Impact of Global Warmingon Sundarbans Mangrove Ecosystem, India: Role of Different Assessment Tools from Ecosystem Monitoring to Molecular Markers

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ABSTRACT

Sundarbans mangrove ecosystem, India, being a 'World's Heritage Site' and largest tidal wetland of the world (jointly with Bangladesh), represents a highly valued ecosystem in terms of economy, ecology and environment. This ecosystem supports the lives of galaxy of flora and fauna in the form of woody halophytic mangrove plants and their associates, benthic algae, phytoplankton, zooplankton, varied forms of benthos ,fishes and hundreds of reptiles, birds and mammals including Royal Bengal Tiger, Pantheratigristigris in diversified habitats like estuaries, creeks, intertidal belts, dunes and mangrove forest. The sea level rise coupled with other global warming mediated changes like salinity invasion, massive shoreline erosion, shifting of mud flats and sand dunes, increased turbidity, temperature, tidal amplitude, and decreased transparency, nutrients and pH are supposed to exert considerable bio-ecological stresses on mangrove biotic community. This has resulted in changes of species composition of biotic communities leading to decline and loss of mangrove dependent detritivores, herbivores and other consumers. The present paper has attempted to record different global warming mediated environmental consequences on a very sensitive, vulnerable and productive mangrove ecosystem of the world using satellite imageries (Multi-Temporal Digital Satellite Data), analyzing of prevailing ecological parameters (biotic and abiotic), recording of geomorphological changes and standardizing of molecular markers.

Keywords: World Heritage Site, Tidal Wetland, Global Warming, Satellite Imageries, Molecular Markers

INTRODUCTION

Global warming is a growing threat to biodiversity all over the world (IPCC, 2000). Rise in temperature affects the biology of a species at its molecular, physiological and biochemical levels thereby altering its distribution patterns as well as community interactions (Das *et al*., 2004). Besides, temperature elevation, some other factors like fragmentation of habitat because of ongoing changing patterns of land uses have compounded the problem and resulted to the non adaptability of species and ecosystem to adapt. The IPCC, 2007 a concludes citing evidential facts that the climate driven extinctions and other change in biodiversity result invasion of exotic species from warmer regions. Changes in the oceans include a pole ward shift of different species of fishes, plankton and algae alongside warming of ocean water (Archer and Rahmstorf, 2010). Coastal zones are particularly vulnerable to the impact of climate change mainly because of warming of water, a reduced nutrient supply of the sunlit surface waters due to more stable layering of water (a thin layer of warm water tends to float on top, preventing mixing), sea-level rise, increased risk of different deseases and acidification. Moreover, coastal ecosystems are threatened by suffocation as the increased stratification and reduced mixing cause a critical loss of oxygen in the water-hypoxic event (Archer and Rahmstorf, 2010).

Sundarbans mangrove ecosystem, (between 21032'–220 40' North and between 880 85'–89000 East) is an unique, productive and highly valued ecosystem in terms of economy, environment and ecology (Chakraborty, 2011). Although, mangroves of India account for only 0.67% of the total designated forest area of the country, their presence remain utterly important under growing concern of global reduction of mangrove habitats and need special attention. The Indian mangroves contribute significantly towards the shrinking of global mangrove reserves with approximately 2.7% of the world's mangroves those exist along the 7516.6km long coastline of India (Giri *et al.*,2011). Several conservation strategies have been adopted to protect Indian mangroves in view of ongoing and persisting ecological and anthropogenic threats.(Bhatt and Kathiresan, 2012). The Sundarbans Mangrove Forest is particularly critical and a highly fragile ecosystem because of its complexgeo-morphological and environmental settings, enormous population density and gradual shrinking of the islands under the rising Sea level (Das Gupta and Shaw, 2013).

In such context, the present paper has attempted to highlight the long term ecological studies undertaken on Sundarbans Mangrove Ecosystem, India to understand the impact of global warming mediated changes in the coastal-mangrove estuarine complex with an emphasis on identification of different assessment tools like eco-biological monitoring, remote sensing and standardization of molecular markers in order to evaluate the mode of structural and functional changes in the ecosystem as well as to assess the impact of elevated temperature stress on the ecophysiology of the species viz. Hsps, Oxidative stress, Enzyme function etc respectively.

MATERIALS AND METHODS

STUDY SITES

Coastal environment of West Bengal selected for the present study, includes a coastal tract of 220 km along two coastal districts-South 24 Parganas and Midnapore (East), West Bengal, India (Fig. 1).

