

Assessment the Impact of Sea Level Rise on Mangrove Dynamics of Ganges Delta in India using Remote Sensing and GIS

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Abstract
The intertidal mangrove ecosystem of Indian Sundarban is now as a critical ecosystem due to climate change induced sea level rise. The present study analyses the responses, migration, destruction and vulnerability of the four deltaic mangrove ecosystem (Bakhali, Bulcherry, Dalhausie and Bangaduni Islands) along the ocean sides. The changes of these deltaic ecosystem studied by using GIS and remote sensing with collecting data about sea level of nearest tidal gauge station Haldia (2.59 ± 1.0 mm/year) and Diamond Harbor (4.67 ± 0.68 mm/year). The study finds that if the sea level rises relative to mangrove surface, the mangrove retreat landward and also decline the land areas, increases soil erosion that affected in southern and southwestern part where these vulnerable mangrove islands is located. Moreover the study indicates that the low level mangrove islands would be threatened with the rates of increasing sea level under present climate change.
Keywords: Sea level rise, Mangrove dynamics, landward migration, Mangrove vulnerability, Sustainable mangrove management.

1. INTRODUCTION:

Mangroves are one of the most important primary resources of intertidal deltas and coastal regions of the tropical and subtropical regions all over the world. The ecosystems also helps in the protection of shoreline and living habitat by the attenuating power of wave energy (Brinkman et al., 1997, Quartel et al., 2007). These coastal habitats are now threatened due to sea level oscillations causing climate change (Alongi, 2008; Berger et al., 2008, Cohen et al., 2008, Gilman et al., 2008). The oscillations may affect to the distribution of mangrove habitats along the coastlines (Rossetti et al 2007, Miranda et al 2009, Rossetti et al 2012), and the displacement of all dependent coastal ecosystems (Chappell 1990, IPCC 1996, crooks and turner, 1999). Mangrove not only affected by sea level rise, also have a significant threat to salt marsh habitat and intertidal wetlands and related ecosystem (Cohen et al., 2006; Nicholls et al., 2007).

The important consequences of present climate warming is sea level fluctuation causing by the melting of Antarctic and Greenland ice sheets, glaciers and the thermal expansion of regional climatic fluctuations (Ragoonaden, 2006). The Intergovernmental Panel on Climate Change (IPCC) report mentioned that, the Predicted sea level of 21th century, increases gradually at the rate of 1-2 mm per year (Boesch, 2002), causing by physical and human-induced Global climate change. The fourth assessment report of IPCC estimates (by tidal gauge observation) that the change of average sea level in the 20th century is about 1.5 ± 0.5 mm per year (church et al., 2001), although Church et al., has been estimated it is about 1.8 ± 0.3 mm per year in between 1950 to 2000. However, the existence of mangrove ecosystem depends on the sea level when the rising rate is up to 9-10 cm per hundred years (Singh, 2003). The declining rates of mangrove coastlines from 198000 km in 1980 to 146530 km in 2000 have been observed by food and agricultural organization (FAOs). Mangrove characteristics should be changed in a devastating way, when the rate of sea level rise exceeds more than 10 cm per hundred years (Singh, 2003). This effect should change the significant adverse impacts on coastal ecosystems. The gradual increase of the water level (Church, 2001, 2004) could affect mangrove diversity and health of the associated changes of the soil salinity, soil erosion, sediment deposition and inundation. All of these adverse conditions can change the mangrove zonation and migration from seaward to landward side along the oceanic regions (Gilman et al., 2006). After sea level rise, Storm surges play the role in the decreasing mangrove area and deteriorate the ecosystem and the effects may be combindly that can accelerate to the landward migration also (Ellison, 2000). The limitation of land and vertical increase of water level may effects of water logging causing death of mangroves with associated flora and related habitats (Jagta et al., 2003). Therefore, the assessment about the impacts of climate change and related events in the mangrove belt as an additional risk which have a significant adverse effect of stressing coastal habitats (Bijlsma, 1997). So the present study analyses the role of sea level rise to the changes, migration and defragmentation of the coastal mangrove habitat and also find some vulnerable area that may influence significantly. Thus the dynamics of mangrove ecosystem in response to projected sea level rise enable to take appropriate planning for reducing threats and human safety of coastal area (Gilman et al., 2007).

2. STUDY AREA AND ITS IMPORTANCE AS A COASTAL BIOSPHERE RESERVE:

Sundarban mangroves are a part of the world’s largest delta of India and Bangladesh. The delta has been formed in the estuarine region of Ganga-Brahmaputra and Meghna River. Sundarban mangroves have also the 'Region of largest halophytic formation' along the coastline. It was also declared a "world heritage site"(1987) and "biosphere reserve"(1989) of which 2125 sq km occupied by mangroves across 56 islands by the International Union for Conservation of Nature (IUCN) and United Nations Educational and Scientific Co-operation (UNESCO) respectively. The Indian part of Sundarban has an aerial extend about 4262 sq km. This part consists of 106 deltaic islands therein 54 have human habitation and all over the region characterized by most of innumerable rivers, tidal creeks and small channels. Sundarban biodiversity has been important as an abandoned biodiversity of which 37 are mangrove species in 87 plant species.

