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Assessment of the Impacts of Sea Level Rise on Mangrove Dynamics in the Indian Part of Sundarbans Using Geospatial Techniques

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Abstract

The intertidal mangrove ecosystem of Indian Sundarban is now as a critical ecosystem due to climate changeinduced sea level rise. The present study analyses the responses, migration, destruction and vulnerability of the four deltaic mangrove ecosystem, such as Jambudwip, Bulcherry, Dalhousie and Bangaduni Islands along the ocean sides. The changes in this deltaic ecosystem studied by using GIS and remote sensing with collecting data about sea level of nearest tidal gauge station Haldia ($2.59 \pm 1.0 \text{ mm/year}$) and Diamond Harbor ($4.67 \pm 0.68 \text{ mm/year}$). The study finds that if the sea level rises about mangrove surface, the mangrove retreats landward and also decline the land areas, increases soil erosion that affected in the southern and south-western part where these vulnerable mangrove islands are located. Moreover, the study indicates that the low-level mangrove islands would threaten with the rates of increasing sea level under present climate change. However, the amount of net loss is about 10009 ha at the rate of 164.08 ha per year of the four more vulnerable islands. In the context of climate change induced sea level rise there also needs long-term thinking and coastal zone management option that must have economic feasibility. Thus, the dynamics of the mangrove ecosystem in response to projected sea level rise enable to take appropriate planning for reducing threats and human safety along the coastal areas.

Keywords: Sealevel rise; Mangrove dynamics; Landward migration; Mangrove vulnerability; Sustainable mangrove management

Introduction

The important consequences of present climate warming are sea level fluctuation causing the melting of Antarctic and Greenland ice sheets, glaciers and the thermal expansion of regional climatic fluctuations [1]. The Intergovernmental Panel on Climate Change (IPCC) report mentioned that, the Predicted sea level of the 21st century, increases gradually at the rate of 1-2 mm per year, 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 [2], although he 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.

Mangroves are one of the most valuable primary resources of intertidal deltas and coastal regions of the tropical and subtropical regions all over the world. The ecosystems also help in the protection of shoreline and living habitat by the attenuating power of wave energy [3,4]. These coastal habitats are now threatened due to sea level oscillations causing climate change [5-8]. The sea level oscillations may affect the distribution of mangrove habitats along the coastlines [9-11] and the displacement of all dependent coastal ecosystems [12-14]. Mangrove not only affected by sea level rise but also have a significant threat to salt marsh habitat and intertidal wetlands and related ecosystem [15-17]. The declining rates of mangrove coastlines from 198000 km in 1980-146530 km in 2000 have been observed by [18-22]. Mangrove characteristics should be changed in a destructive way when the rate of sea level rise exceeds more than 10 cm per hundred years. This effect should change the significant adverse impacts on coastal ecosystems. The gradual increase of the water level could affect mangrove diversity and health of the associated changes in the soil salinity, soil erosion, sediment deposition and inundation [23,24]. All of these adverse conditions can change the mangrove zonation and migration from seaward to landward side along the oceanic regions

J Biodivers Biopros Dev ISSN: 2376-0214 IJBBD, an open access journal [25-28]. After sea level rise, Storm surges play the role in the decreasing mangrove area and deteriorate the ecosystem and the effects may combine that can accelerate to the landward migration also [23-31]. The limitation of land and a vertical increase of water level may effects of water logging causing the death of mangroves with associated flora and related habitats [32,33]. Therefore, the assessment of the impacts of sea level rise as well as climate change and related events in the Mangrove belt as an additional risk that have a significant adverse effect of stressing coastal habitats [34]. So, the present study analyses the changes and vulnerability of Mangrove ecosystem to the increasing sea level rise as the significant coastal habitat of Sundarbans.

Study area and its importance as a coastal biosphere reserve

The study area covers 21°13′- 22°40′ north latitude and 88°05′-89°06′ east longitude in Southern West Bengal, Eastern coast of as a part of Ganga-Brahmaputra Delta (Figure 1). It is located about 100 km south-east 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 seasons, mainly it reaches a maximum during monsoon and minimum during the winter. This tidal level influenced by the direct connection with the sea at the Hugli river mouth and also through the Ganga-Brahmaputra estuaries.

Sundarban mangroves are a part of the world's largest delta of

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India and Bangladesh. The delta has formed in the estuarine region of Ganga - Brahmaputra and Meghna River. Sundarban mangroves also have 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 sqkm occupied by mangroves across 56 islands by the International Union for Conservation of Nature and Natural Resources (IUCN) [35] and United Nations Educational and Scientific Cooperation (UNESCO) [36-38] respectively. The Indian part of Sundarban has an aerial extend about 4262 sqkm. This part consists of 106 deltaic islands therein 54 have human habitation and all over the region characterized by most of the 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 in sea level is now a significant adverse effect on the existence of this fragile ecosystem.