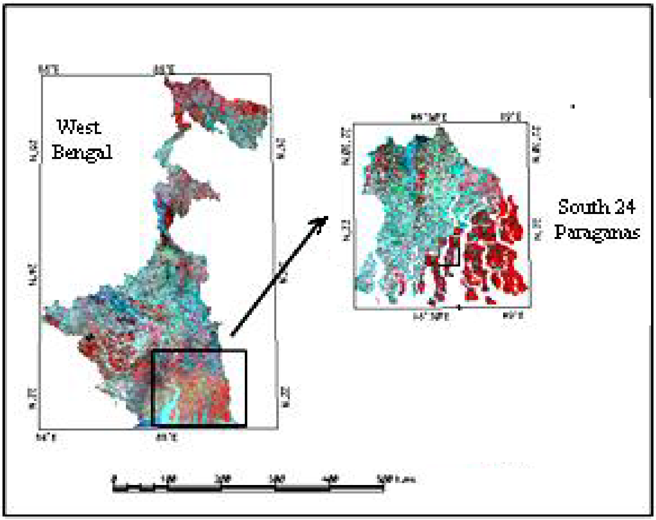

Fig. 1: Location of the Study Site is Presented through False Color Combination (FCC)

ASSESSMENT OF BIODIVERSITY

Field surveys, collection, and identification of floral and faunal components during last two decades following standard literatures (Chaudhuri and Choudhury 1994, Chakraborty, 2011, Giri and Chakraborty, 2012).

RECORDING OF PHYSICO-CHEMICAL AND METEOROLOGICAL PARAMETERS

Different Physico-chemical parameters of soil and water were analyzed following standard methods (APHA, 2005) and with the help of water quality checker (Towa, Model No. WQC 22A Japan). Meteorological parameters (Rainfall, Temperature) of previous decades were collected from the Indian Meteorological Department, Alipore, Kolkata (Chakraborty *et al*.. 2009).

APPLICATION OF REMOTE SENSING AND GIS

Landsat Thematic Mapper (TM) imagery has proven to be effective in mapping temporal and spatial variations in environmental indicators within large water bodies, as well as phyto-environment, pedological characterization, land use/cover system etc. For land use/cover thematisation, Optimum Index Factor (OIF) has been used for selecting the potential band combination, which is based on the total variance within bands and correlation coefficient between bands. The products of vegetation vis-s-vis forest cover mapping derived from remotely sensed images are being objectively verified and communicated in order to enable to chalk out proper strategies for sustainable environmental management. However, the role of vegetation indices and textural images improving land-cover classification performance is still poorly understood, especially in moist tropical vegetated regions such as the Sundarbans mangrove forest areas.

ESTIMATION OF BIOCHEMICAL AND MOLECULAR MARKERS

For studying expression of biomarkers, Bellamyabengalensis, a gastropod having a distribution limt from freshwater to mild brackish water, was selected. Heat Shock Protein 70 (Hsp70), a chaperon andanwell established stress marker has been selected within this bioindicator species as biomarker for biomonitoring. The collected specimens were subjected to different heat stress in laboratory condition and their different organs were used to analyze the Hsp 70 by 10% sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) and detected by Western blotting methods (chemiluminescence or colorimetry). Western blots were scanned and densiometric analysis of the scans was performed by using Image J software (Maiti Dutta *et al*., 2013; Das *et al*. 2004; Banerjee *et al*., 2009).

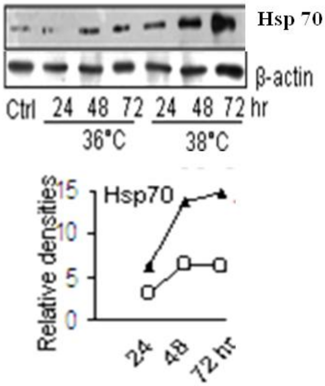

Fig. 2: Expression of Hsp 70 in Bellamyabengalensis

ANALYSIS OF DATA RESOURCES

Already published research papers, reports and text books have been consulted.

RESULTS AND DISCUSSION

PHYSIOGRAPHY AND CLIMATE OF THE STUDY AREAS

The Indian Sundarbans located between 21032”–22040”North and 88085” East to 89000”East in the district of 24 Parganas of the state of West Bengalis endowed with dense halophytic mangrove forest cover in the deltaic estuarine complex (Chakraborty *et al*. 2009) (Fig. 1).