In the last century, the probabilities of flood and bank erosion have accelerated due to increased rate of siltation and erosion of riverbeds. The continuous rise of sea level are now being a significant adverse effects of the existence of this fragile ecosystem.

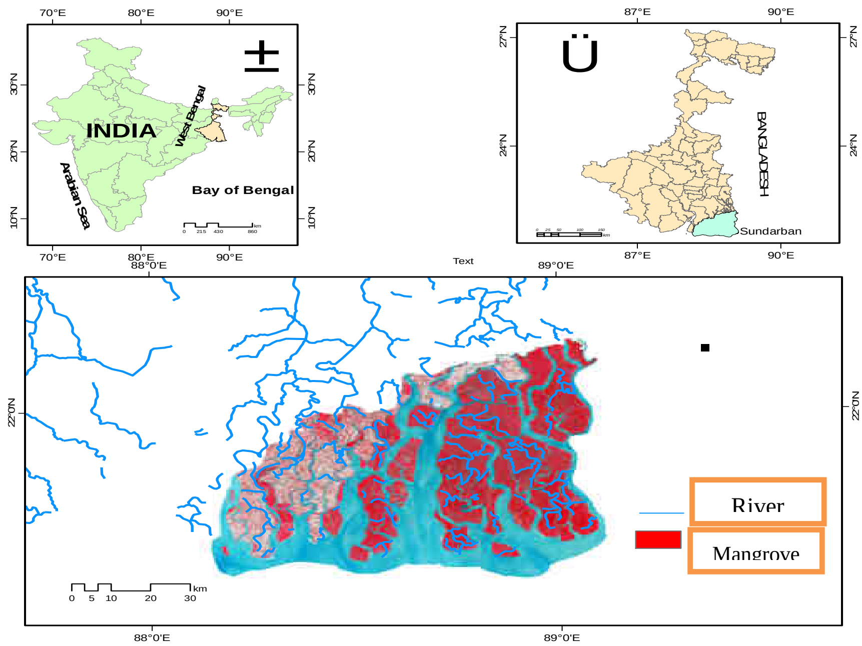


Figure 1: Map of study area

The present study area situated on the eastern coast of India in the southern part of west Bengal (fig-1) in between 21°13´- 22°40´ north latitude and 88°05´ – 89°06´ east longitude. It is located at about 100 km south east of Kolkata in South 24 Pargana district. Most part 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 seasons, mainly it reaches a maximum during monsoon and minimum during the winter (Muniyandi, 1986; Kathiresan, 2000). This tidal level influenced by the direct connection with the sea at the Hugli river mouth and also through the Ganga-Brahmaputra estuaries (Kathiresan, 2000; Rajkumar et al., 2009).

3. MATERIALS AND METHODS:

3.1 Analysis of rising sea level:

The official record of the exact mean sea level of the study area is not available. So, the nearest tide gauge station with available tidal data in the study area is Diamond Hourbar and Haldia. Seasonal changes calculated using the both station's tidal gauge data recorded for 54 years from 1952- 2013 indicates a 2.59±1 mm per year **(**Mahendra et al., 2011). This tidal range is a risk in this area where a large part of the coastal zone is low-lying with a gentle slope that has been always affected by the large inundation as well as increases the vulnerability of the region. The Ganga- Brahmaputra mangrove delta indicates most of the areas are under threat due to lower mean elevation (Mahendra et al., 2011).

3.2 analysis of mangrove dynamics:

3.2.1 Collection of satellite images and Toposheet:

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 (http://glovis.usgs.gov). 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 1975), 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 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.

3.2.2 Identification of mangrove boundary:

The boundaries of the study area were identified by manual digitizing method on the basis of mangrove area and the deltaic environment. The area extracted from satellite images and Toposheet by masking method in arc- GIS 10.2.1 software in different time period.

3.2.3 Identification of vulnerable mangrove area:

From the satellite images, we found four more vulnerable mangrove island in the ocean for the analysis of the trend of mangrove dynamics. The manual digitized boundary of all satellite images and Toposheet fit in a frame at the same scale and latitude. That help to identify the migration of mangrove area to the landward side. The map also visualizes the trend of migration and destruction of the mangrove area and related detail deltaic environments.

