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SEA LEVEL RISE AND SUBMERGENCE OF SUNDARBAN ISLANDS : A TIME SERIES STUDY OF ESTUARINE DYNAMICS

RAHA A.K.[1]*, MISHRA A.[2], BHATTACHARYA S.[3], GHATAK S.[4], PRAMANICK P.[5], DEY S.[2], SARKAR I.[2] AND JHA C.[6]

[1]Department of Forest and Environment Science, Techno India University, Salt Lake, Kolkata- 700 091, WB, India.
[2]Department of Forests, GIS Cell, Government of West Bengal, Kolkata- 700 098, WB, India.
[3]Department of Forest, Government of West Bengal, Salt Lake, Kolkata- 700 091, WB, India.
[4]Department of Forest, Government of West Bengal, Wildlife Division, Jalpaiguri- 736 122, WB, India.
[5]Department of Oceanography, Techno India University, Salt Lake, Kolkata- 700 091, WB, India.
[6]Forestry and Ecology Group, National Remote Sensing Centre, Hyderabad- 500 037, AP, India.
*Corresponding Author: Email- atanu_raha@hotmail.com

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Abstract- The Sundarban mangrove ecosystem in the deltaic complex of the Rivers Ganga, Brahmaputra and Meghna is shared between Bangladesh (62%) and India (38%) and is the world's largest coastal wetland. Enormous load of sediments carried by the rivers used to contribute to its expansion and dynamics. The total area of Indian Sundarban region is about 9630 sq. km., out of which the Reserved Forest occupies nearly 4260 sq. km. At present, out of 102 islands of the Indian Sundarban region, 54 are inhabitated with a population of about 4.2 million (2011 census) and the rest of 48 islands are Reserved Forest with mangrove vegetation. A few studies were conducted in the past to monitor the changes in a few islands of Sundarban estuary which had been identified as most vulnerable in terms of coastal erosion, submergence and flooding due to surge and sea level rise. In the present study, nine southern-most islands of Indian Sundarban estuary, facing the Bay of Bengal, were studied for the period 1999 till 2013, through time-series analysis of satellite imageries. The study showed that while a few islands were undergoing gradual erosion. it also revealed continuous emergence of a few more new islands. The present study has tried to establish that other factors like destruction of mangrove vegetation, sediment deposition, natural subsidence and lack of fresh water flow can have more impact on the dynamics of Sundarban islands than the single factor of sea level rise.

Keywords- Sundarban estuary, Submergence of island, Accretion in Sundarban, Ghoramara, Sea level rise, Climate change, Satellite imageries, Time series analysis, Jambudwip, False Colour Composites (FCC)

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Introduction on Sundarban

The Sundarban Region in India is located between 21° 32' and 22° 40'N latitude and 88°30'N and 89°00'E longitude. It is bounded by the river Hooghly on the west, Ichamati-Kalindi-Raimangal on the east, Dampier-Hodges line on the north and the Bay of Bengal on the south. For administrative convenience the northern boundary has been adjusted to coincide with the Police Station boundaries along the Dampier-Hodges line, which demarcates the inter-tidal zone [1].

Area and Extent

The total area of Indian Sundarban region is about 9630 sq. km., out of which the Reserve Forest occupies nearly 4260 sq. km. At present, out of 102 islands of the Sundarban region, 54 are inhabitated with a population of about 3.2 million (1991 census), spread over 1093 mouzas. The region is spread over two administrative districts, namely South 24-Parganas (13 blocks) and North 24-Parganas (6 blocks) [Fig-1].

There has been premature reclamation of land in the region from 1883 onwards, with more than 3500 km. of earthen embankments protecting the settlements in the region. Most of the reclaimed areas, guarded by the embankments, are lying at lower depth than the riverbeds. The aquifer of potable water lies at a depth of about 350M from the ground level.

Origin of Sundarbans

Two great rivers, the Ganges and Brahmaputra meet the Bay of Bengal along India and Bangladesh to form an intertidal zone, developed by the accretion of alluvium deposited by these rich systems, covering an area of nearly 26000 sq. km., which is known as the Sundarbans. The area contains a rich intertidal mangrove forest which provides appropriate habitat and sanctuary to many rare and endangered animals including the endangered Bengal tigers.

The region consists of an expanse of low flat islands and mud

banks separated by a network of anastomotic tidal channels and rivers. This ramified riverine system has carved out about 102 small islands harboring different habitat conditions, which has encouraged establishment and growth of mangrove forests of a very rich bio-diversity and displaying multiple associations and zonations.

Initially the whole of this Sundarban region was under mangrove forest. Its history is a continuous process of reclamation of mangrove forests for agriculture and settlement. Reclamation started during the 18th century [1].

