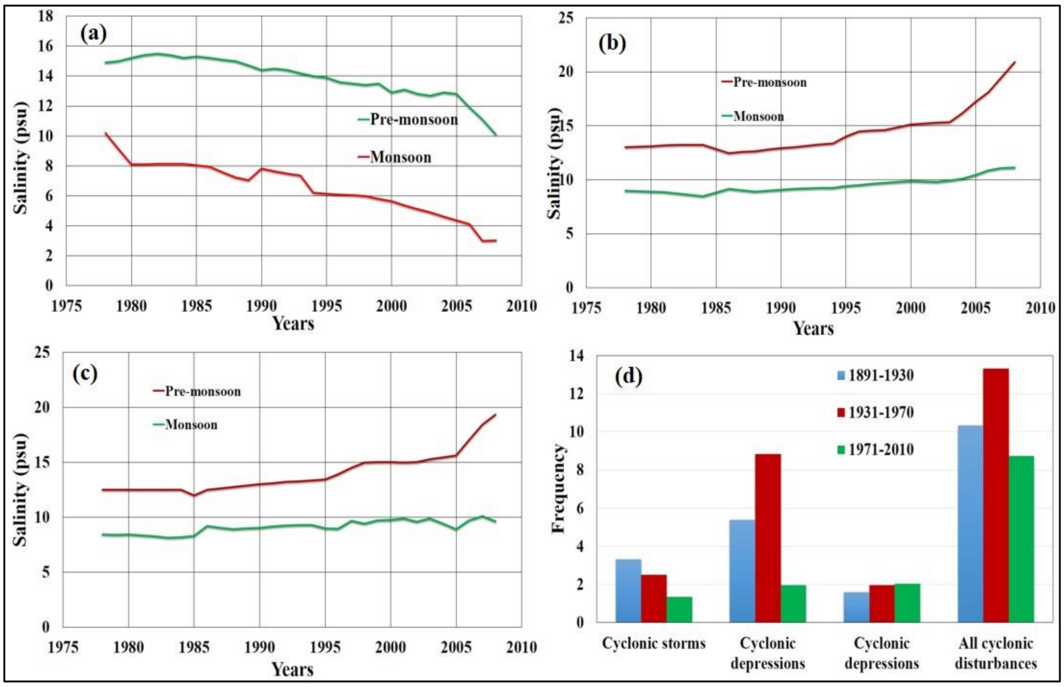

Fig. 2.10 Salinity changes in western (a), central (b), and Eastern (c) part of Indian Sundarbans at the period from 1978 to 2008 (Source: Mitra et al. 2009), and Season wise spatial salinity variations (d) in Sundarbans during 2010-2011 (Source: Mitra et al. 2013).

The annual pattern of salinity changes with the variation of freshwater flow and nature of tide along the Ganga Brahmaputra as specifically total area of Sundarban region. The highest salinity has found in 2001, and 2002 which is about 26 ppt and lowest salinity was found during post monsoon season that is about 5 ppt (IWM, 2003) in the Bangladesh part. Salinity in the east of the Bangladesh Sundarbans, is almost zero due to the flow of Baleswar River (fig. 10) throughout the monsoon season and the salinity of the central and north central part of Bangladesh Sundarban is about 5 ppt during monsoon but gradually increases up to 15 ppt in the dry post monsoon period (IWM, 2003). The station in central (Kultali Block), and western part (Mathurapur to Sagar Block) of Indian Sundarbans aquatic salinity exhibited a significant spatial and temporal variations where the seasonal trend has found in salinity pre monsoon> Monsoon> post monsoon (fig. 11). In the western part, surface water salinity ranged from 1.89 psu (September, 2011) to 27.99 psu (May, 2011), where the average salinity was 14.98 ± 9.16 psu and in the central part, surface water salinity ranged from 4.01 psu (September, 2011) to 29.98 psu (May, 2011) with an average salinity is 20.60 ±

8.82 psu[22] (Mitra, 2013). The relatively lower surface water salinity in the western part of Sundarban (India) region due to Farakka barrage that releases more fresh water through the Bhagirathi Hugli River on a regular basis. however, central part of Indian

Table 2.4 Changing pattern of surface water salinity (1980- 2010) in Indian Sundarbans

Location of estuary		Seasonal trend (decreasing/Increasing)		Pearson Correlation	
Sector	**Position**	**Pre-monsoon (N)**	**Monsoon (N)**	**' r ' value**	**P**
Eastern	Inner	Increasing (26)	Insignificant (16)	0.58/0.23	0.002
	Middle	Insignificant (11)	Increasing (5)	0.43/0.93	0.01
	Outer	Insignificant (6)	Increasing (7)	0.64/0.70	0.04
Central	Inner	Increasing (7)	Insignificant (4)	0.87/0.64	0.02/0.34
	Middle	Insignificant (3)	Insignificant (5)	-1.80/0.48	0.47
	Outer	Increasing (7)	Increasing (6)	0.69/0.83	0.08/0.04
Western	Inner	Increasing (7)	Insignificant (9)	0.97/0.06	0.001
	Middle	Insignificant (5)	Insignificant (7)	0.07/0.45	-
	Outer	Insignificant (16)	Insignificant (16)	0.1/0.28	-

Source: World Bank Report, India (July 2011).

Table 2.5 Changing pattern of groundwater salinity (1980- 2010) in Indian Sundarbans

Location of estuary		Seasonal trend (decreasing/Increasing)		Pearson Correlation	
Sector	**Position**	**Pre-monsoon (N)**	**Monsoon (N)**	**' r ' value**	**P**
Eastern	Inner	Increasing (8)	Increasing (9)	0.86/0.75	0.008
	Middle	Insignificant (3)	Increasing (4)	0.91/0.99	0.004
	Outer	Lack of data	Lack of data	-	-
Central	Inner	Increasing (4)	Increasing (4)	0.75/0.79	0.024/0.021
	Middle	Increasing (5)	Insignificant (5)	0.99	0.001
	Outer	Lack of data	Lack of data	-	-
Western	Inner	Insignificant (4)	Increasing (4)	0.76/0.95	0.24/0.05
	Middle	Insignificant (7)	Insignificant (9)	0.50/0.13	0.25
	Outer	Increasing (7)	Increasing (11)	0.83/0.75	0.022/0.009

Source: World Bank Report, India (July 2011).

[22] Psu is the practical salinity unit based on the properties of water conductivity and salt concentration of ocean. 1 psu =1g/kg

Sundarban faces the lack of riverine discharge and the massive siltation of the Bidyadhari River has blocked the flow of freshwater (Mitra et al., 2009). Therefore, Table 4 and 5 shows trends of salinity during last 3 decades (1980-2010) in Sundarbans, which indicates that living communities of the eastern, central, and western sectors of Sundarbans will be suffered by continuous increasing ground water and surface water salinity (table 2.4 and 2.5).

2.2.2.2 Impact of Salinity Regime on Mangroves:

In Sundarbans, several inhabited Islands, and others land areas are protected by artificial embankments to control saline water ingression and increase the possibility to makes aquaculture and agricultural land (Danda 2007). Out of 3500 km length of the embankment, 800 km lands are mostly vulnerable to the breach at the time of high-intensity cyclonic events. The Recent trend of the rising sea level will have more dangerous effects on these embankments and making susceptible and vulnerable to overtopping and breach. This vulnerable condition of embankments may enforce to the overtopping of ocean water and may also influence to the total wash out during storm surges and other cyclonic events.

Recent global warming and climate change also affects the salinity of ocean water and ground water in two different ways. Primarily, the rising temperature in the open sea would effect to increase salinity through the increased evaporation. Moreover, the salinity of estuaries, coastal waters, and bays would decrease by precipitation and freshwater input from river water and glaciers, and intrusion of ocean water. This increasing salinity may change the pattern and diversity of mangrove ecosystems in India and Bangladesh part of Sundarbans.

The increasing salinity of the Sundarbans ecosystem adversely effects to the forest growth and productivity, retrogression of mangrove forest types and the dying of tops of Sundari and other trees (MPO, 1986). The gradual increase of salinity has an adverse impact on chlorophyll a content, and leaf density and subsequently affect the rate of photosynthesis of Sundari tree as a freshwater loving significant mangrove species (Heritiera fomes) in Sundarban region. Table 2.6 shows the effects of varying salinity level on chlorophyll a concentration and density of the leaves of Sundari tree (Heritiera fomes).

Table 2.6 Impacts of various salinity level on the concentration of chlorophyll a and leaf density of Heritiera fomes (Sundari) in Sundarbans.

Salinity level (psu)	Moisture (%)	Chlorophyll a concentration (mg/100g fresh tissue)	Leaf density G/cm^3)
0	49.9	36.89	0.92
2	56.3	34.56	0.86
5	59.2	32.45	0.80
8	60.0	34.09	0.79
10	60.1	30.77	0.85
12	59.2	28.31	0.54

Source: Mitra et al. 2013.

2.2.3 Effect of Ocean Circulation Pattern, Storms and Depressions:

2.2.3.1 Sea Circulation Pattern:

According to the prediction of IPCC (Intergovernmental panel on climate change), strength of tropical cyclone and hurricanes, extreme wave and storm surge formation, and peak wind intensity will increase of about 5-10 % due to the recent climate change (Solomon et al. 2007). The increasing low pressures and the frequency of strong winds will predict to increase the storm surge heights.

In addition, climate change also influence the hydrological pattern of the ocean due to the heat changes and salinity variation which subsequently affects the circulation pattern of the ocean (Gilman 2008). Although, there is no clear evidence about the changes of sea circulation pattern in the context of climate change (IPCC 2001).

The oceanic water masses (Conveyor cell)[23] are changing through climate change. Mitra et al. indicated that the density, and salinity of Indian Sundarbans have changed significantly from 1980 to 2007 (over 27 years) where in the context of density, western part is becoming lighter, fresher and warmer due to complex deltaic conditions. Moreover, this horizontal contrast leads to the changes in intensity, ecosystem, and circulation path and extend of monsoonal depressions due to differential energy

[23] The oceanic conveyor belt is a deep water circulation of ocean driven by salinity and temperature. www.oceanservice.noaa.gov

distribution from the ocean. The frequency of the destructive storm, and cyclones has increased in Sundarban from 17^{th} century to present times (Mitra 2000) and the severity of storm and cyclones has also risen from 1980 to 1999 in the Bay of Bengal (Fritz and Blount 2007).

Table 2.7 Severe Cyclonic Storm Over Bay of Bengal (North) at the period of 1999 to 2009.

Cyclones name	Occurrence period	Speed (knots)	Category
-	28^{th} Oct 1999	>140	Super cyclonic storm
-	28^{th} Oct 2000	<40	cyclonic storm
-	19^{th} May 2003	<60	Super cyclonic storm
-	17^{th} May 2004	<60	Super cyclonic storm
-	2^{nd} Oct 2005	<40	cyclonic storm
Mala	24 Apr 2006	>120	Super cyclonic storm
-	13^{th} may 2007	<60	Super cyclonic storm
Sidr	15^{th} Nov 2007	>120	Super cyclonic storm
-	28^{th} June 2007	>120	Super cyclonic storm
Rashmi	26^{th} Oct 2008	>40	cyclonic storm
Nargis	27^{th} Apr 2008	<120	Very severe cyclonic storm
Bijli	16^{th} Apr 2009	<60	Super cyclonic storm
Aila	24^{th} may, 2009	<60	Super cyclonic storm

Source: Hazra et al. 2010.

2.2.3.2 Storm and depression:

Frequency and depressions and storms having a direct consequence on the rainfall distribution in Sundarban and its adjacent coastal areas from 1891 to 1970 (over 80 years) (Mishra 2002). The results show that the area faces eight cyclonic events per year which subsequently affects the rainfall as well as weather condition of the region. After 1922 the region has been facing a considerable increase in the frequency of storm and cyclonic activities specifically up to 1953 and after the year of 1964 where the frequency were below the average up to 1922. The Bay of Bengal, the disturbances like cyclonic storms and depression events occurred with the rate of 10.79 per year for the period of 120 years (1891-2010). However, in the last 35 – 40 years (1973 – 2010) the frequency and intensity of severe storms has increased significantly but total no of such events (cyclonic disturbances) decreased remarkably (table 2.9). Singh (2003) also considered that severe cyclonic depressions and storm has increased by about 26% over last century, which intensifying in retreating monsoon (post monsoon) season over the Bay of Bengal. During the year of 2006-2009, registered four high-intensity cyclones (fig. 2.12) as a Nergis, Bijli, Sidr and Aila in the northern portion of Bay of Bengal (table 2.7).

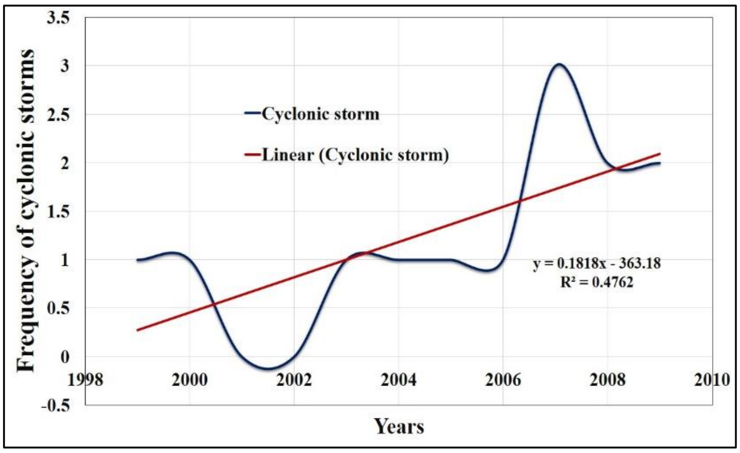

Fig. 2.11 Frequency of Cyclonic depression and storms over Northern Bay of Bengal (Source: Hazra et al. 2010).

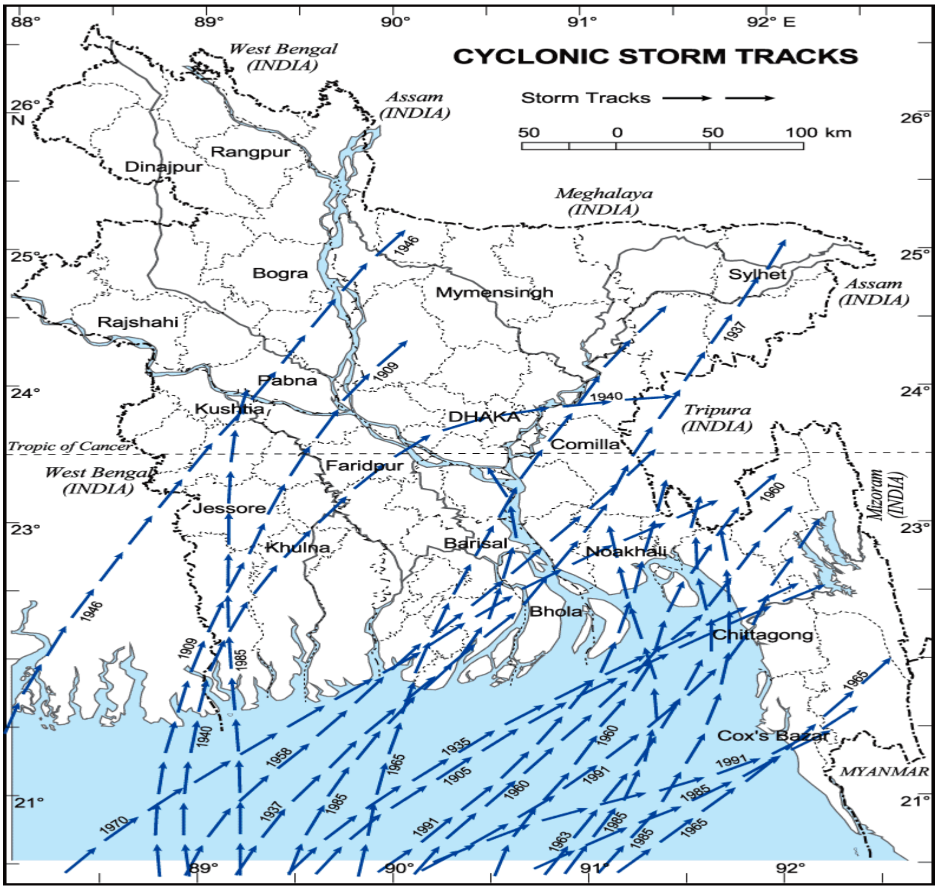

Fig. 2.12 Past Cyclonic storm paths in Sundarbans (Source: World Bank Report on India, July 2011).

Table 2.8 40 years Successive mean frequency of high-intensity cyclonic storms and disturbances over the Bay of Bengal.

Period	Cyclonic storms	Cyclonic depressions	Severe cyclonic storms	All cyclonic disturbances
1891-1930	3.33	5.40	1.60	10.33
1931-1970	2.50	8.83	1.98	13.31
1971-2010	1.35	5.35	2.05	8.75

Source: Cyclone e-atlas, IMD (India Meteorological Department).

The table 2.8 signifies that during the year of 1971 – 2010, the frequency of severe cyclonic storm has increased significantly although the total no of cyclonic storms and depression decreased remarkably. The severe cyclonic storm brings storm surge, heavy rain, and high wind causing devastation and embankment failure through saline water percolation and inundation. The inundation also damages the cultivable lands, houses, ponds and causing washed away and death of domestic animals.

2.2.3.3 Effects on Mangrove:

Changes to ocean circulation pattern may influence the genetic structure and propagule structure, with coincident effect on community structure of mangrove (Duke et al. 1998). It has a significant positive impact on its surrounding environment through increasing gene flow between mangrove species diversity and currently separated populations could increase mangrove resilience and resistance.

The increased frequency and intensity of storm surges has the potential impact to increase loss of mangroves through tree mortality and defoliation. Therefore, to causing stress, storms, sulfide soil toxicity, and tree mortality can alter sediment elevation of mangrove through soil deposition, soil erosion, soil compression and peat collapse (Woodroffe 2002). Areas suffering by little survival of trees and sapling, and subsequently tree mortality might experience through permanent ecosystem conversion, due to the change in hydrology, and sediment elevation where recovery of this effect might not possible through seedling recruitment (Woodroffe 2002). While tsunami (Indian Ocean tsunami, 26th Dec, 2004) events which, are not related to climate change, may cause severe loss of mangroves as well as other coastal ecosystem

Table 2.9 Exposure components of climate change effects on mangroves, sensitivity outcomes and processes affected.

Climate change effects	**Affected processes**	**Sensitivity components**	**Alleviation Strategies**	**Sources**
Increased atmospheric and sea surface temperatures	Mangrove productivity Photosynthesis Respiration Species composition and diversity Flowering and fruiting time	Increased productivity in winter season at high latitudes and decreased productivity at low latitudes	Mangrove plantation to regulate local climate through cloud formation, dissipation of heat content and control over evaporation	cheeseman et al. (1991), Cahoon et al. (2006), Alongi (2008), Farley et al. (2010)
Increased precipitation and Freshwater availability, and changes in monsoonal pattern	Forest productivity Salinity Sediment supply Species diversity Ground water	Increased accretion and surface elevation maintenance, and increased recruitment, productivity, diversity and ground water	Connect mangrove forest area with creeks, backwater and rivers to facilitate continuous drainage during heavy precipitation	Krauss et al. (2003), Rogers et al. (2005), McLeod and Salm (2006)
Decreased freshwater availability	Forest productivity Photosynthesis Salinity Sediment inputs Ground water	Mangrove species changes and landward migration, and reduced photosynthesis, diversity, productivity, accretion and ground water	Connect mangrove forest area with creeks, backwater and rivers to facilitate continuous water supply at the period of lower precipitation	Smith and Duke (1987), cheeseman et al. (1991), Rogers et al. (2005)
Changes in sea level	Forest Productivity Health Recruitment Accretion rates Inundation period	Mangrove mortality, landward migration and dieback from the seaward margin, and depending on lack of barriers, topography and sediment inputs	Develop salt marshes and salt flats behind the mangrove ecosystem to influence the landward migration, Removal of anthropogenic barriers like buildings, roads etc. to reduce landward migration	Ellison (2005), Cahoon et al. (2006), Alongi (2008), McLeod and Salm (2006)
Increased storms, depressions and changing wave circulation pattern	Forest productivity Accretion rates Recruitment Gene flow and propagule distribution	Surface elevation changes, forest damaged, changes in spatial distribution, excess sedimentation and erosion.	Undertake management strategies to proper distribution of propagules and sediments	Semeniuk (1994), Alongi (2008), Lovelock and Ellison (2007)

Source: Adopted from Ellison 2014.

(Danielsen et al. 2005, Dahdouh-Guebas et al. 2006). Mangroves have been reduced the energy of waves during tsunami and storm events and also provides resilience through the erosion of underneath layer (Dahdouh-Guebas et al. 2006). Although, Rhizophora species have the ability to decrease the wave energy of about 50% within 150 m from the seaward edge. The degree of tsunami or storm protection primarily is subject to the forest density and the magnitude of storm events (Danielsen et al. 2005). However, over 6 m height tsunami waves are destroying most of the mangroves. The degree of protection of wave energy in cyclonic storms and tsunamis has influenced by aerial root heights and, types and density of mangrove forest.

Storm activities may influence to deposit the marine sediments into the seaward edge to cause build Chenier ridge or shore parallel dune or mangrove mortality. Sediment deposition and erosion can misrepresent the degree of elevation change due to altering of sub-surfaces processes as an effect of the storm activities (Cahoon, 2006). The mangrove with frequent hurricanes affected areas is more susceptible due to its Coastal location and have a smaller diameter, less complex forest and lower canopy size. Mangrove loss infrequent hurricanes are identified by the uprooting of the plants, breakdown of mangrove branches and stripping of the coastal leaves.

There is a most significant evidence of increase in the frequency, and intensity of heat waves, high rainfall, flood, storm surge, land erosion, drought, tornadoes, salinity intrusion and tropical cyclone etc. which affect the mangrove ecosystem of the coastal region of Bangladesh (Hossain et al. 2012). Subsequently, the Sundarban region (world heritage site of India and Bangladesh) is mostly affected by changing the climate, more specifically from extreme weather events such as a storm, hurricane, tropical cyclone and increasing salinity. However, about the one-third area of the Sundarbans mangrove was destroyed by cyclonic ‘Sidr’ incidence (Arefin 2011).

2.3 Conclusion:

A vast area of Sundarban mangrove ecosystem as a largest mangrove area in Bangladesh and India, is now mostly vulnerable due to continuous increase in sea level (MOEF 2010). The expected sea level rise rate is 4 mm per year. The region has been mostly affected by climate change and their effects where the temperature rising rate is 0.4° C per year, resulting in the recurrence and intensity of the cyclonic storm in Bangladesh (Haq 2010). These climate change effects subsequently will cause the decrease in fresh water flow and an intense salinity level in the Sundarban region (Haq 2010). Therefore the combined flows saline ocean water from the BOB (Bay of Bengal) and the Ganges fresh water supports a uniform growth of fauna and flora in the total Sundarban region. However, the ecological sustainability and balance is presently threatened of this ecosystem due to a gradual increase in siltation as a result of decreased fresh water flow of the downstream river (Haq 2010). Moreover, the canopy closures and vegetation growth density decreased from the eastern part to western part due to intense salinity intrusion from the east to the western sector of the Sundarbans. The negative impacts of increased salinity resulted in 'top dying disease'[24] of Aviecinia species (Sundari tree), subsequent effects to a large-scale mangrove destruction in the Sundarbans (Haq 2010). The disease have first observed in 1930 and macro scale impacts have been observed during 1980. As reported by Forest department of Bangladesh (survey from 1994 to 1996), the disease effects to the destruction of Sundari trees which of about 34287 cum per year (Haq 2010).

[24] 'Top dying disease' is most threatful disease that affects Sundari tree (Heritiera fomes). See Haq 2010

Chapter-3

Mangrove Dynamics and Vulnerability of Trans-Boundary Ecosystem to Climate Change

3.0 Dynamics of Tran's Boundary Mangrove Ecosystem:

The intertidal[25] ecosystem of Sundarbans are unique in their nature and structure. It also characterized by a significant variety of micro-organism, animals, and plants which, have adopted to the most dynamic ecological conditions. It is also a home of mussels, crabs, many fish species, and support aquaculture farming and related activity. In many parts of Sundarbans, aquaculture farming and other livelihood collection, such as honey and wax, Nypa palm etc. are the main resource that extracted by the local inhabitants. This may change the land use and land cover area, canopy closure, embankments, increasing coastal erosion and make threat to the adjacent floral and faunal activity. Also, the climate change and their effects, such as sea level rise, cyclone, storm surges, increasing temperature with increasing anthropogenic activities leads to the reduction, deterioration of mangrove area and make them more vulnerable as coastal ecosystem.

3.1 Land Use and Land Cover Change:

Land use and land cover area of the Sundarbans has been changing over time primarily due to climate change effects, as well as tourism and various anthropogenic activities. Also, the main economic activities of Sundarbans are fishing, farming, and aquaculture, and the collection of mangrove dependent livelihood (fuel wood, timber, honey collection). The forest fire, erosion, inundation have a significant effect on the changes of mangrove and other land use categories over Sundarbans. More specifically, climate change induced natural disasters, like Hurricanes and Tsunamis, has an important role in reducing and their

[25] The intertidal zone is an area under water during high tide and above water during low tide, sometimes is refers as the littoral zone. See https://en.wikipedia.org/wiki/Intertidal_zone

significant changes in an intertidal ecosystem where the interconnected canal, tidal rivers, and creeks are the more influencing factor. However, the land use and land cover status and their changing pattern of Sundarbans (fig. 3.1) have described for different time periods (1973, 1990, 2000, and 2014). In the study areas of Indian and Bangladesh part of Sundarban, five major classes were identified, such as mangrove, water bodies, non-mangrove, barren lands and flooded areas (table no. 3.1). Results of the present investigation of the changes of land use have been represented in table no 3.2 and 3.3. It has observed that all kind of land use categories and subcategories has changed significantly where the dominated classes are mangrove forest and water bodies for each studied year.

Table 3.1 Class definitions for the classification of Sundarbans.

Classes	Class definition for supervised classification
Mangrove	Covering areas of both open and closed mangrove forest
Water bodies	Areas of river and channel water with no emergent mangrove and other vegetation
Non mangrove	Covering areas of croplands, settlement, and other land use without mangrove forest
Barren lands	Areas covered by devoid of vegetation, i.e., exposed soil, sediments and sand dunes
Flooded	Inundated barren lands during the study period

Over the study period, it has been observed that the land use and land cover changes significantly in both India and Bangladesh part of Sundarbans (fig. 3.2). From the 1973s to 2014s, mangrove forest area decreased by 4.16 %. Although the rate of change in forest cover was not uniform from the 1973s to 1990s, from 1990s to 2002s and from 2002s to 2014s. From the 1973s to 1990s, the area of mangrove forest increased by 0.09%. From the 1990s to 2002s, the area lost by 2.75% and from 2002s to 2014s, the area of mangrove decreased by 1.5%. These mangrove forest cover changes are more meaningful when it occurs in a broader temporal scale did the study with changes in a significant amount. In the present study, in the year of 1990s to 2002s is not significant in the context of the dynamic nature of mangrove forest under climate change and the classification errors.

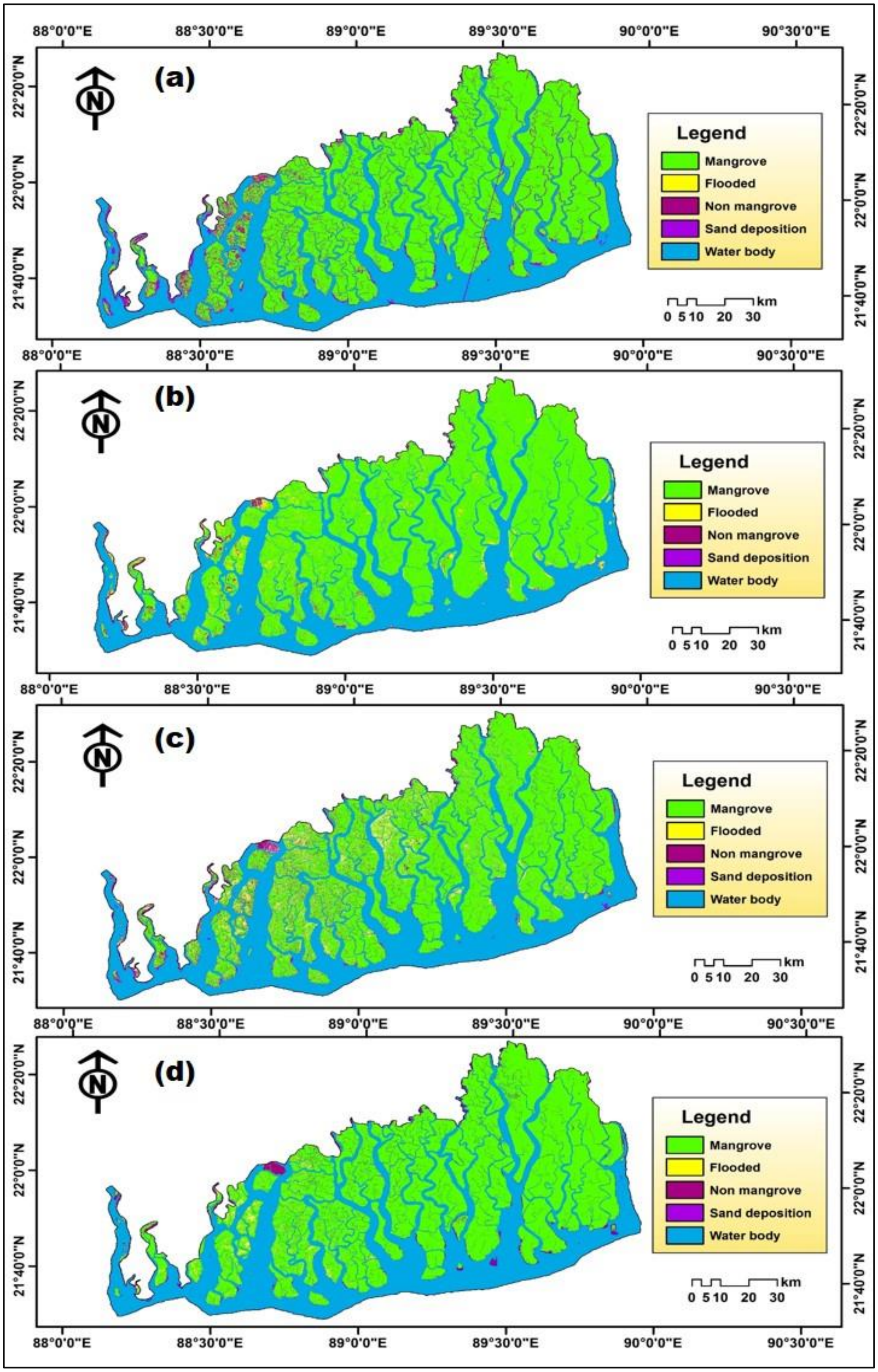

Fig. 3.1 Land use land cover classification (supervised) maps of (a) 1973 (MSS), (b) 1990 (TM), (c) 2002 (ETM), and (d) 2014(OLI) Sundarbans

In 1973, mangrove and water bodies occupied about 58.62% and 38.49% of the total area respectively. The largest area of Sundarbans has primarily associated with mangrove forest cover with creeks and rivers have occupied a significant area of the ecosystems. Non-mangrove covers such as cropland, settlement, and other land use, barren land and flooded areas have not significant land covers in the Sundarbans belt which have covers less than 3% and occupied about 1.15, 0.26, and 1.48% area of all land cover area.