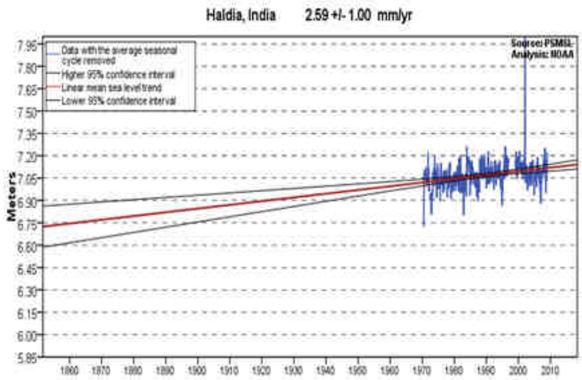
3.2.4 Prepare the digital elevation model:

Slope, elevation is the significant parameters that identify the vulnerable lands of coastal area that much more effects of the vegetation transformation (Gesch et. Al., 2009). This parameter also determines the affecting area by sea level rise along the coastal area. This impact assessed by using ASTER data (2014) that collected from the USGS website. Then find the regional slope and related erosion prone region for the assessment of habitat change and dynamical relationship due to present sea level rise.

4 SEA LEVEL RISE SCENARIO:

The changes of sea level measured by the tide gauge data that related to the change in Eustatic (global average level) sea level, local and regional factors. The rate of sea level change that measured by tide gauge data is mostly used for the regional change of coastal wetlands (Gilman, 2007) as well as mangrove dynamics. But these values differ significantly from global relative sea level. Although regional additional variability also depends on tectonic processes, coastal subsidence, sediment budget, meteorological and oceanographic factor where the coastal wetland situated (Gilman, 2007) and also the distance of the availability of tide gauge data. Sea level data of the present study area is not available.

So, the nearest station of Haldia (figure-2, 4) and Diamond Hourbar (figure-3, 5) tidal gauge data used for the analysis of sea level trends. The rate of sea level change of diamond Hourbar tidal gauge station is about 4.67±0.68 mm per year and Haldia 2.59±1.00 mm per year. The annual mean sea level rise from 1950 to 2014 is about 6.8 m to 7.23 m at Diamond Harbor and Haldia is about 6.92 to 7.17 m from 1970 to 2014. The change of this sea level is approximately 0.30 m within a 50 years can be influenced to the dynamics of coastal wetlands as well as mangrove ecosystems.



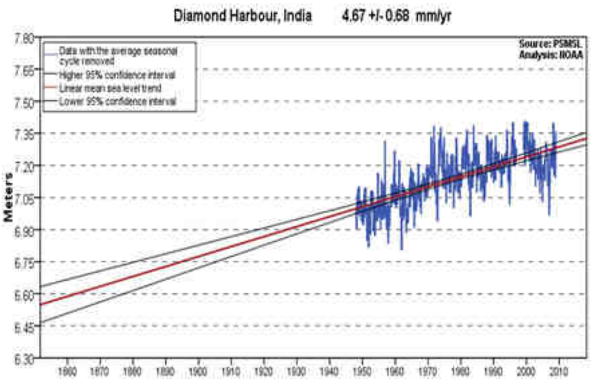


Figure 4: Sea level trend of Haldia

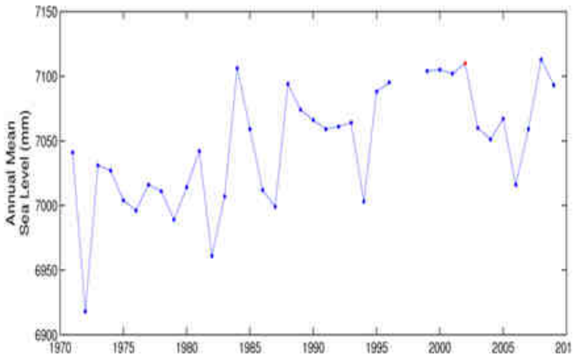


Figure 2: Annual mean sea level of Haldia

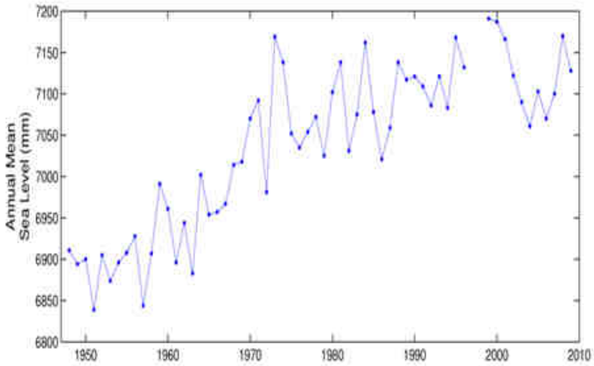


Figure 3: Annual mean sea level of Diamond Harbor

5. RESULTS:

5.1 Mangrove responses to the changes in relative sea level:

Mangrove dominated deltas Sundarban shifted their position due to the responses of sea level rise. Although sea level rise is predominating factor in the analysis of mangrove dynamics, coastal erosion and deposition, sea wave, fishing, agriculture as well as other human activity may possibly play a role to understand these dynamics. In general, there are three ways to explain the mangrove position to sea level trends that can apply to the present study (table-1):