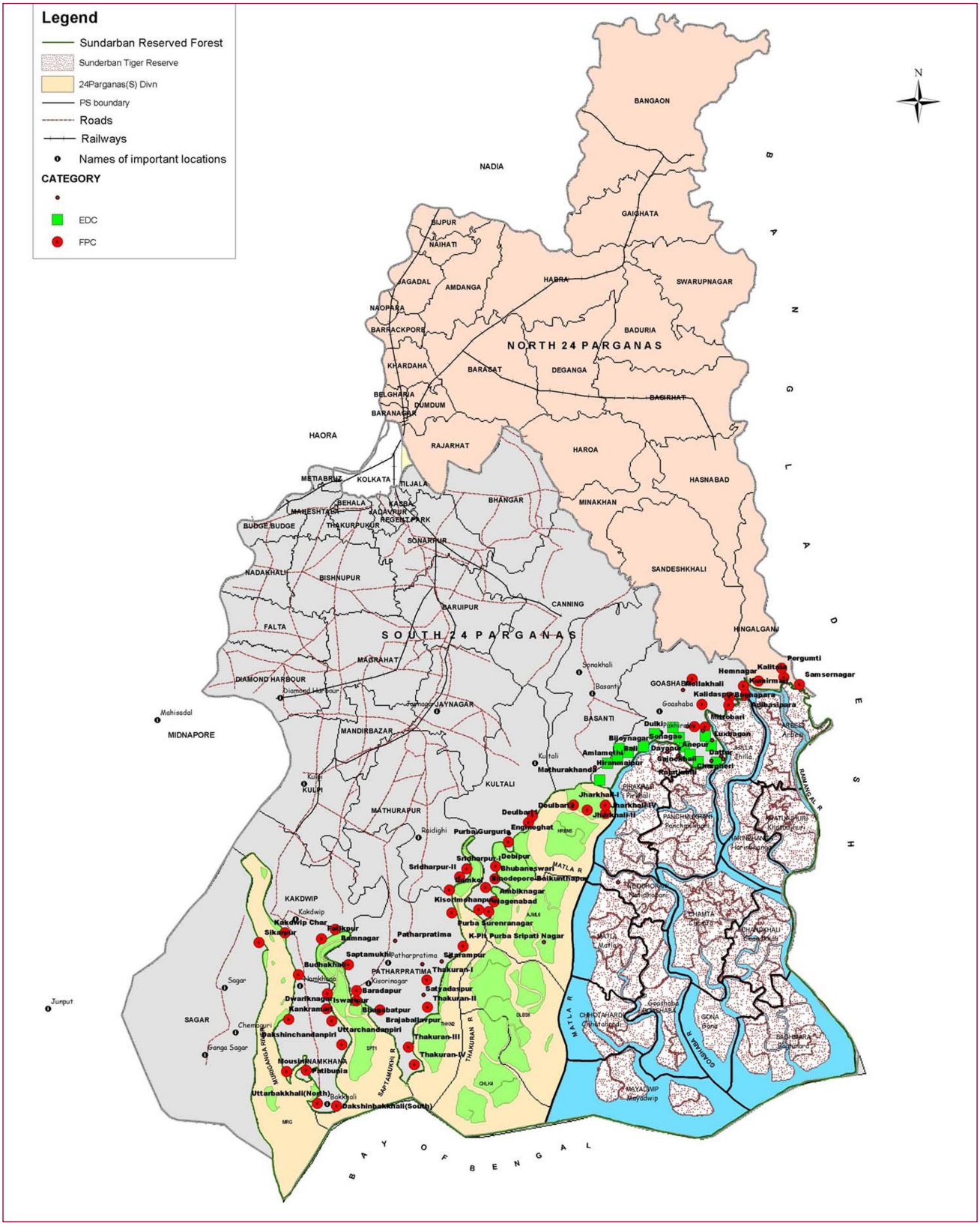

Fig. 1- Map of Indian Sundarbans

Sundarban: A Developing Estuary

Sundarban estuary is still in the process of formation. As per the natural process, silt carried from the catchment of the rivers, draining into the estuary, get deposited and the islands are built up. Simultaneously, because of tidal waves and oceanic current, shape of the islands keeps on changing and accretion/ erosion go hand-in-hand. The Sundarban estuary is acting as a sediment sink and may be largely offsetting the effects of sea level rise in terms of land loss [4,6].

The effect of High tide causes the water level in the tidal rivers rise as high as 12 ft - 15 ft every six hours and large parts of the islands containing mangrove forest, get inundated. Species like *Avicennia* and C*eriops*, which tolerate prolonged water logging and high degree of salinity, come up naturally in such inter-tidal mud flats.

A Study of island formation process for two southernmost islands of Jambudwip and Thakuran Char, over a period of more than 20 years, using the satellite imageries, shows that while the elongated shape of the former has changed into Bell-shape, the latter has grown from below the low-tide level to an island of more than 2 sq km [7]. Similarly, large char land have come up in the coastal regions near Kalas, Chaimari and Baghmara under Sundarban Tiger Reserve, while erosion of river banks/ coastal region has taken place in Goasaba Blocks of STR and Sagar island of 24 Parganas (South) Forest Division. Many small islands like New Char, Haribhanga etc. have come up within/ just outside the estuary over last few decades.

Sundarban Delta and Human Habitations

Out of the102 islands in Sundarban region, 48 islands in southern-most region are declared as Reserved Forest and is out of bounds for human settlement. In the rest 54 islands, which are densely populated, there is 3500 km long embankment, all around these islands, to prevent entry of saline water during high tide [1]. As a result, while the natural island formation process is continuing un-hindered in the forested islands, the silt-load from the fresh water river cannot get deposited on the inhabited islands due the embankment and the same are deposited on the river bed thus gradually raising the river beds even above the village ground level [8]. If, therefore, there is a breach in embankment, the saline tidal water will inundate the villages and won't be able to come out even during low tide [10].

Ghoramara: Lohachara Episode

A few studies were conducted by the Scientists of jadavpur University to monitor the changes in the islands of Sundarban estuary and the coasts of W.Bengal. The Research Paper states that "In Sundarbans, a comparison of the former maps (1942, 1969) and more recent satellite images (2001, 2006) reveals significant amount of land loss in spite of marginal accretion on the sheltered western banks. Two islands, Lohachara and Suparibhanga (within the estuary) have already been eroded and submerged making thousands of people homeless. Ten sea facing islands registered a 85 km^2 net landloss in 30 years (upto 2001). Significant land loss has also been observed on the eastern bank of the Hooghly estuary (Kakdwip area). The establishment of a linkage between the erosion - accretion rate and rate of rise and fall of relative mean sea level is crucial for understanding the vulnerability of Sundarban island system in the perspective of climate change. It has been possible to establish such a relationship using statistical analysis and mathematical correlation studies. These findings and the linkage established have been useful for developing a diagnostic and predictive model of shoreline change. Ten southernmost islands of Sundarban have been identified as most vulnerable in terms of coastal erosion, submergence and flooding due to surge and sea level rise. With the help of the predictive model using GIS, it has been estimated that these 10 southern islands of Sundarban will suffer further land loss of around 90 Km^2 between now and 2020 with present scenario of sea level rise and storm surges" [2,3].

Another study has shown that ten sea facing most vulnerable island -clusters have borne the major thrust of erosion and submergence [5].

Objectives of Present Study

The objectives of the present Study was to:

- To study the erosion - accretion process of a few islands, within the reserved Forests, located in the northern and extreme southern fringes of the Sundarban Reserved Forests over last one decade,
- To test the universality of the presumption that the gradual shrinkage and vanishing of a few islands like Lohachara and ghoramara islands was mostly due to sea level rise, and
- To examine the degree of impact of sea level rise on Sundarban Reserved Forests and village islands due to Global warming.

Materials and Methods

IRS Satellite imageries in digital format for Sundarban region was obtained from NRSC, Hyderabad and the data were processed by the GIS Cell of W.B. Forest Department. The data for the years 1999, 2001 and 2002 were from LISS III scanners on Indian Remote Sensing satellites IRS 1D with a resolution of 23 m in MSS band, the data for 2005, 2007, 2008, 2009 were LISS III data with 23m X 23m resolution and 2010 data was AWiFS data with resolution of 56 m from Indian Remote Sensing satellites IRS P6. The LISS 4 data for 2006 was from Resourcesat 1 and that for Jan 2013 was from Resourcesat2, with spatial resolution of 5.6m x 5.6m. All the data pertained to the period Dec - Feb when the mono-cropped agricultural fields mostly lie fallow due to lack of irrigation facilities in Sundarban region and segregation of mangrove vegetation is easier. Though the resolution of data differed for different period, yet the consistency of final output showed that the exercise served the purpose of rapid survey, using the existing data base.

