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Changes and Status of Mangrove Habitat in Ganges Delta: Case Study in Indian Part of Sundarbans

Pramanik MK*
Research Scholar, Centre for International Politics, Organization and Disarmament (CIPOD), Jawaharlal Nehru University, NewDelhi-110067, India

Abstract

This paper quantifies the changes and present status of mangrove forest in Indian part of Sundarban from 1975 to 2014 using Landsat MSS (1975), TM (1990), ETM (2002) and OLM (2014) satellite imageries. The study used two image processing techniques: Maximum Likelihood Classification for the Land use and land cover analysis and NDVI for the vegetation characteristics and their temporal changes. The research found that the area of mangrove gradually decreases from 203752 hector (44%) to 132723 hector (31 %) and the barren land increases from 15078 hector (2.86 %) to 37247 hector (7.12%) due to natural (sea level rise, salinization etc.) and anthropogenic (livelihood collection and shrimp farming etc.) disturbances and continuous land reclamation. Other land use categories like agriculture, water body, and sand deposition have approximately remained constant. The NDVI values were changed significantly only in 1990 due to the landward migration and defragmentation of mangrove forest. However, the paper signifies that the forest cover is constantly evolving due to deforestation, aggradation, erosion and forest rehabilitation programs in the Indian Sundarban.

Keywords: Mangrove habitat; Sundarban biosphere reserve; Ganga-Brahmaputra delta; Mangrove change; Mangrove vulnerability

Introduction

Mangrove forests are one of the most significant biodiversity of intertidal zones along the subtropical and tropical coastal regions of the world. These ecosystems take the role of attenuating wave energy protect the shoreline and adjacent dependent ecosystem [1-2]. The mangrove ecosystem also plays a significant role in the biogeochemical cycle, coastal protection and also has an economic significance of the region through different activities like fishing, aquaculture, and farming. However, mangrove dependent livelihood such as a collection of fuelwood, forest fire, flood, erosion and other human activities have resulted in the reduction of the mangrove forest in Sundarban [3-6].

The Indian part of Sundarban mangrove is a part of the world's largest delta of Bengal estuarine region. The delta has formed in the estuarine area of Ganga-Brahmaputra and Meghna River. The region is also named as Region of the largest halophytic formation along the coastline. It was also declared a "biosphere reserve"(1989) and "world heritage site"(1987) by United Nations Educational and Scientific Cooperation [7-9] and International Union for Conservation of Nature [10] respectively where 2125 sq. Km area occupied by mangroves across 56 islands. The aerial extent of the Indian part of Sundarban is about 4262 sq. Km where having 106 deltaic islands within 54 has human habitation. The total region characterized by most of the tidal creeks, innumerable rivers, and small channels. The biodiversity has been significant as an abandoned due to the presence of endangered plant species and animals of which 37 are mangrove species in 87 plant species.

In the last century, the erosion, flood probabilities increased heavily due to the increasing rate of siltation of river beds. Also, present continuous rises of sea level are now being a magnificent threat for existing vulnerable or fragile ecosystem [11-17]. So, the present study analyzes an overview of the distribution and changes of mangroves in Sundarban delta by using Remote Sensing and Geographical Information System for the conservation planning and strategies [18,19].

Study Area

The present study area situated on the eastern coast of India in the southern part of West Bengal in between 21°13´- 22°40´ north latitude and 88°05´–89°06´ east longitude (Figure 1). It has located about 100 km southeast of Kolkata in South 24 Pargana district. Most of this district predominated by flood and cyclone prone area. The tides of the study area are semi-diurnal, and floor varies from 0.9 m to 2.11 m above sea level in different regions during different season, mainly it reaching a maximum during monsoon, and minimum during the winter [29]. This tidal level influenced by the direct connection with the sea at the Hugli river mouth and also through the Ganga-Brahmaputra estuaries [20,21].