BIODIVERSITY

Highly productive mangrove ecosystem supports a high abundance and diverse variety of faunal components The faunal biodiversity of Sundarbans includes 215 species of fishes, 7 species of amphibian, 59 species of reptiles, more than 200 species of birds, 39 species of mammals, besides numerous species of phytoplankton (>100 species), algae (150 species), zooplankton (>100 species), ichthyoplankton (29 families), benthos (26 species of brachyuran crabs, 69 species of polychaetes, 110 species of molluscaetc), more than 300 species of soil inhibiting and mangrove plants dependent insects along with 44 species of micro-arthropods. Chaudhuri and Chaudhury 1994, Annon 2003, Chakraborty *et al*., 2009; Dey *et al*., 2010; Chakraborty, 2011) Species composition, distributional pattern, population dynamics and community structure of different groups of fauna have experienced wide range of changes spatially and temporally because of the prevailing fluctuating environmental parameters like tidal exposure and innundation, salinity, temperature, pH etc. (Chakraborty, 2011). Global warming mediated salinity invasion coupled with massive erosion have caused the shifting of freshwater loving mangroves such as Heritierafomes, locally called Sundari and Nypafruticans, locally named as Golpata from Indian part of Sundarbanstowards its Bangladesh counterpart having more freshwater dominance. Moreover, settlement of some mesophyticbioinvasive plant species has enhanced ecological instability many-fold of this sensitive eco-region forcing some other plant species such as Sonneratiaapetala, Avicenniaalba and Acanthus ilicifolius to experience landward movement as evident from their presence in the bank of Ganges near Kolkata(Garden-Reach, Strand-Road, Aheritala etc.)All those factors together with considerable pressure fromecotourism, unplanned development of fisheries and aquaculture etc have caused almost total loss of biodiversity of mangroves and other associated flora and fauna from the Midnapore (East) coast.(Chakraborty, 2009; Bhakat *et al*., 2006).

PHYSICO-CHEMICAL AND METEOROLOGICAL PARAMETERS

Different physicochemical parameters displayed a wide range of temporal and spatial variation. Water temperature, salinity, pH, conductivity, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD) were found to be higher during pre-monsoon, while silicate, phosphate phosphorous, nitrate nitrogen, ammonical nitrogen and nitrate nitrogen were maximum during monsoon. The post-monsoon season was characterized in having lowest temperature, moderate salinity, and other parameters. Soil temperature, salinity, organic carbon and sand contents were found to be higher during pre-monsoon season, while available nitrogen and available phosphorus were maximum during monsoon. The post monsoon season was characterized in having lowest temperature, available phosphorus, available nitrogen and moderate level of other parameters. (Chakraborty *et al*., 2009) Sarkar *et al*., 2013 observed negligible tidal salinity variation in different areas of Sundarbans while their studies have revealed considerable fluctuation of salinity both spatially and seasonally (9.4 ppt to 30.8 ppt). The study of dissolved inorganic nitrogenor nutrient (N)→phytoplankton (P)→zooplankton (Z) dynamics of the Hooghly–Matla estuary is important because the entire grazing food chain of the mangrove ecosystem depends on the litter falls from the adjoining mangrove forest (Chakraborty, 2011).

SURFACE WATER TEMPERATURE

The present trend of global warming has imparted considerable impact on the mangrove-dominated Indian Sundarbansas the elevated temperature has shown considerable influence from the molecules to ecosystem especially for both pre-monsoon and monsoon periods (MaitiDutta *et al*., 2013; Raha *et al*., 2012). Temperatures have risen by 6.14% in the western sector and by 6.12% in the eastern sector of the coastal Sundarbans over the past 27 years, at a rate of approximately 0.05°C/year (Mitra *et al*., 2009). This rate is, in fact, much higher than the observed and documented warming trends in the tropical Pacific Ocean (0.01–0.015 °C/year), tropical Atlantic Ocean (0.01–0.02 °C/ year) and the planet itself (0.006 °C/year) (Mitra *et al*., 2009). Surface air temperature anomaly data over the Sundarbans and adjacent parts of the Bay of Bengal after being analyzed have shown an increasing trend in the yearly rise in temperature. This finding corroborates with the existing global warming phenomena (Hazra, *et al.,* 2002). Of the Indian Sundarbans, the western part showed a significant and continuous decrease in salinity (1.67 psu/decade) whereas the eastern sector exhibited an increase in salt (~6 psu over thirty years) because of the differential flood of freshwater (Mitra *et al*., 2009).