The islands of Ghoramara, Jambudwip, Lothian(Saptamukhi block), Chulkati, Dhanchi (Thakuran block) and Thakuran Char of South 24 Parganas Forest Division and Mayadwip, Gona and Baghmara blocks of Sundarban Tiger Reserve were selected for the study [Fig -2]. Out of the above selected islands, Ghoramara island is situated on Muriganga river, near the northern tip of Sagar island where Hooghly river bifurcates into Muriganga and main Hooghly rivers which meet the bay of Bengal at the southern tip of Sagar island. This island is also outside the boundary of Reserved Forest and is part of 54 non-forest islands having human settlement. All other islands are part of Reserved Forest, with mangrove vegetations and having no settlements. These islands had been chosen as they are most susceptible to impacts of sea level rise as well as the geological processes of accretion/ erosion in the estuaries. The islands having human settlements are protected with mud enbankments all around the island, to prevent entry of river water during high tide,

occurring twice a day, into the villages [8]. On the other hand, the 48 forested islands, which are parts of Reserved Forest and having natural mangrove vegetation, are fully exposed to the vagaries of nature and are subjected to tidal inundations, twice a day during high tides. Hence study of these forested islands will provide better insight into the progressive accretion/ erosion of the islands of this estuary.

Subsets of Registered, Geo-referenced Images were created and classification of the standard FCC were done using Unsupervised Classification methodologies with Standard Deviation of 2 and convergence threshold of 0.980. The software used was ERDAS Imagine image processing ver.8.0. The classified data were grouped into the classes Mangrove, Mudflats, sand/ accretions and waterbodies/ rivers/ creeks. Statistics were computed for each class to quantify areas under mangrove vegetation and total land area of the islands pertaining to each year.

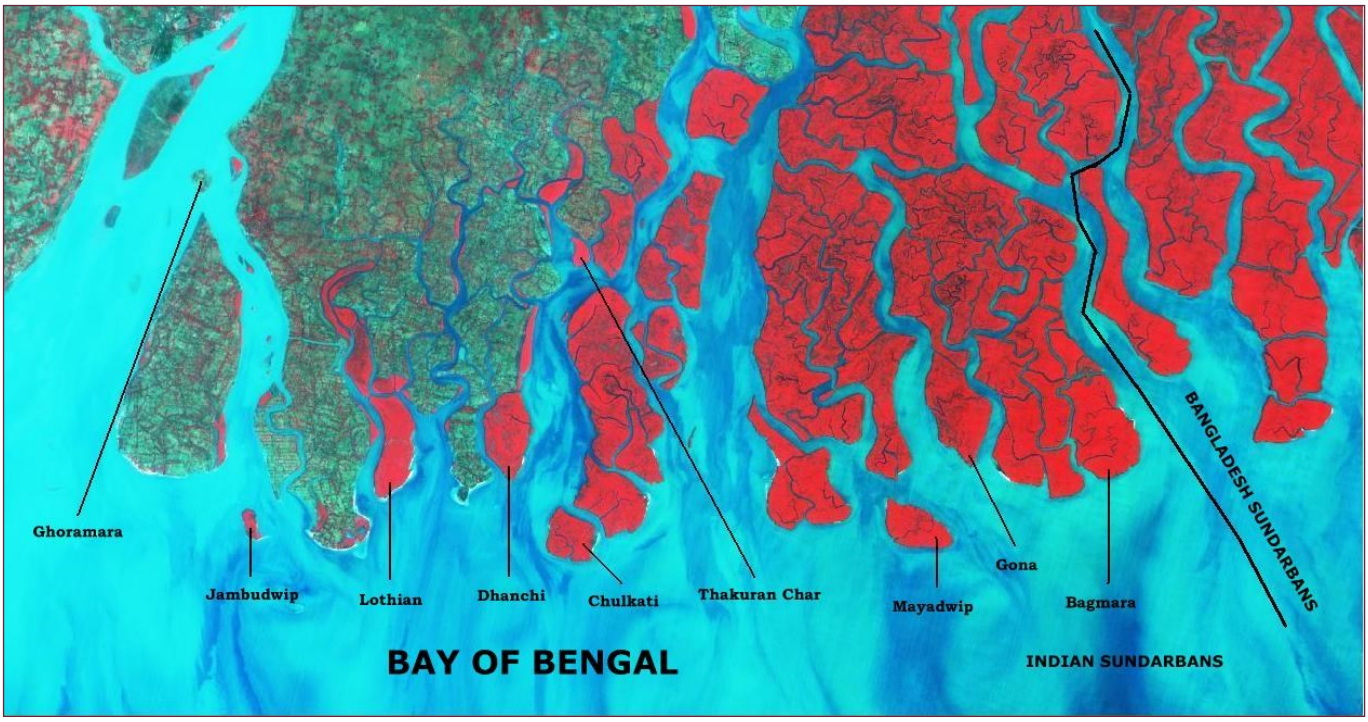

Fig. 2- Study area of Indian Sundarbans Tiger Reserve

Results and Discussion

The present study reveals that the deltaic complex of Indian Sunderbans is extremely dynamic and the process of erosion and accretion occur almost simultaneously in different pockets of the deltaic lobe [Table-1]. The study reveals that the islands in the Hooghly river of western Indian Sunderbans are gradually eroding. On the contrary, the islands in the upper reaches of the central Indian Sunderbans are showing growth owing to accretion. While the erosion level of Ghoramara island in Hooghly river is much reduced now [Fig-3], the other island Thakuran Char, around 40 km East of Ghoramara, have emerged within the Thakuran river during last 25 years and has been steadily growing in area and mangrove cover. Similarly, Jambudwip and Lothian island sanctuary in Western and Central Sundarban have recorded marginal but steady increase in the area of Mangrove vegetation.

Time series analysis of the southernmost islands of Jambudwip, Dhanchi, Chulkati, Mayadwip, Gona and Bagmara shows that there has been marginal erosion in the southern faces of all these islands, leaving the other three faces almost unchanged, though the overall land and mangrove area have steadily decreased for all these islands. On the other hand, a few islands like Thakuran Char, Lothian have steadily grown in total area over the last 15 years. This scenario is not expected if sea level rise is the major driving force of the island dynamics in Sundarban estuary. It indicates that the natural process of erosion/ accretion due to tidal and ocean currents and deposition of sediments play a more dominant role in the island formation process of Indian Sundarban as compared to the combined effects of sea level rise and gradual sinking of Sundarban delta. If sinking is caused due to sea level rise, then shrinkage of the islands will take place uniformly from all the faces. The inflow of sweet water, carrying silt load, into Indian Sundarban is mostly by the river Muriganga/ Hooghly forming the extreme Western boundary, while in the Central and Eastern parts of Indian Sundarban, hardly any fresh water flow takes place perennially due to reclamation of land for agriculture or habitations upstream. As a result, the process of island building through silt deposition is almost nil in the Central and Eastern parts of Indian Sundarban. The results obtained through time series satellite data is consistent with the above primary data on water inflow of Indian Sundarban. It also establishes the fact that rapid shrinkage/ vanishing of islands like Ghoramara and Lohachara are not primarily due to sea level rise but mostly due to other factors in play like erosion due to tidal currents.

Statistical analysis of Time series data of geographical areas of these islands vis-à-vis the mangrove vegetations covering these islands have been carried out. Correlation coefficients as well as Regression Equations have been calculated for studying the nature and pattern of changes of these islands over the last 15 years [Table-2].