Materials and Methods

Data sources

Four multispectral satellite images (Landsat) that covers whole Indian parts of Sundarban Biosphere Reserve were downloaded from the freely available USGS (United States Geological Service) GLOVIS. These orthorectified images (with universal transverse Mercator projection and world geodetic system 84 datum) are Landsat Multispectral Scanner (MSS) data (Columns 1953, Rows 1459, Dated 5 Dec 1973), Landsat Thematic Mapper (TM) data (Columns 3708, Rows 2754, Dated 12 Dec 1990), Enhanced Thematic Mapper plus (ETM+) data (Columns 7809, Rows 5833, Dated 27 Nov 2002) and Operational land imager (OLI) data (Columns 3710, Rows 2771, Dated

***Corresponding author:** Malay Kumar Pramanik, Research Scholar, Centre for International Politics, Organization and Disarmament (CIPOD), Jawaharlal Nehru University, New Delhi, India, Tel: 8587081820; E-mail: malaygeo@gmail.com; malay65ise@jnu.ac.in

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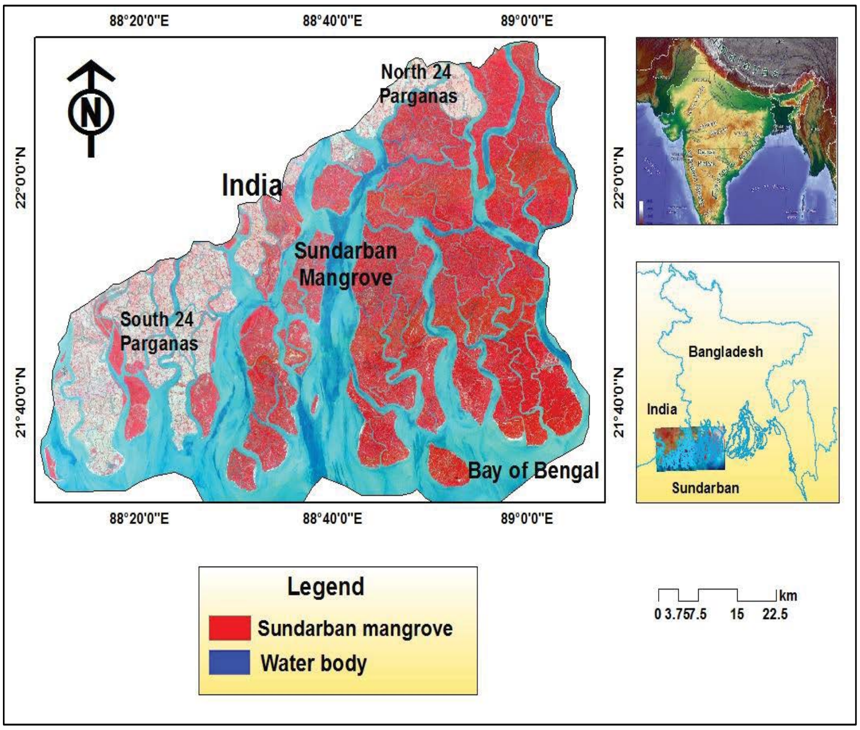

Figure 1: Map of the study area.

23 Jan 2014). These images are possibly collected at same season and less likely to have had miss classification error during spectral analysis of different LULC categories. Topographic maps (NF 45/11, NF 45/12, NF 45/7 and NF 45/8) are used that has been downloaded from Texas library at scale of 1: 250000.

Identification of mangrove boundary

Boundaries of the study area have extracted from four images as well as Toposheet by manual digitizing along the near boundary of mangrove forest.

Image processing

The whole image processing procedure was processed ERDAS IMAGINE 13.0 software. Individual band data stacking to prepare false color composites (FCCs) was done for all bands of MSS, band 1-5 and 7 of TM, band 1-5 and 7, 8 of ETM+, BAND 1-7 of OLI data then haze reduced of all images. After layer stack extract the study area by masking using Arc GIS 10.