GEOMORPHOLOGY

The important geo-morphological settings of the sundarbans mangrove eco system include mudflats, sand beaches, coastal dunes, estuarine networks, shallow creeks and mangrove swamps. (Chaudhuriand Choudhury, 1994; Paul,2002). Sundarbans, the only mangrove tiger-land of the globe is presently under threat of severe coastal erosion due to relative sea level rise. According to Morgan and McIntire (1959), the Bengal Basin deltaic islands of Sundarbans have been gradually tilting towards east. This has probably caused the main fresh water discharge to shift gradually eastward (towards Bangladesh) imposing severe stress on fresh water budget for Hoogly-Matla estuary.

A time series analysis of the change in the shape, size and geomorphic features of the island over the past 32 years (1969–2001) have depicted some important changes like degradation of mangrove swamp and mud flats, increase in salinisation and development of saline banks within mangrove swamp, and overall reduction of land area in spite of feeble delta outbuilding processes (Hazra *et al*., 2002) Coastal erosion and accretion processes have changed in shoreline dynamics. Coastal erosion is constantly reshaping the islands of Indian Sundarbans. Rate of coastal erosion in the Indian Sundarbans have been measured to be about 5.70 km 2 year within the time span of 1989-2014 and eventually it is most dominant in the south western edges of the individual islands. Total land area of 6673 km 2 (approx) of Indian Sundarbans in the year 1989 has been found to be reduced to 5869 sq.kms (approx). in 2014. Erosional zones have been found to be more prominent among the 12 sea facing southern islands including Jambu Island, Sagar Island etc. (Hazra *et al*., 2002; Raha *et al*., 2012). Few islands, like Lohachara and

Bedford (6.212 Km 2), have already vanished from the map. Total erosion over the 30 years time span is estimated to be 162.879 Km 2 (Hazra *et al*., 2002). In the present study, an evaluation of Satelite imageries (Fig. 11) has revealed a trend of erosion and accretion patterns in a time span of 34 years (1989-2014) in the length and breadth of deltaic estuarine complex of Sundarbans in the tune of 116335800 m 2 (erosion) and 28275300 m 2 (accretion).

MEAN SEA LEVEL VARIATION

Comparing the annual sea level variation, it is observed that the annual mean sea level has risen steadily between 1985 and 1998. This indicates a minimum 4 cm rise in relative sea level during a period of 14 years. In the Ganga-Bramhaputra delta, taking into consideration of high sedimentation load as to be 0.1 mm per year, the net rate of sea level rise would be 3.14 mm per year. This is significantly more than the present trend of average global sea level rise of 2 mm per year. Considering the present relative sea level rise @ 3.14 mm per year, it is estimated that by the year 2050, the compounded sea level elevation will become close to the 1 m (Hazra *et al*., 2002).

CHANGING PATTERN OF CYCLONES OVER THE SUNDARBANS

The analysis of available records of cyclones over the Bay of Bengal and adjoining Sundarbans, exhibits an increasing trend in the degree of their intensity and decrease in the frequency of occurrence during last couple of decades. This has significant bearing on the extent of coastal flooding, erosion and saline water intrusion due to storm surges and such increase in the intensity also implies increase in the precipitation pattern over this part of the Bay of Bengal (Hazra *et al*., 2002).

TURBIDITY

Turbidity levels and distribution were estimated by using image processing techniques on the Landsat TM imageries. The application of remote sensing tools have shown that turbidity level shave remained low at the upper sections and extreme southern portions of the estuaries and high at the mouth of the estuaries. Suspended solids in the lower estuary zone occurred in high concentrations (in excess of 150 mg/l) whereas the middle estuary zone was characterized by lower concentrations (less than 136 mg/l); and the upper estuary zone exhibited high suspended-solid concentrations (in excess of 150 mg/l) (Ray *et al*., 2013).