Table-1: Mangrove shifting and changing sea level:

Condition	Effect	Affected areas
Relative to mangrove surface when sea level remains unchanged	Condition Effect Mangrove position remains stable, little change, Internal characteristics of mangrove changed by human activity.	Middle part of Sundarban that dominated by agricultural land.
Relative to mangrove surface when sea level falls	Mangrove margins migrate Seaward, mangrove density will Increase, expansion of land area.	South-eastern part and southern part without deltaic part.
Relative to mangrove surface when sea level rises	Mangrove's seaward and landward margins retreat landward, decline land area, Reduces of mangrove density (NDVI), soil erosion increase, and conversion of land use.	Southern part, south-western part with deltaic environment specially Bakkhali island, Bulcherry island, Dalhousie island and Bangaduni Island.

Slope of the adjacent Coastal area as a major influencing factor in the migration of mangrove but in the presence of barriers can control the landward migration. The landward mangrove boundary Demarcated by sea walls, roads, etc. Some mangroves will gradually be reduced in area, may get restricted to a narrow fringe or face mortality (Avijit et al., 2013). The mangrove - dominated deltas Sundarban is noted for intense erosion and seasonal flood and other devastated physical activity influence the pattern of landward migration as well as mangrove declination. This effect should be a major problem in case of Bakkhali Island, Bulcherry Island, Dalhousie Island and Bangaduni Island (figure-6). These islands may be fully destroyed in the future because of their higher rate of erosion due to present tidal domination. However, Bakkhali Island is only migrating from the sea to landward side with their declining rate of mangrove but other area declined to seaward side.