Table 1- Temporal changes of land and mangrove vegetation in Indian Sundarbans Islands

Year	Total Land Area (Ha)	Total Mangrove Area (Ha)	Year	Total Land Area (Ha)	Total Mangrove Area (Ha)
	Ghoramara			Dhanchi	
1999	538	Nil	1999	3380	2619
2001	548	Nil	2001	3341	2604
2005	498	Nil	2006	3278	2621
2010	464	Nil	2009	3326	2633
	Jambudwip		2010	3268	2637
1999	522	345	2013	3308	2730
2001	515	324		Chulkati	
2005	458	343	1999	8691	7554
2006	483	345	2001	8757	7253
2008	464	368	2005	8043	7097
2009	457	401	2010	7995	6976
2010	429	411	2013	7988	6428
	Lothian			Gona	
1999	3326	2357	1999	4978	4445
2001	3363	2353	2001	4946	4257
2002	3370	2264	2005	4898	3701
2004	3348	2416	2008	4899	3526
2005	3371	2368	2010	4819	3442
2006	3390	2344	2013	4738	3422
2008	3406	2871		Mayadwip (4,5)	
2009	3422	3023	1999	3021	2767
2010	3459	2614	2001	2957	2589
2013	3411	3023	2005	2834	2652
	Thakuran Char		2008	2670	2195
1999	47	17	2009	2634	2164
2001	142	94	2010	2545	2233
2002	182	110	2013	2359	2283
2005	279	220		Bagmara	
2007	369	321	1999	7174	6780
2008	358	335	2001	7379	6486
2009	385	353	2005	7147	6399
2010	397	371	2008	7133	6270
2013	416	392	2010	6586	6358

Table 2- Statistical analysis of changing pattern of Indian Sundarbans Islands

Sectors of Sundarbans	Name of Forest Block	Regression Equation		Correlation coefficient	
		Total land area	Total Mangrove area	Total land area	Total Mangrove area
Western	Ghoramara	-7.6325x + 15806	Nil	-0.96	Nil
Western	Jambudwip	y = -7.573x + 15663	6.4368x - 12546	-0.9315	0.8153
Central	Lothian	7.5933x - 11843	55.769x - 109293	0.8505	0.8158
Central	Thakuran Char	27.612x - 55103	29.582x - 59096	0.9628	0.9745
Central	Dhanchi	y = -5.3801x + 14111	y = 6.2624x - 9923.9	-0.703	0.7507
Central	Chulkati	-58.76x + 126144	-66.213x + 139858	-0.8819	-0.9411
Eastern	Gona	-15.514x + 36001	-78.66x + 161590	-0.9484	-0.9531
Eastern	Mayadwip (4,5)	-46.024x + 95060	-42.228x + 87139	-0.9865	-0.8525
Eastern	Bagmara	-47.692x + 102688	-36.465x + 79556	-0.7447	-0.8597

It has been found that there is positive correlation between the Time period and Total Land Area for the islands Jambudwip, Lothian and Thakuran Char islands located in Western and Central Sundarban which indicates that the process of accretion for these zones is much higher than the combined effects of natural subsidence [Fig-4], [Fig-5], [Fig-6] and the projected sea level changes. On the other hand, the correlation coefficient for the islands Dhanchi and Chulkati in Central Sundarban [Fig-7], [Fig-8] and Gona, Mayadwip and Bagmara [Fig-9], [Fig-10], [Fig-11] in Eastern part of Indian Sundarban is negative, indicating that these islands are gradually shrinking over the last 15 years, though the rates of erosion are different for different islands.

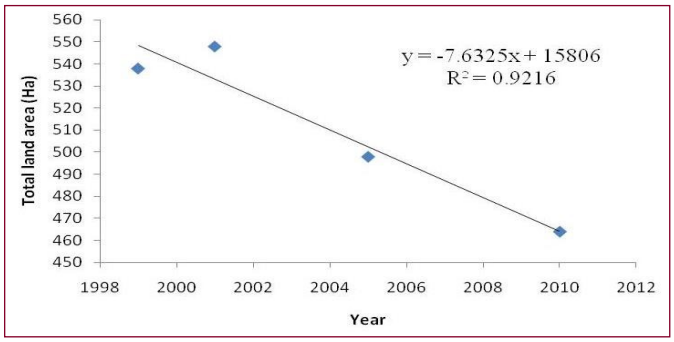

Fig. 3- Temporal changes in Land area of Ghoramara

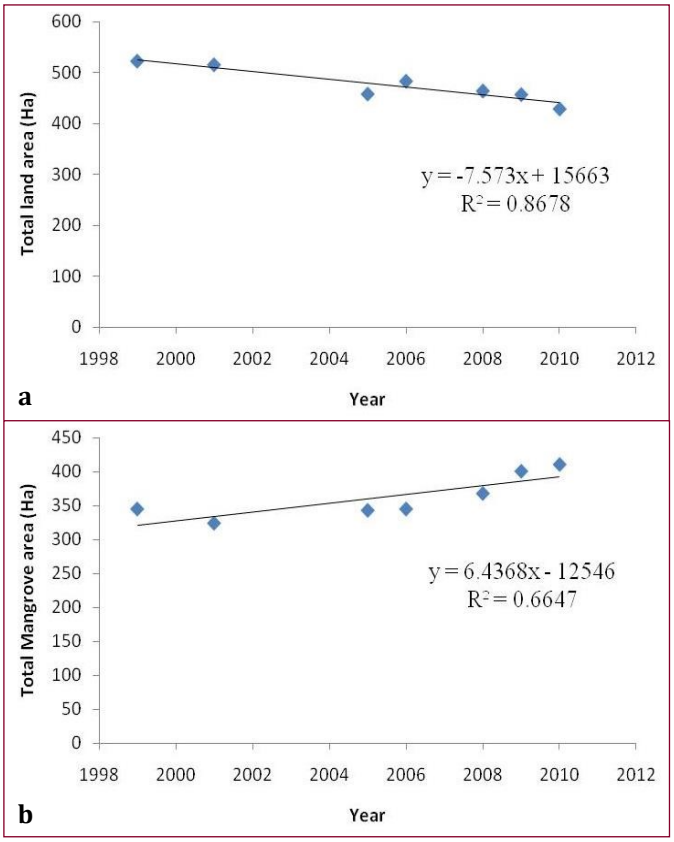

Fig. 4- Temporal changes of Jambudwip land area **(a)** and mangrove area **(b)**