SALINITY (CHLORIDE CONCENTRATION) BASED ON REMOTE SENSING

Distinct tidal variations of salinity were observed only in western sector whereas such results were less pronounced in other parts having negligible salinity difference (1.4 to 2.0 ppt) between high and low tides. In contrast, very marked seasonal variations of salinity were encountered (9.34 to 30.83 ppt) in the entire ecosystem. The most parts of the Sundarbans used to experience almost equal level of salinity in monsoon (12.0 to 14.0 ppt) and summer (29.0–30.0 ppt) indicating less degree of spatial variations. Significant salinity differences between upstream and downstream were however, recorded in winter and pre-summer which exhibited relatively higher values in most of the estuarine networks, highlighting more fresh water influx in this region. (Sarkar *et al*., 2013).

Mangroves being woody halophytic trees and shrubs that normally grow in saline intertidal zones of tropical and subtropical coastline. Salinity, therefore, appears to be one of the key environmental factors influencing the growth and survival of mangrove species. But the tolerance of salinity also varies among the mangroves (Annon 2003). The seedlings of Rhizophoramucronatado better in salinity of 30 psu but R. apiculata do better at 15 psu (Sarkar *et al*., 2013). On the other hand, Sonnaratia albagrows in waters between 2 and 18 psu and S. lanceolata only tolerates salinity upto 2 psu (Ball and Pidsley, 1995). Experimental evidence also indicates that at too high salinity mangroves used to spend more energy to maintain water balance and ion concentration rather than primary production and growth (Clough, 1984). This results in reduction in biomass, leaf area, increase of osmotic pressure in leaf sap and decrease of total nitrogen, potassium and phosphorus minerals (Medina *et al*., 1995). Hence, salinity variation and duration of a particular salinity value in a year within a mangrove forest area play a vital role in the species distribution, their productivity and growth (Twilley and Chen, 1998). The variations in salinity are normally controlled by climate, hydrology, rainfall, topography and the tidal flooding of an area. All these characteristics are known to undergo spatial as well as temporal variations. Accordingly, the distribution, succession, population and diversity of mangrove species along with associated flora and fauna do also vary along with the variation of salinity (Chakraborty *et al*., 2009).

DISSOLVED OXYGEN

The concentration of dissolved oxygen (D.O.) in the Western Sector of the Indian Sundarbans showed an increasing trend in contrast to the eastern part over the last 30 years . The observed increase in the dissolved oxygen levels is around 1mg/l over this period. The increase of D.O. concentration in the western side is in contrast to the prevalent notion of decrease in the D.O. levels with increasing temperature (Mitra *et al*., 2009).

PH

Over the past three centuries, the concentration of carbon dioxide has been increasing in the Earth's atmosphere because of human influences. Owing to gradual increase of CO_2 concentration in the atmosphere, a large fraction tended to be dissolved into the ocean and thereby increased the total amount of dissolved inorganic carbon which contributed a shifting of seawater chemistry towards a lower pH condition. This indicates rising acidification of coastal waters and a decrease in the carbonate ion [CO32-], which is believed to affect the ability of marine animals to build up shells (Mitra *et al.,* 2009). The IPCC in its 4th Assessment Report estimates that by the end of the century, ocean pH will decline from current level of 8.1 to 7.8 due to rising concentration of CO2 (Chandra, 2013).

BIOMARKERS

Western Blot methods applied to a commonly occurring gastropod Bellamyabengalensis have resulted the level of proteins of selected biomarker Hsp70 by immunoblotting. Hsp70 levels in the same species have been found to show an increase to almost six fold when subjected to external heat shocks at 360 C (72 hrs) and this elevated levels of Hsp 70 was further bolstered on exposure to higher temperature of 380 C (72 hrs). Such changes are supposed to be due to elevated temperature mediated stress (Fig. 2). Similar studies relating to thermal stress on carp fishes have been undertaken by Das *et al.,* 2004 and their findings have also established the fact that changes in the surface temperature of the water are reflected in biochemical pathways of the fishes.

ANALYSIS OF THE OUTCOMES OF DIGITAL REMOTE SENSING

In the present study, Remote Sensing techniques are being used to explore the effect of global warming on the Indian Sundarbans–Mangrove Estuarine-Coastal environment and some case studies based research outcomes are presented below after being analyzed.

Remote Sensing in Estuarine Environment

This experiment has been done on the Matla estuarine segment to quantify the environmental parameters and their variabilities of this region. In Matla estuarine complex, 57 samples were taken from the TM image, each with 3 x 3 in extent using the band TM1, averaged and converted to suspended-solids concentration.