Table 3.2 Land use/land cover changes of the Sundarbans.

Land use categories	**1973**		**1990**		**2002**		**2014**	
	Area (ha.)	Area (%)	Area (ha.)	Area (%)	Area (ha.)	Area (%)	Area (ha.)	Area (%)
Mangrove	584073	58.62	584965	58.71	557629	55.96	542622	54.46
Non-mangrove	11433.9	1.15	11576.3	1.16	12928.6	1.3	14772.8	1.48
Water bodies	383547	38.49	391239	39.26	398052	39.95	403728	40.52
Barren lands	2627.3	0.26	4252.8	0.43	10372.5	1.04	13342.7	1.34
Flooded areas	14732.4	1.48	4379.8	0.44	17432.4	1.75	21948.3	2.2
Total area	996414							

(Source: Extracted from satellite images)

In 1990, mangrove and water bodies also a significant portion of the total land cover area about 58.7 and 39.26% respectively. However, the area of mangrove have decreased 0.09%, and the area of water bodies have increased 0.77% in respect to the area of 1973s. There is a significant reduction in flooded areas is about 1.04% and, on the other hand, the area of barren lands have increased, but non-mangrove areas are approximately same as the area of 1973.

On the contrary, in 2002 and 2014 are also the significant land use of Sundarbans where both of the land covers are changes approximately same rates, from the 1990s to 2002s and from 2002s to 2014s. The mangrove forest cover area gradually decreases due to climate change induced inundation, erosion, and mangrove dieback, effects of temperature increase, changes in precipitation and monsoonal pattern, and various economic activities, such as shrimp farming, and the extraction of mangrove dependent livelihood in

Sundarbans. The water bodies including creeks and rivers and oceans area have increased due to the loss of mangrove and landward migration and the destruction mangrove along the ocean margin. The amount of changes in water bodies is about 0.67% and 0.57%. From 1990 to 2002 and from 2002 to 2014 respectively. Rest of the land cover area, such as barren lands, flooded areas, and non-mangrove areas are gradually increases due to climate change induced sea level rise, and anthropogenic activities like shrimp culture, growth of settlement, and sand depositions in the Sundarbans.

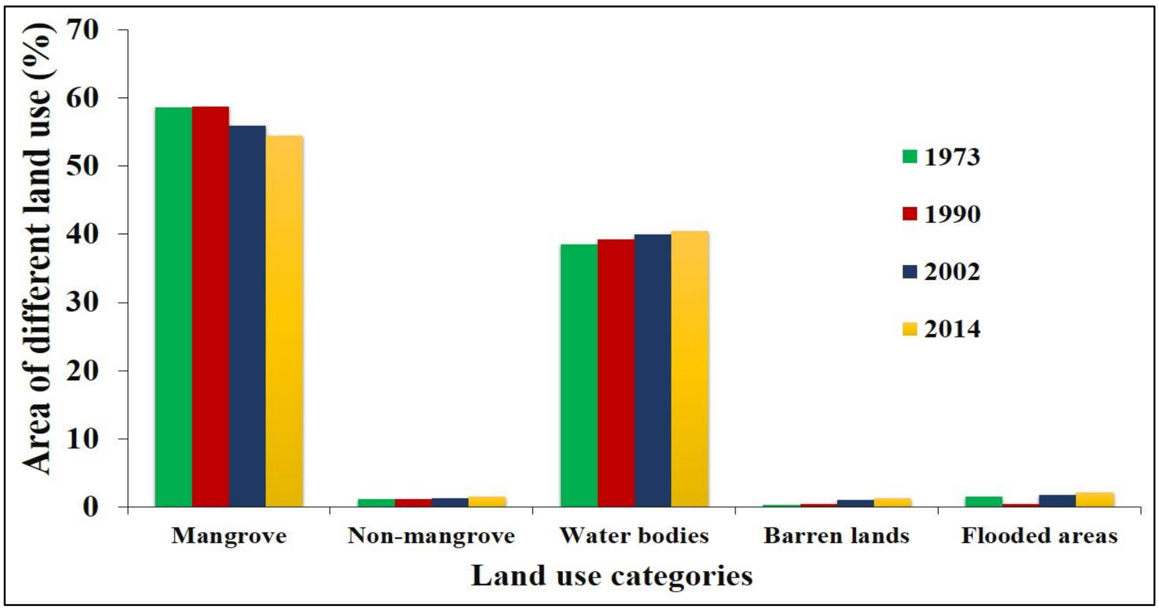

Fig. 3.2 Land use and land cover changes of Sundarbans from 1973 to 2014

The annual rate of changes in land covers are not much significant except mangrove changes and flooded areas over the studied period (Table 3.3). The highest amount of decrease has associated with mangrove forest cover change. The mangrove forest covers has declined at the rate of 0.23% per year, and 0.13% per year, from the 1990s to 2002s and from 2002s to 2014s, and the overall mangrove changes is 4.16% over the period of 41 years (1973 to 2014). The flooded areas also have the most significant changes occurred over the period of 1990 to 2002. Overall 2.27% and 0.18% per year of the flooded have increased from 1973 to 2014 in the both India and Bangladesh part of Sundarbans. Among all the land cover categories, higher decreasing rate has been found in the mangrove forest cover (fig. 3.3) where rest of the land use categories, such as barren land, non-mangrove areas, and water bodies are less significant due to the domination of mangrove cover in the

Table 3.3 Annual changing rate of land use and land cover area of Sundarbans mangrove (1973-2014)

Land use categories	1973-1990			1990- 2002			2002-2014		
	Area (ha.)	Area (%)	Annual rate (ha.)	Area (ha.)	Area (%)	Annual rate (ha.)	Area (ha.)	Area (%)	Annual rate (ha.)
Mangrove	892	0.09	0.006	-27336.9	-2.75	-0.23	-15006	-1.5	-0.13
Non-mangrove	142.4	0.01	0.0007	1352.3	0.40	0.03	1844	0.18	0.02
Water bodies	7692.7	0.77	0.051	6812.3	0.69	0.06	5676	0.57	0.05
Barren lands	1625.5	0.17	0.011	6119.7	0.61	0.05	2970	0.30	0.03
Flooded areas	-2906.4	-1.04	-0.07	13052.6	1.31	0.11	4516	0.45	0.04
Total	13259			54673.8	-	-	30013	-	-

(Source: extracted from satellite images)

total Sundarbans. The changes of non-mangrove areas such as settlement, cropland, and other land cover areas have increased but not in a significant rate due to the coverage of small part of the study area in Sundarbans. The rate of non-mangrove areas changes at the rate of 0.03% in the period between 1990 and 2002. The annual rate of changes in the

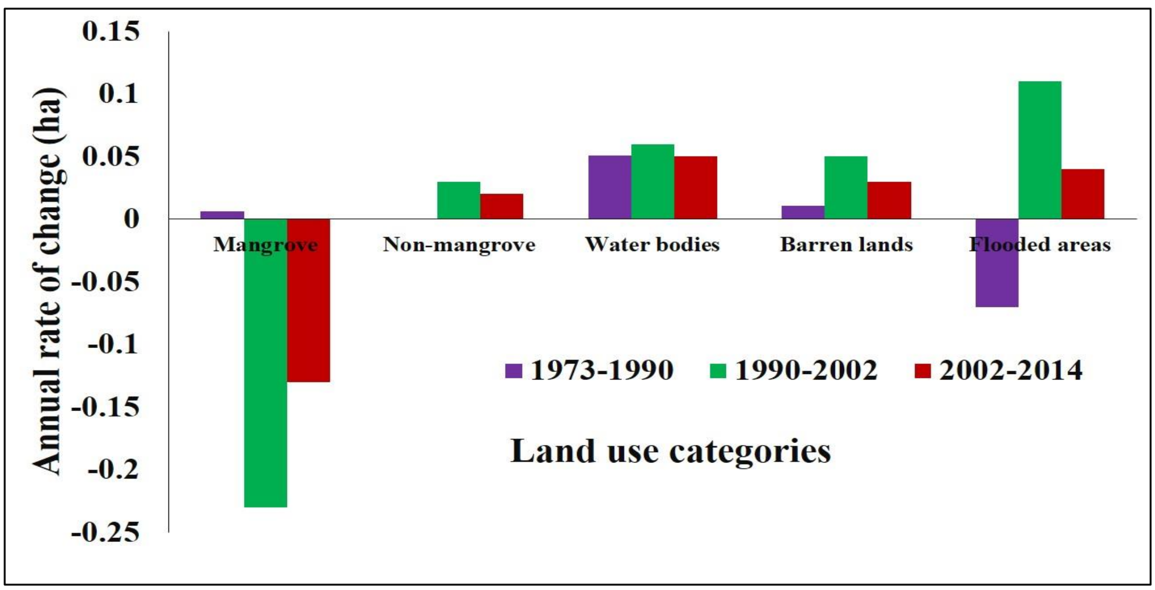

Fig. 3.3 Category wise annual rate (ha.) of land use and land cover changes in Sundarbans in different time period

barren land has increased gradually in between 1973 and 2002 where the rates are 0.011 and 0.05, from 1973s to 1990s and from 1990s to 2002s respectively. The areas of water bodies have also gradually increases but not at a significant rate. The rate of changes in water bodies and barren lands during the study periods has occurred due to the climate change effects. More specifically, sea level rise, increasing temperature, changes in precipitation and monsoonal pattern, and increased storm and cyclonic activities are a more responsible factor for the significant changes in the intertidal region of Sundarbans.

3.1.1 Category Wise Land Use Conversion of Sundarbans Over the Studied Period:

The land use and land cover changes in the different studied period are the outcomes of the conversion of one land use category to another land cover category. In the study area the main land use categories are mangrove, water bodies, and less significant categories are barren lands, flooded, and non-mangrove area where, the most important transformations are the conversion of mangrove areas to water bodies, barren land, flooded area, and non-mangrove area. The region is called "Worst climate change hotspot" (Haq 2010) because climate change effects are more prominent in the Sundarbans. The climate change-induced sea level rise plays a significant role in the conversion of mangrove to water bodies, flooded and barren lands. Recently increasing anthropogenic activities and economic development may cause the gradual reduction of mangrove to non-mangrove areas. In the total area of Sundarbans, the most significant land use and land cover conversion are as follows:

3.1.1.1 Land Use Conversion From Mangrove to Other Land Cover Categories:

The conversion from Mangrove to other land cover areas is the significant land use changes in Sundarbans due to climate change induced increased water level of the world oceans. The important effect of climate change components may reduce the mangrove area over Sundarbans. While the net loss of the Sundarban mangrove forest is not more significant than their changing turnover. For example, 5.2% of the 1973s era mangrove area had changed to water bodies, non-mangrove, barren lands and flooded lands by 2014. The change matrix shows that approximately 39 % flooded lands, 19 % barren lands, 2 % water bodies, and 7 % non-mangrove have converted to mangrove. Approximately similar kind

Table 3.4 Changes in land use and land cover (%) from the 1973s to 1990s, from the 1990s to 2002s, from the 2002s to 2014s, and from the 1973s to 2014s.

1973-1990	**Mangrove**	**Water body**	**Non-mangrove**	**Barren lands**	**Flooded lands**
Mangrove	94.5	0.8	0.1	0.5	4.1
Water body	2.1	94.1	0.0	0.3	3.5
Non-mangrove	7.2	8.1	72.3	0.0	12.4
Barren lands	16.8	20.3	0.0	25.9	37.0
Flooded lands	33.5	21.2	2.8	2.3	40.2
1990-2002					
Mangrove	95.2	0.8	0.2	0.9	2.9
Water body	1.7	94.7	0.0	0.8	2.8
Non-mangrove	3.8	0.2	80.2	0.0	15.8
Barren lands	14.8	10.3	0.0	53.2	21.7
Flooded lands	42.2	17.8	3.4	8.1	28.5
2002-2014					
Mangrove	94.1	0.8	0.1	0.8	4.2
Water body	1.9	95.2	0.0	0.4	2.5
Non-mangrove	8.7	0.3	82.3	0.0	8.3
Barren lands	21.3	9.8	0.0	58.3	10.6
Flooded lands	24.3	19.2	3.8	7.9	52.7
1973-2014					
Mangrove	94.8	0.8	0.2	0.7	3.5
Water body	2.0	95.1	0.0	0.7	2.2
Non-mangrove	6.9	0.3	81.2	0.0	11.6
Barren lands	19.1	15.2	0.0	53.5	12.2
Flooded lands	39.5	18.5	3.6	6.2	32.2

(Source: Extracted from satellite images)

of land use changes has observed in the studied period between 1973s to 1990s, 1990s to 2002s, and 2002s to 2014s. (Table 3.4). In Sundarban, the conversion of mangrove to flooded (2.9 - 4.2 %), water bodies (0.8 %), and barren land (0.5 - 0.9 %) are most significant in all the studied period from 1973 to 1990, from 1990 to 2002, from 2002 to 2014, and from 1973 to 2014 (fig. 3.5). The conversion of mangrove to non-mangrove is less significant over the studied period, that is approximately 0.1- 0.2 % over the studied period. The higher turnover from mangrove to flooded lands, mangrove to barren lands, and mangrove to non-mangrove areas are due primarily to erosion, aggradation, encroachment, and mangrove re habitation programs. The loss of mangrove via erosion activity is highest at the southernmost coastal edges of Jambudwip, Bulchery, Bhangaduni, Holiday, Dalhousie Island in India and Talpatti, Putney and Dubla Island in Bangladesh.

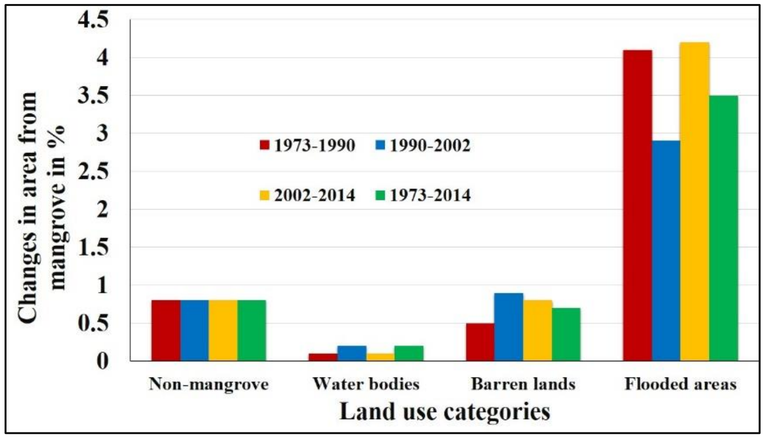

Fig. 3.4 Conversion area (%) of land use from mangrove to other land use categories (1973-2014).

3.1.1.2 Land Use Conversion From Water Bodies to Other land Cover Categories:

The transformation of the land cover area from water bodies to other land cover categories includes the aggradation of islands and sand deposition of the coastal lands. In Sundarbans, significant conversion of land cover from water bodies to other land use categories are mangrove, flooded lands, and barren lands respectively but the conversion to non-mangrove areas is less significant in the studied period. Also, the change matrix represents that averaged 1.9 % mangrove, 0.55 % barren lands and 2.75 % flooded lands were converted to water bodies in all the studied period (fig. 3.5). In all four classifications, 94-95 % of water bodies did not change, and 4.9 % of the 1973s era water areas had changed to barren lands, mangrove and flooded lands by 2014s.

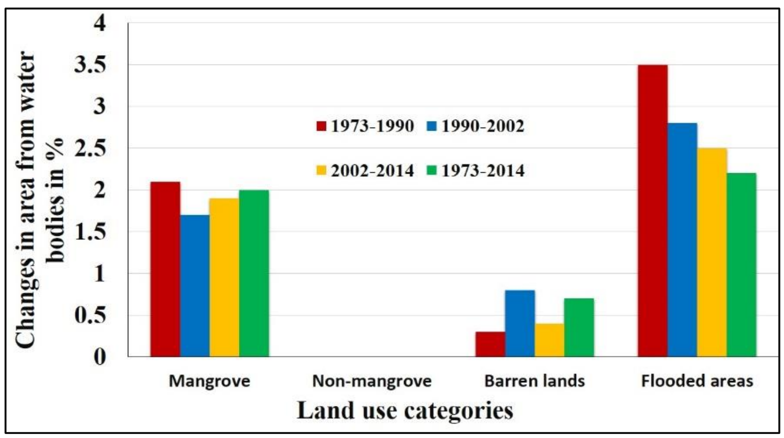

Fig. 3.5 Conversion area (%) of land use from water bodies to other land use categories (1973-2014).

3.1.1.3 Land Use Conversion From Flooded Lands to Other Land Cover Categories:

The conversion from flooded lands to other land cover categories is the essential aspect in the context of climate change and sea level rise. The sea level rise is the main determining factor for the analysis of the change of flooded lands where, daily and seasonal fluctuation of the water level. It can play a significant role in the analysis the conversion of flooded lands to other land cover categories. In the study areas, the major conversion of land cover areas from flooded lands to other land use categories are mangrove (24-42 %), water bodies (18-21 %), barren lands (2-8 %), and non-mangrove area (3-4 %). In all four classification matrix approximately only 28 to 53 % areas did not change which signify that the flooded lands are more dynamic in nature than other land use categories where the maximum percentage of changes has occurred. For example, 68 % of the 1973s era flooded land had changed to mangrove, water body, barren lands and non-mangrove areas by 2014. The largest amount of flooded lands has converted to mangrove (39.5 %) and water bodies (18.5 %). Similar patterns of flooded areas were observed from 1973s to 1990s, from 1990s to 2002s, and from 2002s to 2014s (fig. 3.6).

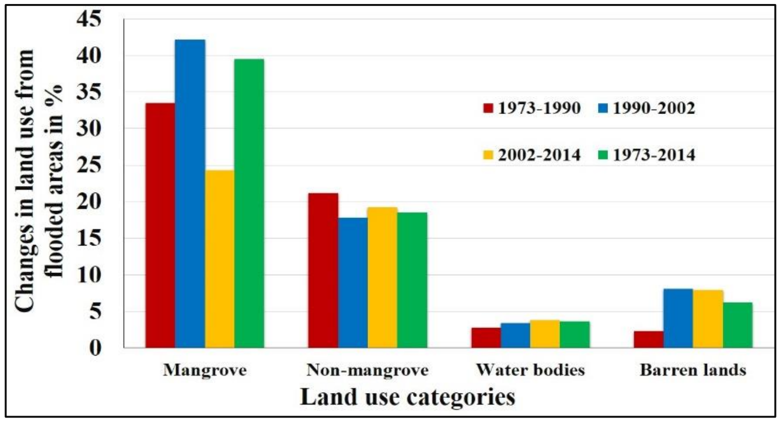

Fig. 3.6 Conversion area (%) of land use from flooded areas to other land use categories (1973-2014).

3.1.1.4 Land Use Conversion From Barren Lands to Other Land Cover Categories:

The conversion from barren lands to other land cover categories and other land cover categories to barren lands are the most significant attributes in any area of the tropical regions. It includes the current fallow and the permanent fellow lands also. In Sundarban, the major conversion is barren lands to flooded lands, barren lands to water bodies and barren lands to mangrove areas. In this region, the temporal change of barren lands changed due to erosion, aggradation, the variation in tidal inundation and the rehabilitation of mangrove areas. The results shows that 53.5 % barren lands did not change, and 46.5 % had change to mangrove (19.1 %), water bodies (15.2 %) and flooded lands (12.2 %), and the conversion of barren lands to non-mangrove is least significant in the period between 1973 to 2014s (fig. 3.7). In all four classification matrix, likely 25 to 59 % areas did not change and the turnover of barren lands is quite high. The changes of barren lands to mangrove is also very high due to afforestation that have located in the Zilla reserved forest block along the northern mangrove forest boundary of Indian part. In this region is approximately 400 ha area had fully degraded in 1975, there also had been reestablished the mangrove habitat by 1989 which was indistinguishable from nearest mangrove areas in a satellite image by 2002s.

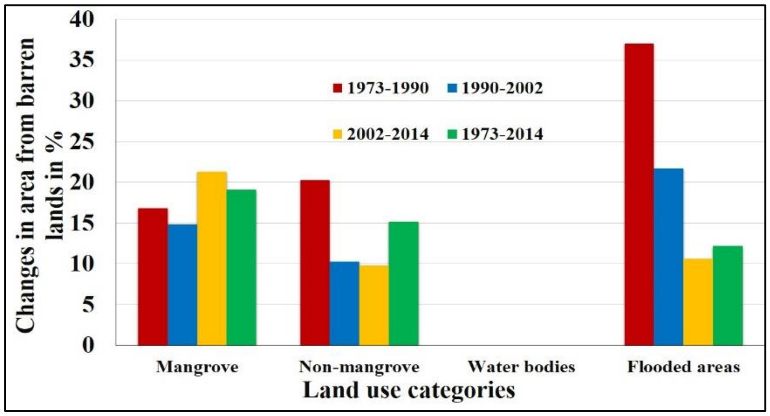

Fig. 3.7 Conversion area (%) of land use from barren lands to other land use categories (1973-2014)

3.1.1.5 Land Use Conversion into Non-mangrove From Other Land Cover Categories:

The transformation into non-mangrove includes croplands and built up area from mangrove, barren lands, water bodies, and flooded areas had changed basically due to the deforestation of mangrove covers for the agricultural activities and the livelihood collection by local people. The continuous increase of built-up area is the result of

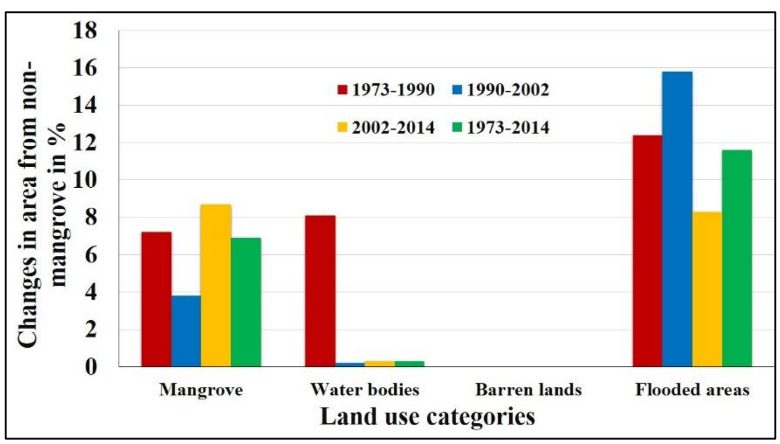

Fig. 3.8 Conversion area (%) of land use from non-mangrove to other land use categories (1973-2014).

the changes in flooded lands and mangrove cover. Non-mangrove cover areas have found in the outer periphery of the eastern and western part of the total Sundarbans. Also, the major change of non-mangrove areas were concentrated near the shoreline and in the outer periphery, caused by natural forces and anthropogenic, respectively. The high turnover have observed due to erosion, encroachment, aggradation, and mangrove rehabilitation programs. While, the measures area of non-mangrove is quite small, and 72-82 % area did not change in all four classification results, and 18.8 % of the 1973s-era non-mangrove had changed to the areas of mangrove (6.9 %), flooded (11.6 %), and water bodies (0.3 %) by 2014 (fig. 3.8).

3.1.1.6 Land Use Land Cover Change Through the Error Matrices:

Error matrices compare the relationship between an automated classification results and a reference known data on the basis of the category by category (Lillesand et al. 2008). The matrix represents the sequences of pixels in a columns and row of a square, and the main diagonal representation of the matrix is the accurate land cover categories and representation of the non-diagonal is the commission (row components), and omission (column components) error of land use/land cover misclassification (Lillesand et al. 2008). In all four classified images, category wise changes of the pixel (1973, 1990, 2002 and 2014) signifies the category wise changes of pixel no. in all studied period. The category wise pixel changes have represented in the appendices section. The pixel no. Determines the particular land use area that calculated by multiplying with the resolution of satellite images. The pixel-wise results show that the pixel no. of mangrove cover reduced in 2014 significantly which associated with the reduction of vegetation cover area. On the contrary, the pixel no. has been increased significantly in case of non-mangrove. Flooded areas, barren lands and water bodies. The probable reasons for the significant increase or decrease have already been mentioned earlier in the all land cover categories (table A1.1-A1.4).

3.2 Change Detection of Vegetation Indices:

The Normalized Difference Vegetation Index (NDVI) is an index which reflects ‘the photosynthesis activity’ or ‘Greenness’ of a plant. The canopy closure layer of Sundarban region derived from Normalized Difference Vegetation Index measurements for the four

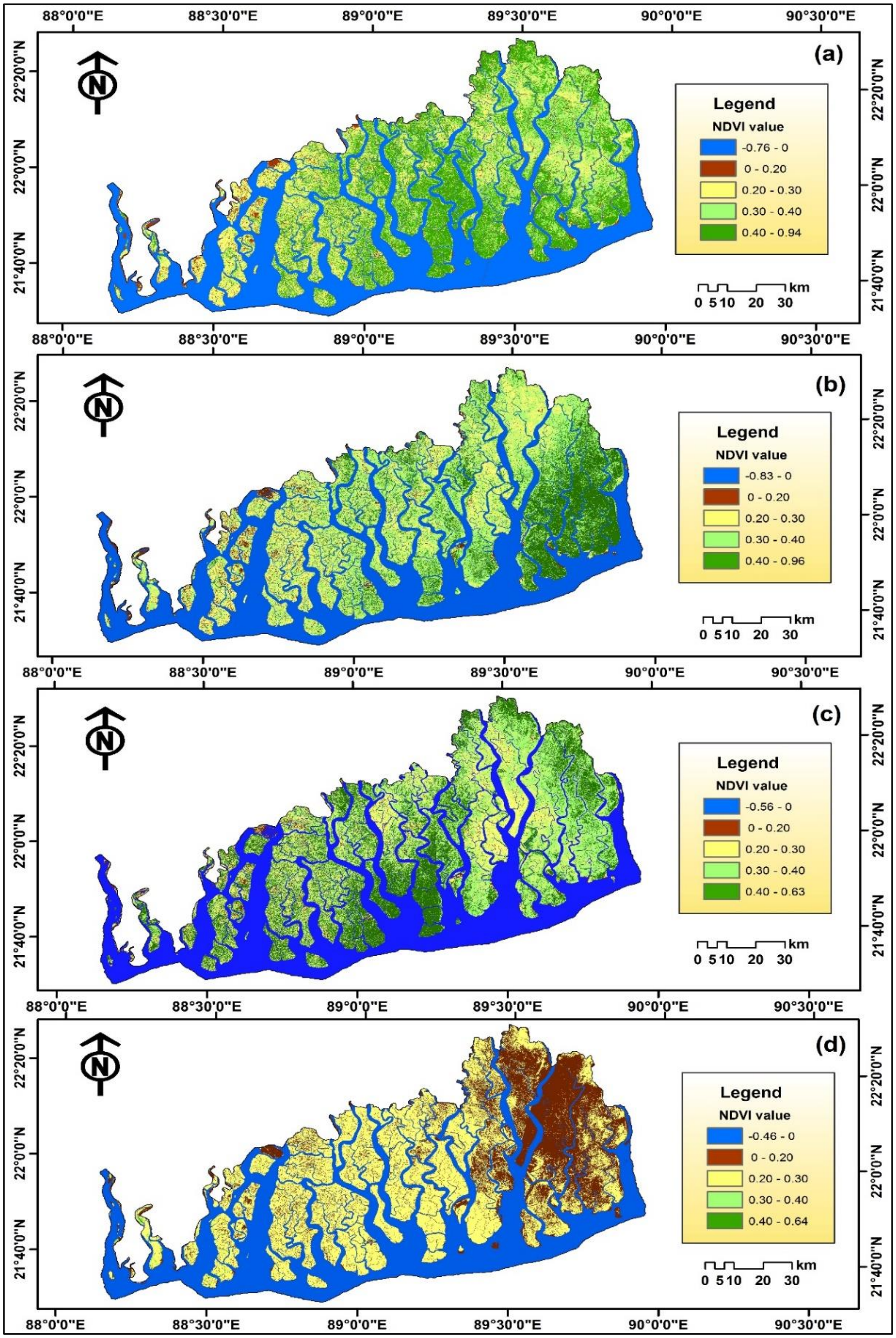

Fig. 3.9 NDVI value of Sundarbans in (a) 1973 (MSS), (b) 1990 (TM), (c) 2002 (ETM), and (d) 2014(OLI)

Table 3.5 Area under different Normalized Difference Vegetation Index (NDVI) value in Sundarbans

Value of NDVI	Area in %				Remarks
	1976	1990	2002	2014	
Below 0	38.49	39.26	39.95	40.52	Water bodies, flooded areas
0-0.20	2.4	3.0	10.6	24.20	Soil, degraded land, barren land, bare rock
0.20-0.30	4.9	11.4	10.1	35.28	
0.30-0.40	35.3	32.2	30.65	0	Less dense mangrove areas
Above 0.40	18.91	14.14	8.7	0	Very dense mangrove areas

mosaics shows the changes in forest health and condition. The indices are based on the information that different types of surface reflect various types of light differently. Moreover, photosynthetically more active vegetation, absorb largest amount of the red band that hits it while near infrared band is reflecting much for this vegetation. Also, the stressed or dead vegetation reflects much for the red band and less for the infrared band. The value reflects the total plant cover area, soil and plant moisture, plant stress and biomass cover of Sundarbans. It is also correlated with different ecosystem attributes, such as net primary productivity, bare ground cover in Sundarbans.

However, the pattern and condition of healthy upper layer mangrove characteristics is different in different classification periods. Therefore, more healthy areas in 1976s are different from the least healthy areas of 2014s correlates to the areas of ‘Top dying disease’ of Sundari (Heritiera fomes) (Haq 2010). As mentioned above, the lack of multiple set of images for each period, the different image acquisition seasons of different era and the variation in the tidal inundation degree of different satellite images restrict comparison of absolute values of canopy closure layers. However, the canopy closure layer has been reduced in different time period of 1976, 1990, 2002, and 2014 (fig. 3.9). The positive value of NDVI gradually decreases due to the increasing flooded areas and barren lands in last 40 years. The value of NDVI over 0.40 indicates the dense mangrove cover area that significantly changes over the periods where 18.91% of area in 1973 changes to 8.7% in 2002, and finally lost this healthy vegetation in 2014 due to intense cyclonic effect of ‘Sidr’. The dense mangrove areas in 1973 are equally distributed all over the area of Sundarbans but in 1990s areas of dense mangrove only found in the south-eastern part of Bangladesh Sundarbans and in 2002s areas are found in the middle portion of the

Sundarbans (table 3.5). The degraded land, barren lands are gradually increased over different time period where 7.3% area of 1976s converted to 60.08% area in 2014 (fig. 3.10). This may signify that the mangrove dominated total Sundarbans are totally influenced by climate change and their related effects over the periods.