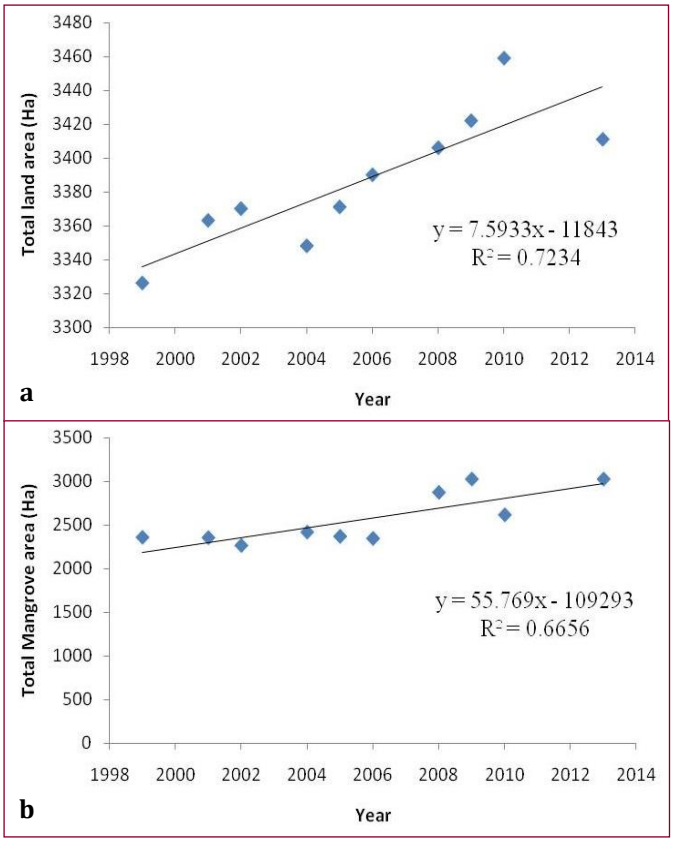

Fig. 5- Temporal changes of Lothian land area **(a)** and mangrove area **(b)**

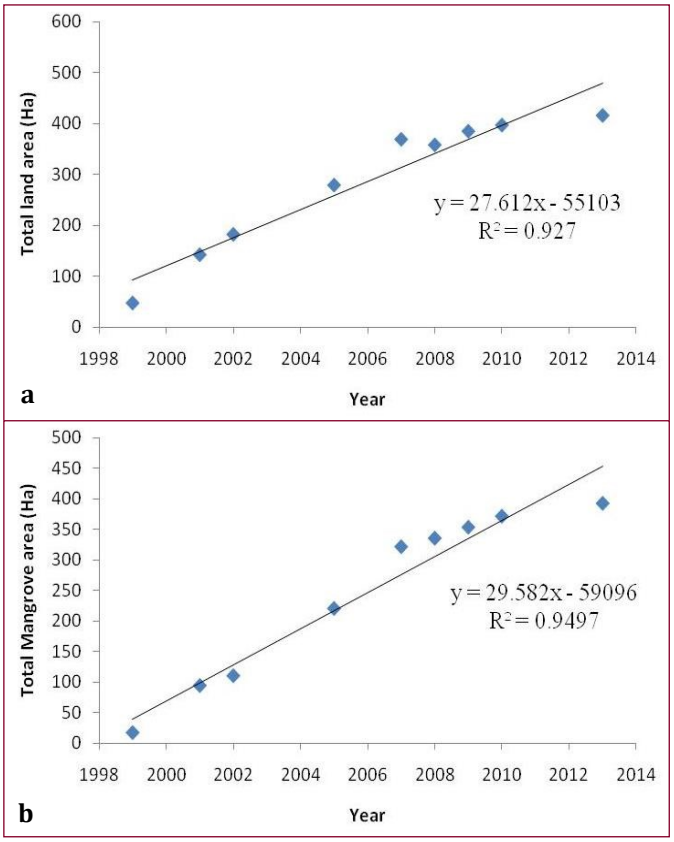

Fig. 6- Temporal changes of Thakuran Char land area **(a)** and mangrove area **(b)**

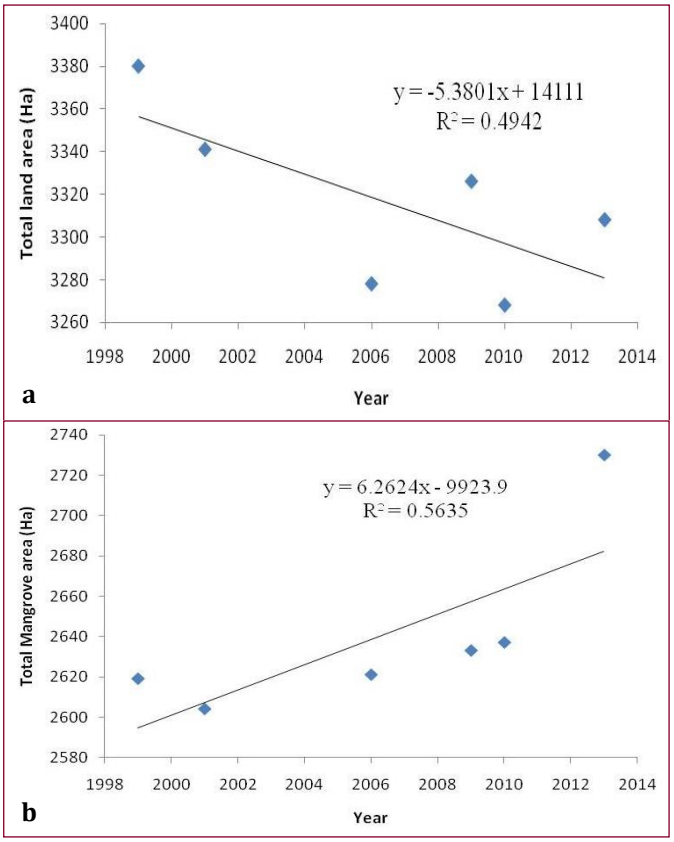

Fig. 7- Temporal changes of Dhanchi island land area **(a)** and mangrove area **(b)**