The resultant values (Fig. 3) were mapped. This figure suggests that the suspended-solids distribution can be divided into three zones: the lower estuary zone with high concentrations (in excess of 150 mg/l); the middle estuary zone, characterized by lower concentrations (less than 136 mg/l); and the upper estuary zone with high suspended-solid concentrations (in excess of 150 mg/l). In the lower estuary zone, mud flats were characterized by a very high suspended-solids concentration (in excess of 166 mg/l), as the water is very shallow in this area, as revealed from field evidence (Ray *et al*., 2013).

Depending on the pattern of the suspended-solids distribution (Fig. 3), the output image from the contrast stretching and density slicing techniques, and field observations, an automatic classification (Parallelepiped) was performed; representative samples (training areas) for the five zones were taken. Besides, an experiment was also done with Normalized Difference Turbidity Index (NDTI) using Green and Red band.

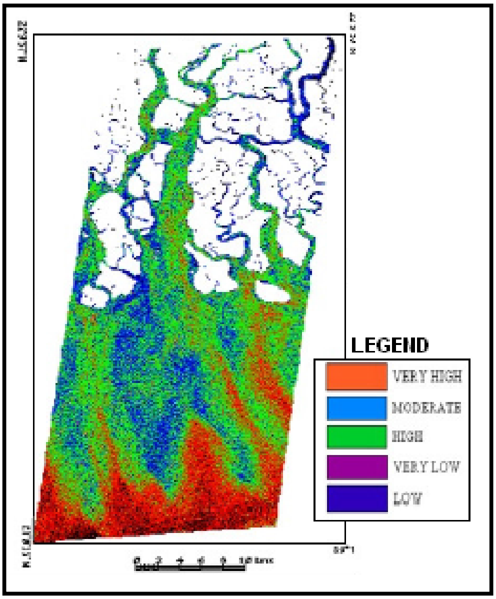

Fig. 3: Spatial Distribution of Suspended Solid (mg/l)

This has been simulated with the parallelepiped classification for turbidity zonation. It is seen that the turbidity level was found to be low at the upper section of the extreme southern portion of the estuary and exihibited higher results at the mouth of the estuary (Fig. 4).

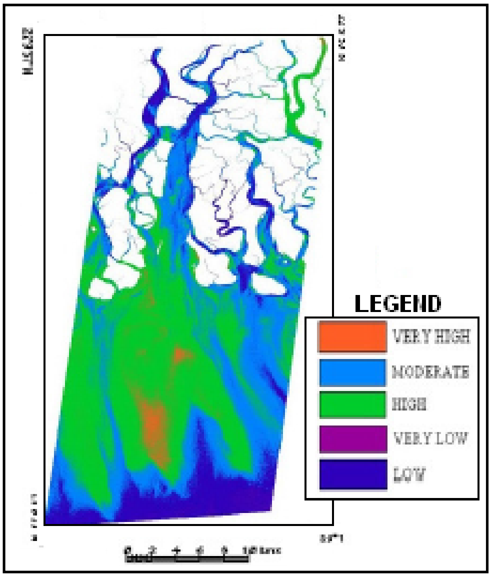

Fig. 4: Estimated Turbidity Status

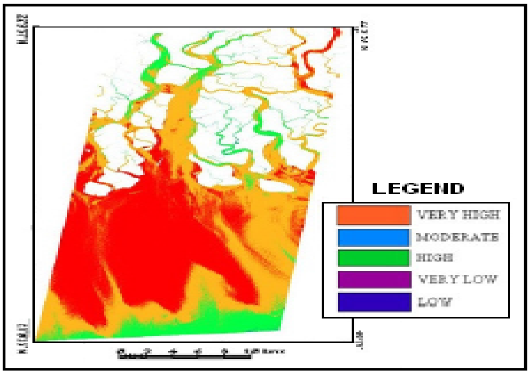

Fig. 5: Estimated Salinity

Temperature patterns reflect variations resulting from the mixing of freshwater and saltwater, upwelling, outwelling, waves, eddies etc. alongside revealing nutrients rich areas. The thermal bands (band 61 and 62) of Landsat-7 ETM+(Enhanced Thematic Mapper Plus) are being used to detect thermal radiation released from objects on the earth surface and thereby to calculate water surface temperatures which are to be validated with ground truth information. After processing the thermal band, it is seen that the temperature ranged from 16 to 200C. (Fig. 6)