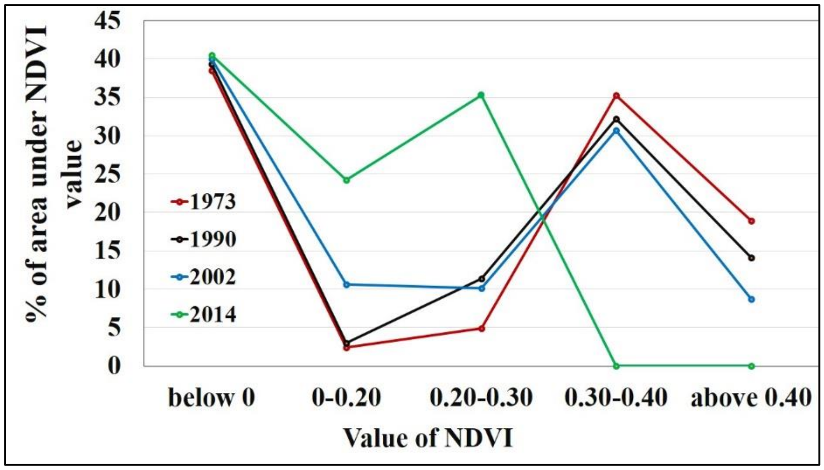

Fig. 3.10 Area (%) under different NDVI value of Sundarbans in 1973, 1990, 2002, and 2014

3.2 Erosion and Accretion of Sundarbans:

Coastal accretion and erosion measures change in the dynamics of shoreline and modify

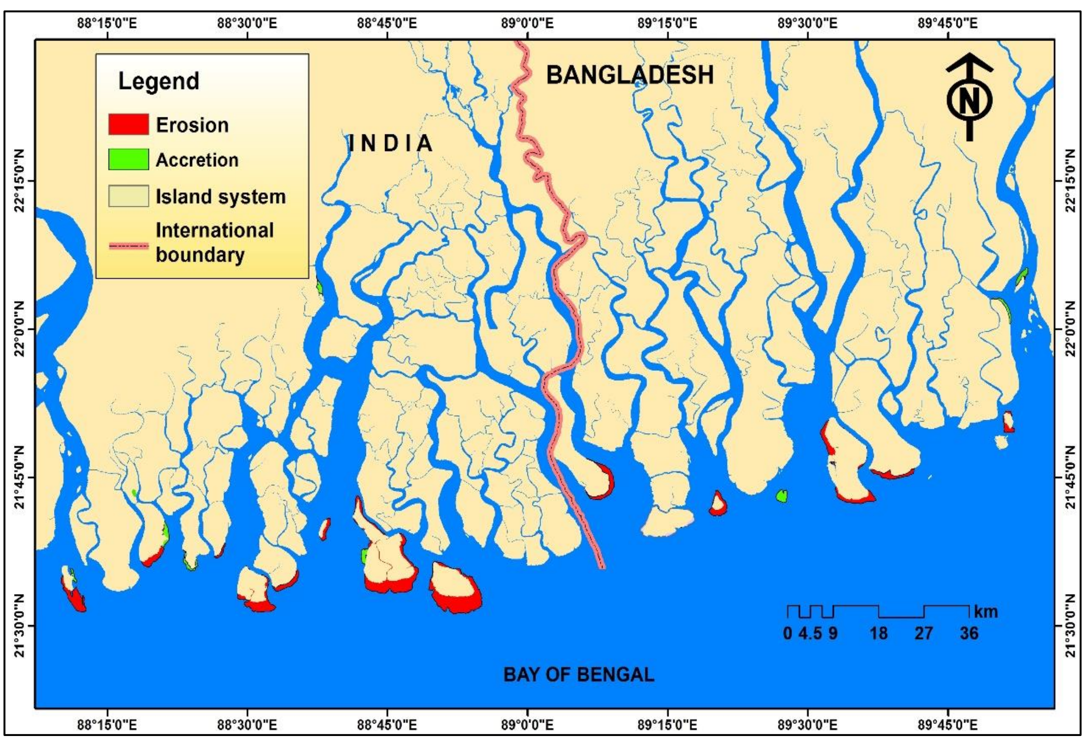

Fig. 3.11 Erosion and Accretion prone region of Sundarbans (1957-2014).

the coastal area. The detailed monitoring and various measures of these changes are a most important aspect to analyze the impact of the global sea level rise and climate change. All of these information regarding shoreline changes may help to predict and assess future changes and also to prepared the management and adaptation policies for sea level rise.

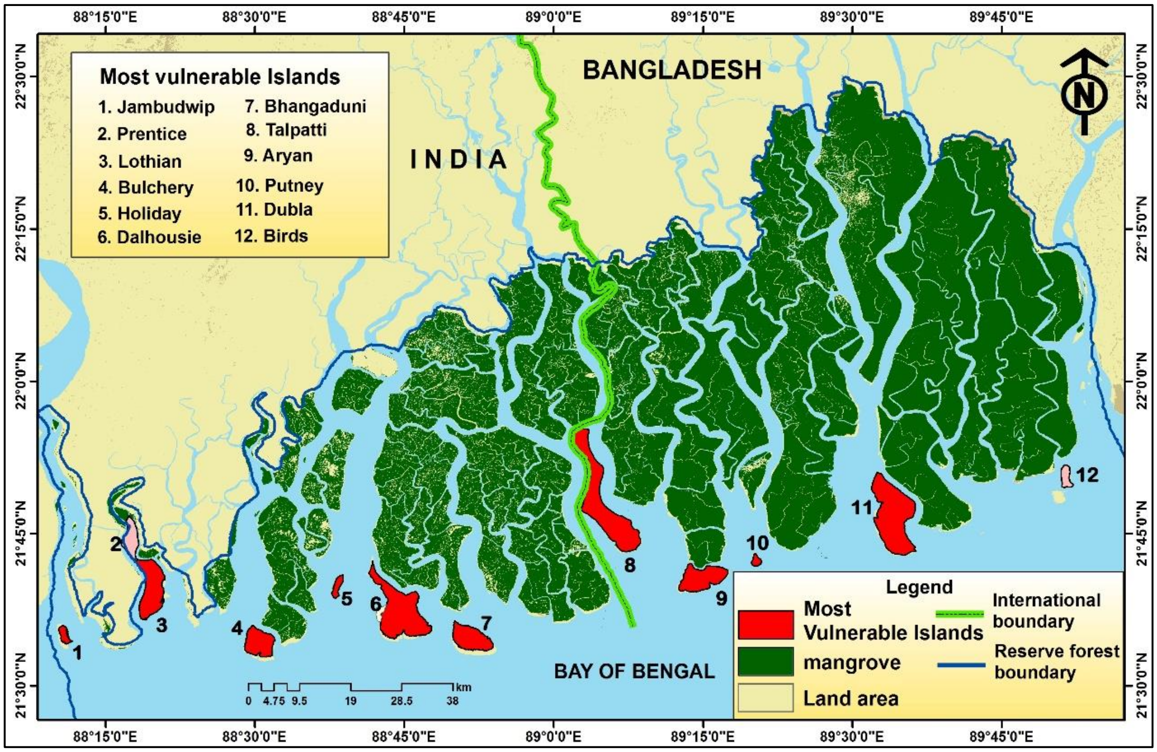

Fig. 3.12 Location of the most vulnerable islands of Sundarbans in the study between 1957 -2014

Coastal erosion and accretion are constantly reshaping the total area of Sundarbans and specifically area of coastal islands. With regular water supply, and more or less constant amount of sedimentation in the Ganga- Brahmaputra estuary, within the concerned period, coastal erosion, and accretion occurs to be an outcome of tidal hydraulics, and sea level changes. With continuing storm surges and tidal influences of higher intensity, previously equilibrium sediments are eroded, deposited and are dis-loosed, eroded within the subtidal areas and the channels. The results have shown in continuous shallowing of near islands bathymetry, and channels floor with reduction of islands area of Sundarbans. The eroded or disloosed sediments may be transported by tidal currents and river water to the north and may redeposit along the tide dominated areas of east and north. However, climate change induced extreme cyclonic events like a tidal surge, cyclone, storm are causing the erosion to a large extent. In the present study, represent that the total 12 islands (7 in India and 5 in Bangladesh) are active in the study area, where 10 islands (6 in India and 4 in Bangladesh) are facing erosion activity, and 2 islands are facing accretion activity (fig. 3.11). Few islands viz. Bed Ford, Suparibhanga, Kabasgadi, Lohachara have already vanished from the coastal areas of Sundarbans. Most erosion-prone vulnerable islands are Jambudwip, Lothian, Bulchery, Holiday, Dalhousie, Bhangaduni islands in India (fig.3.12) and Talpatti, Aryan, Putney, Islands in Bangladesh and accretion prone islands are Prentice in India and Birds in Bangladesh (fig. 3.12). In general, the eastern banks of all rivers less vulnerable to erosion activity than the west and the sea-facing islands and sea facing oblique shorelines are most affected by erosion.

The erosion has also affected both mudflats and sandy beaches. Even islands area with dense mangrove cover in the eastern part of India such as Dalhousie, Bhangaduni, Bulchery and the western part of Bangladesh Putney have been subsequently eroded and submerged due to sea level rise.

Marginal erosion and accretion have localized in the river margins and inner estuaries specifically along the coast and along the northern and eastern margins of islands where it is mostly sea facing, and east-west oriented. The present study, conducted during 1957-2014 reveals that, the total studied Islands area of 45600 hectares of the Sundarbans (both in India and Bangladesh) in the year 1957 have reduced to 33157 hectares in 2014. This amount to a net loss of studied islands area is about 11731 ha at the rate of 205.81 ha per year which includes erosion 13638 ha and the accretion 190 ha. (Table 3.6). In the middle of Sundarbans, matured islands are found which comparatively more stable due to the lesser anthropogenic activities and the presence of thick and dense mangroves. Shoreline recession and erosion has associated with an increase in the vulnerability of the coastal areas to the storm surge, sea-level rise, and wave action and have a potential threat to the destruction of the natural resource.

The southernmost coastal island are experiencing the amount of maximum erosion, and this is well understood from the representing graph given below (fig. 3.13 and 3.14). The

Table 3.6 Accretion and erosion rates of southernmost 12 vulnerable islands in 58 years (1957-2014) of the last century

Sl. no	Islands	Location in Sundarbans	1957 (ha)	1973 (ha)	1990 (ha)	2002 (ha)	2014 (ha)	Loss from 1957 to 2014 (ha)	Gain (ha)	Rate of loss/gain (ha)	% of loss/gai n
1.	Jambudwip	India	1175	637	631	526	403	772		-13.54	65.70
2.	Prentice	India	64	1233	1310	1340	1392	-	1328	+23.30	95.40
3.	Lothian	India	3448	3368	3311	3305	3303	145		-2.54	4.21
4.	Bulchery	India	3648	2941	2651	2356	2076	1572		-27.58	43.09
5.	Holiday	India	415	275	209	168	31	384		-6.74	92.53
6.	Dalhousie	India	9539	7711	7156	6597	6030	3509		-61.56	36.79
7.	Bhangaduni	India	6517	4185	3754	3023	2361	4156		-72.92	63.77
8.	Talpatti	Bangladesh	8170	7956	7694	7298	7180	990		-17.37	12.12
9.	Aryan	Bangladesh	3843	3682	3295	3039	2778	1065		-18.68	27.71
10.	Putney	Bangladesh	952	410	341	298	241	711		-12.47	74.68
11.	Dubla	Bangladesh	7889	6973	6878	6847	6783	1106		-19.40	14.02
12.	Birds	Bangladesh	-	-	139	204	579	-	579	+10.16	100.0
Total	12 Islands							14410	1907		

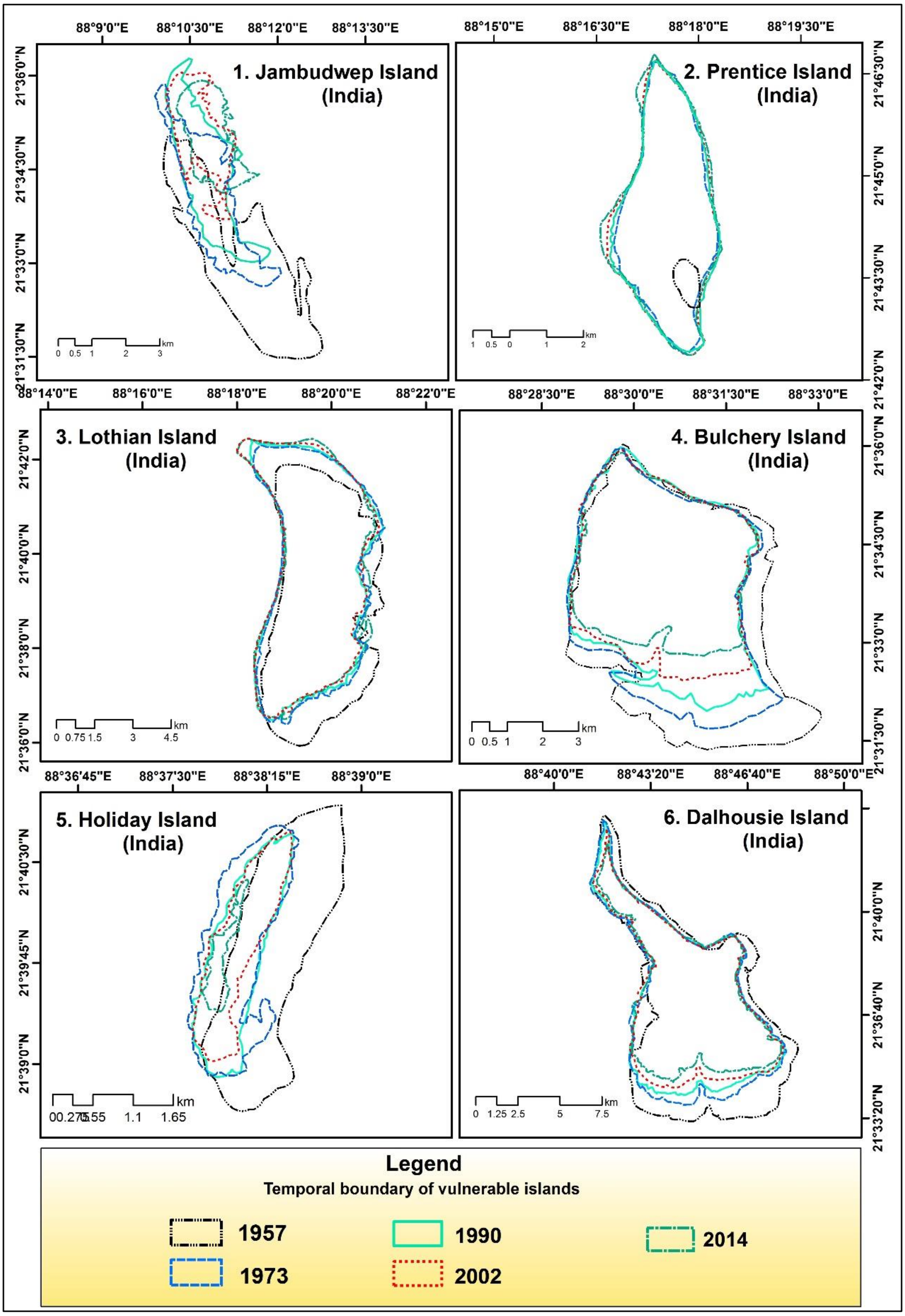

Fig. 3.13 Change detection of the most vulnerable islands 57 years of the last century (1957-2014)

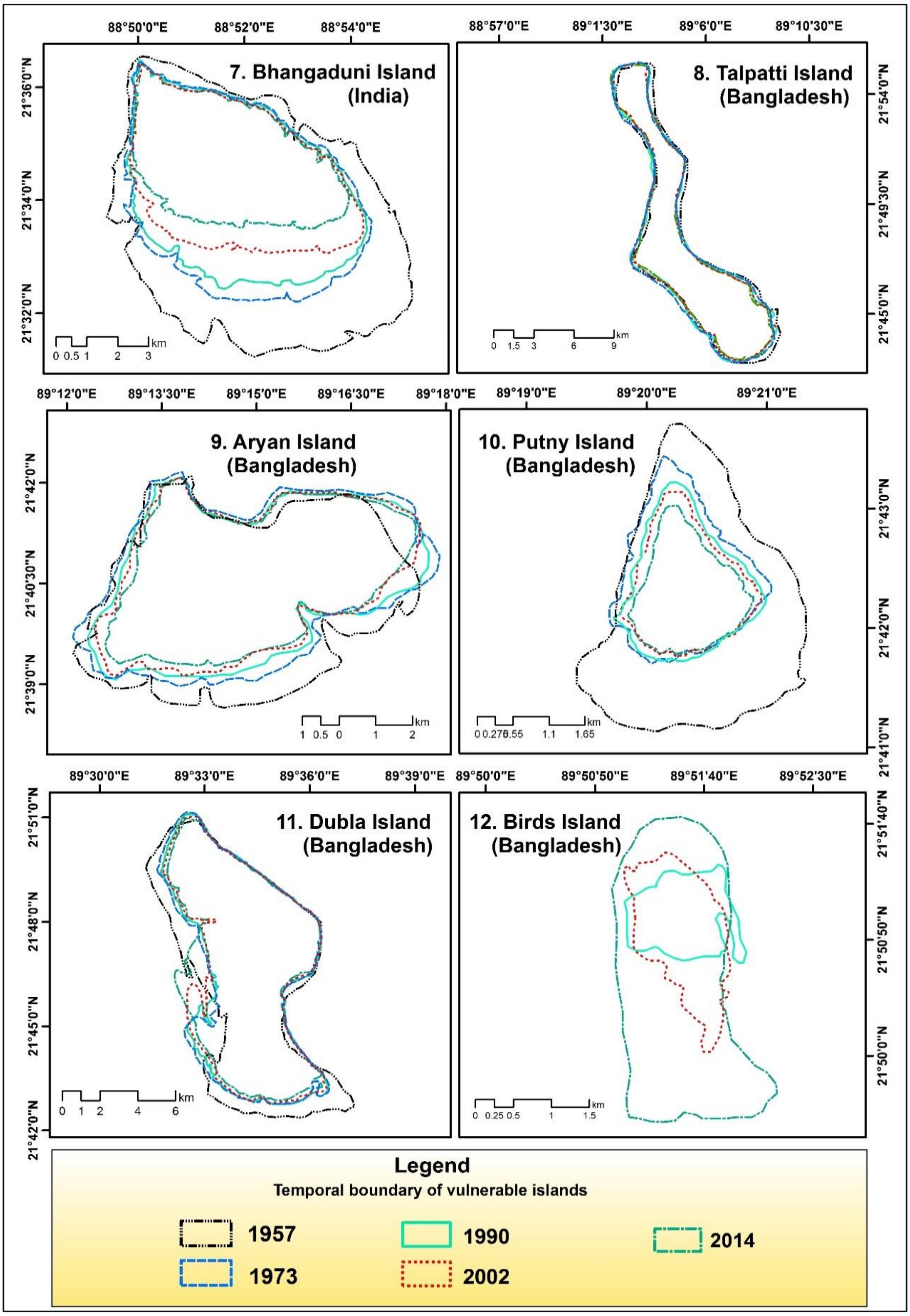

Fig. 3.14 Change detection of the most vulnerable islands 57 years of the last century (1957-2014)

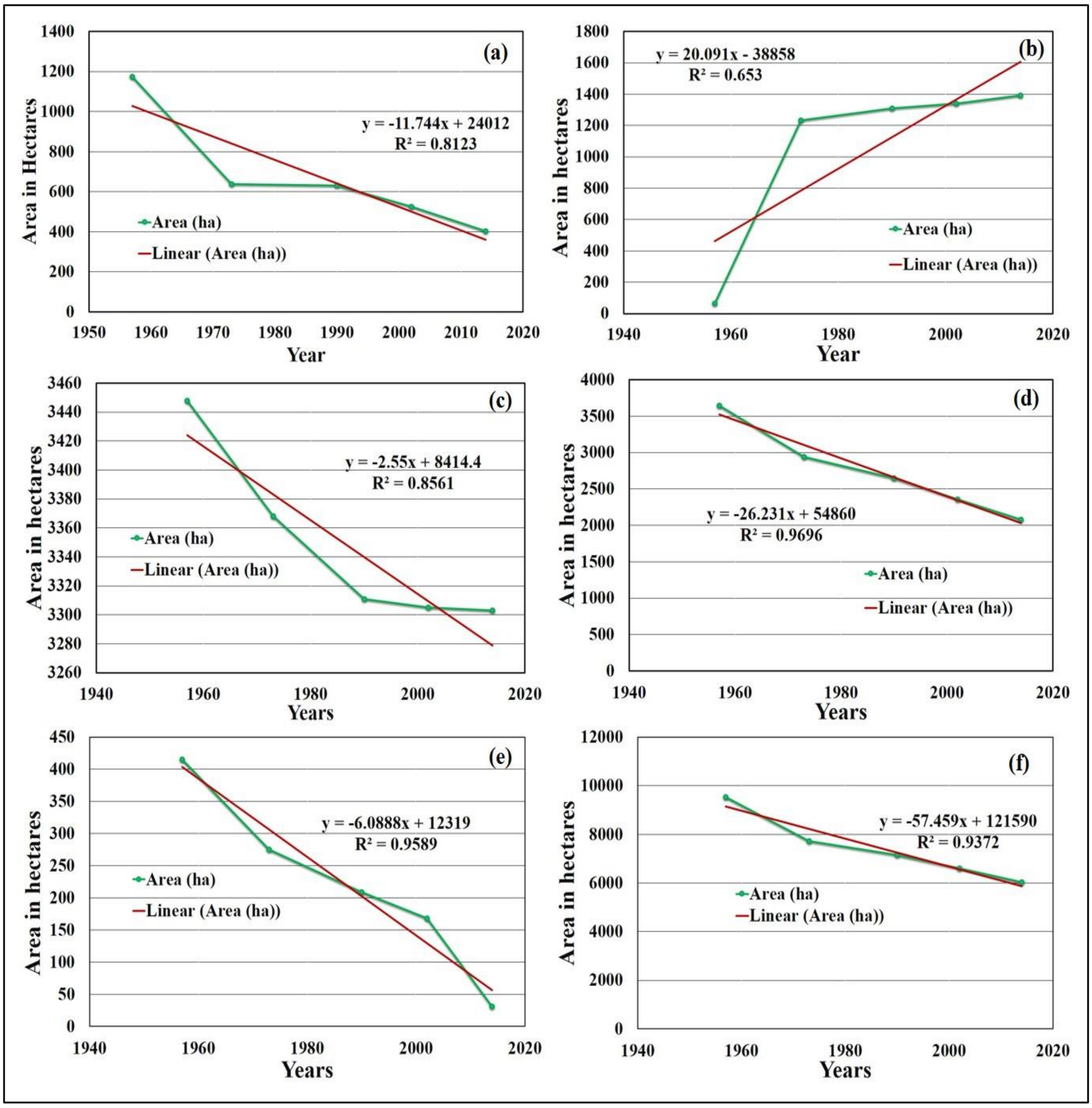

Fig. 3.15 Erosion and accretion rate of Jambudwip (a), prentice (b), Lothian (c), Bulchery (d), Holiday (e), and Dalhousie (f) islands of Sundarbans in the last 57 years of the last century

table 3.5 is showing the loss, and rates of erosion in the context of the studied year 1957 to 2014 of the following 12 coastal islands of the total area of Indian, and Bangladesh part of Sundarbans (table 3.6). The erosion and accretion rates is also much higher for these coastal islands than the total area of Sundarbans, which is established from the fig. of change detection, and erosion rate in the last 57 years of the Sundarbans (fig. 3.13, 3.14, and 3.15, 3.16).

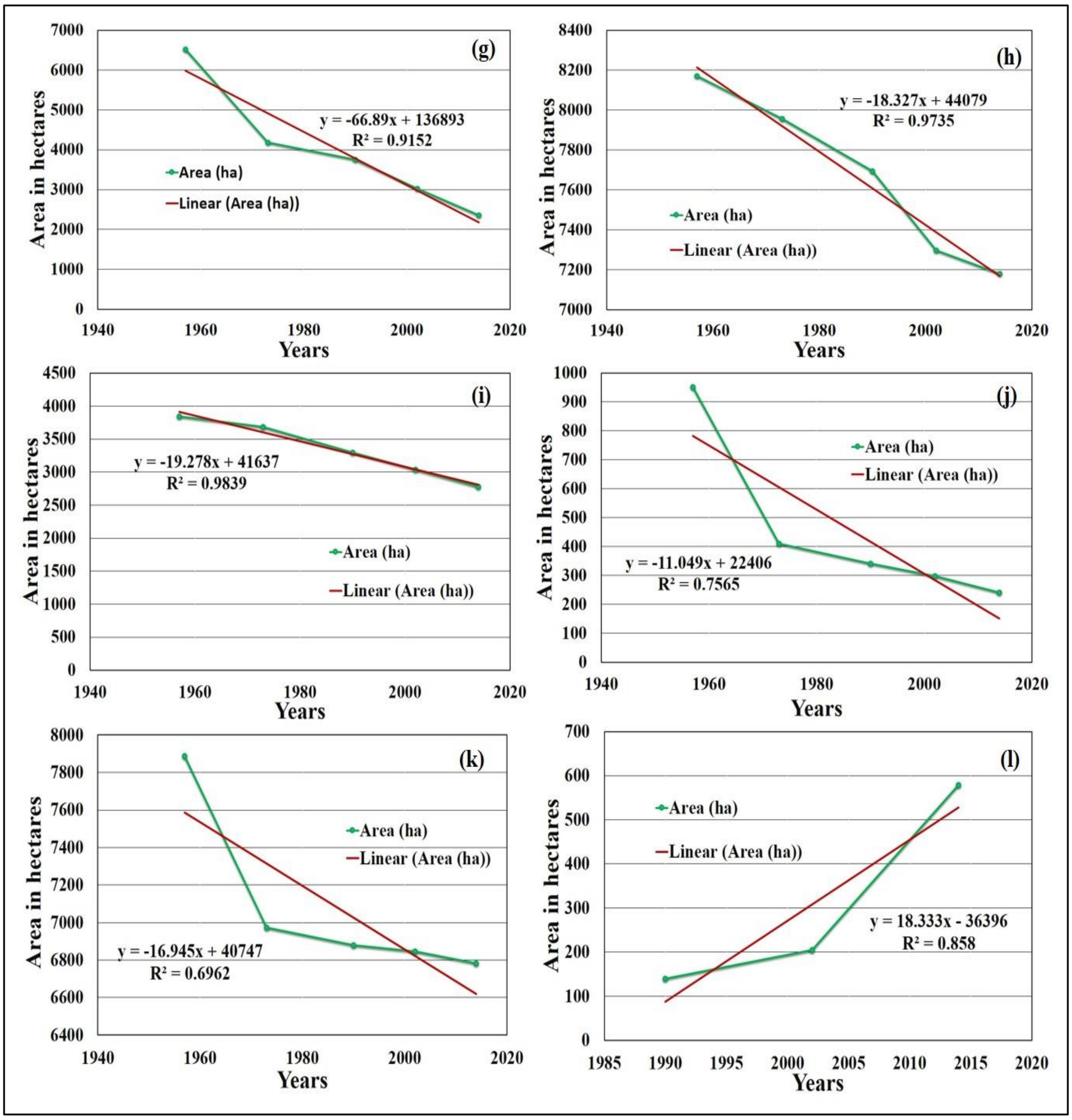

Fig. 3.16 Erosion and accretion rate of Bhangaduni (g), Talpatti (h), Aryan (i), Putney (j), Dubla (k), and Birds (l) islands of Sundarbans in the last 57 years of the last century

3.4 Vulnerability of Embankments:

In Sundarbans, several inhabited Islands, and others land areas are protected by artificial embankments to control saline water ingression and increase the possibility to makes aquaculture and agricultural land (Danda 2007). Out of 3500 km length of the embankment, 800 km lands are mostly vulnerable to the breach at the time of high-intensity cyclonic events. The Recent trend of the rising sea level will have more dangerous effects on these embankments and making susceptible and vulnerable to overtopping and breach. This vulnerable condition of embankments may enforce to the overtopping of ocean water and may also influence to the total wash out during storm surges and other cyclonic events. The earthen embankments of Sundarbans built in mid-19th century that have been destroyed in several locations and help to raise the river beds through continuous siltation in most of the rivers of this region remains above the contiguous areas. The slope and the crest height, top and bottom width of water level, material used and alignment for maintenance of the recent embankments are not investigated to be the useful defense to the continuous rising trends of relative sea level and to protect the inhabitant islands from flooding or inundation. The present condition of embankments in alarming as any east wind having 30-40 km per hour wind speed at the ebb tidal period can overlapping with sea water and damage or threats several km of adjacent embankments. Those can be greater amount of wash out during storm surges and cyclonic activity. During such event, the river water speedily enter into the estuaries and islands, and destroy everything within a few minutes and damage many lives, livelihood, and assets of the people.

3.5 Tarns-boundary Mangrove Ecosystem: Vulnerability Analysis

Despite the mangrove ecosystem values of wildlife and fish habitats, carbon sequestration, coastal protection, pollution, and sediment trapping, mangrove forest have rapidly decreased in recent decades and many dependent habitats suffer by unscientific use, and misuse of forest resources. In recent, climate change and related events have started to compound the impacts of direct anthropogenic pressures. Loss and degradation of these coastal habitats due to direct human and climate change impacts annihilate the coastal protection. It also provide during extreme weather events and also increase their vulnerability and cumulative effects, with significant social, economic and environmental consequences for the local inhabitants.

3.5.1 Vulnerability:

The vulnerability of mangrove ecosystem is a comprehensive idea of assessing environmental, economic, and social response to changing environment that can defined as the predisposition, and prosperity to be skeptically affected (Mertz et al. 2009). Vulnerability assessment of mangrove ecosystem under climate change have followed, and endpoint/outcome interpretation of vulnerability were solutions are in exposure reduction through sectoral and technical adaptation, and climate change mitigation to reduce negative impacts.

Vulnerability have been characterized to have three significant dimensions: exposure components to stresses, sensitivity components, and associated adaptive capacity (fig. 3.16). Vulnerability includes an extended range of parameters or components, in building qualitative and quantitative understanding of the outcomes and processes of vulnerability, and its utilization to intertidal ecosystem has the scope to improve adaptation planning under climate change (Adger 2005).