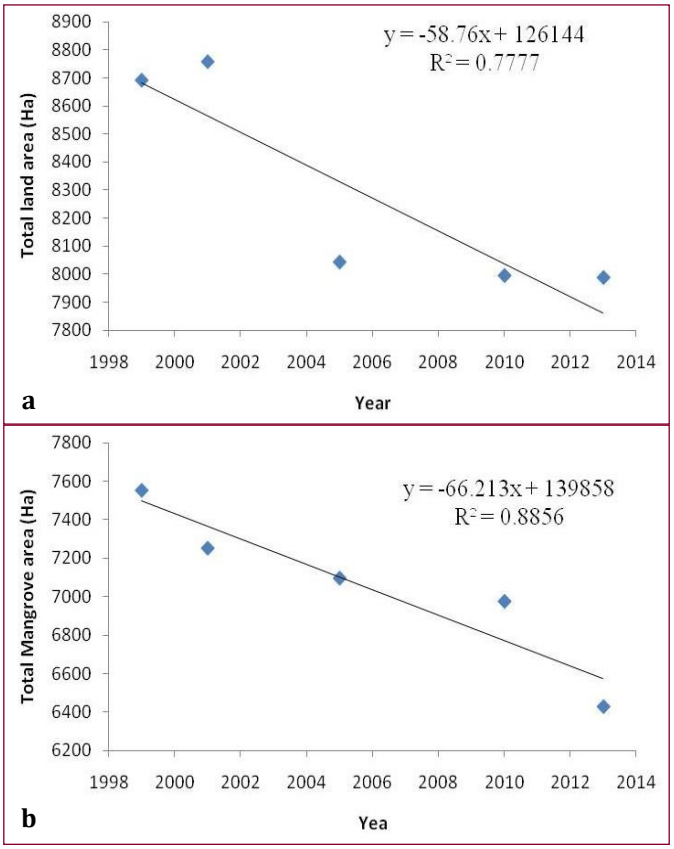

Fig. 8- Temporal changes of Chulkati land area **(a)** and mangrove area **(b)**

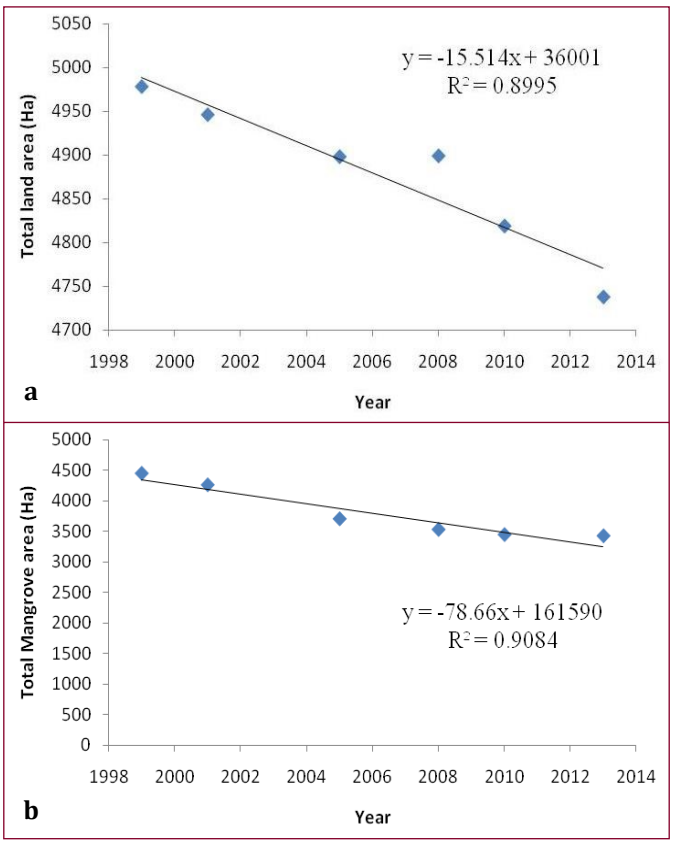

Fig. 9- Temporal changes of Gona land area **(a)** and mangrove area **(b)**

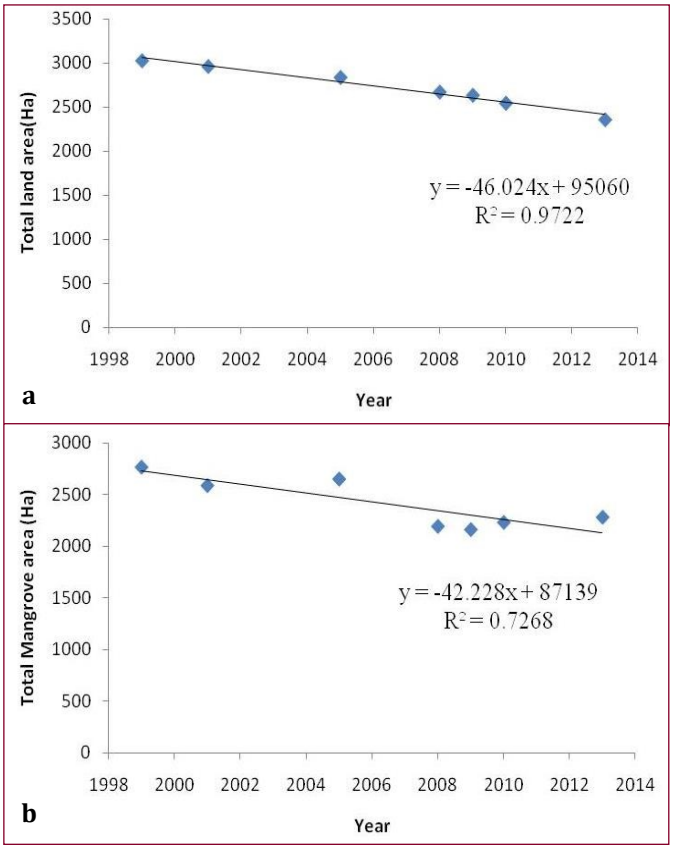

Fig. 10- Temporal changes of Mayadwip 4,5 land area **(a)** and mangrove area **(b)**

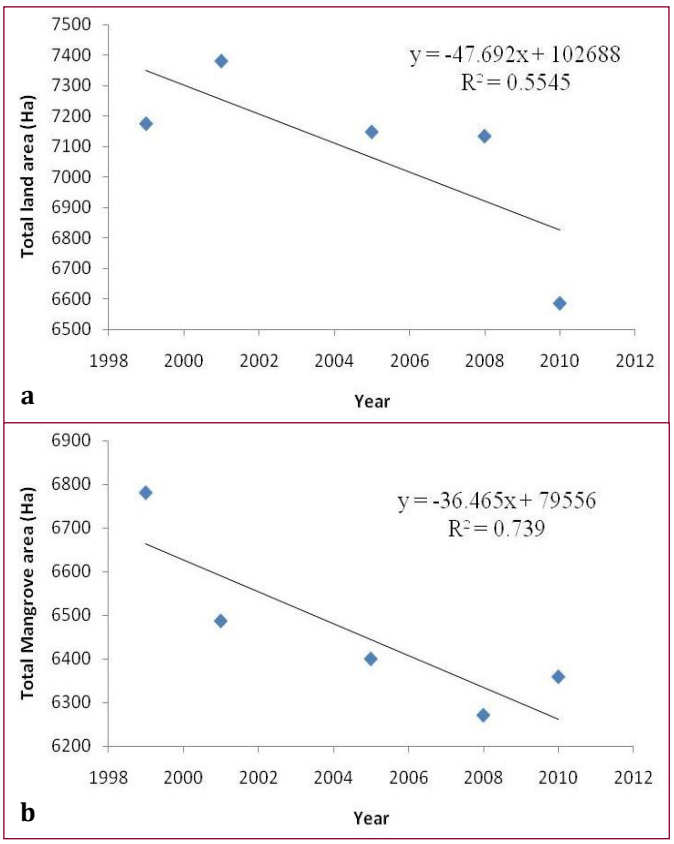

Fig. 11- Temporal changes of Bagmara land area **(a)** and mangrove area **(b)**

Similar results are obtained for the Mangrove vegetations of islands Lothian and Thakuran Char where the correlation coefficients are positive and the total extent of Mangrove vegetation are increasing over the last 15 years. For the islands Jambudwip, Dhanchi, Chulkati, Gona, Mayadwip and Bagmara, the Regression lines for Mangrove vegetation have negative slopes indicating the gradual loss of Mangrove Forest during the same period.