Materials And Methods

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 Harbour 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. 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 extensive 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 [39].

Analysis of mangrove dynamics

Collection of satellite images and toposheet: Four multispectral

satellite images (Landsat) that cover 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 5th Dec, 1975), Landsat Thematic Mapper (TM) data (Columns 3708, Rows 2754, Dated 12th Dec 1990), Enhanced Thematic Mapper Plus (ETM+) data (Columns 7809, Rows 5833, Dated 27th Nov 2002) and Operational Land Imager (OLI) data (Columns 3710, Rows 2771, Dated 23rd 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 the scale of 1: 250000.

Identification of Mangrove Boundary:The boundaries of the study area were identified by a manual digitizing method by 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 period.

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 manually digitized boundary of all satellite images and Toposheet fit in a frame on the same scale and latitude. This 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.

Prepare the Digital Elevation Model: Slope, elevation is the most significant parameters that can identify the more vulnerable lands of the coastal areas and also identify the zone of vegetation transformation, as well as mangrove forests. This parameter also determines the affecting area by sea level rise along the coastal area. This impact assessed by

using ASTER DEM 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 dynamic relationship due to present sea level rise.

Sealevel 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 in coastal wetlands as well as mangrove dynamics. However, these values differ significantly from global relative sea level. Although additional regional variability also depends on tectonic processes, coastal subsidence, sediment budget, a meteorological and oceanographic factor where the coastal wetland situated and also the distance of the availability of tide gauge data. Sea level data from the present study area is not available [40-41].

So, the nearest station of Haldia (Figure 2A,2C) and Diamond Hourbar (Figure 2B,2D) 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 increases from 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 by the dynamics of coastal wetlands as well as mangrove ecosystems.

Results and Discussion

Mangrove responses to 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 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).

The 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 reduce in the area, may get restricted to a narrow fringe or face mortality [42]. The mangrove-dominated deltas Sundarbans 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 effaject should be a major problem in the case of Jambudwip Island near Bakkhali, Bulcherry Island, Dalhousie Island and Bangaduni Island (Figure 3). These islands may be fully destroyed in the future because of their higher rate of erosion due to present tidal domination. However, Jambudwip Island is only migrating from the sea to landward side with their declining rate of mangrove but other area declined to seaward side.



Condition	Effect	Affected areas		
About mangrove surface when sea level remains unchanged	Condition Effect Mangrove position remains stable, little change, Internal characteristics of mangrove changed by human activity.	The Middle part of Sundarban that dominated by agricultural land.		
About mangrove surface when sea level falls	Mangrove margins migrate Seaward; mangrove density will Increase, expansion of the land area.	South-eastern part and southern part without the deltaic region.		
About 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.	The Southern part, south-western part of deltaic environment especially Jambudwip island, Bulcherry island, Dalhousie island and Bangaduni Island.		

Table 1: Mangrove shifting and changing sea level.





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The responses of the Jambudwip Island (Figure 4) is more complex in nature due to differential erosion of Hooghly River where tidal gauge data fluctuated significantly. The area of Jambudwip Island destroyed along the riverside and also migrated towards the landward side. The destruction rate is about 2/3 within 40 years.

Bulchery Island (Figure 5) 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 freshwater, causing frequent tidal floods and sedimentation in the creek. The erosion of the islands is more dominant than the accretion. This island may again show up intermittently if the accretionary processes predominate in the future.

Dalhousie (Figure 6) and Bangaduni islands (Figure 7) both are located at an elevation of 1 mtrs 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 a lower elevation. Seaward side significantly threatened by tidal and river erosion but others side.

Erosion rate of mangrove islands

Coastal accretion and erosion measures change in the dynamics of shoreline and modify the coastal area. The detailed monitoring and various measures of these changes are a most important aspect to analyse the impact of the global sea level rise and climate change. All of this 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. 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 sub-tidal 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 disclosed 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, and storm are causing the erosion to a large extent. In the present study, represent that the total four islands are facing most erosion activity (Figure 3). Few islands viz., Bed Ford, Suparibhanga, Kabasgadi, Lohachara have already vanished from the coastal areas of Sundarbans. Most erosion-prone vulnerable islands are Jambudwip, Bulchery, Dalhousie, Bhangaduni islands in the Indian part of Sundarbans (Figure 3). 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 Sundarbans such as Dalhousie, Bhangaduni and Bulchery have been subsequently eroded and submerged due to sea level rise. Marginal erosion has localized in the river margins and inner estuaries







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specifically along the coast and along the northern and eastern margins of islands where it is mostly seafacing, and east-west oriented. The present study, conducted during 1954-2014 reveals that the studied islands area of 20879 hectares of the Sundarbans in the year 1954 reduced to 10009 hectares in 2014. This amount to a net loss of studied islands area is about 10009 ha at the rate of 164.08 ha per year (Table 2).