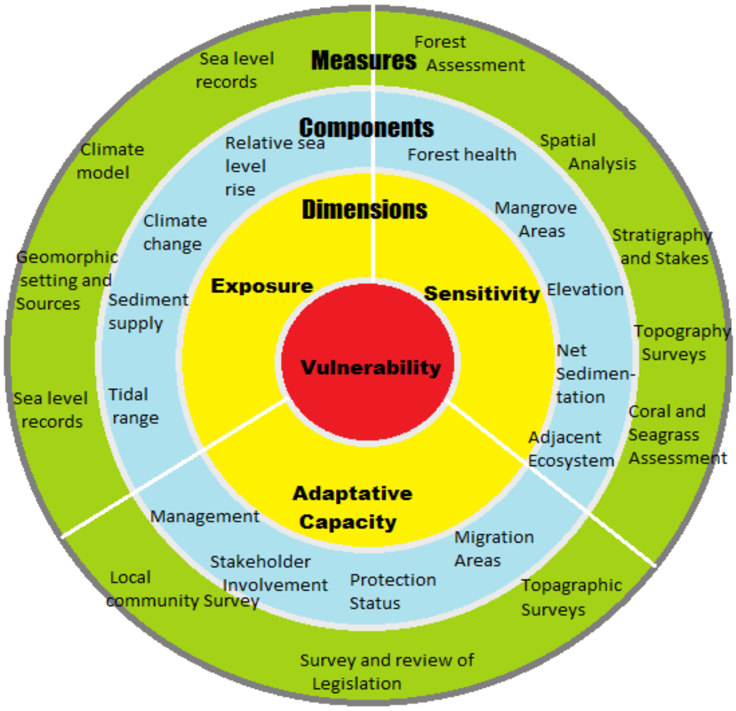

Fig. 3.17 Vulnerability Dimensions and its components, and measures

However, vulnerability is a quantitative method but rather is a not measurable, relative dimensionless property. The three considerable dimensions of mangrove vulnerability have classified into the abstract features, or components upon which to assess exposure sensitivity parameters and adaptive capacity. These dimensions can each be evaluated using a no of parameters, which are the observable measurements of each of the features (fig. 3.17). The following parts of the chapter analyze the exposure, sensitivity components, and adaptive capacity of mangrove ecosystem, to identify useful measurements.

3.5.2 Exposure Components:

Exposure of an ecosystem refers to external threats, such as the rate and magnitude of change that a system or species is possible to experience. Table 2.9 chapter reviews the main exposure components to climate change that affect mangroves. Global warming and the direct effects of increased temperature and subsequently increase co_2 have been initiated to be significantly advantageous to mangrove ecosystem, latitudinal range and increasing mangrove productivity (Alongi 2008). However, the relative sea level rise have been created to be the main exposure of interest, with harmful effects on mangrove ecosystem (table 2.9).

Other environmental parameters, as well as global warming and climate change, increases the susceptibility of a mangrove ecosystem to harm. While reduced precipitation and sea level rise is exposure factors that directly related to recent climate change, mangrove also has exposure components independent of climate warming that may cause enhanced sensitivity as threat increases. These are attributed to various geomorphic setting of mangrove and also include fluvial sediment supply, tidal range, a vulnerability in wave action, and lead to various specific vulnerabilities (table 3.7). River dominated geomorphic

Table 3.7 Geomorphic setting of mangrove and their controlling attributes (Source: Ellison 2009)

Attributes	Tide dominated	River dominated	Wave and river dominated	Low island
Mangrove locations	Islands and tidal creeks	Distributions and seaward edge	Lagoons and low energy distributions	Basin or fringing
Geomorphic setting	Estuarine with elongated islands	Deltaic distributaries	Lagoons and distributaries	Marine dominated
Tidal range	High	Low	Any	Low
Sediment source	Allochthonous	Allochthonous	Allochthonous	Autochthonous
Dominant process	Tidal currents	Freshwater discharge	Freshwater discharge and wave energy	Sea level
Specific vulnerability	Sediment budget changes, increased tidal action	Change in sediment supply and discharge	Sediment supply decreased	Low net accretion rates

settings are more vulnerable to catchment runoff changes, and therefore sediment supply and freshwater availability, while low-lying island may be more susceptible to the sea level increase owing to a combination of low root mass accumulation, and limited mineral sedimentation (McKee 2011). On the other hand, tide-dominated systems developed mostly on active tidal currents with higher tidal range, where variation in sediment supply may cause mangrove vulnerability and coastal erosion.

3.5.3 Sensitivity Components:

Sensitivity indicates to intrinsic characteristics of system or a species, and consider the degree of changes to which the systems or species is affected by exposure factors, such as problem arising from an increase in the height, and frequency of flooding due to relative sea level rise (IPCC 2014). There is also a well-researched article on the impact of environmental conditions on composition, structure, and productivity of mangroves, and the degree of the human impact interpretation and these approach can be used to climate change sensitivity (Alongi 2008). Hence, mangrove vulnerability is exposed by decreasing biodiversity, increase in mortality, and decline in productivity, forest condition (table 2.9), relative to productivity characteristics and forest biomass of intact mangrove physiognomic types or pattern at different latitudes.

Mangrove mortality and deterioration as an outcome of exposure components, such as drier conditions, or sea level rise. It causes coastal retreat or mangrove area loss, and such type of shoreline change is a sign of the risk of relative sea level rise (Giri et al. 2011). Analysis of spatial change showing the seaward retreat of mangrove has characterized to total sea level rise or human impacts. Hence, it may applied as an indicator of the sensitivity of mangrove ecosystem.

3.5.4 Adaptive Capacity:

Adaptive capacity indicates the ability of a system or species to cope or accommodate with climate change and sea level rise impacts with minimum disruption. It can analyzed through species response or ecosystem, and through anthropogenic actions that decrease vulnerability to expected or actual changes in climate.

For mangrove ecosystem of any coastal area, if net accretion does not in balance condition, with sea level acceleration then adaptation planning is through landward migration, and there depending on available areas, and suitable topography (Gilman et al. 2007).

Stakeholders and local communities also promote adaptive capacity through their management strategy, supported by useful legislation that helps mangrove protection from non-climatic threats. Effective management sustainably promotes resilience capacity, which linked with appropriate adaptive strategy as the ability to recover and absorb the impacts of disturbance (IPCC 2014).

3.5.5 Ranking for Vulnerability Analysis:

Rank hazard based approaches are a recent conceptualization of ecosystem vulnerability is its developments over last 3-4 decades, coastal risk categorizations have designated ranks to selected variables, such as rock type, sea level trends, shoreline development, tidal range, wave height, relief, and geomorphology (Gornitz et al. 1993, Hedge and Reju 2007, Dwarakish et al. 2009). The shoreline of mangroves has ranked as a very high vulnerable zone, and coastal wetlands or sedimentary shores also considered as very high vulnerability (Gornitz et al. 1993). This assigning rank has developed by such vulnerability databases including both quantitative and qualitative information of mangrove of the coastal region (Gornitz 1993).

Sea level rise is a vital component of the risk assessment of the coastal area, including local variables, such as sediment compaction and long-term regional down warping that influence to subsidence. However, relative trends of sea level in mangrove environments can be recognized from paleoecological records or information if such sea level determining factors are precisely related to a tidal datum (Gornitz et al. 1993).

The tidal range components have been analyzed differently in the vulnerability assessment of coastal mangroves. Some ranked coastal micro tidal region as a low-risk category and the coastal macro tidal region as a very high-risk category (Gornitz et al. 1993). This was substantiated because of micro tidal regions result in an extended zone of intertidal coastal wetlands, which subsequently increase the coastal inundation, and related hazards, and also have recognized with strong tidal currents enable to erosion (Gornitz et al. 1993). Other considered coastal micro tidal region to be a very high-risk category, considering that these micro-tidal coastal areas are more vulnerable to storm surge effects as sea level is always within one meter. On the other hand, high tidal range (about 4 m) of shoreline is 50% probability, that the tidal water level will be two meters below HTL (high tide level), when a storm surge hits the coastal area (Dwarakish et al. 2009).

In mangroves, coastal gradients and tidal range control the edge side extend to the species zones and coastal swamp within the mangroves area due to the location between high tide elevations and mean sea level (Ellison 2006). The mangrove areas with similar gradients represent in the micro tidal region have a large lateral extent than the mangrove extent of micro tidal regions. Sea level rise causes upward shifting of the tidal range that introduced a range of mangrove vulnerability to sea level rise.

$$V_r = \frac{S_r}{N}$$

Where, V_r indicates the vulnerability rank, Sr refers the total rank score of the components, and N signifies the no of completed components.

3.5.6 Significant of Vulnerability Assessment:

Participatory vulnerability assessments grant for the identification of multiple salinity beyond linked with climate, and mangrove vulnerability assessment under climate

Table 3.8 Vulnerability dimensions, component, and measurement techniques in mangrove areas

Vulnerability dimensions	Component	Measurement	Sources
Exposure	Sea level rise trends	Stratigraphy, tide gauge records, pollen analysis	Ellison and Zouh (2012)
	Tidal range	Tide gauge records	PSMSL 2014
	Type of sediment supply	Geomorphic setting assessment	Table 2
	Precipitation change	Climate projections assessment	Fiu et al. (2010)
Sensitivity	Mangrove health	Mangrove productivity, mortality, recruitment, change of basal area	Ellison et al. (2012), Fiu et al. (2010)
	Retreat of seaward edge	Satellite image analysis using GIS, recent changes of mangrove area	Ellison and Zouh (2012)
	Mangrove area reduction		
	Within the mangroves elevation	Topographic survey	Ellison and Zouh (2012)
	Net accretion rates	Sedimentation rods, Radiocarbon dating on stratigraphy	Ellison and Zouh (2012), Fiu et al. (2010)
	Adjacent ecosystem resilience	Sea grass and coral reef monitoring standard methods	Fiu et al. (2010)
Adaptive capacity	Status of mangrove protection	Structured questionnaire survey, workshops, knowledge of local community	Fiu et al. (2010)
	Stakeholder involvement		
	Local management strategy		
	Elevations above mangrove zones	Topographic survey	Ellison and Zouh (2012)

change, and sea level rise. It has been accepted by United Nations Environment Program (UNEP) as needs to be capable to bring remedial measures and early warning. While adaptation options and mangrove vulnerability have examined, these did not develop into recognized measurements, components, and dimensions of vulnerability to grant a generalized replicable approach.

A risk category system for ecosystem management could identify the aspects of the mangrove forest system most sensitive to disturbance function under climate change. It also helps to sustain of mangrove framework to site-specific assessment strategy of mangrove vulnerability (Gilman et al. 2006). Vulnerability situations that socio-economic scenario and coupled ecosystem research have also been establishing as a needs for coastal ecosystems. Identifications of suitable metrics for weighting mangrove vulnerability to effects of sea level rise and climate change is an urgent need for designing ‘climate smart’ mangrove conservation.

3.5.7 Methodology for Vulnerability Assessment:

The vulnerability assessment methodology was devised to identify the fundamental components of the mangrove ecosystem that may be experiencing climate change and sea level rise impacts, and which were also most vulnerable to their related impacts.

An integrative sequence of approaches was trialed, preceded by an inventory review existing information of importance. The overall review of existing information fulfilled necessary steps before the assessment of mangrove vulnerability of site definition and stakeholder’s involvement (Ellison and Fiu 2010). Analysis and field methods for each trialed elements and measurement techniques has contributed by the sources that listed in Table 3.8.

To get an overall vulnerability assessment of mangrove, results from the systematic measurement of the selected components of vulnerability we assigned ranks (Table 3.8), on the basis of guidance from the listed literature provided in Table 2.9, 3.7. Criteria based rank developed for each vulnerability extent at each of the considering site, which are displayed in Table 3.10, and where 4 is high vulnerability and 1 is low, and final results were averaged to present an overall vulnerability rank of mangrove ecosystem.

Fig. 3.17 shows the component used to measure mangrove vulnerability scoping layout that allows significant approaches to the assessment of vulnerability in various regional setting, here used to mangrove ecosystem.

Stakeholders group of people has involved throughout implementation and planning stages (Gornitz 1993) with workshops used for information showing and scoping at the initiation of the vulnerability assessments. Stakeholder's contribution was enabled by various kinds of ongoing communications through e-mails, facilitator consultation, showing of reports, meeting and related results. However, towards the edge of the vulnerability assessment, particularly workshops contributed the results of vulnerability assessment to regional scale planning, selection of management priorities to support adaptation measures and the improvement of policy. Local management capacity, the effectiveness of legislation and stakeholder's involvement in the mangrove locality has evaluated from structured interviews results with local community members and stakeholders, with ranking allowing observation of quantitative and qualitative information.

3.5.8 Trans-boundary Mangrove Vulnerability:

To analysis mangrove vulnerability of Sundarban, consider the trans-boundary perspective of the both countries as India and Bangladesh (table 3.9). The total region of Sundarban has located in estuarine or deltaic geomorphic setting, 'climatic hotspot' with high fluvial sediment supply. It has found that the rainfall, temperature, salinity, sea level rise were significant changes and have some difference between two countries to assess the vulnerability of mangrove ecosystem.

For the assessment of mangrove vulnerability, at Sundarban mangrove forest are recruitment trends, mangrove changes, and basal area measurement were carried out by geospatial techniques as previously discussed. The mortality and changes of mangrove are much higher in Bangladesh part than the Indian part of Sundarbans, due to large storm events, and cyclonic activity, with strong tidal effects (3-8 m), and the landward migration is also highest at Indian Sundarbans due to higher rate of sea-level rise at different stations.

Analysis spatial change in Sundarban mangrove from 1973-2014 in the Indian part showed a significant amount of seaward edge retreat where Bangladesh part of Sundarban signifies stable landward margin along the coastal area. In the last 30 years, landward migration of Sundarban recognized the causes are mainly for aquaculture (shrimp farming) conservation from mangrove areas. The net accretion rates of mangrove are subtle for the both parts of the Sundarbans than the erosion rates in the studied period, and the accretion prone islands are Prentice islands in India and Birds Islands in Bangladesh.

Table 3.9 Environmental and socio-economic settings of the Indian and Bangladesh part of Sundarbans

Characteristics	Indian Sundarbans	Bangladesh Sundarbans
Latitude	21.55°-22.15°	21.65°-22.50°
Longitude	88.20°-89.10°	89.10°-89.86°
Physical characteristics		
Mangrove area (km^2)	4071	5771
Geomorphic setting	Ganga and Hugli estuary	Ganga-Brahmaputra and Meghna estuary
Tidal range (m)	2-4	2-8
Climatic characteristics		
Annual rainfall (mm)	1920	1800
Precipitation patterns	Monsoonal (5, June)	Monsoonal (1, June)
Air temperature (°C)	20-48	25-43
Relative humidity (%)	82	80
Demographic characteristics		
Total population	4.5 million	7.5 million
Population density	900-1000 persons/km^2	500-700 persons/km^2
Major economic activities	Agriculture, fishing, aquaculture, honey collection and animal husbandry	Timber collection, agriculture, aquaculture, honey and wax collection, fishing and crab collection
Replicate sites	N/A	Coastal regions of bangladesh and priority to replicate themselves
Site co-ordination sites	WWF India, other NGOs and UN agencies	UNESCO, MOEF Bangladesh, USAID, UNDP

Elevations within the mangrove areas were analyzed as part of sea level reconstructions or restoration (Ellison and Zouh 2012), finding both in Indian and Bangladesh part of Sundarbans. Rhizophora and Heritiera species are occupied the higher elevational ranges within 20 cm in Indian part, and little greater elevational features (20-50 cm)

Table 3.10 Criteria for ranking of all measures for the assessment of mangrove vulnerability

Rank	**1**	**2**	**3**	**4**
Exposure parameters				
Tidal range (m)	>5	3-5	1-3	<1
Sea level rise (SLR)	Site uplifting	Uplifting slightly	Stable	Subsiding
Rate of sediment supply	High	Medium	Low	Very low
Change in climatic elements (salinity, rainfall and temperature)	Less changes	Moderately changes	High changes	Very high Changes
Sensitivity components				
Basal area change	positive	No change	Negative	High negative
Mangrove condition	No impact	Medium impact	High impact	Very high impact
Litter productivity (%)	High	Medium	Low	Very low
Mortality (%)	Low	Medium	High	Very high
Recruitment	All species producing seedlings	Most species producing seedlings	Few species producing seedlings	No seedlings
Seaward edge retreat	None	Some	Moderate	Significant
Mangrove area reduction	Little or none	Moderate	Significant	Very significant
Mangrove elevation zones (cm)	>80	50-80	20-50	<20
Mangrove accretion rates (mm)	>1 mm greater than SLR	<1 mm greater than SLR	Equal to SLR	<1 mm less than SLR
Adjacent sea grass resilience	High	Moderate	Low	Very low
Adjacent coral reef resilience	high	Moderate	Low	Very low
Adaptive capacity parameters				
Community management Capacity	Good	Moderate	Poor	None
Elevations above mangroves	High availability of mangrove areas	Mostly availability of mangrove areas	Some migration areas available	No availability
Mangrove protection legislation	Good	Moderate	Poor	None
Stakeholder involvement	Good	Moderate	Poor	None

have found in Bangladesh part of Sundarbans (fig. A2.1). Potential migration areas of mangrove has suggested coastal areas of Bangladesh part using differential GPS (Global Positioning System) survey (Ellison 2012), but it has not found in case of India for the management conservation priorities in the future development of mangroves.

Table 3.11 Vulnerability assessment ranking results of trans-boundary ecosystem (India and Bangladesh part of Sundarbans) and the average vulnerability for each site of the ecosystem

components	**Sundarbans (India)**	**Sundarbans (Bangladesh)**
Exposure components		
Tidal range (m)	2 (2-4 m)	1 (3-8 m)
Sea level rise (SLR)	2 (uplifting slightly)	1 (Uplifting)
Rate of sediment supply	1 (High)	2 (fairly high)
Change in climatic elements (salinity, inundation, rainfall and temperature)	3 (high changes)	4 (very high changes)
Sensitivity components		
Basal area change	4 (high negative)	3 (negative)
Mangrove condition	3 (high impact)	4 (very high impact)
Litter productivity (%)	1 (High)	2 (Medium)
Mortality (%)	3 (high)	4 (very high)
Recruitment	3 (Few species producing seedlings)	4 (no seedlings) 3 Some
Seaward edge retreat	4 (significant)	4 (significant)
Mangrove area reduction	3 (significant)	3 (significant)
Mangrove elevation zones (cm)	4 (<20)	3 (20-50)
Mangrove accretion rates (mm)	4 (<1 mm less than SLR)	4 (<1 mm less than SLR)
Adjacent sea grass resilience	4 (very low)	4 (very low)
Adjacent coral reef resilience[26]	4 (very low)	4 (very low)
Adaptive capacity parameters		
Community management Capacity	2 (moderate)	1 (good)
Elevations above mangroves	2 (mostly availability of mangrove areas)	3 (Some migration areas available
Mangrove protection legislation	2 (moderate)	1 (good)
Stakeholder involvement	2 (moderate)	2 (Moderate)
Total	53	57
No of components	19	19
Vulnerability rank	**2.79**	**3.0**

[26] Coral reefs (See Pramanik 2014) and Oyster both are the oceanic community. Oyster reefs are extensively found in the near shore region and river mouth but coral reef live in the open sea.

An extensive coral reef and seagrass resilience also help mangrove to their health and diversity along the coastal regions (Fiu et al. 2010). Coral reef and seagrass inventories used earlier monitoring's by World Wide life Fund (WWF 2002), and found that the offshore reefs condition has remained resilient, but seagrass beds of inshore region showed significant impact on sedimentation rates. Both the regions of coastal India and Bangladesh part of Sundarbans has found the little presence of coral reef and seagrass to help mangrove resilience, ecosystem health, and other protective functions.

The local community participation has involved in the monitoring and the assessment of mangrove productivity and condition. Maximum area of the Bangladesh part of Sundarban, are under Ramser sites or reserve forest category, then the Indian part that signifies the conservation planning and policy is more effortful to this part of the Sundarbans.

Overall results based on ranking of all selected components from both (India and Bangladesh) part of Sundarbans has shown in the table (table 3.11). Using rank characteristics for the evaluation of each measurement (table 3.10) to interpret results or evaluation outputs from both parts of Sundarbans. Details sources of results for each parameter has given in Table 3.8. Rank results are finally arranged (table 3.11) to find an overall vulnerability rank for both parts of Sundarbans.

Vulnerability assessment ranking results using up to19 components found both part of Sundarbans to have some measurements of vulnerability (table), where 4 is very high, and 1 is a low vulnerability (table 5). The assessment ranks 1 indicate that have current mangrove resilience and rank of 2-3 would consider medium vulnerability that prioritized some management options could improve. The vulnerability ranks of above three would signify mangrove ecosystem with the very high vulnerable condition, requiring immediate or undertake proper management strategies.

3.6 Vulnerability Adaptation Strategies of Mangrove Ecosystem:

Bangladesh part of the Sundarban mangroves has found some inherent vulnerability, such as very high mangrove mortality, very high tidal range and very low accretion rate of mangroves. These vulnerability could be decreased by better controlling strategy of non-climatic threats to enhance the resilience of mangrove species, and habitats to the significant impacts of climate change, which can be managed through reduction of anthropogenic impacts, and the enhancement of local management strategies. Priorities for management planning in mangrove zones, which situated in low-lying tidal areas are to plan inward migration, and established protected areas of mangrove, and to undertake management strategies, then increase the accretion rates within the mangrove areas (Ellison and Zouh 2012). Management planning for inward migration zones could consider to engaging collaboration plants of most favorable areas with local communities and removal of obstacles to migration. Protected mangrove areas that are very strategic during climate change and sea-level rise are those with high species diversity and reliable sediment supply.

The Indian part of mangroves have also found some inherent resilience capacity, with a lower tidal range (2-4 m), lower mortality, and higher accretion rates than the Bangladesh part of Sundarbans, positioned at the estuaries, and delta of Ganges river with experiencing slight tectonic uplift, and high sediment inputs. The delta and estuary region have currently predicted that average rainfall is reduced as a result of climate warming, although there is unevenness and uncertainty of monsoonal precipitation. Maximum portion of the delta is affected by the devastated storm surge events and flooded much of the coastal area. While forest assessment results, and GIS analysis showed resilience in the major portion of the mangrove areas, there have been decreasing of mangrove area on the seaward margins owing to sea-level fluctuation, particularly converted mangrove area to flooded, water bodies, and barren lands. The vulnerability of the ecosystem in the Indian part can be decreased through the efforts by the engagement of stakeholders and local communities to replant the deteriorated mangrove areas, that enhance accretion through sediment trapping in root system and root mat growth.

Chapter 4

Mangrove Dependent Livelihood Vulnerability to Climate Change

Livelihood is a generous term encompassing social, economic and ecological assets of a country being guided by human capabilities capital as well as a human resource. In other words, livelihood comprises of human activities, assets, and capabilities of a household or community (including both social resource and material resource), simply it refers to the activities needed for mode of living (Chambers and Conways 1991). The livelihood have determined as sustainable, when it can survive and recover from stresses, enhance capabilities, and contribute livelihood opportunities for the future and present generation, without disruption of natural or environmental resources (Chambers and Conways 1991).

A well-standard livelihood generation can resolve if the utilization of existing resources is maximum and wastage is minimum. This livelihood can be expressed by,

$$\mathrm{Y} = \frac{X_{ru}}{X_{ra}}$$

Where, Y= standard livelihood, X_{ru}= utilized resources and X_{ra} = existing resources to the individual, community, and society. Moreover, in most cases the existing resource and material resource remain unutilized due to the lack of management strategy, policy and perfect technology etc. and sometimes political and social interventions and thus the standard livelihood value (value of Y) hardly becomes one. It is also important that in the context of standard livelihood generation does not indicate exploitation of resources. The total resource must and to be sustain through appropriate technology, policy and the utilization of renewable energy resources.

4.1 Direct and Indirect Effect of Climate Change:

Climate change and global warming, which is an important truth of the recent time, has already initiated more pressures on livelihood by stirring the assets and resources directly and indirectly as discussed below:

4.1.1 Direct Effect of Climate Change on Livelihood:

- ❖ Ambient Temperature increase is affecting agriculture production, plant growth, and human death by heat waves.
- ❖ The rise of sea level is causing salinization of the ground water aquifer and coastal land.
- ❖ Sea level rise is also posing a negative impact on freshwater fishery and agriculture.
- ❖ The increasing level of tidal surge affecting coastal vegetation and mangrove loss, and crop loss.
- ❖ Also reduced the availability of economically most significant fishes from estuaries and coastal waters.

4.1.2 Indirect Effect of Climate Change on Livelihood:

- ❖ The increase in sea level cause a decrease of mangrove forest and influence the landward migration of mangrove areas, concomitantly threatening the nursery ground of shellfish and finfish juveniles.
- ❖ Salinity alteration is affecting plankton community (as the fish feed) thereby influencing the fish population.
- ❖ Depression of pH level is causing Oyster and Coral reef deterioration that subsequently affect the shelter ground of fish communities.
- ❖ Increasing temperature enhances the microbial diseases in fishing and aquaculture by accelerating plankton bloom. Such as seaborne plankton named as Vibrio cholera that blooms and warms the sea surface.
- ❖ Increasing temperature also effects to increase the probability of disruption of human infectious diseases.

Finally, climate change and sea level rise has potential role to pose the negative impact on the flow of resource, and their utilization which can seriously influence the economic condition of poor landless people, fisherman, and marginal farmer who directly depend on the environmental resource base. The adverse effect of climate change and related events on livelihoods is also a combination of the geographical configuration of the area. In recent, continuous increase of ice melting due to accelerating temperature rise (since 1980) is of main interest for the countries that are low-lying islands and coastal low lying regions.

4.2 Mangrove Dependent Livelihood:

Mangrove is the rich and unique ecosystem which furnishes the substantial ecosystem services for the local communities. The world largest and richest single tract Sundarban mangrove provides a significant range of forest ecosystem services and subsidies to the socio-economic development of both India and Bangladesh and the neighboring countries. Over 4 million population of India (Census 2011), and 3.5 million population of Bangladesh lives in the neighboring area of Sundarbans, where they are indirectly or directly dependent on the mangrove ecosystem, and their services (Giri et al. 2007). Also, Sundarban mangroves reduce coastal erosion, coastal flooding, storm surges and winds and serve as a coastal protection (Giri et al. 2007). The coastal zone of total Sundarban also plays a role as a filtering system and provides a larger buffer zone for the deltaic coastal ecosystems. Also, the mangroves have global, regional and local importance for its economic and ecological resource. Ecosystem services of mangrove, such as ecological products (e.g. timber, food), erosion control, water retention, purified water supply can substantially support the livelihood generation of the local inhabitants. The diversified ecosystem services, the regulating, provisioning, cultural functions, and supporting of ecosystem, not only contribute livelihoods for local inhabitants, but also often assist as a ground of human endurance: for instance, sustain vital diversity of food, ecosystem services against extreme events of the adjacent countries or secure to provide safe drinking water (fig. 4.1). Mangrove ecosystem also create a significant monetary value of preserving the ecosystem services contribute to local households, and national economy as well as to the global environment, substantially transcends the benefit of economic, and commercial advancements, such as prawn and shrimp farming (Swapan et al. 2011).

Currently, Sundarban mangrove is more vulnerable to both natural and anthropogenic factors. The natural factors include in particularly, climate change induced salinity increases and sea level rise. It has been predicted that the climatic hotspot, and rich

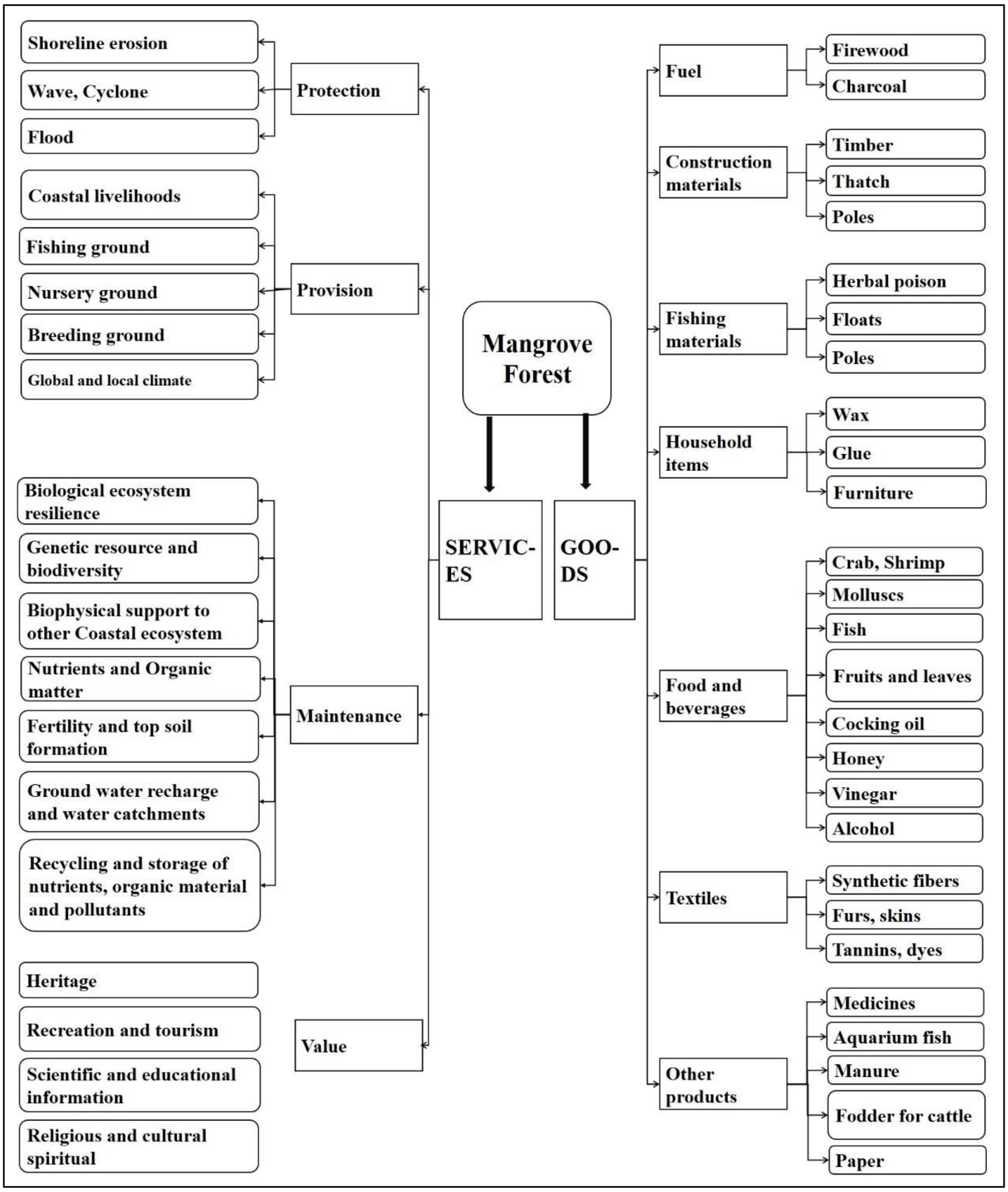

Fig. 4.1 protective and productive role of mangrove as services and goods (Source: Hossain 2009)

biodiverse areas of Sundarban mangrove will be shortened from 60% to 30% in the increase of 88 cm sea level in the year of 2100 with compare to the year of 2001. Subsequently, the concomitant effect of the sea-level rise would ultimately diminish the production of the mangrove products, ecosystem services and also threatened the dependent livelihoods (CEGIS 2006). The changes in the forest services and products of the Sundarban mangrove areas are clearly discernible on the provisioning products, primarily on the fisheries and tree production that are mostly affected in the local livelihoods.

4.3 Determinants of Livelihood Services at Sundarban Forest:

The local households of Sundarban fully depend on mangrove oriented natural resources for their livelihood and subsistence, and also face limited income. In recent, there are various threats to the generation of revenue, both actual and potential in the context of climate change. Fig. 4.2 represents a brief overview of risk and threats to income generation and sustainable livelihood, based on the expert interviews and focus group discussions at Bakkhali in the Indian part of Sundarbans.