Image classification and accuracy assessment

For supervised classification follow a parametric decision rule of each images , i.e., classification techniques adopted by Maximum Likelihood Classification method because this classification algorithms produces consistently a better results for the mangrove habitat zonation [22]. However, five land use and land cover classes were taken for image classification based on Google Earth visit and locational experience of the study area. The classes are mangrove, water body, sand deposition, agricultural land and barren land. After classification, accuracy assessment has performed by error matrices of all images. All accuracy has different to each other.

Mapping of vegetation attributes

Spectral vegetation attributes used for the analysis of vegetation density and canopy structure. NDVI is the most important of all vegetation indices. The basic principle is that the rates of the difference between NIR (4^{th} band) and Red (3^{rd} band) of an image that can help to know the green plants. The green characteristics of plants influenced by topography as well as regional deltaic slope [3]. So, the NDVI calculated by the following equation in Arc GIS.

NDVI=NIR-RED/NIR+RED

NDVI maps have generated from the NDVI ratios of four LANDSAT images used for the present study. Generally, Biomass contribution of mangrove leaves (chlorophyll portion) reflect more in middle infrared region and NDVI value ranges from -1to+1 where the 0 indicate the bare earth but higher negative value denotes water content and the value beyond 0.5 represents green vegetation. However, the study areas NDVI are 0.7 to 0.9 for the dense mangrove.

Change of land use and land cover

The change of land utilization and land cover analyzed by overlaying GIS techniques (Figure 2) adopted within ERDAS IMAGINE to explore the different temporal land cover change at approximately ten years interval. Using GIS database these data are tabulated and quantifying their temporal transformation.

Results

Land utilization and land cover change through classified image

The present study of mangrove forest area has been classified into five categories of Land use and land cover area as mangrove, agricultural

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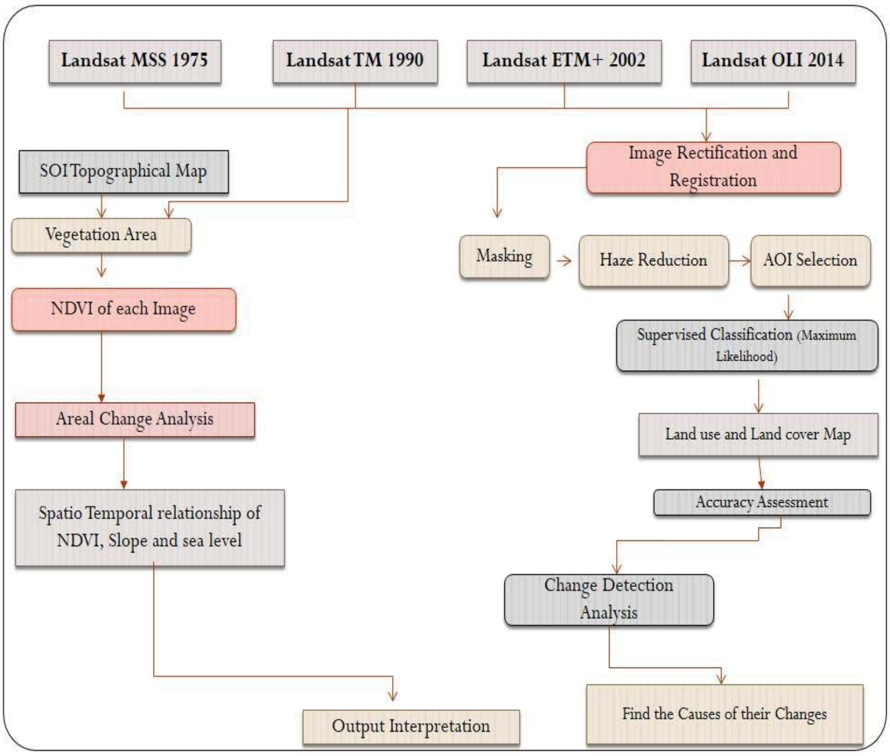

Figure 2: Framework of methodology followed in the present study.