Jambudwip and Chulkati, the two Southernmost island in the mouth of Hooghly and Thakuran river merging into Bay of Bengal, show a contrasting trend in land area vis-à-vis mangrove vegetation. In case of Jambudwip, the island is changing shape rapidly due to deposition of silt coming from upstream along river Hoogly and new char land is growing with time in the southern faces, but total extent of land is gradually reducing due to overall effects of erosion of land on Southern side containing mangroves. Satellite imageries (LISS 3 data) of these 9 forested islands for the period 1999 and 2010/ 2013 show the changes in the 9 southern-most estuarine islands over a period of 15 years [Fig-12], [Fig-13], [Fig-14], [Fig-15], [Fig-16], [Fig-17], [Fig-18], [Fig-19], [Fig-20]. The difference between Ghoramara island and other 9 forested islands is that while silt deposition on Ghoramara island is artificially prevented by the embankments constructed around the island to save the villages from inundation during high tide, the tidal waves are at full play for the 9 forested islands, depositing sediments carried by the rivers.

There are no islands where temporal changes in Total area or mangrove vegetation show a zero correlation showing that the temporal changes in Sundarban estuary are not unpredictable, and the effects of accretion, erosion, tectonic subsistence and sea level rise form a complicated relationship which needs more detailed study.

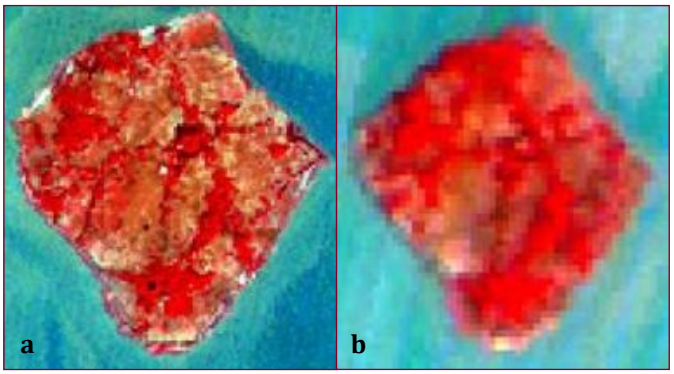

Fig. 12- FCC of Ghorama 1999 **(a)** and 2010 **(b)**

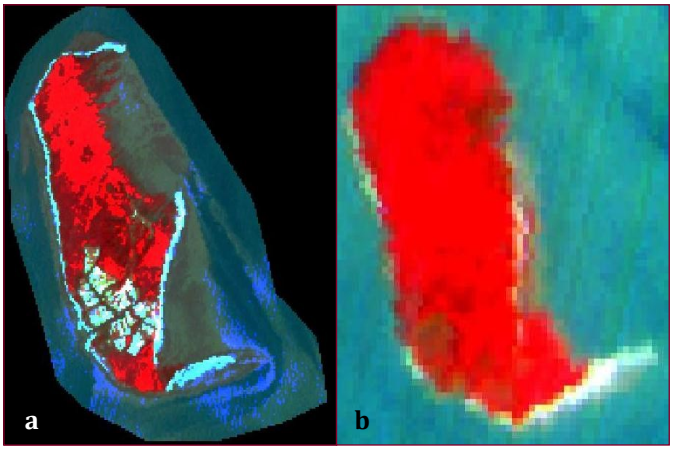

Fig. 13- FCC of Jambudwip 1999 **(a)** and 2010 **(b)**

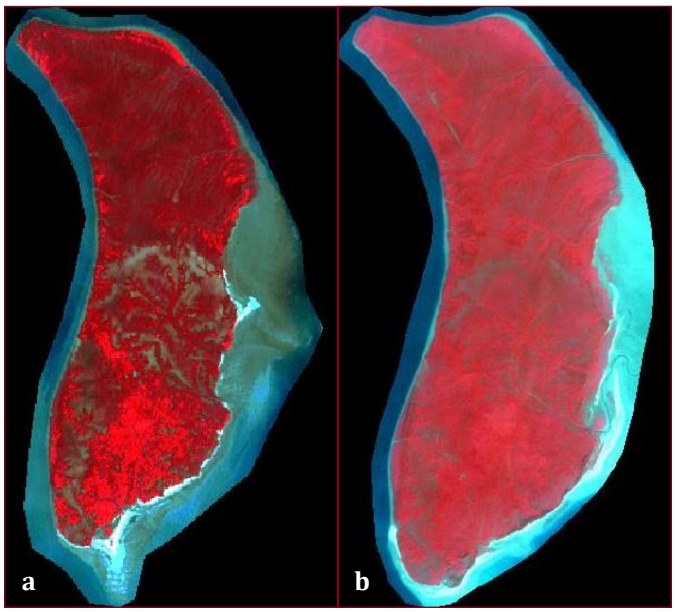

Fig. 14- FCC of Lothian 1999 **(a)** and 2013 **(b)**

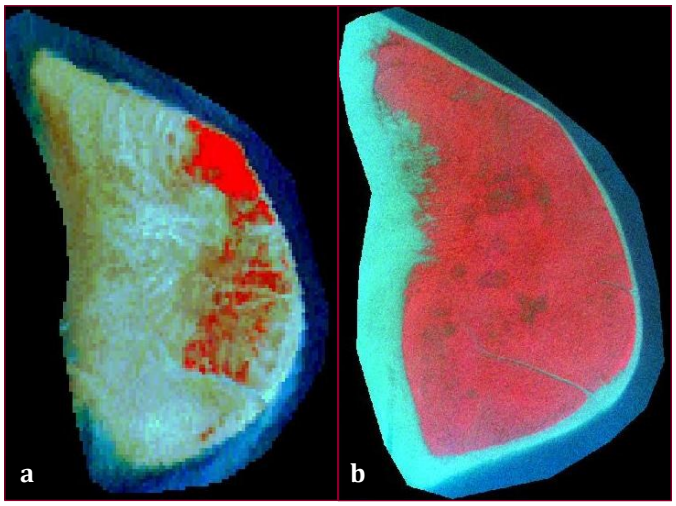

Fig. 15- FCC of Thakuran Char 1999 **(a)** and 2013 **(b)**

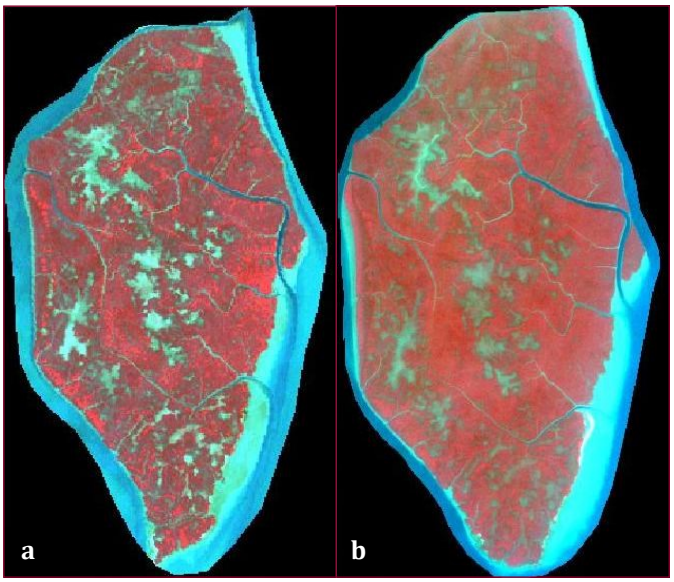

Fig. 16- FCC of Dhanchi 1999 **(a)** and 2013 **(b)**

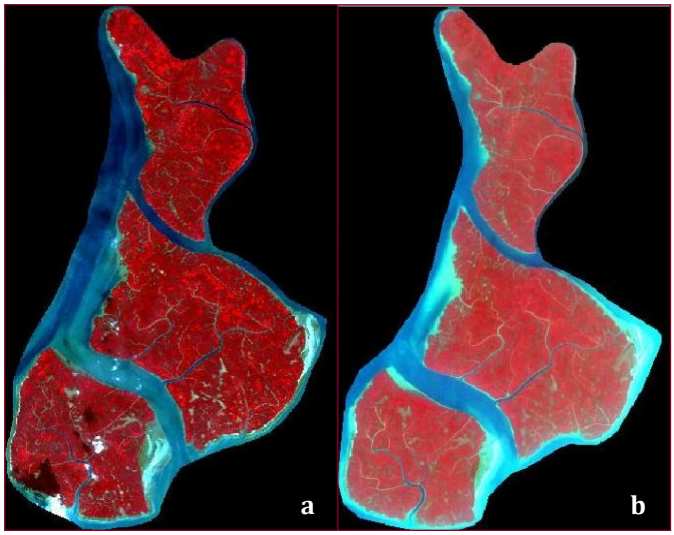

Fig. 17- FCC of Chulkati 1999 **(a)** and 2013 **(b)**

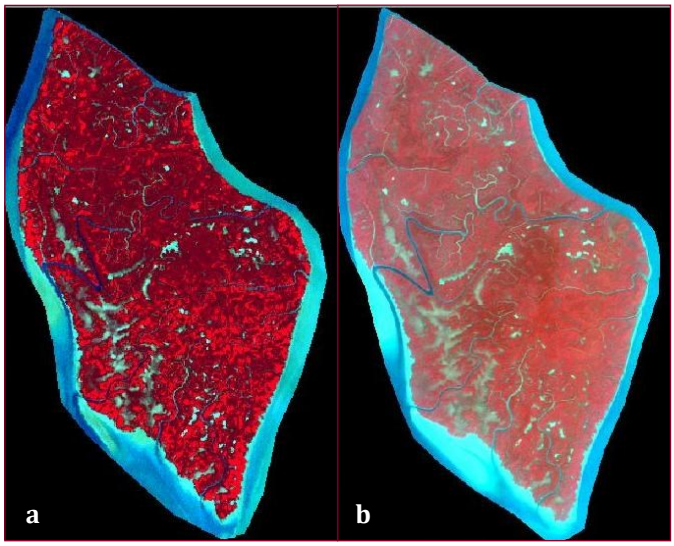

Fig. 18- FCC of Gona 1999 **(a)** and 2013 **(b)**

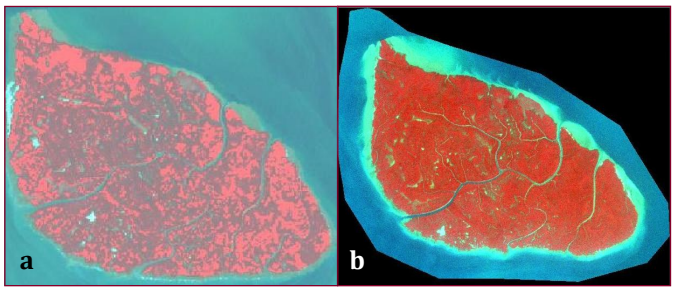

Fig. 19- FCC of Mayadwip 1999 **(a)** and 2010 **(b)**

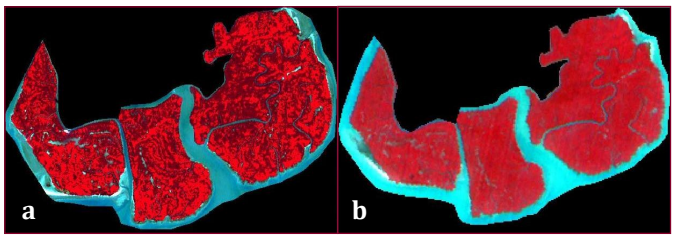

Fig. 20- FCC of Bagmara 1999 **(a)** and 2010 **(b)**

The study thus indicates the degree of impact of sea level rise on forested and village islands in the context of existing pattern of inflow of sweet water in Indian Sundarban estuary.