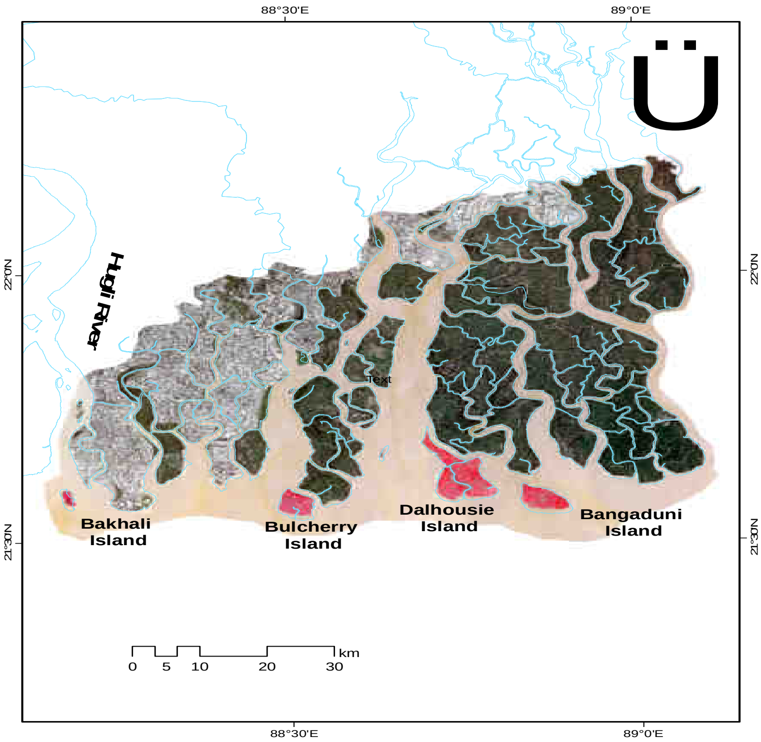


Figure 6: Location of four most Vulnerable Islands due to sea level rise

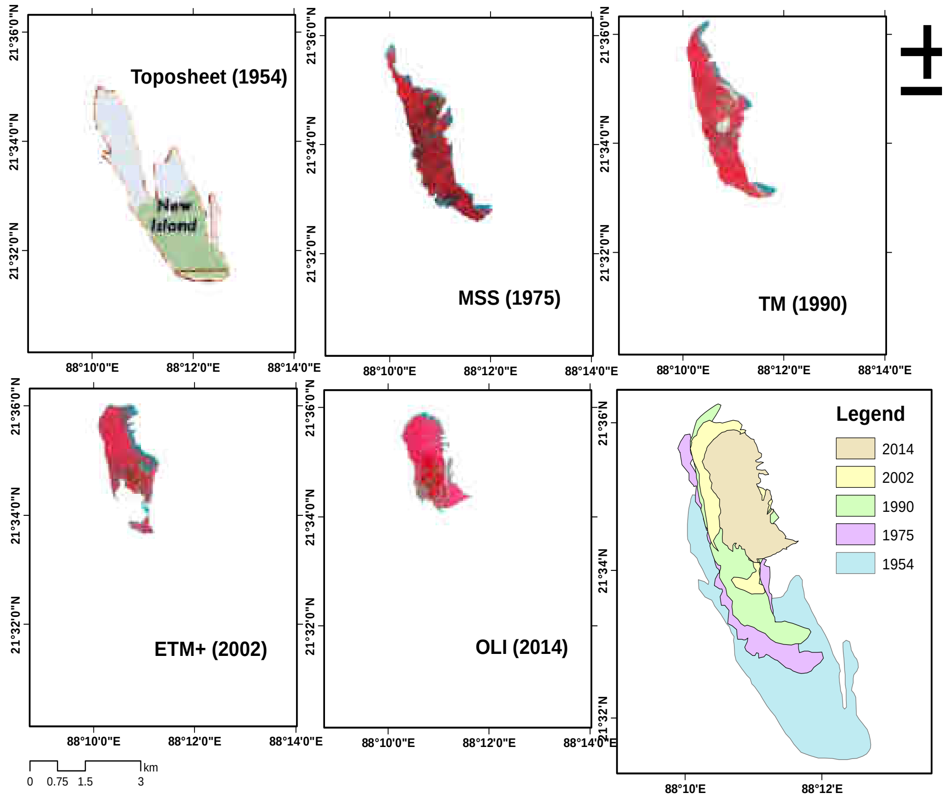


Figure 7: Mangrove destruction with landward migration of Vulnerable Bakkhali Island

The responses of the Bakhali Island (figure-7) is more complex in nature due to differential erosion of Hooghly River where tidal gauge data fluctuated significantly. The area of Bakhali Island destroyed along the river side and also migrated towards landward side. The destruction rate is about 2/3 within 40 years.

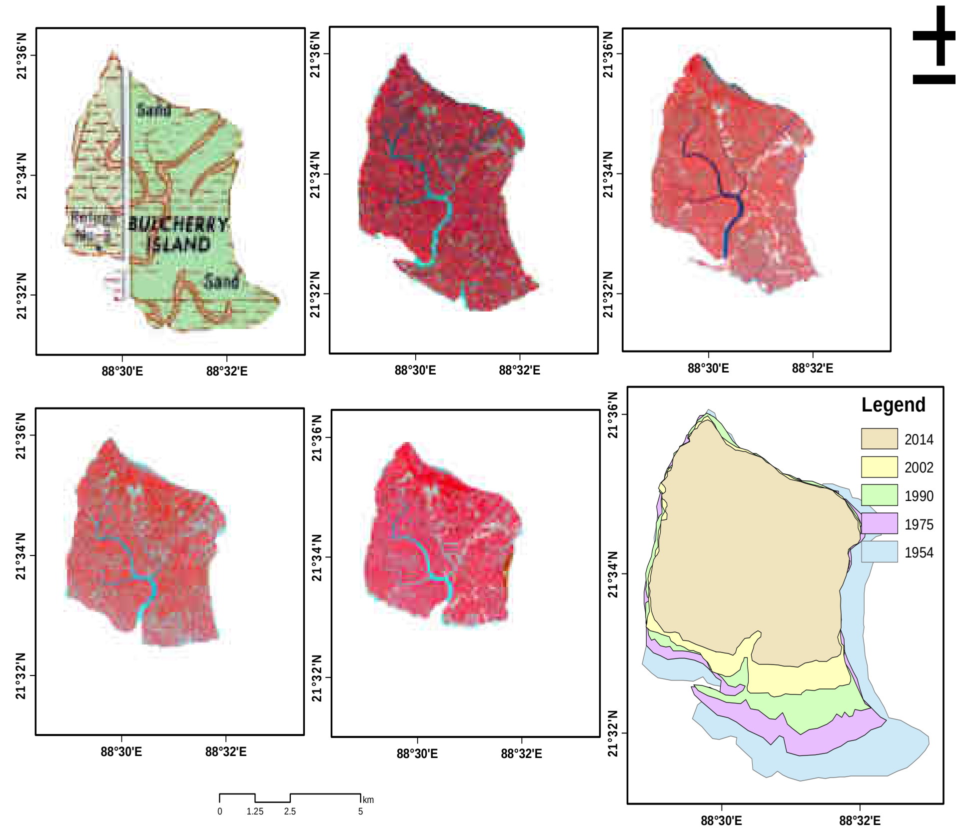


Figure 8: Destruction of Bulcherry mangrove Island in seaward side due to rise of sea level

Bulchery Island (figure-8) is affected by significant erosion that dominated to the destruction and degradation of mangroves. The destruction of mangroves and erosion-accretion accelerated to the mixture of salt and fresh water, causing frequent tidal floods and sedimentation in the creek. The erosion across the islands is more dominant than the accretion. This island may again show up intermittently if the accretionary processes predominate in the future.