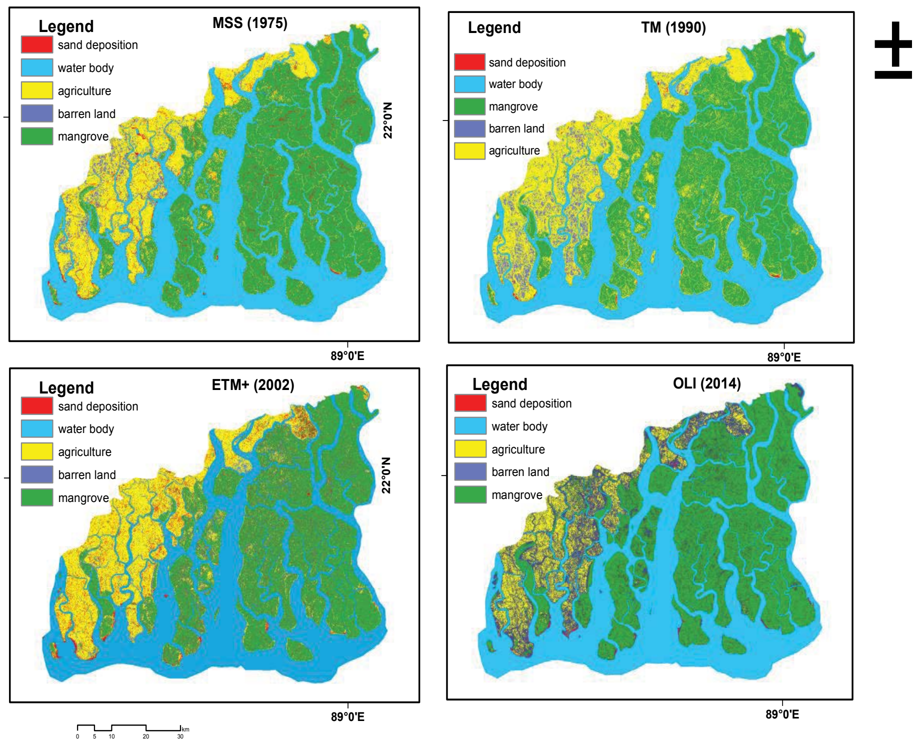

Figure 3: Land use and land cover of the study area in different time period of 1975, 1990, 2002, and 2014.

land, Barren land, sand deposit and water body (Figure 3) of all satellite images. These estimated areas under different land use categories of the study area have shown in figure 2 and 3. In 1975, areas of mangrove and agriculture land were approximately 203752 hector (44%) and 94764 hector (18%), respectively. These mangroves were found in the remote areas of human habitation, partly along the river banks and mouths. The area of mangroves is spatially a continuous zone along the coastline of the study area. The agriculture area is less due to dense vegetal cover but most of the agriculture areas occupied in sparse mangrove areas. Barren land occupied the less area approximately 15078 hector (2.86%) along the River within the study area.

In 1990, 2002 and 2014, the area of mangrove gradually decrease is about 182345 hector (40%), 156711 hector (35%) and 132723 hector (31%) respectively (Figure 4). Mangrove area decreases probably due to forest clearing and continuous land reclamation during this period [3,20]. Agricultural lands are remains constant, but barren land drastically increase from 2002 (32355 Hector) to 2014 (69596 Hector) is about 7.12% (37241 hectors).This drastic change of barren land occurred due to the error of miss classification (kappa coefficient value 81.26) and may be of image that collected in different time period for the not availability of cloud-free images in same season. So, during this field studies several agricultural locations and open mangrove were found in corresponding to the barren land category. Most of the farmland has found in the northwestern part of the study area, and the conversion of mangrove to barren land and agriculture to barren land is a maximum of this part also.

Change detection in vegetation indices

NDVI was used for the analysis of land use change to delineate the mangrove dynamics from 1975 to 2014. Four NDVI maps are used for visual interpretation to understand the density of mangrove and their fragmentation due to sea level change. The change observed higher along the river and coastal margins due to high rates of bank erosion. The value of NDVI gradually decreased from 1975 to 2014 due to positive changes in human population and gradual decline of open mangrove, as well as conversion of agricultural lands, barren land and built-up areas [23,24]. However, positive changes of NDVI found only limited areas like Lothian, Chulkati island, other protected forests and vegetal riverbanks. However, higher positive changes found in the north-western part of the study area due to the initiative of man-made vegetation. Moreover, landward migration of mangrove forest and defragmentation of mangrove were also handling the declining NDVI values.