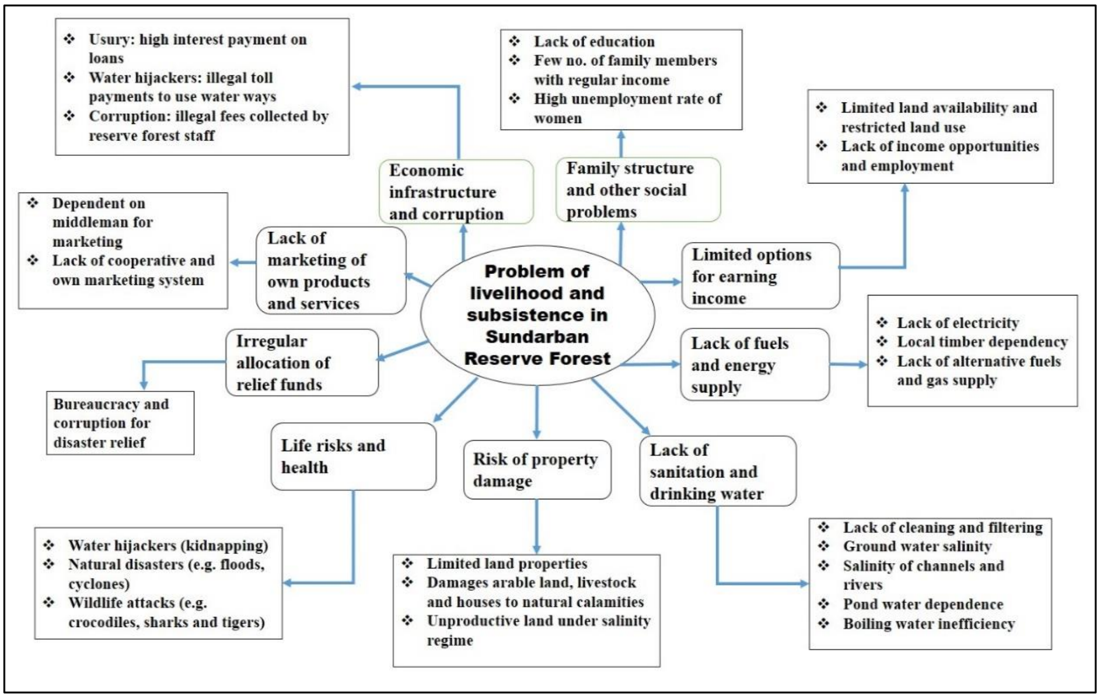

Fig. 4.2 Problem of securing livelihood in Sundarban Reserve Forest

First, An extended range of threats arising from natural disaster, climate change as well as human activity and man-animal conflicts. Although human and wildlife conflicts may be most common natural in the reserved or protected forest of Sundarbans. Where the monitoring, different management policies, and rules might help to reduce this problem (Barlow et al. 2008). The salinity of Sundarban poses severe threats to livelihood, as well as the quality of life in particular. Due to the essence of mangrove forest and their specific location (such as, dependence on climatic condition, flooding, and arbitrary policies persevered by Reserve officials), communities and local inhabitants are under common threat of losing their livelihood and subsistence sources, especially usability and availability of mangrove oriented natural resources. Therefore, some problems cannot be identified by uncertain management regime of the mangrove forest due to their origin, e.g. depends on upstream agricultural practices, and groundwater salinity in Sundarbans.

Second, the socio-economic risks due to unemployment, education and limited opportunities for the sources of substitute income generation.

Third, the institutional (legal), political and economic infrastructure are fragile in terms of supporting basic security as well as property rights. The corruption of park officials and government, usury, and hijacking pose a severe threat to persistent income generation. Generally, in vulnerable mangrove ecosystem such as, these institutional infrastructure and strong regulatory framework have demonstrated to be of most significance, the paucity of which leads to poor management strategies, and overuse of natural resources. Furthermore, disaster and hazard relief arrive too late to help local inhabitants after natural catastrophes. Moreover, finally, the trading structure and the market, especially regarding the transporting livelihood products and goods to the market and the dependency on middleman for selling, are most significant problems in Sundarbans.

4.4 Main Livelihoods of the Local Inhabitants:

The provision of highest range of ecosystem products, and services are an important benefit for the provisioning of the Sundarban Biosphere Reserve, and its adjacent buffer zone as the richest and most diverse areas of the reserve forest in both India and Bangladesh. The mangrove ecosystem services also may be globally or nationally important in the context of global climate change and frequent natural disaster e.g. Tsunami, cyclone, etc. (Alongi 2008).

To assess the role of Sundarban mangrove forest to the main livelihood of local inhabitants, a comprehensive field survey was undertaken from November to December 2014 at Bakkhali as a part of Indian Sundarbans. The field survey consisted using standardized questionnaires, secondary data collection, targeted and expert stakeholders and focus group interviews, integrated with a review of the extensive relevant literature. The results reveal that the inhabitants depend on ecosystem goods and services in two ways, First, local inhabitants collect cash income by selling ecological products such as honey and wax, nipa palm, crab and fish at local, national and global markets.

Second, the ecosystem provides substantial subsistence resources, such as timber, fresh water, and food.

However, from the investigation timber production and associated honey and wax production, and aquaculture are mostly dominated services and products of the Sundarbans that presently more vulnerable due to climate change.

4.5 Timber Products in Sundarbans:

The Sundarban mangrove is one of the oldest consistently managed forest ecosystem in the world. It comprises about 51% area of the reserve forest in the Bangladesh and earns significant amount (41%) of the forest income. It contributes about 45% of the fuel wood and total timber collected from the public forest of Bangladesh (FAO 1994). Moreover, diversified non-forest products are also estimated from mangrove area of Sundarbans. Where, more likely one million inhabitants collect their livelihood materials from the Sundarban forest (Das and Siddiqi 1985). As a shelterbelts, the mangrove protects south-east part of Bengal in India and south-west part of Bangladesh against tidal surges and cyclonic storms. The ecosystem also protects adjacent agricultural land against saltwater intrusion from the sea. But different evidence suggest that the mangrove ecosystem is showing indication of depletion and under stress (Das and Siddiqi 1985).

4.5.1 Status of Forest Species for Timber Production:

The Sundarban is one of the most important biodiversity with rich mangrove species in the world that supports 245 genera with more than 300 plant species. Gewa (Excoecaria agallocha) of Euphorbiaceae family and Sundari (Heriteria fomes) of Sterculiaceae family are the two main tree species of Sundarbans. Sundari (Heriteria fomes) is the climax tree species in the mesohaline and oligohaline zone where as Gewa (Excoecaria agallocha) is mixture with other species such as, Goran (Ceriops decandra) and Passur (Xylocarpus mekongensis) forms the climax condition in the polyhaline zone. Local inhabitants of Sundarbans have extracted the services and products from the mangrove forest, and more diversified livelihood materials have collected over centuries. But recent climate change, and related events are the big threat to tree production from the

Sundarban mangrove. Also, human interventions have modified this forest which is now degrading ate a significant rate.

4.5.2 Role of Mangrove Tree to the Livelihood and Services:

The mangrove ecosystem services and products of the Sundarban biosphere reserve can be classified into four types, such as

a. Supporting services
b. Cultural services
c. Regulating services, and
d. Provisioning services.

The most important provisioning services and products are timber, fish and aquaculture, fuel wood, Nypa palm, medicinal plants, honey and waxes; and the cultural services are recreation, tourism, Hindu's worship of Goddess, and recognition as heritage site. The regulatory services of the mangrove includes protecting from storm surges and cyclone, waste assimilation, tidal inundation, carbon sequestration, erosion control, nutrient cycling; and the supporting services includes creating nursery ground to numerous fishery and wildlife, and habitat for important fauna and flora in the Sundarbans.

Among the above maintained mangrove ecosystem services, cultural (e.g. tourism) and commercially important provisioning services (e. g. timber) are the great interest to the neighboring communities and forest departments of Sundarbans.

4.5.3 Timber Production in Sundarbans:

The dominant mangrove species Sundari (Heritiera fomes) was once in great amount across the whole Ganga-Brahmaputra delta (Islam 2001). Also, reliable estimates of the coverage area of Sundarban mangrove are not available earlier to 1857. From different available literature the forest area has been estimated that during 1870-1930, the area has been declined from 6000 sq. km to 7500 sq. km. But the boundary of mangrove forest remained unchanged. Also the vegetation inventories estimated that the tree coverage area has been declined by 0.004% per year during the period of 1926-1995 (Curtis 1993) (Fig. 4.3).

In addition, depletion in the growing stock of the mangrove tree has been observed. Also, average stand density has been declined by 87% and that Gewa (Excoecaria agallocha) and Sundari (Heritiera fomes) has been reduced by 95% and 84% respectively during the period of 1926-1995 (Iftekhar and Islam 2004) (fig. 4.4). There is a clear evidence of large amount of uncontrolled extraction of Goran (Ceriops decandra), the main source of fuel wood collection in the mangrove forest. Subsequently, non-wood mangrove products and materials, such as Oyster shells, honey and wax collection have equally declined. Historical records also shows the extinction of three tree species of Bruguiera genus, vulnerability of Rhizophora species, Amoora cuculata, and Cynometra ramiflora, and decline of Baringtonia species and Lumnitzera racemosa (Karim 1994).

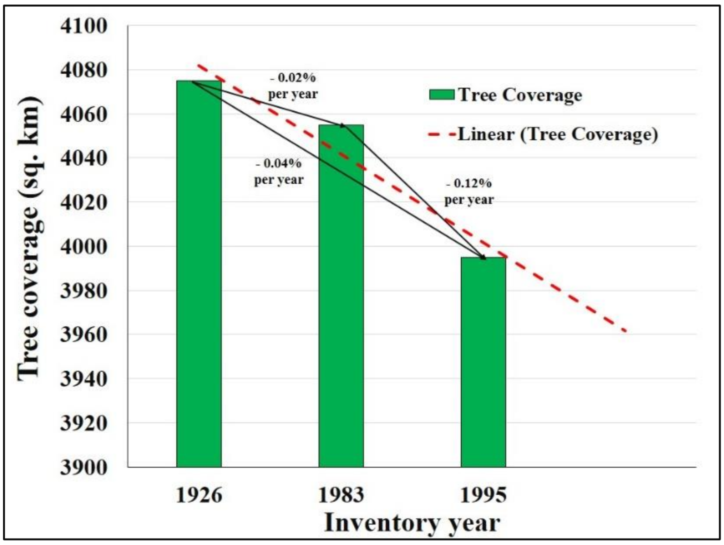

Fig. 4.3 Mangrove area of Bangladesh Sundarbans in different inventory year (Source: Iftekhar and Islam 2004)

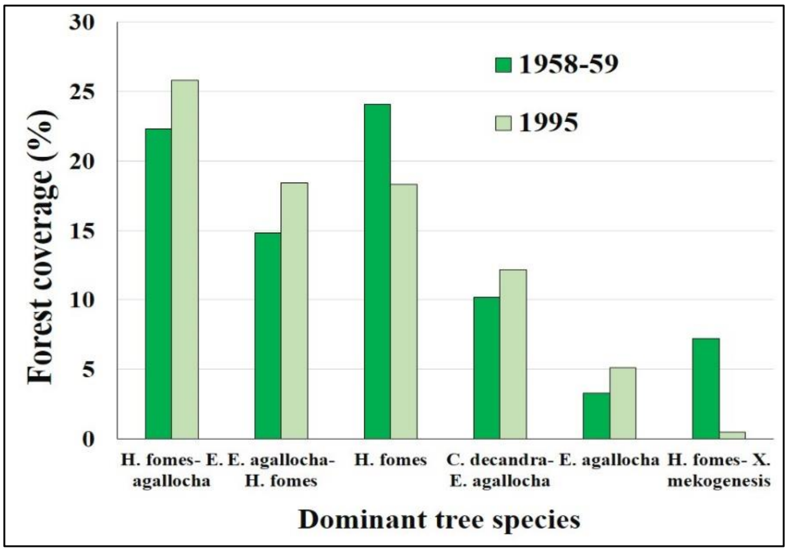

Fig. 4.4 Changes in dominant tree species in the Sundarbans (Source: Iftekhar and Islam 2004)

Evidence of tree reduction can be found in the destruction of pure Heritiera fomes (Sundari) forest types at the rate of 0.17% per year. The reduction is cause for the crown death or 'top dying disease' (Haq 2010). Conversely the coverage area of Excoecaria agallocha is gradually increasing ate the rate of 0.05% per year due to their higher tolerance capacity. Regeneration status of Excoecaria agallocha and Heritiera fomes constitutes 45% and 41% seedling appearance. The proportion of sea area also prograding at the rate 0.05% per year. All of these components have resulted in the reduction of average height and canopy closure of the forest. Thus it could be proved that in a maximum portion of the mangrove degraded retrogradation or succession is taking place (Karim 1994).

4.5.4 Impact of Climate Change on Timber Products of Sundarbans:

Recently, climate change will affect the physiographic condition, and subsequently change the supporting services of the mangrove ecosystem (habitat for animal and plants, nursery ground for wildlife and fisheries) will be largely affected. The alteration in the supporting services of the mangrove ecosystems due to sea level rise and climate change would be greatly evident of the provisioning services of mangrove ecosystem, primarily on the fisheries and trees production. Climate change induced relative sea level rise will change the salinity pattern and inundation in the Sundarban regions that will affect the potential suitable areas for the mangrove trees. According to CEGIS (2006), the suitable area for two most important timber tree species Gewa (Excoecaria agallocha) and Sundari (Heritiera fomes) would decrease 45% by 2100 at 88 cm sea level rise and 14% by 2050 at 32 cm sea level rise from the base year of 2001. Also, the suitable area of Gewa (Excoecaria agallocha) would decline maximum 7% by 2100 (table 4.1) due to relative sea level rise. Finally, the stock of Gewa (Excoecaria agallocha) and Sundari (Heritiera fomes) tree species may be declined in future likely to the change of mangrove area.

Table 4.1 Suitable area of dominant mangrove trees in Sundarbans (CEGIS 2006)

Year	Suitable area (ha)
Sundari	
2001 (Base year)	80489
2050 (32 cm SLR)	69571
2100 (88 cm SLR)	43884
Gewa	
2001 (Base year)	59027
2050 (32 cm SLR)	58992
2100 (88 cm SLR)	55021

Also, the changes of mangrove species composition in Sundarban region due to relative sea level rise evidenced that the most important biodiverse areas with significant species composition would be declined. The reduction have may be 60% to 30% at 88 cm sea level rise in the year of 2100 compare to the year of 2001, which would potentially decrease the livelihood production of the provisioning services and forest products (CEGIS 2006). Moreover, the variety of wildlife that dependent on the mangrove habitat, would be vulnerable due to the impact of climate change. In this context, world famous Royal Bengal Tiger found in Sundarban forest along with other wildlife species may be at great risk. Changing floristic and hydrological composition will change the food web and food chain in the Sundarban forest that may lead to the gradual extinction of wildlife's and their lives as it occurred in the past.

In the context of timber tree species, the fishery resources both capture and culture, would be affected by the sea level rise and climate change. The potential changes in the fishing ground (nursery) would alter the composition of fisheries capture not only inside the mangrove belt but also the adjacent marine and freshwater areas, which would have a great impact on the national and local economy. Subsequently, the production of the other important non-timber forest products, such as Golpata (Nypa palm), honey and wax, medicinal plants etc. would be changes or restrict due to climate change. Moreover, the cultural services of the mangrove dominated Sundarbans completely depend on the existence of valuable tree species, wildlife, and its natural beauty. If sea level rise and climate change significantly change the forest diversity and coverage, tourism activity with attractive components will be reduce in a long run. Also, the regulatory services of the Sundarban region would be altered due to sea level rise and climate change. Further, the role of Sundarbans as reducing cyclonic impact and carbon sequestration will be declined if the mangrove extend decreases in a larger scale.

4.6 Honey and Wax Products:

A number of mangrove products like fuelwood, timber, Golpata leaves, honey and wax, fish, fish fry, grasses and shells are collected from Sundarban region. Among them honey and wax collection are the most significant product harvested from Sundarban reserve forest. Although, it is a minor mangrove product relative to timber and aquaculture. There are three main important species of honeybees in mangrove area of Sundarbans. They are Apis florea, Apis cerena, and Apis dorsata. Wax and honey collection only utilizes the species of Apis dorsata. The Sundari, Goran, Gewa, Bean, Kankra, and chaila are considered as a good nectar or honey producing plant species for Apis dorsata. Moreover, the honey collection in the mangrove areas continued for a period of three month from April to June. The nectar and honey yielding plant species may be classified into two categories, such as plants may be identified as nectar and honey producing plant and the others may be termed as late honey and nectar producing plant species. Keora, Passur, Khalsi, Kankra are early pollen or nectar producing plants, and Hargoza, Bean, Kankra, Gewa are late pollen and Nectar producing plants species. Khalsi is the most important pollen and nectar producing plant species. The production of honey from Khalsi flower has a significant demand and produced honey is of good taste and fragrance, does not easily crystallize and best quality with less moisture. A small amount of Khalsi honey crop collection, in unripe and ripe condition, is collected or harvested, rather robbed, by Bawali (leaf cutter and wood collector) and Jele (fisherman) before regular harvest by the Mauwali people in the month of April to June. This practice is most harmful for the bee population and bee lives.

4.6.1 Production of Honey and Wax in Relation to Forest Types:

The highest amount of honey and wax are produced in the western part of Bangladesh Sundarban division. Which is located in the very dense mangrove and extreme saline zone of Satkhira range (Gani 2001). The salinity of this area gradually decline from west to east, and the extreme salinity water gradually changes to low saline water or fresh water. The Chandpai range of Bangladesh Sundarban have observed as no honey and wax harvested area, which is located in the low to moderate saline zone (Gani 2001). Moreover, honey and wax production is observed as a longer duration (April to June) in the extreme saline water zone of Satkhira forest range and the production is a shorter duration (Only April) in the fresh water zone of eastern region (Sharonkhola range). There is also observed as a remarkable changes in the forest types and condition between the east and west. In the east, there is presence only early nectar and pollen producing plants. But in the west, there is present late and early nectar and pollen producing plants (Gani 2001).

Maximum honey and wax is produced in the Goran, Sundari, Gewa, Passur, and Khalsi dominated Satkhira forest division. Another high production area is located in the Khulna range, which is located near of the Satkhira division, which is also dominated by same mangrove species like Satkhira range. However, it is clearly found that Gewa, Goran, and Khalsi are the dominant mangrove species which are highly productive for wax and honey production. Eastern parts of Khulna forest division are dominated by Sundari tree and fresh water supply that signify as no honey and wax is produced. It is found that the Sundari dominated Chandpai range is signify that there is also not produce honey and wax. But in the Sharonkhola range, little amount of wax and honey is produced due to the present of Goran and Keora types of forest, although it situated in the fresh water zone. The relation between honey production and forest types along with monthly variation of production is shown in fig. 4.5.

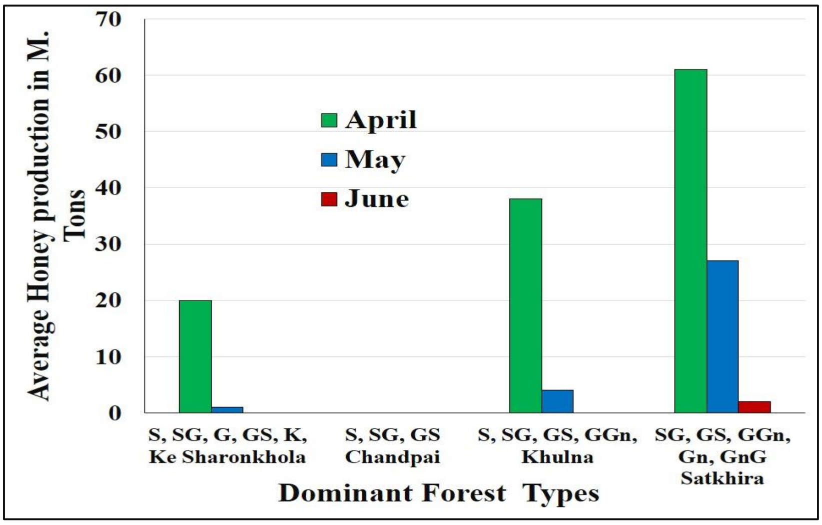

Fig. 4.5 Honey production under dominant forest types (Source: Gani 2001) G-Gewa, Ke-Keora, B-Bean, S-Sundari, P-Passur, K-Kankra

4.6.2 Production of Honey and Wax from Sundarbans:

The production of wax and honey in Bangladesh part of Sundarban and South 24 Parganas (West Bengal, India) are shown in fig. 4.6. The data represent that the honey production varies between 86 metric tons and 321 metric tons (1972-2000), and the production of South 24 Parganas varies from 119 Quintal to 200 Quintal. The average revenue earnings from wax and honey production in Bangladesh

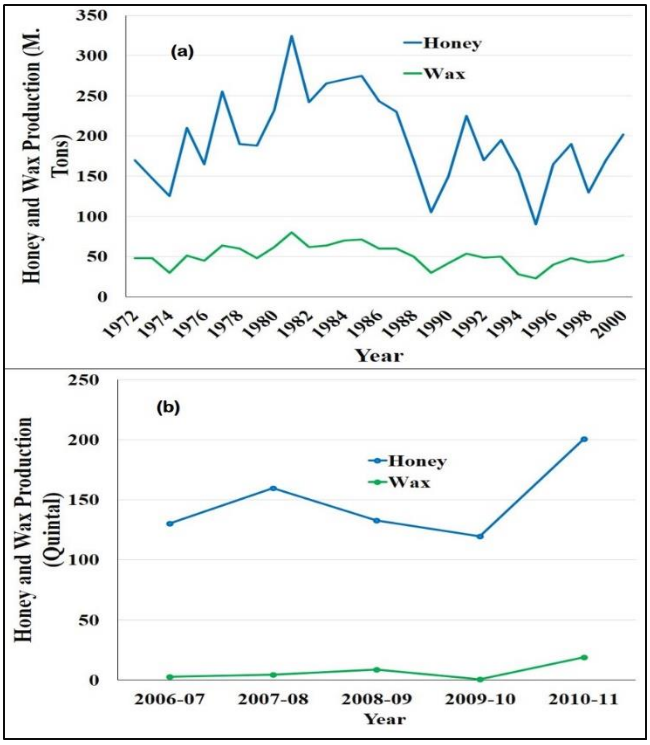

Fig. 4.6 Production of Wax and Honey in Bangladesh (a), Indian (b) part of Sundarbans (Source: Sundarban division (a), District statistical handbook, south 24 Parganas (b)

are Tk. 92000 (US $ 1643) and 398012 (US $ 7107) respectively. Although, the amount does not give the actual value as the Bangladesh forest department has fixed the amount of 20 kg wax and 75 kg honey per Mauwali/month as revenues collection. Moreover, there is a robbing of wax and honey by the Bauwalis and Jele from the reserve forest, which does not include under the production amount. The production of honey and wax has changed significantly in different time period due to climate change induced hazards or storms in the Sundarban. The average production of honey and wax also have declined due to unscientific collection strategies, and the recent increasing climate change effects. However, the production of honey and wax can be increased, if specific scientific measures could be established under the proper guidance of an apiculturist. In addition, wax and honey is not collected from the wildlife sanctuaries and core area of reserve forest. It is also considered that annually and average 2,000 Mauwali people enter into the forest for wax and honey haunting, and Mauwali people can earn about Tk. 5,000 to Tk. 10,000 in one seasons (Gani 2001).

4.6.3 Honey Production in the Context of Climate Change:

The changing nature of climatic variables bound to have a negative effect on the survival of honey bee species or these ecotypes that are closely related with their environment. It can reduce or increase colony harvesting development, capacity, and alter the characteristics of the floral environment. Changes in their behavior, lifestyle, and migration could help them to exist or survive in new biotopes. Honey bees communities will also need to adjust to a total array of pathogens, parasites, and predators summing them.

Migration of honey bees has started during the end of winter season (January), migrated from the countryside to Sundarban reserve forest (SRF), when there are few no of flowering plants are present in the countryside. The quality of honey is related to the pattern and amount of monsoon rainfall. Also, the collected honey during the monsoon season have higher amount of moisture content which have little time to ferment and does not obtain an adequate value in the market.

4.7 Brackish Water Aquaculture Activities in Sundarban:

Brackish water aquaculture, and fishing has become an influential source of shellfish, finfish, and seaweeds especially for production and human foods which, is expected to increase well in the future if sea level rise keeps its present level. It has been indirect and direct effects on biodiversity through the waste production and natural resource consumption. In most cases, the brackish water aquaculture, such as prawn farms and shrimp firms have grown in the mangrove ecosystem (Sundarban) as the water, and tidal actions have congenial parameters.

Brackish water aquaculture refers the farming in the Delta mouth, coastal, estuarine and similar kind of brackish water environment. An increasing and large no of animals and plants is being cultivated in diluted sea and river water. Unlike brackish water aquaculture and inland, water aquaculture comprises the culture of invertebrates, plants not only cultured for food but also for chemicals (Alginates) and decoration (Pearls and Shells). The aquaculture is a commercial activity that alters environmental and natural resources through inputs of labor and capital into products valued by the community as well as a society. The effect of aquaculture on biodiversity and the environment thus originates from three main processes,

- The aquaculture farming process itself,
- The utilization and consumption of resources, and
- The production and management of waste material (Beveridge et al. 1994).

According to the statistics made by the Food and Agricultural Organization (FAO), world total aquaculture production in around 25 million tons, which is equal to world's 20% fisheries production (culture and capture both) by weight (FAO 1994). Production from the aquatic environment reports as around 51% of total aquaculture production in the context of weight (about 53% by value) and also is growing a few percentage (5%) per annum. Although only 4% of cultured fish produced from the sea and almost all farmed Molluscs, more than 90% of cultured crustaceous, and all farmed macro algae has produced from brackish water and marine environment.

Brackish water aquaculture and mariculture practices, which are subsequently pond or cage cultures and have an effect on the carrying capacity of the marine environment on any coastal area. However, eutrophication is an important issue in the marine environment. Generally, from the fish feed 80-88% carbon (C), 52-95% of nitrogen (N), 85% of phosphorus are lost to the environment. Specifically, in the prawn and shrimp culture of the eastern coast of India are run by Thailand design where, fish feed lost 30% phosphorous, 24% nitrogen and the remaining percentage is exported to the natural environment (Briggs et al. 1994).

Aquaculture and Fishery as the ‘backbone of economy’ in the total area of Sundarban, which have earn widespread economic and social benefits (Chand et al. 2012). A large and most no of people of Sundarban engaged and also dependent on capture and culture fishery. Sundarban contributes a lion share of brackish water and coastal aquaculture production in the world. Apart from the brackish water and coastal aquaculture, freshwater aquaculture and firm is growing day by day, livelihood security and contributes parallel economy in the Sundarban mangrove and Sundarban eco-region. Sundarban region boasts approximately 20 species of prawn, 36 species of shrimp, 44 species of crabs with two commercial species, and 172 species of fishes.

4.7.1 Uniqueness of Major Ecosystem and Its Contribution to Brackish Water Aquaculture:

Sundarban acts as the fishery and farm ground and shares more than 90% of the brackish water aquatic species of both India and Bangladesh. The availability of significant commercial aquatic species of the continental shelf where both the countries, mostly depend on density and health of mangrove ecosystem. As a Delta, Sundarban mangrove contributes physiographically favorable environment with respect to salinity, temperature, rainfall, and other significant physiochemical parameters such as sea level rise, tidal influence, and wave amplitude, etc. Moreover, the estuary receives many nutrients from heavy quantities mangrove organic detritus and land drainage that is a significant source of energy for an extended variety of riverine and estuarine consumers. Also, most of the commercial estuarine and riverine fishes flourishes here and develop an extensive amount of the nearshore fishery of the Bay of Bengal (northern part). Other fishes, prawn and shrimp that spend more of their lives in the brackish water and fresh water descend per year to the estuaries and river for their spawning. Therefore, fish, and much freshwater and marine prawn and shrimp need this suitable environment to complete their spawning and life cycle. In Sundarban, mangrove based aquaculture is based upon both marine and inland fishery resources. Finally, the proper interconnection between the two farming and culture systems and most suitable environment can change the total outlook of brackish water and marine aquaculture in Sundarbans.

4.7.2 Shrimp and Prawn Farming:

The coastal aquaculture in Sundarban is dominated by brackish water shrimp farming (Penaeus monodon) and brackishwater prawn farming (Macrobrachium rosenbergii). India and Bangladesh both are also considered as most favorable countries in the world for their significant amount of shrimp and prawn farming due to Sundarbans, which has the most favorable physiographic and agro-climatic condition and its resources. A vast area of estuarine and shallow water bodies and subtropical monsoon climate administered a unique opportunities for shrimp and prawn production and their maintenances (Islam 2008, Ahamed et al. 2008). The practice of shrimp and prawn is extensive and widespread in the coastal Sundarbans, due to a favorable biophysical resource, low-lying suitable aquaculture land and the abundance of wild postlarvae. Over 75% of shrimp and prawn farms (locally named as ‘gher’) of Bangladesh are located in the southwestern part in particular Satkhira, Khulna and Bagerhat districts with some southeast region of Bangladesh. The Indian part of Sundarban cultured most portion of the farming in Namkhana, Sagar, Basanti, Kultali, Sandeshkhali block of South and North 24 Parganas in West Bengal.

The total area of shrimp and prawn cultivation in Sundarban has been increased day by day for the livelihood generation of the local inhabitants and the income generation by exporting of the cultured product. The growth rate also has decreased due to climate change induced extreme weather events, salinization and sea level rise, subsequently impact on prawn and shrimp, and decrease and their mortality. Present farming mechanism in agricultural fields composed of the high demand, and prices for shrimp and prawn in the local and international market, and fish and rice production for household utilization and local markets also have led expanding number of aquaculture farmer (Islam 2008). Because of export assets, the performance of shrimp and prawn farming is important for the local economy of Sundarban, and adjacent region which, is one of the most densely populated, and the poorest region in the world (FRSS 2012). However, while shrimp and prawn farming support huge benefits with environmental impact (Islam 2008). With the view of environmental consequences, it is more important regarding the potential benefits of shrimp and prawn culture as a whole, specifically the economic development in Sundarbans.