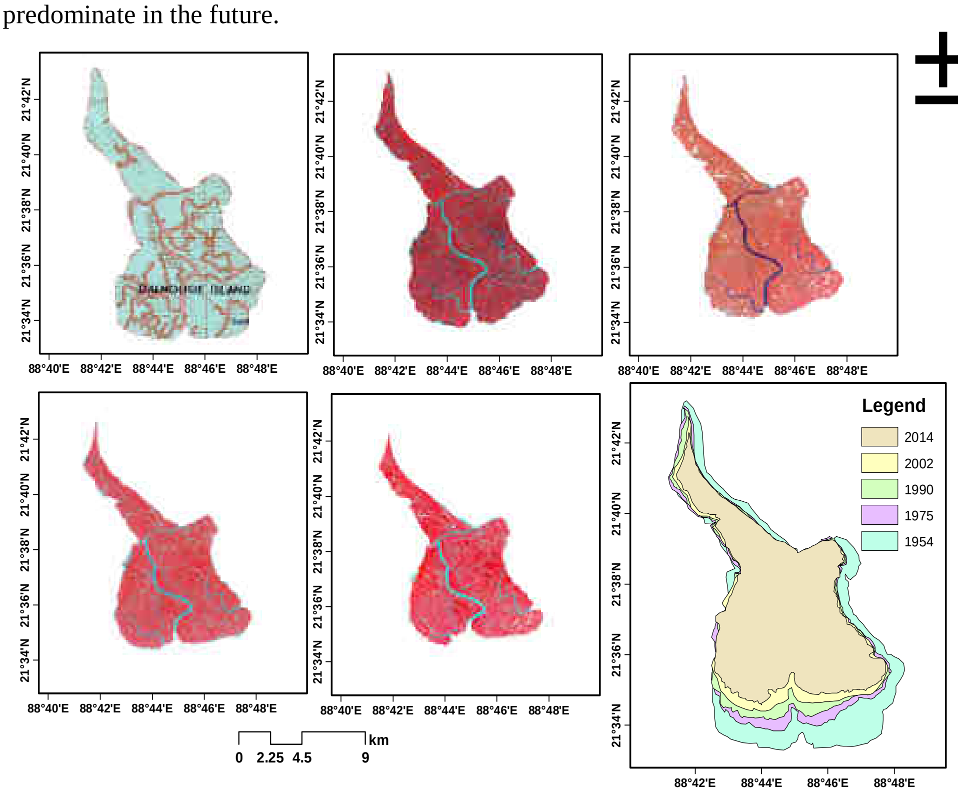


Figure 9: Responses of Dalhousie mangrove Island in seaward side due to rise of sea level

Dalhousie (figure-9) and Bangaduni Islands (figure-10) both are located at an elevation of 1 meters above sea level where a tract of land, smaller than a continent, surrounded by the high water. The island eroded and submerged significantly due to lower elevation. Seaward side significantly threatened by tidal and river erosion, but others side affected by the erosion and sea level.