Conclusions

Sundarban estuary is an extremely dynamic landscape which is under the combined impacts of (i) Siltation from fresh-water carrying rivers flowing into the estuary, (ii) natural subsidence of the delta and (iii) sea level rise due to global warming. Though the fact of sea level rise at global level is beyond controversy, yet the Sundarban estuary is still undergoing the dynamic process of new island formations as well as erosion of a few islands. Construction of barrages upstream, for irrigation purposes is preventing the silt-carrying river water from draining into the estuary and assisting the natural process of accretion through deposition of silt load.

The uniqe aspect of this study is to show that, as compared to the much publicized belief, islands of Sundarban are not facing similar threat from the impacts of Global warming. While the predicted sea level rise will have marginal impact on sundarban islands having mangrove cover, formation and emergence of new islands, through accretion/ deposition of silt load, gives a new dimension to the profile of this estuary. The general predictions that Sundarban will gradually vanish due to sea level rise, may be a bit too far extension of the imaginary threat as the dynamics of this estuary has made Sundarban extremely resilient.

The presence of natural mangrove vegetation on these islands, which are part of the Reserved Forest, is decelerating the natural process of tidal wave erosion. With gradual increase of salinity in the estuary [9], there may be gradual and climatic changes in the species composition in various parts of Sundarban mangroves, but the rate of decrease of extent of mangrove vegetation as compared to rate of decrease of island area is always much less, indicating that mangrove cover on the islands are a natural measure against impact of climate change. However, the impact will be different on those islands, having human habitations and devoid of mangrove cover, but surrounded by embankment all around the islands. The strategies for adaptation/ mitigation measures against climate change will have to be different in case of forested islands and islands with human habitations [10]. Advance action should be taken to prevent new human settlement on these newly created Char (accretion) land within the estuary, and ensure that these new accretions are brought under permanent mangrove cover.

Conflicts of Interest: None declared.

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