In 1973, the NDVI values were more or less same but the NDVI of 1990, 2002 and 2014 (Figure 5) differ significantly from the previous one. In 1990, NDVI valued higher in north-western part and lowered in the mangrove areas due to defragmentation of dense mangrove. However, in the year of 2002 south-eastern part of the study area covers higher values remaining part holds their medium NDVI values. Moreover, recent NDVI (2014) values not differ significantly from 2002.

However, the pattern and condition of healthy upper layer mangrove characteristics is different in different classification periods. Therefore, more healthy areas in 1973s are different from the least healthy areas of 2014s correlates to the areas of 'Top dying disease' of Sundari (Heritiera fomes) [25]. 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 1973, 1990, 2002, and 2014 (Figure 6). 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 1). 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 (Figure 3). This may signify that the mangrove dominated total Sundarbans are totally influenced by climate change and their related effects over the periods.

Discussion

Sundarbans ecosystem has located in climatic hotspot and also has highly susceptibility sea level rise [4-6]. Except sea level fluctuation, the region faces many difficulties like Monsoonal high floods, cyclones, storm surge and high drainage density, and Stalinization. Moreover, the sea level change, salinization, and other related events are the major

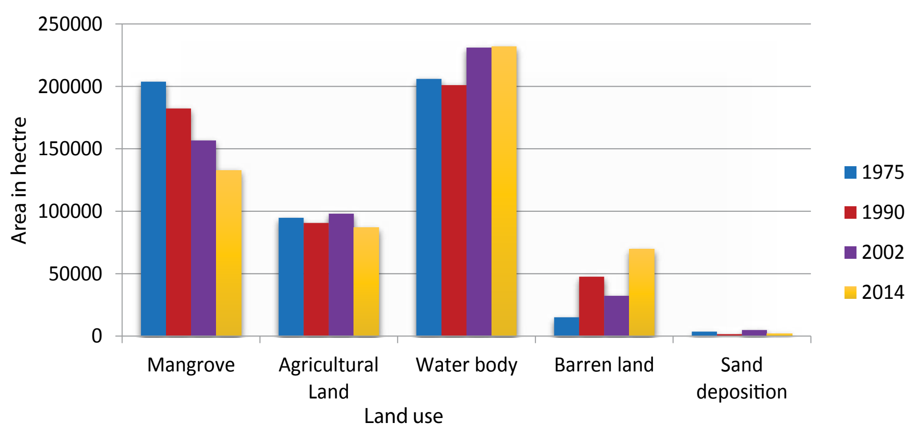

Figure 4: Amount of land under different land use and land cover classes in 1975, 1990, 2002, and 2014.