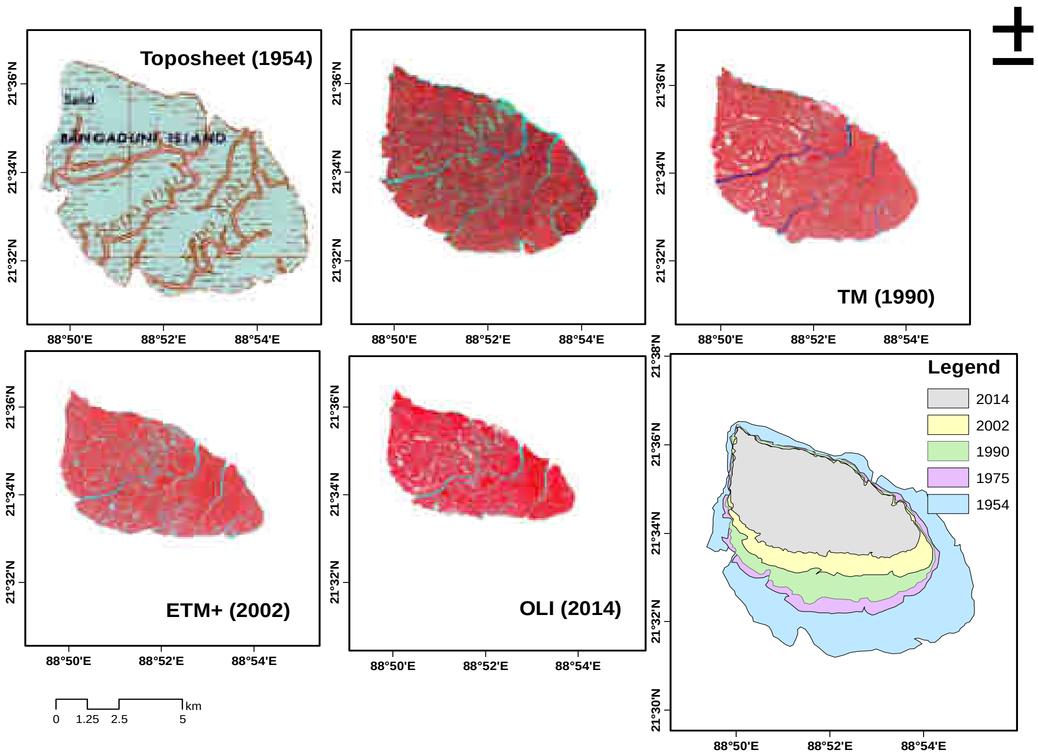


Figure 10: Migration of mangrove along the Seaward side of Bangaduni Island

6. DISCUSSION

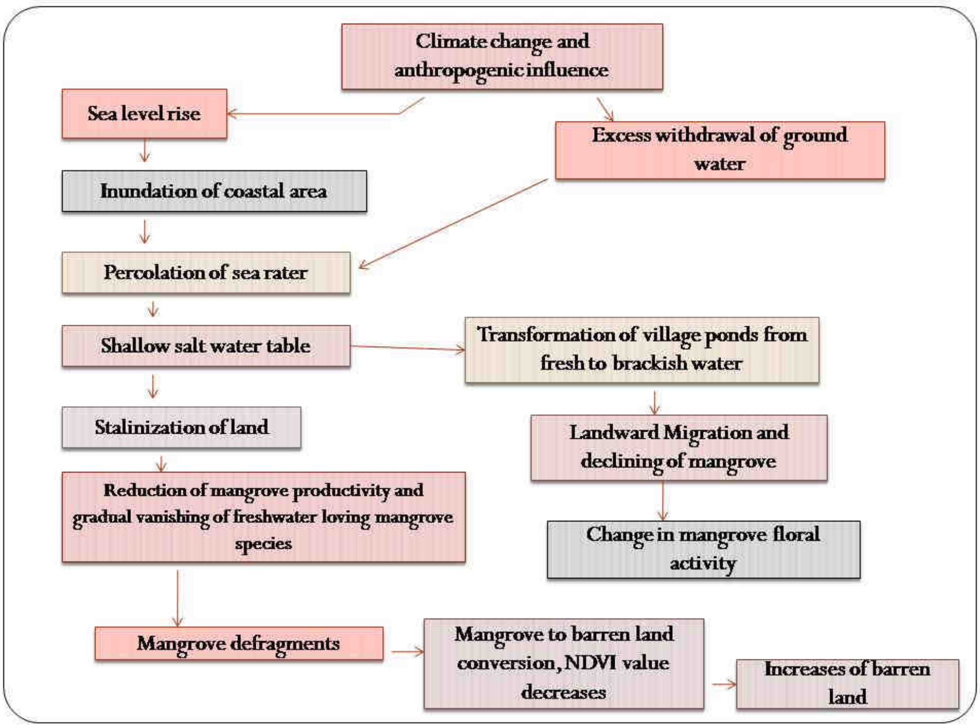


Figure 11: Impacts of SLR on mangroves via ground water system (modified from Avijit Mitra, 2013)

Sundarban as a highly susceptible to climate change induced sea level rise (Pengra et al., 2007). With respect to sustainable management of natural resource in the Sundarban region faces many difficulties like cyclones, Monsoonal high floods, sea surge and high drainage density, mud flats and Stalinization also. Moreover, the sea level change is the major factor which may influence other kind of problems. The Stalinization problem of the study area is a kind of big threat. High salinity