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 is experiencing the amount of maximum erosion, and this is well understood from the representing graph given below (Figure 8). In the (Table 2) is showing the loss, and rates of erosion in the context of the studied year 1954-2014 of the following four coastal islands of the total area of Indian Sundarbans. The erosion rates are 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 61 years of the Sundarbans (Figure 8).

Sundarban as a very vulnerable to climate change induced sea level rise. On the 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 that may influence another kind of problems. The Stalinization problem of the study area is a kind of big threat to high salinity. 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. The change of these any one can lead to altering the mangrove systems (Figure 9). The rising of sea level may affect some edaphic changes, generally changes of soil and salinity, tidal dominated flat surfaces and groundwater also.

However, the mangroves hydrologically adjust to a new level of sea wave and higher frequency of inundation [27]. This adjusted nature also depends on geomorphic, sedimentologic, hydrologic and biologic nature of the deltaic coastal zone [5,16]. The slope of this region also promotes to the adjustment and dynamics of mangrove forests along the coastal area (Figure 10). That's why the referred four vulnerable islands submerged and eroded easily due to their lower heights. However, for those coasts that are had a gentle slope, not having the significant change. The major change in these areas depends on:

- a) Migration of ground water fields.
- b) Increased frequency of inundation.
- c) The inundation of barred high tidal areas.

SI. no	Islands	1954 (ha)	1973 (ha)	1990 (ha)	2002 (ha)	2014 (ha)	Loss from 1957 to 2014 (ha)	Rate of loss (ha)	% of loss
1.	Jambudwip	1175	637	631	526	403	772	-13.54	65.70
2.	Bulchery	3648	2941	2651	2356	2076	1572	-27.58	43.09
3.	Dalhousie	9539	7711	7156	6597	6030	3509	-61.56	36.79
4.	Bhangaduni	6517	4185	3754	3023	2361	4156	-72.92	63.77



Table 2: Erosion rates of southernmost four vulnerable islands in 61 years (1957-2014) of the last century.

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Mangroves may respond with geomorphic and stratigraphic setting along the shoreline, and the suitable substrates may change the major landward 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 the 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 link to 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.

Conclusion

Management of the mangrove-dominated coastal ecosystem is a major issue of the present climatic complexity. There will follow a comprehensive way to incorporate information of both qualitative and quantitative nature of the decision-making processes. As demonstrated, the present study of integrated remote sensing and GIS technique provides some relevant 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 [43]. The potential impact also varies from one place to another place along the coastline due to the availability of limited resources along with lower technological, financial and social ability for adaptation. Moreover, multiple environmental stresses likely make the 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 [44]. In this study, the extend of sea level rise along the coastal areas was assessed using ASTER 30 m DEM. Five coastal islands of the Indian part of Sundarbans are at high risk category due to the continuous rise in relative sea level. Therefore, to enhance resilience and to reduce coastal vulnerability to increasing sea level rise scenarios, mainstreaming adoptation startegies is required as one of the appropriate responses as a management option of the coastal areas. Management options can excerbate and ameliorate a system's vulnerability to increasing sea level rise and consideration of sea level rise impacts and appropriate adoptation options can help to ensure that managers actions to improve resiliency, reduce the risk, and excerbate rather than ameliorate the vulnerability to their coastal ecosystems. These management options primarily aim to preserve vulnerable coastal islands and its dependent coastal mangrove resources to sea level rise. There, it is an urgent requirement for preparedness and effective adoptation and taking suitable measures together with the local community [45,46] in response to the increasing impacts of sea level rise and to find ways to ensure human security and coastal sustainability [46,47].

An effort, in particular, the low-lying coastal areas need an adoptive option for their proper management. Thus, the adaptive options of mangrove sustainability are mostly dependent on their location characteristics as well as economic activities [48-52]. There also needs long-term thinking, related to climate change in the coastal zone management option that must have economic feasibility [53]. Thus, the dynamics of the mangrove ecosystem in response to projected sea level rise enable to take appropriate planning for reducing threats and human safety of coastal area [40].

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