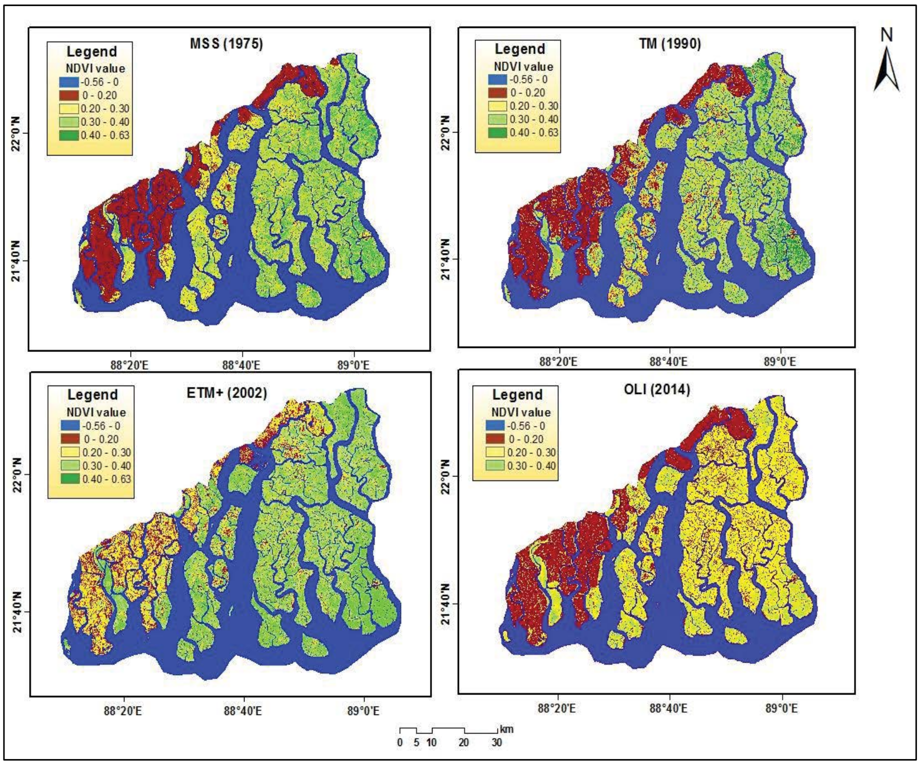

Figure 5: Normalized difference Vegetation Index (NDVI) in different time period of 1973, 1990, 2002, and 2014.

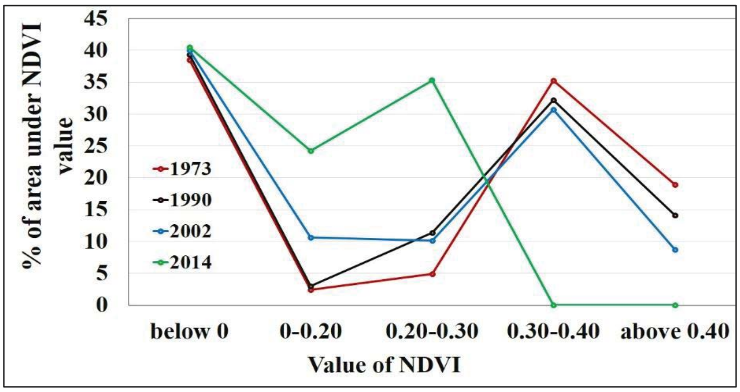

Figure 6: Area (%) under different NDVI value of Sundarbans in 1973, 1990, 2002, and 2014.

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

Table 1 Area under different Normalized Difference Vegetation Index (NDVI) value in Sundarbans.

factors that may influence the changes and dynamics of mangrove ecosystems [26,27]. In respect to sustainable management of natural resource in coastal areas closely related to the association and density of mangrove community [28-30]. These characteristics primarily associated with slope, soil, habitat stratigraphy as well as salinity regimes [31]. that can alter the mangrove systems. The increasing sea level and salinity regimes may affect some edaphic changes, general changes of soil and salinity, tidally dominated mud flat and groundwater