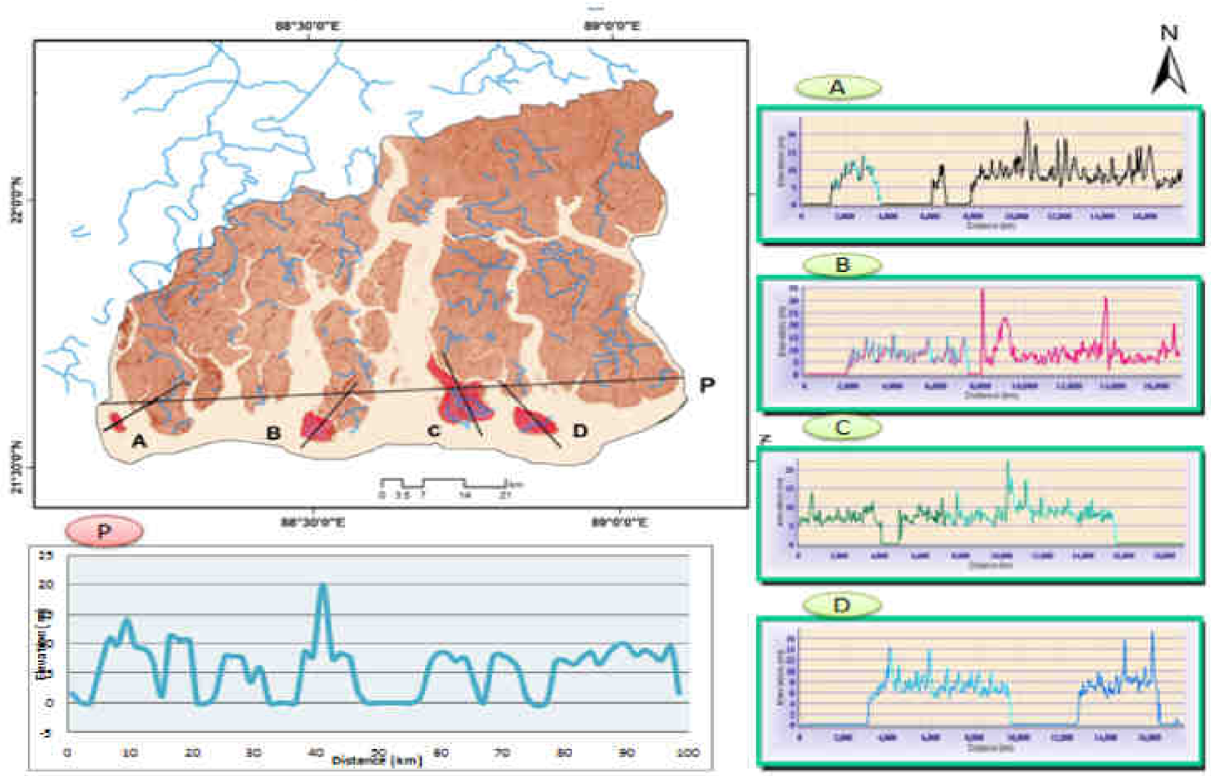


Figure 12: Cross section along the coastal area and most vulnerable Islands

increases the amount of sulfate in seawater and tidal water, which create the anaerobic decomposition of peat and increasing the mangrove's vulnerability (Snedaker 1993, 1995). These problems primarily caused by inundation due to the increases of tidal activity. Mangrove association and zonation are closely related to slope shoreline, soil, habitat stratigraphy as well as salinity regimes (Semeniuk, 1994).the change of these any one can lead to alter the mangrove systems (fig-11). The rising of sea level may effects some edaphic changes, generally changes of soil and salinity, tidal dominated flat surfaces and groundwater also. However, the mangroves are hydrologically adjust to a new level of sea wave and higher frequency of inundation (Semeniuk, 1994). This adjusted nature also depends on geomorphic, sedimentologic, hydrologic and biologic nature of the deltaic coastal zone (Woodroffe, 1990; Pernetta, 1993). The slope of this region also promote to the adjustment and dynamics of mangrove forests along the coastal area (fig.12) that's why the referred four vulnerable Island submerged and eroded easily due to their lower heights. But, for those coasts that's had a gentle slope, not having the significant change. The major change of these areas depends on:

1. Migration of ground water fields.
2. Increased frequency of inundation.
3. The inundation of barred high tidal areas.

Mangroves may respond with geomorphic and stratigraphic setting along the shoreline and the suitable substrates may change the landward major encroachment. On The other hand, smaller scale geomorphic units adjust the new equilibrium position of mean sea level. However, the response of Sundarban mangrove to gradual rising of mean sea level will be a most difficult to predict for the least involvement of mangrove response. The present study about mangrove dynamics can be linked with the global eustatic sea level rise, due to the high increase of surface temperature and glacier melting of all over the world during the last century.

9. Conclusion

Management of the mangrove dominated coastal ecosystem is a major issue of the present climatic complexity. There will be follow a comprehensive way to incorporate information of both qualitative and quantitative nature for the decision making processes. As demonstrated, the present study of integrated remote sensing and GIS technique provides some important information about mangrove dynamics, the optimum possibility for success cannot be achieved. However, the changes of sea level and mangrove dynamics are positively related to each other. The magnitudes of sea level rise vary from place to place. This variation mostly depends on local topography, geological structure, natural land use type as well as human activities. The potential impact also varies from one place to another place along the coastline. Multiple environmental stresses are likely make a most vulnerability. The low lying coastal areas and higher population with greater mangrove density are the most vulnerable because of their lower social, technology and financial adaptation. An effort, in particular the low-lying coastal areas need an adoptive option for their proper management. Thus the adoptive options of mangrove sustainability are mostly dependent on their location characteristics as well as economic activities. There also needs long term thinking, related to climate change in the coastal zone management option that must have economic feasibility (Tol et al., 1996).

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