4.7.3 Prawn and Shrimp Farming Status in Sundarban:

Growth of brackish water aquaculture and fishing in Sundarban region has centered on prawn and shrimp culture. The dominant species of Shrimp and Prawn culture is Tiger shrimp or Penaeus monodon and Giant freshwater prawn or Macrobrachium Rosenbergi respectively due to their higher unit price and over increasing export demand and market. Scientific farming of shrimp and prawn started mid 80's decade and 90'decade in 20th century, and presently (2010-2011) more than 314,092 ha of area (where India share 37,600ha, and Bangladesh share 276,492 ha area) comes under culture in mangrove dominated Sundarbans. Estimated production of prawn and shrimp farming through aquaculture in Sundarban increased from 92,884 metric tonnes (where India shares 12,500 metric tonnes, and Bangladesh shares 80,384 metric tonnes) during the year of 1990-91 to 280,185 metric tonnes (where India produced 40,725 metric tonnes and Bangladesh produced 239,460 metric tonnes) in 2010-11. However, the accelerated growth of both prawn and shrimp farming industry interrupt suddenly in 1996-97. In addition, the annual production of prawn and shrimp farm traditional areas (in Bangladesh named as 'gher' and in India named as 'bheries') is very small which, is approximately 200-300 kg per ha (table 4.2). However, commercially this farming has practiced in shallow water bodies and low-lying areas, influenced by fluctuated tidal water particularly during the lunar phases and in the brackish water. In general, brackish water refers to the adjacent water bodies such as, lake, backwater, creek, lagoon, and river etc. allowed by gravity flow to a shallow and large area of 10-100 ha, which, also enclosed by constitute earthen bunds on its perimeter. Entry of water into this farming has monitored through a wooden slice built by bamboo poles and planks. Screen formed by bamboo have utilized for filtration of the entered water and also helps to purification. Although, the seed of various shrimp and prawn species, and fish also want to entry these areas with the saline tidal water. However, farmer's usually stock hatchery produced and natural seeds of Macrobrachium rosenbergii (prawn) and Penaeus monodon (shrimp) for better production. In most cases, Penaeus monodon and Macrobrachium Rosenberg seeds are primarily released specially encircled nursery area of less than one hectare located nearest to the reared for about one month and main rearing area. After that, these seeds are easily allowed to entered to main 'bhery' or 'gher' area by the destruction of the earthen bund along cultured pond or cage are at 3-4 different places. Harvesting and stocking are periodic that determined by the lunar phase of the tide. Harvesting has usually done for three days after and two days before during the new moon and for six days' time during the full moon using cast netting and traps formed by bamboo. In most cases of the 'bheries' and 'gher', a single channel is utilized for both draining out and letting in the water. The depth of the breeding or rearing areas varies from one foot to 3 feet limited water exchange is accepted during the lunar tidal phases for taking facilities of the tidal height of neap and spring tides.

Table 4.2 Distribution of Shrimps and Prawn farming (2010-11) in Sundarbans.

Country	Location	Area (ha)	Farms	Production (tonnes/year)
India	Namkhana, Basanti, Kultali, Sandeshkhali	46000	-	33000 (MPEDA 2010-11)
Bangladesh	Bagerhat, Khulna, Satkhira	276492	1150	124648

Also the natural growth of aquatic macrophytes and filamentous algae in this shallow and large rearing areas give an attractive natural environment for the culture and growth of shrimp. Basically in established or traditional farming methods, no others supplementary feed is used and prawn and shrimp culture on the natural way and natural productivity. With the variation of salinity in the water, bodies are exclusively used for farming fish species and together with the prawn and shrimp. The areas with higher salinity range are about 10-35 ppt, experiencing most of the shrimp monoculture. In this areas, farming begins during the months of January/February, and harvesting have finished by October/November months.

4.7.4 Role of Shrimp and Prawn Culture in Sundarbans as an Important Livelihood:

The coastal aquaculture, mainly in Bangladesh part of Sundarban has associated with "green economy" (fig. 4.7) (Ahmed 2013). The practice of prawn and mixed shrimp culture now have an advantageous site in the context of increased water salinity. Therefore, a few no of advanced farmer recently started the mixed prawn and shrimp culture in Sundarban. Nowadays, saline water intrusion has been gradually increased due to climate change-induced sea level rise. Also, the mixed farming system in continuously increasing the importance for Sundarban farmers has a higher monetary returns from both shrimp and prawn. Therefore, mixed farming of shrimp and prawn can optimize profitability, resource utilization, and productivity. In this section, describe the role of shrimp and Prawn cultivation in the livelihood generation of Sundarbans;

4.7.4.1 Food Production for the Inhabitants of Sundarban:

The coastal aquaculture in Sundarban has an important positive impact on food production. In Bangladesh, the total shrimp and prawn production likely to be 239, 460 metric tonnes in 2010-11, where 57,823 metric tonnes have obtained from inland capture (24%), 124,648 metric tonnes comes from inland culture (52%), and 56,989 metric tonnes comes from marine fisheries (24%) (DOF 2012). The domestic consumption, export of shrimp and prawn, and the production remarkably increased

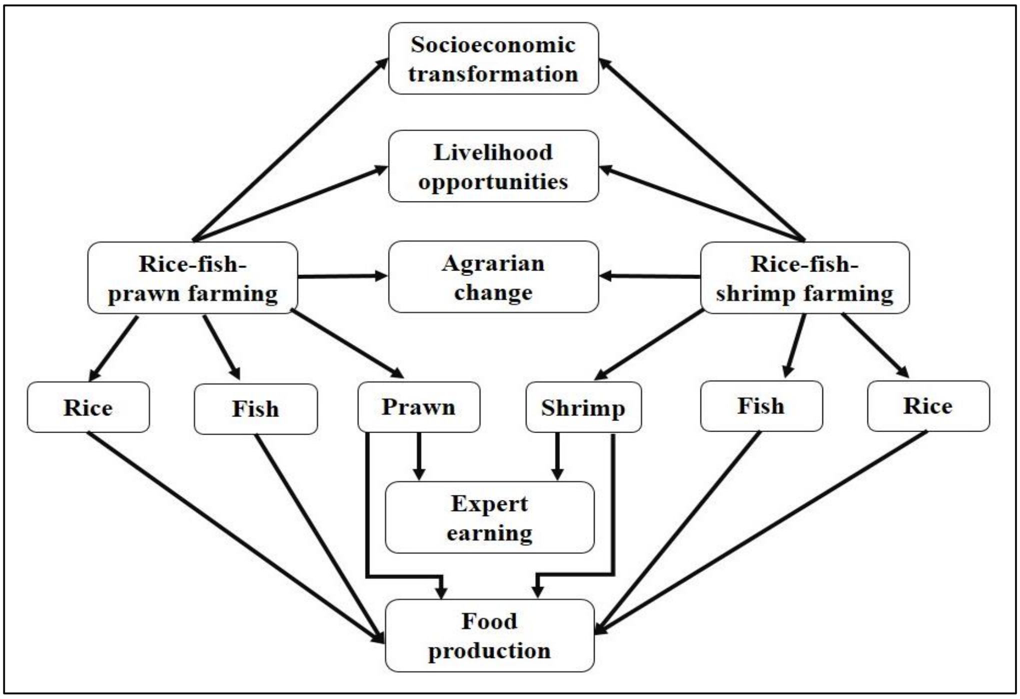

Fig. 4.7 Linking Shrimp and Prawn culture towards a green economy in Sundarbans

over the last 2-3 decades (table 4.3). In the local or domestic markets, higher income category by shrimp and prawn, with a large amount consume by restaurants and hotels. Recently, globalization has led to Sundarbans to orient shrimp and prawn production to challenge, and demand of global market (Islam 2008), particularly the United States, Asia, and the European Union (FRSS 2012).

Integrated shrimp and prawn farming contribute basic food supply of fish, rice, and dike crops (fruits and vegetables), thus consumption of food has increased by farming community members and households (Ahmed et al. 2010). The culture of shrimp and prawn in rice field has increased 8-15%, although total production of rice decreased due to the conversion of coastal aquaculture from rice fields (Mishra et al. 2004). However, the loss of rice culture is 3-5% that replaced by the significant increase of mixed rice-fish farming that is about 9% area of Bangladesh (Gurung et al. 2005).

4.7.4.2 Diversifying Livelihood:

Shrimp and prawn production and culture have brought most diversifying livelihood option for the poor communities of Sundarban. This farming sector is supply three extended components of subsistence:

1. Market-oriented urban livelihood,
2. Multi-location based nonfarm livelihoods
3. Farm oriented rural livelihood.

In Bangladesh part of Sundarban, 1.15 million farmers engaged in shrimp and prawn farming and also associated with 4.8 million population with this sector (DoF 2012). In addition, this farming provides livelihood be around 0.4 million inhabitants, many of them children and women which, has linked with shrimp and prawn fry fishing in the Bangladesh part of Sundarbans (Ahamed et al. 2010).

Table 4.3 Production of Shrimp and Prawn during last two decades in Sundarbans (Bangladesh) (Source: DoF 2012)

Year	Inland capture	Inland culture	Marine fisheries	Total
1990-91	43,262	19,489	17,633	80,384
1995-96	44,079	46,223	26,353	111,655
2000-01	44,343	64,970	31,037	140,350
2005-06	77,381	85,510	48,119	211,010
2010-11	57,823	124,648	56,989	239,460

Landless farmers, poor and marginal farmers, and rural households have benefitted from shrimp and prawn culture due to an extended range of livelihood generation (Ahamed et al. 2010). The movement or migration of Sundarban poor has decreased as a result of extended and a wide variety of subsistence opportunities delivered from shrimp and prawn culture, including marketing of feed, prawn and shrimp, and fry. The interconnection between marketing and farming is the key strength of diversifying livelihood generation. In fact, shrimp and prawn marketing extensively provide livelihood option to the most of coastal poor (Ahamed et al. 2008). Most numbers of day laborers execute post-harvest activities like handling, sorting, cleaning, grading, icing, and transporting, and also many women populations are also engaged fish processing plants for beheading, cleaning of shrimp and prawn, and packaging activities (Islam 2008). Ultimately, urban and rural livelihood option in this farming system provides more advantage for the poor people of Sundarbans.

4.7.4.3 Export Earnings:

The coastal aquaculture sector of Sundarbans has converted into a multimillion dollar industry due to the transnational importance of Shrimp and prawn. Both are economically most dominant farming and commercially also known as 'white gold' of Sundarban region (Islam, 2009). From the Bangladesh part of Sundarbans, total exported amount is 54,891 metric tonnes of shrimp and prawn which, valued at 446 million US dollar of which, 70% have contributed by shrimp, and the remainders 30% by prawn in the year of 2010-2011 (FRSS 2012). The production, and export earnings have significantly reduced after the year of 2006-2009, although there has been found a conspicuous increase in the value of shrimp and prawn export over last two or three decades (fig. 4.8). After readymade garments, shrimp and prawn farming is the 2nd largest industry on the basis of export as a whole. Export earnings from shrimp and prawn make an important role to the Sundarban as well as the national economy. In recent, the accelerated growth of this farming sector has appeared as a mode of rapid economic growth (Ahmed et al. 2010).

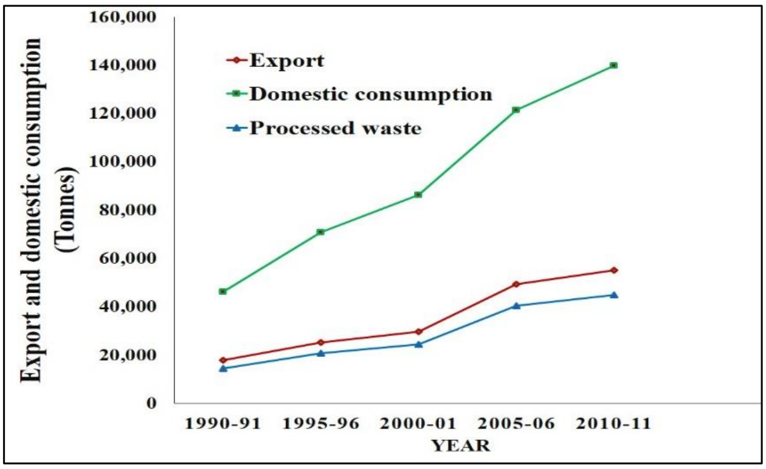

Fig. 4.8 Domestic consumption and export of Shrimp and Prawn culture in Sundarbans (Bangladesh) (Source: DoF 2012)

Although Shrimp and prawn market have increased significantly, in value and volume over the last two or three consequent decades, Sundarbans region facing troubles in maintaining the quality standard, and good reputation in the international market.

4.7.4.4 Socio-economic Transformation:

Shrimp and prawn farmings have grounded by a significant deal of economic and social transformation. Most of farmers and workers have experienced impressive upgradation in their living standard and living style, social environment of employees has upgraded greatly. Shrimp and prawn related activities and farming have brought about a significant improvement in social interaction and communication (Islam 2009). There have been also found a significant transformation and development in economic activities. Shrimp and prawn marketing introduced an unprecedented amount of money into the local or regional economy. The cash flow of households has increased greatly due to different crops are cultured at various seasons and time of the year. It can offer much income and income generating activities such as petty business, livestock rearing and agriculture to the farmers. Also, it also has evidence that the positive effect of Shrimp and prawn culture is much higher for those farmers who have engaged in a large farm (Ahmed et al. 2010). Small and medium farmers have also advantaged from Shrimp and prawn farming. However, monetary benefits are unevenly delivered among beneficiaries, and increasing difference of affluence between poor and rich has been observed (Ahmed et al. 2010).

The growing participation of women in different aspect of Shrimp and prawn farming and related activities in Sundarbans have been a great indicator of raised empowerment of the society and household level (Ahmed et al. 2010, Islam 2008). Moreover, the women’s empowerment and participation has given them social mobility, greater equity, more authority, better behavior, attitude and decision-making.

The unprecedented expansion of Shrimp and prawn culture has accompanied with a number of negative impacts, including increased robbery and thief incidents, friction between poor and wealthy, and dowry payments (Ahmed et al. 2010). Although, the consequences of negative social effects seem small compared to the expanded economic profits. However, overall coastal aquaculture of Sundarban appears to have had significant positive benefits for economic and social sustainability and also development.

4.7.4.5 Agrarian Change:

Agricultural change has found in coastal Sundarban due to accelerated development of Shrimp and Prawn farming. Low lying estuaries and coastal areas in Sundarban have converted into Shrimp and prawn farms. The significant cause for converting aquaculture firm from rice fields was for much income generation, through Shrimp and Prawn production and it is more profitable activity but riskier, than agricultural activity (Ahmed et al. 2010). In recent, hundreds of hectares agricultural lands are uninterruptedly transformed into Shrimp and Prawn firms. Also, the prices of land gradually increase due to the population growth, the productivity of land and the high cost of Shrimp and Prawn farming. The value of lease land has also increased remarkably due to significant demand of the maximum no of the population hoping to engage in aquaculture activity. The growing value of land has also suggest that increase agrarian conflicts and land disputes. Rich people often enforced farmers or others people to sell their unproductive land using through muscle power (Ahmed et al. 2010). The maximum benefits of farmers from agrarian reforms can retrieved through less costly transfer and rapid land transformation to efficient users.

Potential agrarian conversion can resolve through rural development and technological changes. Agrarian transformation in coastal Sundarban has developed roads, telecommunication and transportation, including rural infrastructure (Ahamed et al. 2010). Upgraded rural infrastructure and development has established processing plants through encouraging marketing agents. Market integration and facilities have developed due to the transport facilities and development. Other community facilities like health, communication and education have upgraded in Shrimp and prawn farming areas of Sundarban.

4.7.5 Impact of Climate Change on Aquaculture in Sundarbans:

Shrimp and prawn culture with ‘green economy’ (Ahmed 2013) has associated with economic and environmental sustainability. However, recently, the impacts of climate change and associated events are expected to pressures on Shrimp and prawn farming in Sundarban (fig.4.9). Climate change and global warming have already intensified various kind of extreme weather events, i.e. cyclones, droughts and floods, sea level rise and saline water intrusion (Ahmed et al. 2010).

Climate change induced sea level rise, and Himalayan glacier melting would inundate estuaries and coastal areas of Sundarbans as the areas have long coastal zones and vast estuaries along the Bay of Bengal. About 66% areas of the Bangladesh is belonged to less than 5m above mean sea level (MSL) (Dasgupta et al. 2011), and One meter increase in sea level would impact on the areas of Shrimp and Prawn farming in Sundarbans (World Bank 2000). According to the prediction of World Bank (2000), the mangrove ecosystem of Sundarbans would be destroyed totally and subsequently affect the Shrimp and Prawn farming.

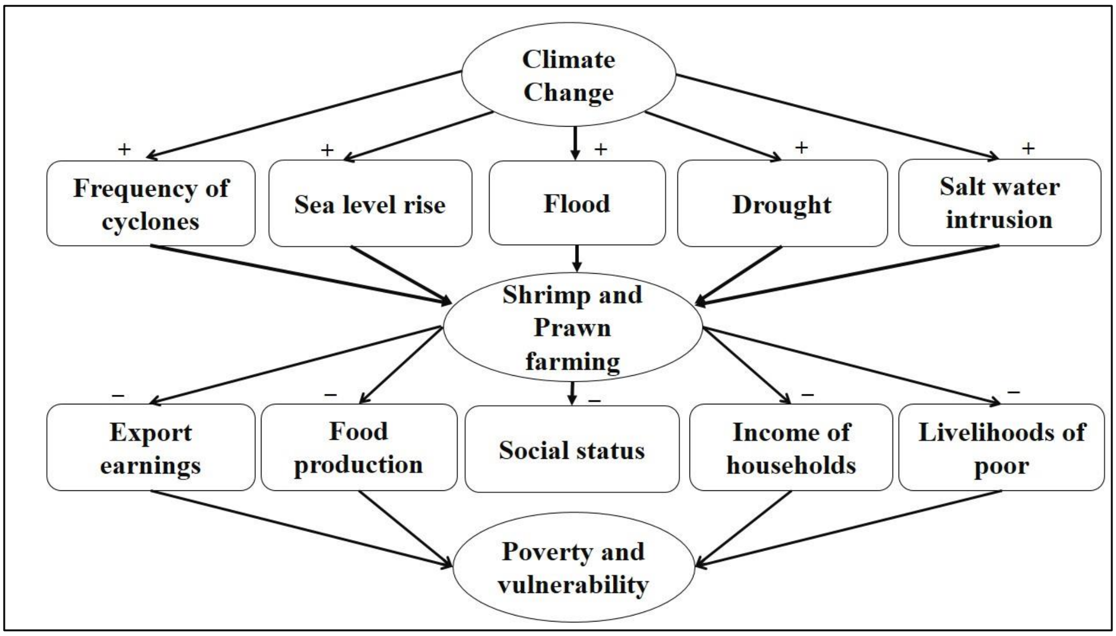

Fig. 4.9 Possible effects of climate change on Shrimp and Prawn culture and its consequences (- sign indicates negative impacts and + indicates increase frequency and level of impacts (Source:Ahmed 2013)

The entire coastal areas of the both (India and Bangladesh) part of the Sundarban is prone to tropical cyclones and violent storms, that developed in the northern Indian Ocean and their track developed through the northern Bay of Bengal (BOB) region (Ali 1996). Tropical cyclones and storms are strongly affected by raising surface water temperatures (Dasgupta et al. 2011). Storm and cyclones are most significant vulnerability events in the Sundarbans, with largest ones occurs in 1970 when killed more than 3 lakh people, and also in 1991 the documented death amount was 1.38 lakhs (World Bank 2000). The coastal areas of Sundarban were effect by the destructive tropical cyclone named Sidr in November 2007. More than 8.9 million population were affected, and death's toll is about 3406. Cyclone 'Nargis' also devastated the life of coastal people of Sundarban in May 2008. In April 2009, tropical cyclone named 'Bijli' deflected away from the coastal boundary of the Sundarban region. After one-month Cyclone Aila (May 2009) crashed into the middle of Sundarban (Dasgupta et al. 2011). Sundarban also escaped the main thrust of the tropical cyclone named Giri and it heated along the Myanmar coast in October 2010. Finally, we claimed that the frequency and power of tropical cyclone, storm surges and associated events often cause immediate damage to Shrimp and prawn firms.

Cyclones and sea level rise with tidal surges with related to saline water intrusion and inundation in the estuaries and coastal areas of Sundarban. Ground water and soil salinity are predicted to change about 2 million hectares of the area by 2050 (Conway and Wage 2010). Therefore, rice productivity have reduced due to water and soil salinity. About one-fifth million tonnes of rice cultivation would reduced as a result of saline water intrusion in coastal Sundarban (World Bank 2000). Water and soil salinity in Shrimp and Prawn culture have already raised which in turn have decreased water quality and soil salinity.

Sundarban is a flood prone region, and a total portion of the area is usually flooded all time in a year. The prime reasons of the flooding are higher monsoonal rainfall, tidal surge and river outflow (Banerjee 2010). As Sundarban is a low-lying area, siltation in the river can intensify the level of inundation. Increasing rainfall causes the higher intensity of river bank erosion and higher frequency higher frequency of river floods. The occurrence of flood events now become more intensifying due to El Nino event (Conway and Wage 2010). Shrimp and Prawn firms are more vulnerable to coastal flooding and over siltation. Prolonged or sudden floods often disturb coastal aquaculture and fishing activities. Preventing the escape of Shrimp and Prawn is most difficult during the inundation, and aquaculture farmers are unable to increase the height of low and narrow dikes due to unplanned construction.

Drought is apparent incident in coastal Sundarban during low rainfall during low rainfall in monsoonal time and dry season. Global warming with El Nino event can cause the south-west monsoon to turn into a dry condition, resulting in heavy reductions in monsoonal rainfall leading droughts season (Conway and wage 2010). Recent, the frequency of droughts condition has increased in Sundarban. Drought is also one of the most leading environmental limits to shrimp and prawn farming. Prolonged and severe drought events often cause for limited farming periods.

The significant effects of climate change on shrimp and prawn culture could have serious impacts on livelihood generation of the poor farmer and their economic condition, export earnings and food production (Fig. 4.8). Declining fish and rice production may influence the food security and livelihood generation in coastal communities and households. Reducing shrimp and prawn production and activities could lead to reduced export earnings from the international market that in limited turn income and reduced livelihood means of the coastal communities and poor farmers. Threatening the farming sector in the context of climate change and related events could have effects on the economy of Sundarban.

4.7.6 Aquaculture Adaptation Strategies in Sundarbans:

Concerning global warming, climate change and related events, there is a significant challenge to development and sustainability of Sundarban aquaculture. Various adaptation strategies to recover the impacts of climate change on Shrimp and prawn farming must be developed to manage a 'green economy'[27] as a foremost means of livelihood. Considering livelihood vulnerability to the climate change effects in Sundarban, community-based management and adaptation strategies are necessary to recover the challenges of climate change. Afforestation of green belt and the construction of embankment would help to minimize the impacts of salinity intrusion and cyclones in the Sundarbans. Plantation of mangrove would also contribute to increasing resilience to global warming and climate change threats and reduce environmental degradation. The mixed farming of shrimp and prawn could be designed to facilitate adaptation methods to salt water intrusion in estuaries and rice fields. Finally, the establishments of salt tolerant rice cultivation may subsequently increase the rice production in the Sundarbans.

[27] See Ahmed, N. Occhipinti-Ambrogi, A. Muir, J.F. (2013), "The impact of climate change on prawn post larvae fishing in coastal Bangladesh: socioeconomic and ecological perspectives", Marine Policy, 39: 224-233.

Chapter-5

Climate Change Adaptation: A Management Strategies for Trans-boundary Mangrove Ecosystem

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Climate change is a significant to Sundarban mangrove ecosystem and is exposed to be a considerable challenge that ecosystem will face this serious condition (Ellison 2013). Even the various projection results about climate change effects on mangrove argued that the effects will continue to be an extreme risk beyond the end of the century (IPCC 2007). Although, others ecosystem i.e. coral reefs and seaweeds are most vulnerable to co_2 increase, as well as temperature and extreme weather events, those effects of increased co_2, projected temperature and related extreme weather events are hopeful to be more beneficial to mangrove ecosystem, increasing mangrove biodiversity and productivity particularly in the higher latitudes (Gilman et al. 2008). The advantages of raising co_2 are however dependent on various limiting factors of humidity, salinity, and nutrients. Humidity and rainfall changes have leading significance for mangroves, with decreased rainfall reducing biodiversity, and productivity causing relative sedimentation and subsidence (Ellison 2013). Increased precipitation is possible to be beneficial, causing sedimentation and productivity along with less saline habitat and enhanced groundwater. Of all the impacts of climate change, the sea level rise effects, are likely the most harmful to mangroves, exposed first by mangrove mortality at the edge of seaside and migration landward, but there depending on human modification and sediment budgets to migration. Therefore, it is most important that the ways to increase the adaptive capacity and enhance the resilience of Sundarban mangroves to climate change and sea level rise be developed. In this context, this chapter suggest some probable management options, and the contexts that can help mangrove protection and associated anthropogenic systems accord with climate change related sea level rise vulnerability and can take appropriate adaptation strategies for the conservation of Sundarban mangrove.

5.1 Legal Status of the Sundarban Mangrove Forest:

In Asia, most of the human populations have used the mangrove forest for more than thousand years. In Sundarban delta, besides using the mangrove for fuel and timber, the forest was changed to established crop cum fish cultures. Historically, mangrove were natural pool resources that were deliberately taken over at various time periods by the different rulers who subsequently controlled their management strategies. In India, during the fourteenth century, the clearing of shrubs and trees for rice cultivation was strongly developed by the then Turk rulers of Bengal (Eastern part of India). It followed by Mughal emperor, up to the middle of eighteenth century when East India Company has taken this area under their empire. Available evidence advocates that the Portuguese rulers learned about the Indian traditional technique of rice-fish culture in mangrove forest and during the 14^{th} century this technology also transferred to Mozambique and Angola. After that during the British Empire, the conversion of the Sundarban mangrove into agricultural lands was promoted deliberately and actively (Richards 1990). Records on reclamation, settlement stem and forest clearing from 9^{th} decade of 18^{th} century, the first management and conservation legislation was the forest act (1876) and the charter of Indian mangrove forest. where the Sundarban mangrove forest has declared as a reserved forest category by the government of British Indian. The first forest conservation policy for transboundary Sundarbans (undivided India) was declared in 1894 under British Indian Government that implement the base for all future rules and acts which establish the administrative ground of the Sundarban reserved forest for both India and Bangladesh. The commissioner for the Indian Sundarban was change with implementing the task of ‘managing and regulating the waterlogged swamps and forest of the Sundarbans delta’ and ‘to assure that private landowners reclaimed, settled, and cleared swamps and Sundarban forest for rice and shrimp culture’ (Richards 1990). The British colonial mangrove forest department desire to conserve most areas of the Sundarban tidal mangrove forest areas by granting them legal status as protected or reserved forests. Then it then effectively managed to contribute a sustainable supply of firewood and timber. However, table 5.1 highlights the historical or chronological changes of planning and policies in the management of the sundarbans mangrove.

Table 5.1 Legal status and changes in the management of the Sundarbans mangrove (1876-2005) (Adopted from Roy and Alam 2012)

Periods	Legal initiatives	Main objectives	Major outcomes
Before 1757 (Pre-British rule)	No management issues	Extraction of resources	Resource extraction
1757-1947 (British rule)	Charts of India Forest, 1855	Generation of conservation idea for controlling the resources	First regulations regarding feeling trees for revenues and awareness with importance realization
1894 (Indian Forest Act)	'Reserve Forest' declaration,1875-76 under Indian Forest Act, 1894	Formal forest policy initiatives to be executed Targeting benefits with commercial management of non-wood and wood mangrove products for the local people and for public at large under rights and regulation	Resource extraction
1947-1971 (Pakistan Rule)	Forest policy of Pakistan, 1955	Classification of the Sundarban mangrove on the basis of its objectives and utility Enhancement of timber harvesting	Protection of habitat and wildlife Ecological degradation Realization of overuse
	Reserved Forest policy of Pakistan, 1962	Higher regeneration for more harvesting Ignorance the rights of local people and the principle of sustainable forest use	Over-exploitation of Sundarban forest resources
1971 –present (Bangladesh Rule)	National Forest Policy, 1979	Coastal mangrove protection Quantitative improvement based on technology and modern trend for utilization and extraction of mangrove resources Plantation of coastal mangrove	Inappropriate land tenure agreement caused encroachment of the land and illegal feeling of mangrove trees Inconsistencies as conservation leaves little incentive to expand forest based industries and becomes detrimental to mangrove health by enhancing degradation through illegal harvesting
	Reserved National Forest Policy, 1994	Use suitable extraction technology Protected areas identification Ensuring local people participation Milti-dimensional uses of mangrove resource including fish and water Consideration of climate change and global warming and keeping the bio-environment intact for its existence	Sustainable management

5.2 History of the Sundarban Mangrove Management Policies and Regulations:

In South East Asia. Management of any mangrove forest area was scientifically first introduced in the Sundarbans mangrove forest in the seventh decade of 19^{th} century when the forest administration was under the British India government. It established particularly for the management and conservation of Sundarban mangrove forests. Specific management instructions have systematically developed for the sustainable uses of non-wood and wood forest products. These instructions was primarily formulated with a view to securing refurbishing of the harvested area of the mangrove forest through mangrove regeneration. The earliest ten years of the mangrove management plan and policy were formulated in 1893 for the Sundarban reserve forest (SRF).

In practice, the accountability of mangrove conservation at the national or local level has been empowered on the basis of sectoral development to executing the government agencies, for example, agriculture, fishing, and forestry departments. Mangrove ecosystem is the most important to the national economy, as well as to the livelihood generation for the local community. To sustain ecological and environmental balance, most no of countries having mangrove forests have established different management plans and policies for utilizing the mangrove based resources on a well maintained and sustained basis. The formulation and application of adequate policies and legislation regarding the management of mangrove forests are up to the upper body of government, but stakeholder assistance must be organized at both the conservation policies and implementation phases. In most of the nations, the main stakeholders are fisheries, agriculture, forestry, tourism, industry and mining sectors within most cases, and representation from both the private and public bodies. Also, some countries have well established reserved, or protected areas with agriculture with aquatic natural resources and most have identified preferences for conservation and protection in national conservation strategies, and national environmental and ecological action plans.

Historically, the Sundarban reserve forest has constantly been managed as a contiguous area of mangrove forest ecosystem with no permanent living place for habitation inside. Subsequently, conservation planning aimed to encourage the sustainable harvesting of the mangrove forest products and managed its coastal area in an approach that meets the requirements of the local inhabitants. In the Sundarban reserved forest, the forest policy was first initiated on 1894 to allocate the forest resource for the comprehensive asset of the dependent people, and the importance of the local inhabitants got high priority. However, the prime objective of the management plans was to extract available natural resource that ultimately caused degradation and destruction of the mangrove forest. To prevent detorioration, the ‘working plan’ and ‘Lloyd plan’ has taken during the time of 1904-08 as supported by its supporting authority but failed to reduce or reverse the deterioration. After the British Empire, during the period of 1947-71 (the Pakistan period), forest policy was legislated for huge extraction of mangrove resource, where right or power of the local inhabitants were denied (Kabir et al. 2008). After the period of independence of Bangladesh in 1971, first national forest policy was adopted but repeatedly failed to address the main issues like community participation, co-operation, and their livelihood generation and sustainability. Consequently, due to the absence of established rights and defined ownership, enormous dependent inhabitants of the Sundarbans region have not been capable to be a part of the activities and strategies aimed, at preserving the mangrove and using the forest resources sustainably.

5.3 Climate Change Adaptation:

Climate change adaptation refers to the adjustment of ecological, social or economic systems in response to expected or observed alterations in climatic conditions and related adverse effects (Adger et al. 2005). Vulnerability and adaptive capacity have become valuable concepts to determine the human-environment response (coupled system) to climate change and their impacts (Adger et al. 2005). However, vulnerability is possibly more harmful by the combination of sensitivity and exposure to stresses that decreased by the capacity building to those stresses (Mertz et al. 2009).