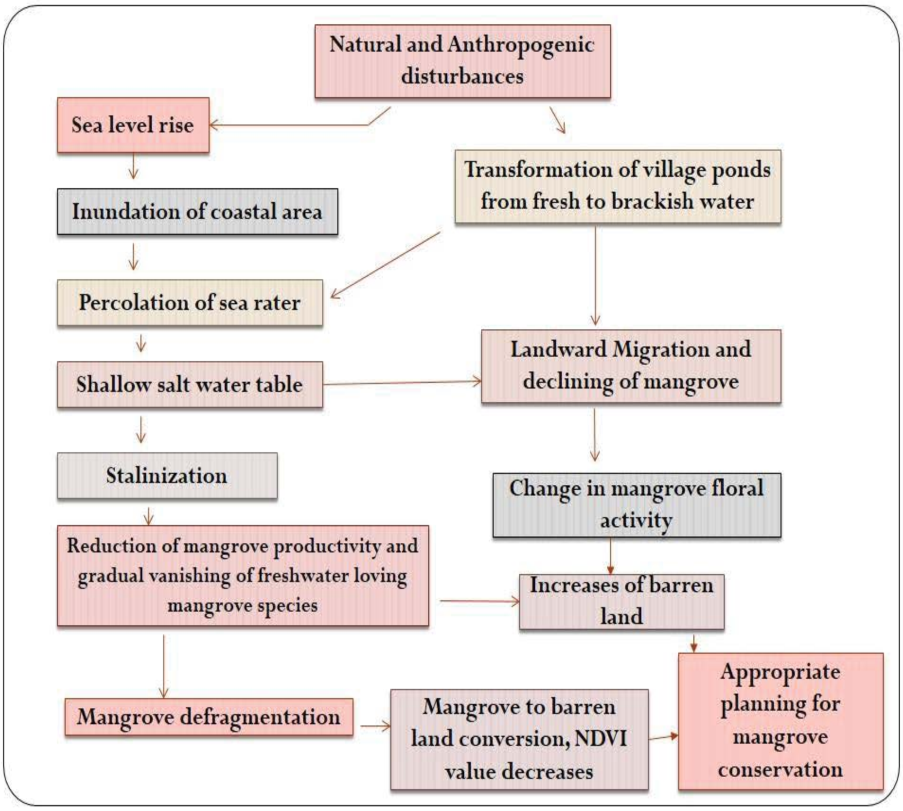

Figure 7: Impacts of SLR on mangroves via ground water system (Source: Modified from Avijit Mitra, 2013).

fluctuation and their quality. The slope of this region also influences the dynamics and adjustment of mangrove forests along the coastal areas. The dynamics and change mangrove association depends on:

1. The inundation of high tidal areas.
2. Ground water fluctuation.
3. Increasing inundation frequency.

In the view of the sustainable mangrove management, Sundarban has overcome many difficulties like cyclones, inaccessible terrain condition, and high flood events. However, harmful human activities for their traditional livelihood generation like, timber collection, farming, and honey collection are not conducive to their sustainability [3]. In the last few decades experienced that the rural peoples had destroyed the open mangrove covers without any management initiative [32,33]. However, the existing mangroves are not able to protect against the cyclone like Aila (25 may 2009) and havoc tsunami waves, which caused of landslide, flooding, tree uprooting, bank erosion and loss of human lives and property lead to the defragmentation and destruction of mangrove habitat in the intertidal region [34-37]. The northern part of Indian border and the adjacent portion has experienced maximum growth of shrimp farming that influenced the higher rate of deforestation activities (Figure 7). According to Wikramanayake et al. report, unsustainable shrimp farms leads to the destruction of mangrove habitat in Sundarban areas [38]. Islam suggests that the ecosystem management system is inadequate, and the highest numbers of people are economically dependent on the mangrove ecosystem [26].

Conclusion

Management issue of the intertidal mangrove ecosystem is a major problem due to the climatic complexity and present human interventions. The academician, planner, and researcher can follow a comprehensive way to incorporating qualitative and quantitative information for the decision-making processes and management initiative. As demonstrated, the present study of integrated remote sensing and GIS technique provide some important information about mangrove dynamics, changes, existing status but the optimum possibility for success cannot achieve [39,19]. Multispectral satellite images can be used potentially to measure forest cover and mangrove forest cover change if carefully image processing methods has adopted. The completely deforested and fragmented area can be simply detected using the maximum likelihood algorithm. Also subpixel classification algorithm and NDVI differencing method can be used for the differences of forest cover of the Indian part of Sundarbans.

The potential changes and dynamics vary from one place to another location along the coastline. Multiple environmental stresses likely make the most vulnerability [40,41,27]. The low-lying coastal areas and higher population with greater mangrove density are the most vulnerable because of they are lower social, technological and financial adaptation [5]. An effort, in particular, the low-lying coastal areas need an adoptive option to their proper management. Thus, the adaptive options of mangrove sustainability are mostly dependent on their locational characteristics and long-term thinking as well as economic activities.

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