Exposure includes mainly external factors, i.e. the nature of change, its rate, and magnitude, which a species or system may experience. In mangrove ecosystems, exposure factors in the context of climate change consist of the rate of sea level rise, salinity increase and the degree of changes in rainfall (Ellison 2012). The exposure also includes some factors that concern about the setting of mangrove ecosystems, such as the rate of sediment supply and the tidal range.[28]

[28] The tidal range indicates the vertical difference between the low tide and the succeeding high tide

Sensitivity includes the internal characteristics of a system or species, which indicates the resistance capacity to changes in rainfall, temperature, humidity, fire or sea level. In coastal mangrove, sensitivity is identified by a deterioration in forest condition, such as biodiversity, recruitment and productivity (Gilman et al. 2007, Ellison 2012). The sensitivity of mangrove is also referred to the Spatio-temporal change of mangroves, such as reduction of area and retreat of seaward edge (Gilman et al. 2007). The sedimentation rates of the river within the mangrove area also refers sensitivity, specifically if less than or close to the rate of sea level rise (Ellison 2012).

Adaptive capacity refers to the power of a species or system to accommodate and cope with the impacts of climate change and relative sea level rise with minimum interruption. which can possible through species or ecosystem response, and also through the anthropogenic actions. This steps may reduce mangrove vulnerability to projected or actual changes in climatic conditions. Resilience is the ability to recover and absorb the impacts of disruption, and the resilience of mangrove is the capacity to resist change and maintain their function. However, adaptation actions ultimately simplify those that decrease vulnerability, enhance resistance and resilience (Adger et al. 2005).

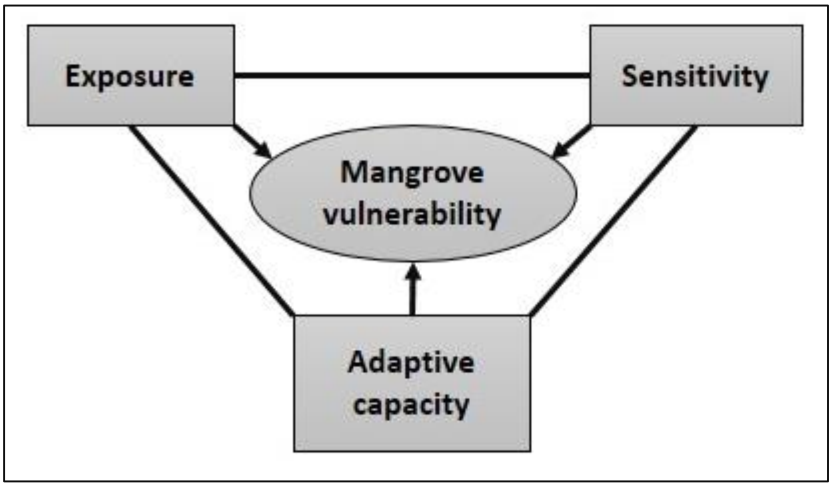

Fig. 5.1 Mangroves Vulnerability as a combined function of sensitivity, exposure, and adoptive capacity

Adaptation options have used to the economic or human form of vulnerability, in the deliberation of human systems i.e. public health, natural hazards, and agriculture (Adger et al. 2005). United Nations Development Programme (UNDP) adaptation policy structured addressed application of adaptation strategies that established human progress in the context of climate change and related impacts, including an efficient approach, measures, and policies. More recently, an environmental system such as ecosystem, habitats, and species have become more evaluated for vulnerability to climate change (Lovelock and Ellison 2007). Finally, vulnerability is characterized as a combined action of three components: sensitivity, exposure and adaptive capacity (fig. 5.1).

5.3.1 Adaptation Approaches:

Adaptive capacity to climate change can functionally be signified as how much structure or system can adapt to the stresses of existing vulnerability as caused by sensitivity and exposure factors (Mertz et al. 2009). However, adaptability indicates that how much practices and processes, community structure can prepare to modification in response to projected or actual changes in climatic conditions (Mertz et al. 2009). In the context of mangrove, adaptability indicates to the community, managers of the mangrove area, stakeholders, with the consideration of how mangrove ecosystems are changing or unstable and how they may become a change in the future. The mangrove adaptation options can be anticipatory recent climate change impacts, sensitive after these enter into effect, that also planned as an outcome of policy decisions or findings in response to anticipated or actual changes or an ecological changes in an ecosystem.

In a mangrove ecosystem both the people and ecosystem dependent upon their most valuable natural resources such as agriculture, fishing, and other ecological products (Honey, wood, Nypa palm and crab culture etc.) are included in adaptation strategy. However, adaptive capacity indicates that how much the people living around and in the mangroves and the mangrove systems can adjust to changing climate and also take advantage and notice of any opportunities arising as an outcome of climate change restraint within the ecosystem.

5.3.2 Stakeholders Involvement:

Adaptation strategies are the best assistance, involving stakeholders, such as group, individuals, organization, government agencies and communities that have a significant interest in the resource of the mangrove ecosystem. Therefore, a participatory approach to involving stakeholders allows their knowledge and perspective, and it comprises engaging local inhabitants living in and around to the forest area and including local communities in planned adaptation actions. Engaging various stakeholders, including local inhabitants, in the adaptation process and vulnerability assessment is an important principle to adaptation planning and policy. Stakeholders have various exposures to the impacts of climate change and careful involvement creates adaptation planning more significant from these different perspectives.

Table 5.2 Community education framework regarding mangrove zones climate change adaptation strategies (Adopted from Khan et al. 2012)

Objectives	**Purpose**	**Climate change context**	**Content**	**Adaptation strategies**
Convey information	Information supply	Sensitivity and exposure	Science of sea level rise and climate change	Newspapers, community radio, exhibits, posters, street plays, brochures
Understanding building	Perspectives exchange	Vulnerability and Impact	Impacts on local people and mangrove ecosystem	Community discussions, focus groups, climate witness programs, workshops
Build skills	Capacity improve	Capacity building	Ways to prioritization active adaptation planning and increase mangrove resilience	Demonstration fieldtrips, workshops, use of vulnerability assessment manuals
Enable actions	Allow monitoring, action planning, and action	Adaptation planning	Community participation in actions to permit mangrove adaptation	Action planning, resourcing, ground works, participation, ongoing monitoring and evaluation

Stakeholder's involvement can also be upgraded by identifying and employing with the existing natural resource management process and structures at both national and local levels. Also, stakeholder's workshops are also helpful at initial stages of adaptation strategies as an information sharing action, such as the identification or description of other important adaptation approaches being undertaken.

Ongoing communication implements Stakeholder's contributions through workshops, information exchange, facilitator consultation, meeting and sharing of results and reports. Involvement with local inhabitants can benefitted by the publication of materials in useful formats, such as publication by local language and focus on involvement, using a communication plan and policy, should impregnate all of the adaptation approaches and vulnerability assessment.

Education and awareness-building of the community members enhances the sustainable usage of mangrove oriented resources, helps to decrease the direct human effects, and built capacity and strength for climate change adaptation strategies. That can be possible through workshops, meetings, reconnaissance survey that engage community members, following the main objectives presented in the table 5.2.

5.3.3 Reduction of Vulnerability:

The vulnerability is the susceptibility and exposure to harmful impacts, combined with this capacity to react to those stresses (Mertz et al. 2009). Therefore, specific vulnerability to climate change and related effects can be analyzed to allow adaptation action was emphasized that may be used in various socio-economic and ecological context. Identification of particular site vulnerability, i. e. low sedimentation rates, micro-tidal range, and specific elevation bracket species habitat allows the site-specific prioritization for adaptation actions that can be used to decrease such vulnerability.

Adaptation of vulnerability assessment include the analysis of spatial changes in mangrove areas by the comparison of present and past Arial images and also verified by the survey of the local community (Ellison and Zouh 2012). In addition, permanent areas of mangrove are a well-established method for long-term monitoring, from which reliable data collected can be provide, and compared a basis for analyzing mangrove community structure, growth, productivity and biomass, mangrove condition and pattern survey carried out in association with the participants of local community can provide valuable information on anthropogenic indication and impact levels of natural changes. Rehabilitation of the sites sea level history can permit local subsidence elements to be identified by analyzes relative rates of sea level rise and mostly useful

Table 5.3 Adaptation options to reduce mangrove vulnerability to recent climate change

Vulnerability	Adaptation priority
Small tidal range	Strategic protected areas Promotion of mangrove accretion Proactive planning for mangrove change conditions
High relative sea level rise	Promotion of mangrove accretion Proactive planning for mangrove change conditions
Lower rate of sediment supply	Promotion of mangrove accretion
Drier conditions according to climate modelling	Degraded forest rehabilitation Monitoring
Mangrove recruitment, condition, poor tree growth and high mortality	Improved legislation Improved local management Non-climatic stressors reduction Strategic protected areas Degraded forest rehabilitation Proactive planning for mangrove change conditions
Retreating seaward edge	Promotion of mangrove accretion
Mangrove area reduction	Proactive planning for mangrove change conditions
Elevation within mangrove tight	Promotion of mangrove accretion Proactive planning for mangrove change conditions
Mangrove unavailable elevations	Proactive planning for mangrove change conditions
Sedimentation rates in mangrove low	Promotion of mangrove accretion
Adjacent coral reef resilience low	Rehabilitation of reefs Non-climatic stressors reduction
Adjacent Seagrass resilience low	Non-climatic stressors reduction Rehabilitation of seagrass
Local community management capacity low	Improve local management
Poor stakeholder involvement	Improved local management Improve legislation
Weak mangrove protection legislation	Improve legislation

to Sundarban region with mangroves lacks short and long term tide gauges. Finally, results from these factors of vulnerability assessment assign to identifying particular vulnerabilities of mangrove, from which adaptation strategies can established. Table 5.3 shows the adaptation priorities and actions that may reduce the vulnerability of mangrove system to climate change.

5.3.4 Climate Critical Mangroves:

Mangrove areas with high vulnerability and low resilience are unlikely to readjust to the impacts of climate change without immediate and significant interventions. Vulnerability assessment of mangrove can identify these areas as those with low biodiversity and productivity, low sedimentation rates with exhibiting dieback. So allowing their importance for adaptation plans and actions, such as rehabilitation and special zoning.

'Climate critical' species refers those being less competitive and more liable to be threatened or under-represented species with restricted habitats. For example, in Sundarban region two mangrove species was found as a critically endangered, Bruguiera Hainesii and Sonneratia Griffithii, primarily due to habitat loss owing to clearance. Moreover, two mangrove species, Heritiera globasa and Philippinense, have been recorded as endangered, due to the conversion of mangrove areas for agriculture, aquaculture and other human pressures in the Sundarbans. Critically endangered and endangered mangrove species that are already under pressure from non-climatic threats will be more susceptible to climate change and decreasing nonclimatic threats will raise their resilience.

5.3.5 Enhancement of Mangrove Resilience:

Mangrove resilience indicates the degree of distress that an ecosystem can resolve without changing its strength and lies in the diversity of functional systems in the ecological or environmental systems that supports for recovery (Gunderson 2000). Enhancement of ecosystem resilience is the risk resolving measures in the context of climate change adaptation actions that conservation management options may adopt (Gunderson 2000).

A fundamental premise to increasing ecosystem resilience to recent climate change in the protection and enhancement of its natural ability to respond to stress and change (Adger et al. 2005). Most of the ecosystems have some competency within their internal difference to allow natural adjustment or adaptation that permits more resilience. Management options that increase the ecological productivity and diversity of an ecosystem give a potential safeguard against climate change and related impacts. It also helps to capacity building for local inhabitants to the rehabilitation of degraded mangrove, community-based monitoring and management of mangrove areas.

Mangrove community may also be resilient to climate change and sea-level rise, if they are high diversity, healthy and if there are presence suitable elevation areas for inland migration, and active sedimentation condition along the coastal areas and estuaries.

Hence, adaptation actions also may increase resilience and reduce vulnerability, and adaptive capacity includes the potential capability to an ecosystem to strong response to the sea level rise and climate change and their variability. Adaptive capacity in environmental and ecological systems involves increasing and maintaining their diversity and has also been characterized as the strength of an ecosystem to any modification or change in resilience (Adger et al. 2005).

Response capacity of mangrove may differ between various adoption areas, because of varying ecological, socio-economic and biophysical conditions. Different management strategies and plans during adaptation actions to climate change and sea level rise are not different from conservation techniques, but there is significantly emphasis on protected mangrove habitats that have been managing for increased distress, more resilient and maintaining flexibility that climate change and related threats will bring.

Adaptation planning to recent climate change in mangrove area encompasses a series of response capacity that will increase mangrove resilience through the reduction of climate change vulnerability. Therefore, this kind of adaptation actions have categorized in three main groups: active adaptation actions, reduction of the impact of non-climatic stressors and regular monitoring in the mangrove areas.

5.4 Adaptation Actions for Mangrove Areas:

5.4.1 Reduction of the Impact of Non-Climatic Stressors:

Reduction the impacts of non-climatic stressors enhances the resilience of species and habitats to the effects of climate change and climate variability, subsequently the vulnerability to climate change and sea level rise of natural resource dependent inhabitants is increased if their mangrove resource are degraded by misuse or overuse and if their conservation strategies are not effective (Adger et al. 2005).

The non-climatic threats on mangrove ecosystems are considerable in various parts of the world, with the pressure of economic development and human activity in the low-lying coastal area, leading to deteriorating coastal environment through the pollution of water quality and also other form of habitat degradation. Also, mangrove productivity and diversity has also been distressed by timber over-harvesting and other unsustainable utilization of mangrove resources, i. e. crabs and fish. Mangrove habitat or ecosystem totally have been drained, converted and enclosed for agriculture and brackish water aquaculture ponds or landfill for housing conversion, tourism activities or other related coastal infrastructure. Therefore, worldwide mangrove areas have loss over the last 3-4 decades at alarming rates, due to human pressures and extreme natural hazards, such as tsunami.

Unsustainable use of mangrove forest occurs due to the large dependency on mangrove resource by local communities, such as crustaceans, fuel wood, and fish that can reduce the resilience capacity of mangrove. Hence, a significant adaptation strategy is improved by awareness building, education, proper management, and community involvement in the mangrove area. Also, a reduction the impacts of non-climatic stressors may increase the mangrove productivity that can achieved through elevation gain of tidal estuaries and wetlands.

The adaptive strategy can be improved in a mangrove ecosystem by the enhancement of mangrove situation, allowing more reproductivity and vigorous growth. Where the mangrove condition is already deteriorated or degraded, accelerated sea level rise and climate change is likely cause of degradation worse. Moreover, by rehabilitating degraded areas and this positive response can be interrupted by reducing the present anthropogenic impact on the mangrove ecosystem. Anthropogenic pressure on mangrove ecosystem (for example, fuelwood collection and food gathering) has increased by the participation of local communities and capacity building to improve planning and management.

5.4.2 Improved Local Management:

A most important approach to the protection of wetland and the sustainable management, such as mangrove is facilitated by effective legislation and their access to technical support, through the engagement of local inhabitants (Ellison 2009). Awareness building and education of the community members increase the values of mangrove and also enhanced sustainable utilization of mangrove resource. That may help to decrease direct anthropogenic impacts and also builds adaptation capacity for climate change impacts. Community support and their engagement can improved by capacity building and education for adaptation actions that are primary responsibilities for many conservation and mangrove management institutions. Outreach program and education regarding the mangrove value allow a change in behavior and attitudes among individual persons on the community members (Gilman et al. 2008). Better management options developed specifically community-based mangrove conservation areas where local authority and committees restrict their unsustainable use, based on the condition and state of resources.

5.4.3 Improved Legislation for Mangrove Areas:

The involvement of local inhabitants in the sustainable management of ecosystem areas is essential, but there must sustained by government legislation that allows management planning and protects mangrove ecosystems. Application of existing laws and rules also need to be mostly effective. However, legislative policies and regulations to protect mangrove ecosystem are fragmented and frequently week across extent of non-specific laws or legislation that has enforced by the governmental departments lacking the natural resources to implement this legislation.

Such unspecified laws or legislation for the sustainable use and protection of mangrove resource needs to be improved and identified, and conservation practices can help in this process through advocacy and lobbying, ongoing stakeholder discussions. Management agencies support, and further built capacity to staff understanding and enforce the legislation of adaptation actions and mangrove vulnerability.

Stakeholder involvement and community participation are an overarching objective of adaptation planning and vulnerability assessment. The results sharing from the human impacts, degraded mangrove areas and the feedback from local community signify the need for changes the mangrove management options that subsequently support to the legislative improvement.

At the local or regional level, strategies for already improved mangrove management options can be successful through community participation in developing resource management communities in the mangrove areas (Ellison 2009). Finally, improved management actions are helped by dialog and consultation with the main stakeholders involvement, such as local councils, local administration, and local government bodies, the particularly environment, fisheries, and forestry.

5.4.4 Strategic Protected Areas for Mangrove Conservation:

Protected areas are the support centers of mangrove biodiversity and give refugees for wildlife. Mangrove management under climate change, it is important to select more resilient areas and protect mangrove as an under-represented ecosystem in marine protected areas. In addition, mangrove setting or sites that are critical choices in the context of climate change induced sea level rise are those that represent limited spatial change over recent times, and have high species diversity and productivity, have positive rate of sediment supply, as all of these components enhance resilience (Ellison and Zouh 2012).

Resilience building of mangrove areas is one of the significant risk reduction strategies in consideration of climate change adaptation actions that conservation planning may adopt. In the context of climate change induced pressures, improved land use planning and marine area, that connect adjacent habitat and support each other in mangrove reserves which are most significant strategy to build resilience to sea level rise and climate change impacts. Monitoring and community surveillance enable response to the committee on the decline is crab or fish availability, or any resource abuse, and management proposals have prepared on this basis. However, community-based management in the mangrove protected areas enhance resilience capacity to climate change related impacts by community surveillance and reducing non-climatic stressors over time.

Adaptation capacity to climate change in mangrove protected areas is enhanced if there have landward migration areas with low gradients. Larger mangrove protected areas may allow inland migration and support habitats association for a variety of mangrove habitats, which enhances the adaptive capacity through higher biodiversity.

5.4.5 Rehabilitation of Degraded Mangrove Forest:

Degraded mangrove rehabilitation system is a useful technique for resilience building to climate change, particularly where healthy ecosystem has mostly degraded. Healthy mangrove support higher rate of sediment accretion and coastal deposition, where degraded mangrove zones are more probably to have decrease resilience to the river and coastal erosion (McKee et al. 2007). Dense seedlings also increase the rate of sediment accretion. Degraded mangrove areas within a particular ecosystem are can be recognized through forest survey results, spatial analysis sign of forest decline, or assemblage of local community knowledge.

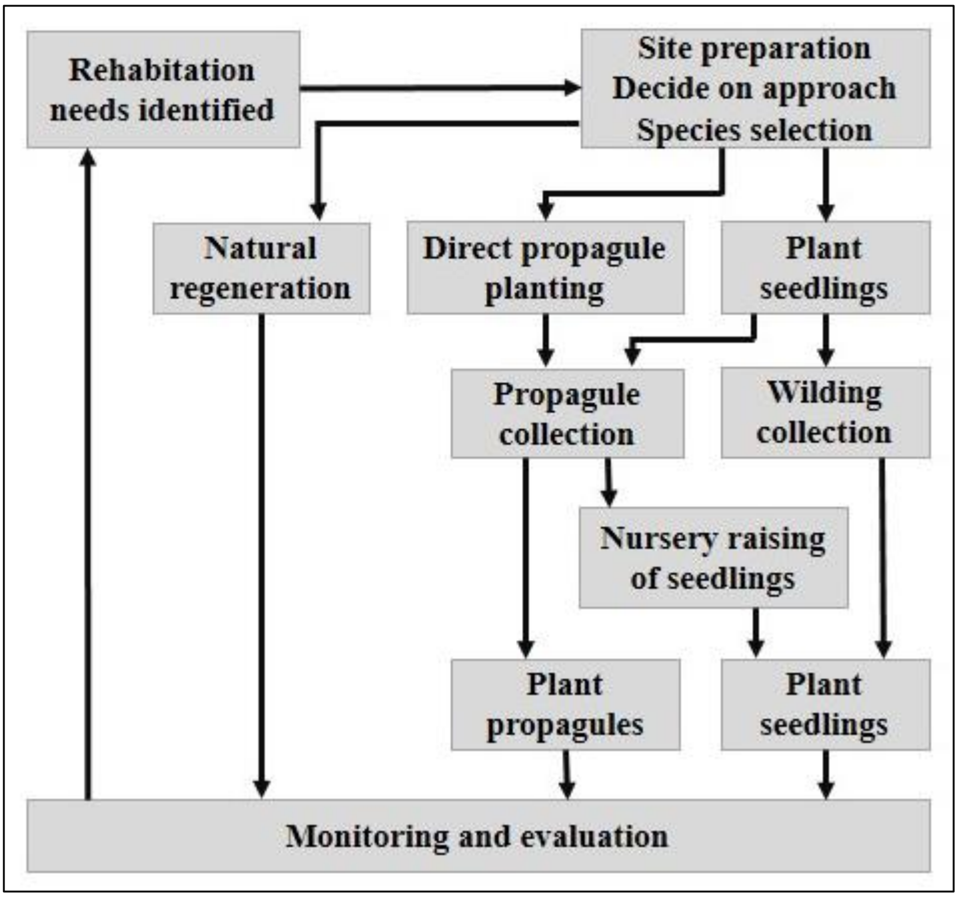

Fig. 5.2 Flowchart of stages and approaches of mangrove rehabilitation

However, there is a rich experience in mangrove replanting, restoration, and reforestation in many countries that can be significantly used to help increase adaptive capacity. Also, various restoration activity can help to reduced the degradation of mangrove forest and subsequently enhance the mangrove sustainability. Successful replanting or reforestation comprises the flowchart of potential strategies shown in fig. 5.2.

5.4.5.1 Plantation of 'Climate Smart' Mangrove Species:

Understanding the ecology of mangrove species is a significant step in successful mangrove restoration plan, particularly by the choosing suitable sites that have favorable hydrological regimes in the context of the duration and frequency of tidal flooding. Restoration also requires to consider changing future hydrological and climatic conditions, selection of suitable planting areas rehabilitation and species selection. Therefore, 'climate smart species' indicate the species, those have the highest adaptive capacity, and such as those have extensive plastic ranges than other species. These species are mostly appropriate to choose for mangrove replanting and rehabilitation planning.

The significant climate change response or sensitivity of mangrove ecosystem is to sea level rise, as the leading stress to mangrove trees enhance the inundation period. The relative sea level rise is envisaged to enhance the influence of mangrove species. Although they can tolerate, they will have to migrate with continuous rising in relative sea level during their living periods. Therefore, the more resilient mangrove species to changing relative sea level will be those have a tolerance capacity of a large elevation bracket on the landward side, and which can be identified by elevations survey at which various mangrove zones occur.

However, in the micro tidal[29] regions of Ganga-Brahmaputra estuary, and delta, this was found to be Heritiera fomes (Sundari) and Laguncularia, which occupies narrower elevation bracket (10-20 cm) where the tidal range is 2-4 m, while Rhizophora racemosa, occupied 48 cm within tidal range. That signifies that the Rhizophora species

[29] A micro-tidal environment refers to the distance between high tide and low tide (the tidal range) which is less than two meters https://en.wikipedia.org/wiki/Lagoon

have more capabilities to tolerate recent rising sea level in the coastal area (Ellison and Zouh 2012).

5.4.5.2 Tidal Regime and Selection of Mangrove Species:

The tidal regime is mainly comprised of tidal frequency, timing, duration, and amplitude, and also experienced in various parts of the intertidal coastal zone. Usually, these components are influenced by the regional or local elevational action due to sedimentation process. Different species of mangroves react differently to various tidal regimes. In Sundarban, mangrove tree stand that experiences diurnal inundation variation, is dominated by A alba and Aviecinia marina while, Acanthus ilicifolius, Ceriops decandra and Excoecaria agallocha dominate where the sites have not largely inundated and Nypa fruticans species seems to prefer coastal sites with low tidal limit of inundation.

The inundation duration is a mostly important one area with irregular elevation profile and an irregular tidal regime where the mangrove vegetation can be better responses by the inundation duration and day wise inundation. Different field and experimental studies, have shown that Kandelia obovata had higher tolerance power to soil flooding than Bruuiera gymnorrhiza, while the optimal expansion and growth of the Kandelia obovata species were found at 2-4 hour flooding period per tidal cycle. Sonneratia apetala has higher tolerance capacity to high tide.

5.4.5.3 Site Selection for Mangrove Rehabilitation:

Site selection is a crucial parameter for mangrove restoration planning. The choice of site is difficult to generalize for prosperous mangrove restoration. Therefore, it depends on socio-cultural context, suitability of planting species and local environmental factors. In Southeast Asia, the restoration program of mangrove habitat exist in 3 major types of sites; 1. Raised lands (high elevation areas), 2. Within shrimp firms and 3. Mudflats. Raised lands and shrimp farming lands offer a little option for mangrove site selection but near a running water bank has determined by selecting a mangrove site (IUCN 2005). The selection near the river bank is not a better idea to developed mangrove in the mudflats for restoration planning, except accelerating zone or formal site for a natural mangroves generation. Special consideration is need for mudflat preference where deposition and erosion are frequent and always ideal, or suitable rehabilitation sites must be select on the deposition site near the river bank or coastal areas. Within deposition part, forest substrate should be stable mudflat land as new deposition can be eroded or washed away by tidal influence or river water before plant establishment.

a) Status of Mangrove Species in Sundarban:

The active delta of coastal Sundarban region at the mouth of 'Bay of Bengal' in India and Bangladesh, having a complex hydrological and geomorphologic characteristics with significant storms and various climatic hazards. In this region, has a large area of the forests with diverse flora dominance. The region contains 334 plant species and 245 genera, and significant portion of the mangroves are dominated by the Euphorbiaceae and Malvaceae, while most of the mangroves area of the world has characterized by Avicenniaceae, Rhizophoraceae and Combretaceae. However, the flora of Sundarbans is dominated by the abundance of Heritiera fomes (Sundari), Excoecaria agallocha (Gewa), Ceriops decandra (Goran), and Sonneratia apetta (Keora), all of which exist mostly throughout the regions. However, the coastal ecosystem and natural environment of this 'world heritage site' and the 'Biosphere Reserve' is under stress of climatic disaster, excessive and unscientific human interference.

However, according to forest inventories (1985) report, a declining in volume of the key commercial mangrove species Excoecaria agallocha (Gewa), and Heritiera fomes (Sundari) by 45% and 40% respectively within 1959 to 1983. The species also are under IUCN red list of an endangered species of mangrove. That may suggest that the areas required proper management strategies or enhance the rehabilitation program to sustain the status of the mangrove species.

b) Site Suitability Mapping for Mangrove Rehabilitation:

Massive degradation and the lack of appropriate laws, regulations and management issues of mangrove ecosystem suggest a significant movement to plant new areas and also use proper management strategies for their regeneration. Unfortunately, mangrove replanting has often been followed by simply planting the mangrove seedlings, without adequate evaluation or subsequent site assessment of the success of rehabilitation at the ecosystem level. In this present study, applied Geographic Information System (GIS), and reclassifying and weighted overlay method to generate site suitability mapping or find the proper location for mangrove rehabilitation strategies in the Ganga-Brahmaputra delta.

c) Site Suitability Modelling Variables:

To find the proper site, have used six variables and GIS techniques, weighted overlay method. The selected variables are salinity, temperature, flooded areas, drainage buffer, elevation, and slope those are most preferable to mangrove species, the reclassify the variables and then given a weight on the basis of preferences/weightage (table 5.4). The GIS model have developed on the basis of following criteria presented in Table 5.4.

Table 5.4 Technical guidance for species wise mangrove rehabilitation in Sundarbans

Sl. no	Factors	Heriteria fomes (Sundari)	Ceriops decandra (Goran)	Excoecaria agallocha (Gewa)	Weightage
1	Salinity (psu)	Low salinity (0-15)	High salinity (>25)	Moderate salinity (15-25)	30
2	Temperature °C	Low temperature (below 25)	Moderate temperature (above 25)	Low temperature (below 25)	20
3	Stream buffer (m)				20
4	Flooded areas (days)	6-9 months	0-3 months	3-6 months	20
5	Elevation (m)	Medium	Low	High	5
6	Slope (degree)	Low	High	Moderate	5

The Sundarbans, freshwater and tidally dominated swamp forest are a tropical broadleaf forest region of India and Bangladesh where salinity is more noticeable. Historically, the mangrove vegetation types have been established in significant co-relation with varying level of water salinity, physiography and freshwater flashing. The Sundari (Heriteria fomes) tree is mostly sensitive to salinity level and being threatened over time with the extinction. The strong seasonal variation and larger duration of moderate salinity is most preferable for Gewa (Excoecaria agallocha) as a dominant woody species. The higher salinity level, is most preferable for Goran (Ceriops decandra) and sometimes Passur (Xylocarpus mekongensis). Similar trends of preferences has found in terms of temperature. This condition with the increased level of salinity and around 1.5° C increase in surface water temperature have posed a threat to the existence of the Sundari tree. It is also responsible for the 'top dying disease' of the Sundari tree at a significant rate.

The frequent and period of flooding, is most favorable for Sundari tree (Heriteria fomes) tree dominate the flora, and interspersed with Passur (Xylocarpus mekongensis), Kankra (Bruguiera gymnorrhiza) and Gewa (Excoecaria agallocha) but not favorable for the Gewa (Excoecaria agallocha) tree. The Sundari (Heriteria fomes) trees have the higher performance rate under frequent, flooding condition, and higher sea level which may be 6-9 months, but more than 9 months flooding condition is more destructive to Sundari (Heriteria fomes) tree, that may cause the mortality and disease of the mangrove habitat.

High drainage density and more flowing are the key factors for the deposition of higher clay and sand in a riverine environment. This condition usually can help to mangroves for their growing through drainage and aeration. Both drainage and aeration in fine, and coarse textured sediments. Soil aeration is mostly important to mangrove environment in root respiration through the supply of oxygen. Aeration is highly variable and directly linked with the drainage of the soil. It also depends on steepness, slope, and elevation of any topographic feature. Moreover, clay can deposited in sandy sediments areas in the frequently inundated region, even a low deposition of clay can significantly reduce soil aeration that may increase the physical reworking of coastal sediments by waves and tidal action. However, clayey and sandy soils usually known as the two extremes conditions in which mangrove habitat will grow. It indicates that higher drainage density and minimum distance from streams signifies as a most favorable condition, although during flooding condition mangrove seedlings are totally wash out and create a significant barrier to mangrove regeneration.

d) Suitable Locations for Mangrove Rehabilitation in Sundarbans:

Habitat suitability index developed from analysis of the selected variables in fig 5.3 and 5.4. Moreover, district wise suitable location is also shown in the table 5.5. An area of 211182 ha, 752923 ha, and 655950 ha were found to be less suitable for the Sundari (Heriteria fomes), Goran (Ceriops decandra), and Gewa (Excoecaria agallocha) tree rehabilitation. The most suitable locations for the rehabilitation of mangrove zones are Satkhira and Khulna, which is about covers 42532 ha and 13976 ha area respectively. The most suitable area of Goran (Ceriops decandra) is south 24 Parganas (11382 ha) and Gewa (Excoecaria agallocha) is mostly suitable in Satkhira (18339 ha) and Bagerhat (11083 ha) district (table 5.5). The area of Sundari and Goran for replanting

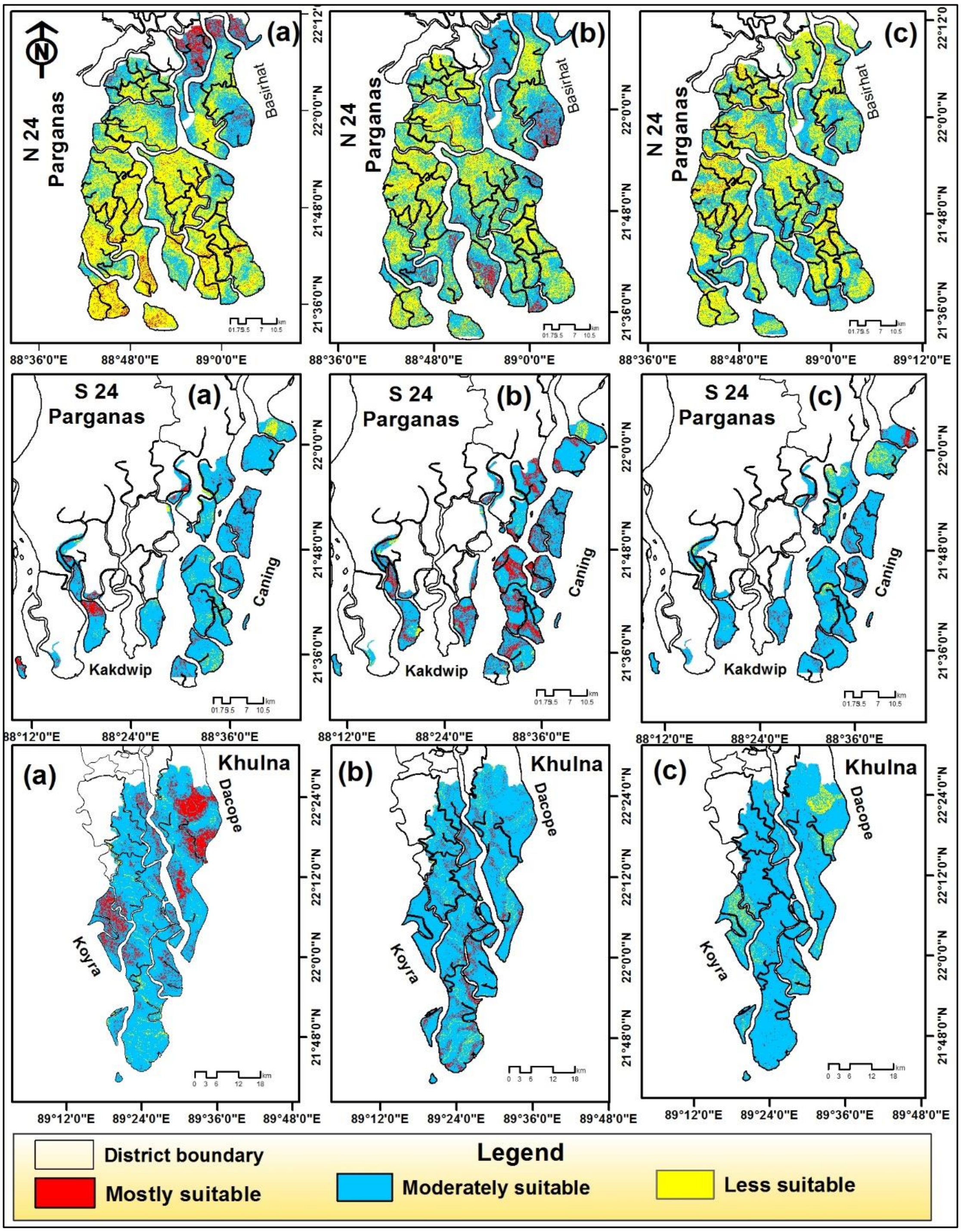

Fig. 5.3 District wise Site suitability map of Sundari (a), Goran (b), and Gewa (c) tree of North 24 Parganas, South 24 Parganas (India), and Khulna (Bangladesh) district In Sundarbans

is more found than the Gewa tree in the total area of Sundarban reserve forest. The most suitable rehabilitation area is also found in Bangladesh comparative to Indian reserve forest area due to vast economic and commercial activity, which subsequently cause the increase of salinity and temperature. The high rate of increasing temperature and

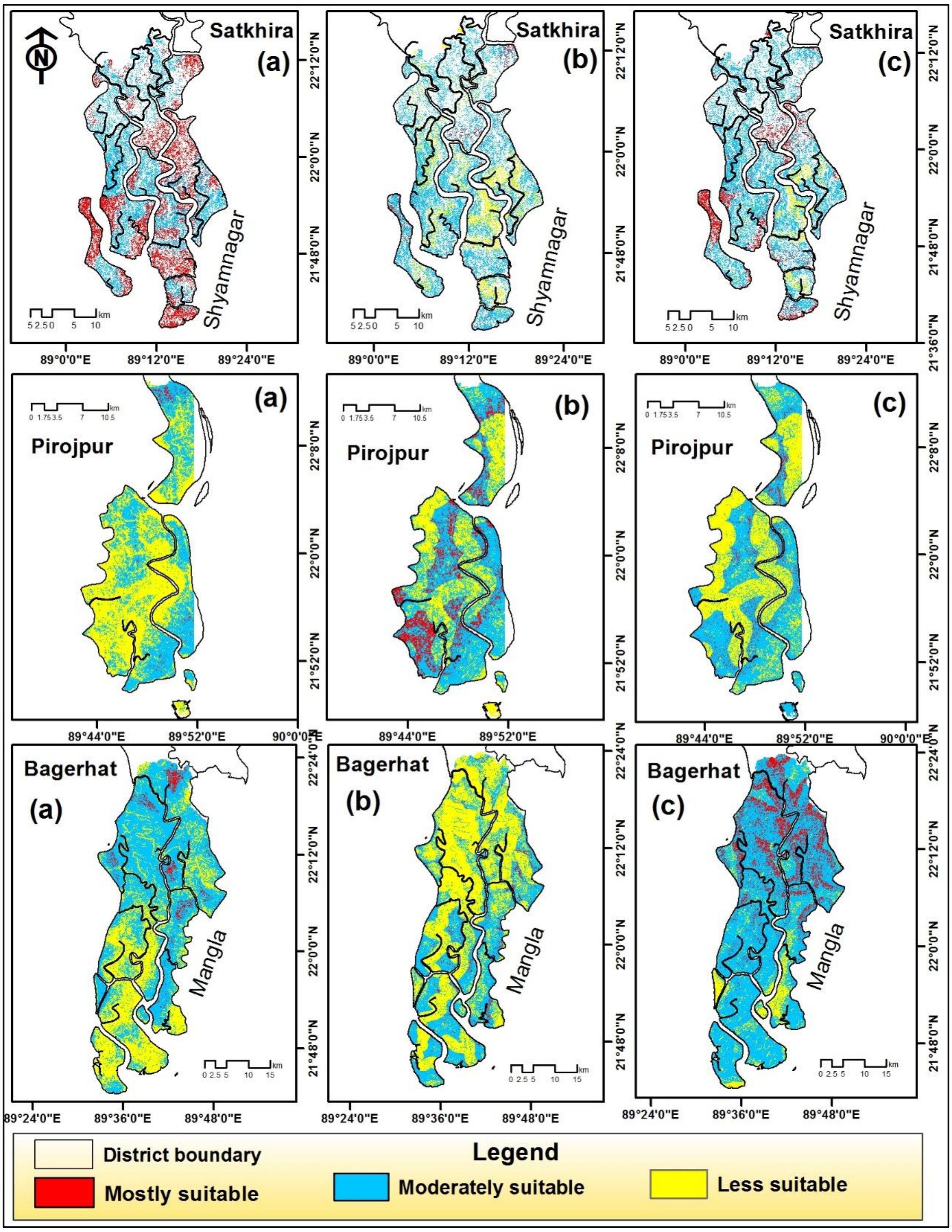

Fig. 5.4 District wise Site suitability map of Sundari (a), Goran (b), and Gewa (c) tree of Satkhira, Pirozpur and Bagerhat (Bangladesh) district In Sundarbans

salinity is less favorable for mangrove rehabilitation and also help to mangrove deterioration and enhance the 'top dying disease' of mangrove. District and species wise habitat suitability areas, has shown in Table 5.5 where rehabilitation area of Sundari tree is highest which is about of 75633 ha but the lowest rehabilitation area have been found for the Goran species (30095 ha) due to the abundance of flooded areas where over 3 months flooding condition and higher tidal range (3-8 m) is the main characteristics of the estuaries and coastal regions.

Table 5.5 District wise most, moderate and less suitable areas of Sundarbans

species	Suitability (Ha)	India		Bangladesh				Total suitable area
		North 24 Parganas	South 24 Parganas	Satkhira	Khulna	Bagerhat	Pirozpur	
Heriteria fomes (Sundari)	Most suitable	8388	2830	42532	13976	6583	1329	75633
	Moderately suitable	42923	49919	56732	133069	76518	10677	369838
	Less suitable	112235	6432	10570	1792	40432	39721	211182
Ceriops decandra (Goran)	Most suitable	5749	11382	1321	2632	3972	5039	30095
	Moderately suitable	796532	41367	89421	145176	46928	29231	1148655
	Less suitable	638740	3972	19092	1029	72633	17457	752923
Excoecaria agallocha (Gewa)	Most suitable	489	1132	18339	930	11083	3295	35268
	Moderately suitable	75518	45617	70152	138171	98971	27006	455433
	Less suitable	87534	12432	21343	9736	13479	21426	165950

5.4.6 Promotion of Accretion in Mangrove Areas:

Sedimentation in mangrove areas allows the forest substrate to maintain pace with relative sea-level rise, which leads to the natural adaptation measure in mangrove ecosystem and decreased the impacts of enhanced inundation stress. Moreover, sediment accession also permits the mangrove ecosystem substrate to spread upwards.

In the mangrove area, major external sources of sediment supply include longshore transport, gains from offshore which originates mostly from tsunami events, high-magnitude storm, input from channels and estuaries in riverine settings. During the sudden extreme weather events exceeds the level of sediment deposition that gradually deteriorate the mangrove ecosystem and kill mangrove habitats (Ellison, 1998). On the other hand, sediment losses to the ecosystem includes erosion, and down coast longshore transport, which can be increased by enrich energy situation, i.e. boat wakes, which also leads to the impacts on vulnerable mangroves of creek margin locations and seaward edge. Sediment accretion is also affected by the organic matter decomposition, root mat growth, and internal supply of organic matter.

Root mat growth of mangrove has been found higher under healthy, dense mangrove forest and be lower under scrub or dwarf mangroves. Increased mangrove productivity leads to the elevation gain of the marsh communities. Dense seedlings may enhanced sedimentation including from the gain of sediment surface elevation under densely and healthy replanted mangroves at both low and high tidal sides, and root mat development. Moreover, seeding density also increases accretion rates by enhancing friction to tidal water fluctuation to promote sediment settling and movement. Strategies to increase root mat productivity that include regenerating of degraded areas with dense mangrove seedlings and the decrease of non-climatic stressors, which subsequently enhance substrate accretion of the mangrove ecosystem.

Reduction in sediment supply along the coastline can result from a gradual increase of coastal populations and development activity, i.e. jetties construction. Foreshore developments can decrease longshore sediment drift, thus concomitantly reducing the supply and production of sediment into mangrove areas.

Fluvial dam construction may reduce water discharge and riverine sediment supply to coastal margins, leading to the deficit of sediment supply. Mangrove resilience under sea level rise particularly depends on sediment supply that enhance to the increased vulnerability. Mangrove adaptation actions that increase and maintain the accretion of mangrove substrate, therefore, should include infrastructure managers, coastal planners, and river management agencies, to established efficient designs that control sediment supply effectively to the mangrove belt. The management strategies can enhance and maintain the sediment and substrate accretion of mangrove in intertidal[30] and coastal environment.

[30] The intertidal zone is an area under water during high tide and above water during low tide, sometimes is refers as the littoral zone. https://en.wikipedia.org/wiki/Intertidal_zone

5.4.7 Proactive Strategy for Changed Condition:

Proactive planning during the sea level rise and climate change includes inland zoning for the migration of mangrove in future as a part of multi-sectoral coastal planning in a region that integrates mangrove ecosystem into the total adaptation strategy. Therefore, a reserve of possible migration areas of mangrove towards inland would increase future mangrove resilience.

The significant obstruction to migration of intertidal coastal wetlands with the relative sea level rise is key barriers that may prohibit wetland habitat from accessing most suitable adjacent areas (Gilman et al. 2008). Therefore, coastal lowlands and estuaries behind mangrove are main locations for transport, such as railways and roads, which turn to close access mangrove propagules and tidal exchange to the higher areas on the landward side.

Areas of important interest are mangrove ecosystem areas that have an intertidal range, due to the relocation of the mangrove habitat upon a soil surface areas that was earlier a non-mangrove habitat. In IPCC report (2007), the projected sea level rise is 0.18 - 0.59m by 2099. So, considering 30 cm sea level rise in micro tidal areas would totally relocate from upslope intertidal zone to micro tidal areas of the mangrove ecosystem.[31] Micro tidal areas of the Sundarbans low-lying islands and estuaries, where fresh water and sediment input from channel and groundwater are low comparative to continental coasts or lowlands. Hence, the capacity of forest substrate to hold up will be not significant.

Planning for future climate change and relative sea level rise should consider the following conditions;

a. Barriers to mangrove migration, i. e. railway tracks and roads,
b. Gradient and elevation of lowland areas behind mangroves,
c. Sedimentation rates within ecosystem and areas behind ecosystem.
d. Background of sea level trends in the mangrove area, and

[31] See IPCC (Intergovernmental Panel on Climate Change) (2007), "Climate change 2007: synthesis report", Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva.

e. Any development activity that responsible for more problematic due to inundation. Such as, local communities and rubbish dumps that must need relocation.

Moreover, identification of probable future problems also promotes conservation to higher level of government, and stakeholders to allow enough lead time to establish economically viable, environmentally acceptable, and socially sound management strategies (Gilman et al. 2008). This planning needs acceptable policy environments, multi-sectoral collaboration and adapted institutions at national and local levels. Such planning can examined through the use of vulnerability assessment results to point out requires to stakeholders and governmental.

5.4.8 Ongoing Monitoring and Evaluation in Mangrove Areas:

Scientific management and conservation strategies are dependent on multi-scale bio-complex systems to permit for effective discussions, and such understanding capacity is provided through efficient monitoring. Given the uncertainties condition about climate change, and future relative sea level rise, as illustrated by the error margin and ranges of the protected changes, and the uncertainty condition of how sea level rise, changing rainfall and increased co_2 will combine to affect people and mangrove ecosystem, ongoing monitoring might be the most significant adaptive management strategy of all. Moreover, standardized method among different sites permits the separation of regional or local influences from global influences on change as caused by global climate change and sea level rise (Ellison et al. 2012). In this context, the following parameters are important for ongoing monitoring of sea level rise and climate change effects on mangrove ecosystem;

a. Mangrove condition and extent,
b. Permanent plots showing recruitment, biomass, mortality and community structure, and
c. Sedimentation rates in the mangrove areas.

Management of mangrove areas has best governed by useful information about mangrove condition and extent. Ongoing repetitive surveys and observation will provide effective monitoring information needs climate change impacts and management success. However, continuous monitoring of mangrove areas also permits the evaluation of adaptation actions when they have implemented and providing information on how the ecosystem respond (both local communities and mangrove). Community involvement including ongoing monitoring permits information about mangrove condition, and the extent to directly notify the local management decisions.

5.5 Existing Management Strategies in Sundarbans for Mangrove Conservation:

The conservation process of the mangrove ecosystem to manage biodiversity began after the independence of India and the partition of the Sundarban (Indian) between East Pakistan (now known as Bangladesh) and India. For the protection of mangrove, three wildlife sanctuaries were formed (spread over last three decades) within the western part of the Sundarban (Holiday Island, sajnekhali wildlife sanctuary, and Lothian Island) in India. In 1973, 2585 sq. Km area has declared as the Sundarbans tiger reserve [32]where 1330 sq. Km core area[33] of Sundarbans was later named as a national park of Sundarban. Also, these protected areas focused on wildlife conservation, such as the Royal Bengal tiger, wild boar, rhesus macaque, and spotted dear. In Bangladesh (1977), after the creation of the sovereign state, three wildlife sanctuaries were formed in three separate deltaic islands of Khulna district in the Sundarban forest division. These reserved wildlife sanctuaries[34] are west (Mandarbaria), east (Hiron Point), and South (Katka, Kochikheli) wildlife sanctuaries. The Sundarbans national park has created in 1987 and in 1997 Bangladesh part of Sundarban, comes under the world heritage list (IUCN 1997). Moreover, the total part of Indian Sundarban, including reclaimed lands, and estuaries has been designated as the biosphere reserve, and the tiger reserve and the national park also found in the core zone of Sundarban Biosphere reserve. In Bangladesh, most of the area of Sundarbans Reserve forest has been identified as a Ramser site.

[32] Sundarban tiger reserve was established in 1973, and comprised as a reserve forest in 1978
See http://www.wpsi-india.org/tiger/sundarban.php

[33] Sundarban National Park was declared as the core area of Sundarban Tiger Reserve
See https://en.wikipedia.org/wiki/Sundarbans_National_Park

[34] Sundarbans West Wildlife Sanctuary is a World Heritage Site (UNESCO) and animal sanctuary in Bangladesh. The area of the reserve covers about 715 km
https://en.wikipedia.org/wiki/Sundarbans_West_Wildlife_Sanctuary

5.6 Management Problems in Sundarbans:

The management of mangrove based resources has changed over the present decades from exploitation (utilization in a sustained way) to rehabilitation (restoration) and conservation of degraded forest. We often talk of ecosystem-based management and sustainable management which sustains the structure, composition, ecosystem services, and functioning. It requires appropriate understanding process operating and ecological interactions within a mangrove ecosystem and also needs the setting up of explicit policies and goals.

After the degradation and extensive loss of mangrove of Sundarban, some areas are protected for the extensive conservation of ecosystem products and biodiversity. Monocultures pattern of mangrove species is increased in the degraded areas in the context of protective and productive function of management. However, these type of ‘management practices’ avoid the variety of ecosystem services, and products of mangrove and also fail to identify the negative changes of mangrove due to various causes, including salinity levels, changing hydrology, deteriorating water quality, and invasive species. For worldwide conservationists, mangrove ecosystem presents considerable immediate challenge. Mangrove ecosystem is an aquatic resource, tidal flow, the ecological process, and the fresh water flows in the aquatic environment are generally protected the mangrove management.

Chapter-6

Conclusion

Mangroves are the most important component of the intertidal coastal ecosystem. It has significant ecological and economic values and also plays a critical role in the local livelihood and economy of the coastal inhabitants offering an extended amount of services and goods. The services are timber and wood production, supporting fisheries, reducing the coastal erosion, salt production, and protecting the coasts from storm and cyclones. However, the mangrove forests are now facing significant threats from climate change and subsequent sea level rise. The key climate change components affecting these ecosystems are a change in precipitation pattern, temperature, ocean circulation pattern, storm and cyclonic intensity, and changes in relative sea level. Global emissions of important Greenhouse gases (GHG) are expected to increase the sea level rise and air temperature at a significant rate.

Therefore, the Sundarban is a 'climatic hotspot region' and located in the inhospitable zone between sea and land that would create more susceptible condition to recent climate change and subsequent relative sea level rise. Due to the climate change and relative sea level rise, the seaward erosion and landward migration of mangrove area may occur. It also changes the mangrove health, density and canopy closure and increases flooded areas within the mangrove area which may cause the 'top dying disease'. The insufficiency of the landward area would cause a vertical increase of ocean water resulting in flooding and water logging and finally deteriorate or destroying mangrove ecosystem and other associated faunal and floral communities.

The growing adverse impact of climate change and subsequent deterioration of mangrove ecosystem would interrupt the collection of mangrove dependent livelihood to the local communities of Sundarbans. The effects may cause the reduction of economic activities such as timber gathering, honey and wax collection, aquaculture and fishing, crab collection and other related activities in Sundarbans. Therefore, there is an immediate requirement preserve this important ecosystem for global, regional and local interests. Otherwise mangrove dependent livelihood services and other significant utilities of the mangrove will be lost or reduced perpetually. However, an accurate management strategy is required for sustainability and conservation of the Sundarban mangrove ecosystems. The predicted impacts of various climate change components on the mangrove forests and strategies to reduce the effects of climate change have discussed in chapter 5. To protect the valued mangrove ecosystem, and to mitigate the impact of climate change effects, there is an immediate action for proper management strategies and suitable conservation policies. The existing forests should stringently protected from cutting and encroachment. The expansion of forest cover area by increasing the regenerating or rehabilitating potential and planting of most threatened and valuable mangrove species in the estuarine and intertidal areas are some of the crucial management options. The rehabilitation and adaptability of the threatened mangrove species should implement through the habitat suitability modelling have been established in the previous chapter (section 5.4.5.3). The most threatened species in Sundarbans with less adapting capacity to climate change and associated effects should be promoted to regenerate or rehabilitee in new areas. The continuous monitoring of the sea level rise, as well as climate change effects on mangrove ecosystem, should be documented to get consistent inputs for crucial management strategies (Singh 2003). The mangrove responses to recent climate change and their effects differ from one place to another place and hence a location specific plan and policy on the basis of recorded input of changes should be established for implementation. Some of the most significant management strategies can be undertaken for the protection and conservation of mangrove ecosystem of Sundarbans are,

1. To enhancement of the landward migration of mangrove communities during inundation resulting from high precipitation or sea level rise,
2. Facilitation of the peat building capacity by continuous supply of sediments and freshwater,
3. Proper management of the distribution of propagules and sediments,
4. The components that promotes regeneration and spread the recovery of mangrove tree should implement.

Also, approximately 5% of the total mangrove covers of the Indian part have been conserved jointly by the state government, and the Government Of India by constituting some MPAs (Marine Protected Areas) under the WPA (Wildlife Protection Act, 1972). In this regard, mangrove dominated areas of Sundarban have declared as a ‘Sundarban Biosphere Reserve’. Different most significant management strategies of mangrove forest for their recovery have resulted in the increase of mangrove forest areas in Sundarbans. The present study of mangrove through Geographic Information System depicted the total mangrove cover area increase in a small amount from 5840 sq. Km in 1973 to 5850 sq. Km in 1990 and then significantly decreased due to the lack of implementation of the proper management strategies and increasing climate change and their effects.

In coastal areas and estuaries, have emerged three main type of risk of mitigation planning and policies to addressed projected recent climate change induced sea level rise: relocation and retreat inland, engineered coastal protection and accommodation in situ. Accommodation mainly involves reduction of exposure, and sensitivity to the significant effect of relative sea level rise for the existing extensive mangrove areas. Planning for landward migration of mangrove habitat in case such accommodation options is not fully successful, particularly if projection of higher relative sea level rise occur in the near future, is a pre-alerted back up plan.

Three types of adaptation actions for management planning have been described for a mangrove ecosystem. Actions or strategies that decrease existing stresses include the enhancement of improving legislation, and local management that facilitates sustained use and mangrove protection, rehabilitation of degraded areas and the formulation of strategic protected mangrove areas. These strategies would serve to enhance mangrove resilience to the negative impacts from recent climate change. Adaptation action also refers the identification of ‘climate smart’ species in any rehabilitation purpose, along with the maintenance and formation of protected zones, management strategies to help sediment accretion and proactive strategies for changed conditions of mangrove. Ongoing monitoring and evaluation allow future actions as climate change significantly appears and proper adaptation actions are implemented. The success of adaptation results may include its inclusiveness, equitability, flexibility, and consistency, and the mangrove strategies must set for the management actions. Stakeholder involvement in the mangrove management allows awareness of neighboring sectoral plan in coastal planning, policy, coastal management, transport, infrastructure and economic development, to allow most efficient utilization of national and regional resources, and compatibility. Involvement and engagement of local inhabitants around the mangroves is most significant to successful climate change adaptation actions.

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Appendix 1

Table A1. 1 Land use change detection through the pixel changes in error matrices of 1973

Classified data	1973					
Land use categories	Water body	Barren land	Mangrove	Flooded areas	Non mangrove	Row total
Water body	674394	0	0	0	0	674394
Barren land	1704	1377	84	0	0	3165
Mangrove	10	0	36822	0	0	368302
Flooded areas	0	4	46	20	3	73
Non-mangrove	0	5	3	0	88	96
Column total	676108	1386	36955	20	91	714560

Table A1.2 Land use change detection through the pixel changes in error matrices of 1990

Classified data	1990					
Land use categories	Water body	Mangrove	Non-mangrove	Barren land	Flooded area	Row total
Water body		0	0	0	0	2777790
Mangrove	3	180846	0	1	0	180850
Non-mangrove	0	2	2414	2	0	2418
Barren land	733	27	5	1831	0	2596
Flooded area	2210	147	15	0	357	2729
Column total	2780736	181022	2434	1834	357	2966383

Table A1.3 Land use change detection through the pixel changes in error matrices of 2002

Classified data	**2002**					
Land use categories	Water body	mangrove	Barren land	flooded	Non mangrove	Row total
Water body	2517426	0	0	0	0	2517426
mangrove	0	142240	0	3	0	142243
Barren land	146	2	1752	0	4	1904
Flooded	1	317	0	1153	43	1514
Non-mangrove	6	824	2	6	1668	2506
Column total	2517579	143383	1754	1162	1715	2665593

Table A1.4 Land use change detection through the pixel changes in error matrices of 2014

Classified data	**2014**					
Land use categories	Water body	Non-mangrove	Barren land	Mangrove	Flooded area	Row total
Water body	3314235	4	0	0	0	3314239
Non-mangrove	67	7078	6	12	10	7173
Barren land	1765	50	4487	224	2	6528
Mangrove	75	0	3	293504	3	293585
Flooded area	0	2	0	977	1123	2102
Column total	3316142	7134	4496	294717	1138	3623627

Appendix 2

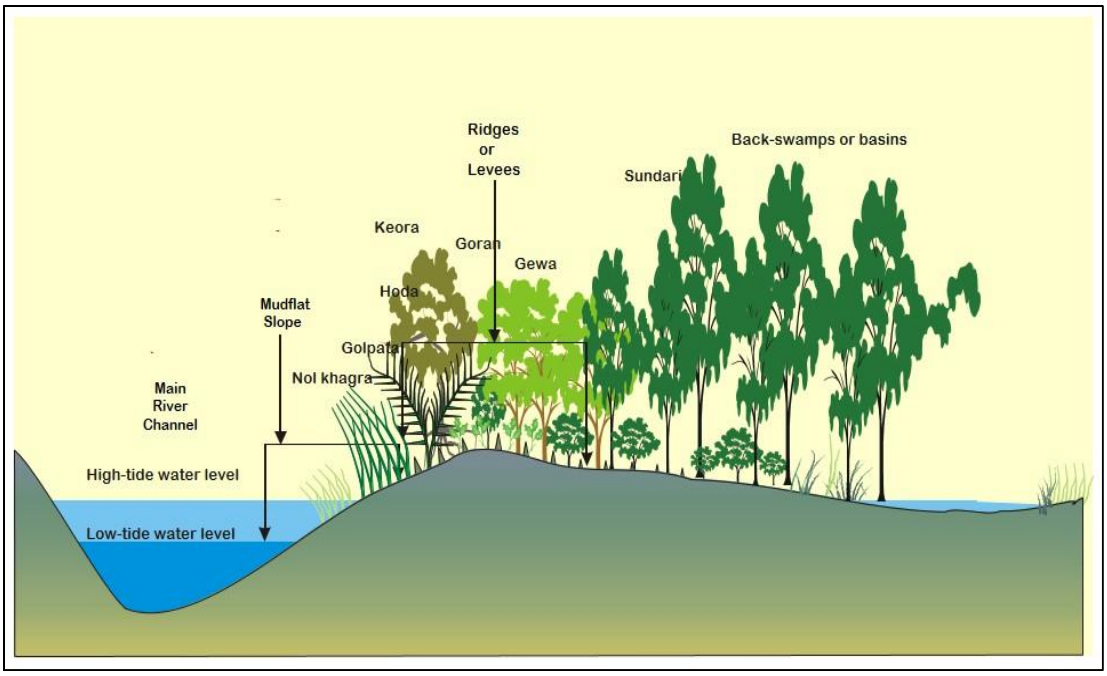

Fig. A2.1 schematic representation of the mangrove species dominance on the basis of elevation and distance from channel

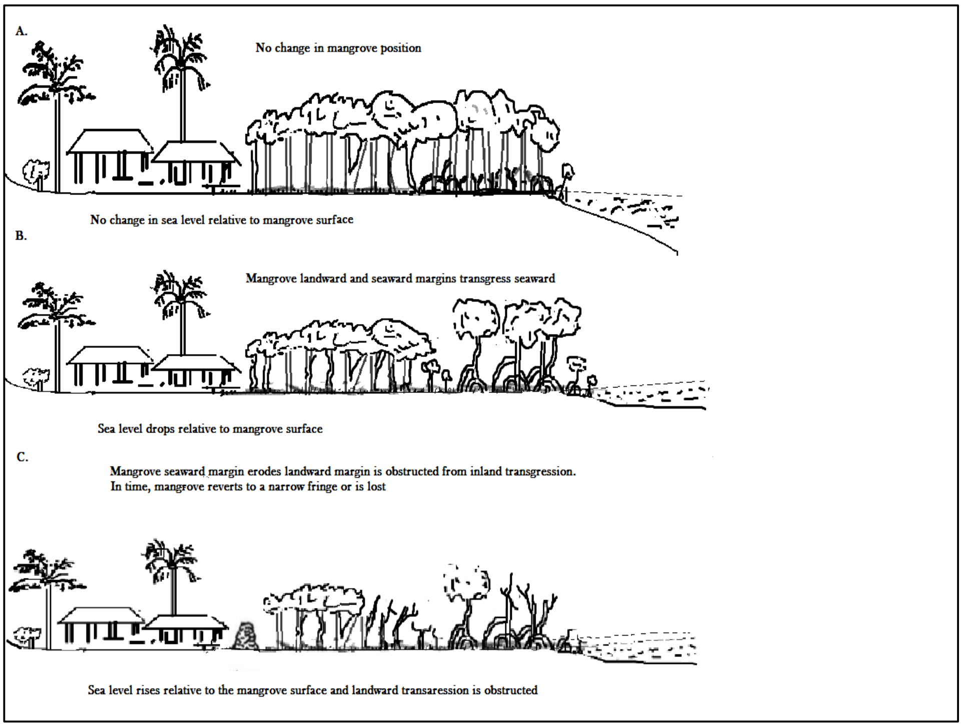

Fig. A2.2 A schematic representation of the relative rea level rise and mangrove resilience

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