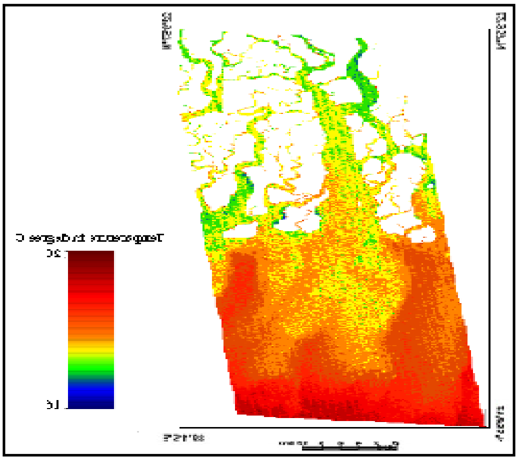

Fig. 6: Estimated Tempareture

Assessment of Salinity Profile

Salinity has no effect on water spectral characteristics, as has been proved by laboratory studies (Scherz *et al*., 1969). Nevertheless, salinity has been successfully predicted from the spectral data (Baban, 1993). It is clear that a correlated parameter highly associated with salinity, affects the optical properties of the water. Here 45 (3 x 3) averaged samples were extracted in TM3 and converted to salinity and resultant salinity values are mapped (Fig. 5).

Quantification of Chlorophyll

Quantifying chlorophyll a concentrations in estuaries has revealed variable results (Fig. 7). The inconsistency is partly due to two factors. First, chlorophyll a and inorganic sediment are not separable and, secondly, suspended sediments, which dominate the total reflectance in this environment, behave as a broad band back scatters. Thirty-six (3x3) samples were taken from TM1, TM2 and TM3, and averaged values were converted to chlorophyll a concentrations.

The results are presented graphically in Fig. 7, in which the apparent concentrations of chlorophyll a ranged between 986 mg/l and 1266 mg/l. The distributions of suspended solids, turbidity, temperature and salinity appear to have a similar pattern, which is distinguished by high values at the mouth of Matla estuary, low values in the middle (Fig. 8). In order to support this observation, a cross-section AB is taken through Matla estuary starting above the confluence and ending at the EW corner of the mouth, consisting of 18 sample locations. For comparison purposes, the values of each parameter were scaled as high, medium and low, and assigned numerical values ranging from 3 to 1,the results of such analyses are plotted in Fig. 8. This figure demonstrates the existence of a similar pattern for all the indicators in Matla estuary, which are mainly due to the effect of suspended solids. This pattern has been imposed on Matla estuary by flood-ebb and sedimentation processes. The two extremities receive the heaviest loads, which consist of relatively coarser sediments, leaving the finer material to settle in the middle (Ray *et al*. 2013). This finding indicates that Matla estuary follows Fairbridge's (1980) definition of an estuary where an estuary is divided into three sections: marine or lower section; middle section; and fluvial or upper section. The borders between these sections, however, vary according to the differential ecological influences of different seasons (Ray *et al*., 2013).

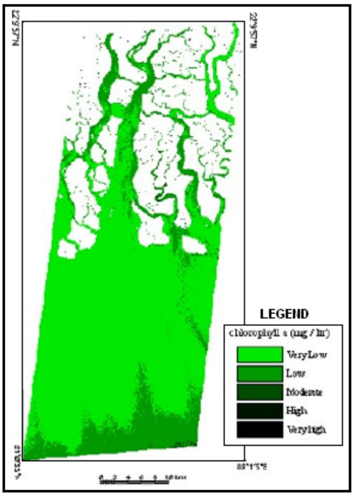

Fig. 7: Estimated Chlorophyll Concentration

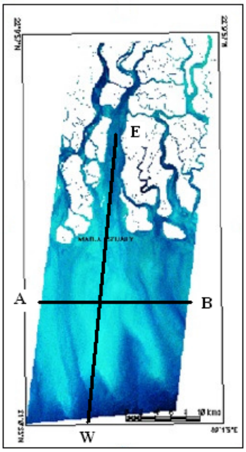

Fig. 8: Alignment of Section Lines Over the Matla Estuarine Sector

Remote Sensing in Vegetation

Remote sensing could play an important and effective role in the assessment and monitoring of mangrove forest cover dynamics. In this present study an object oriented enhancement technique has been applied which is basically known as supervised enhancement having a basis of the prior spectral designations and algebraic band combination. This kind of enhancement algorithm has appeared to be very fruitful in expressing and also recognizing the separability of different objects (Ray *et al*., 2013).

On the basis of spectral sensitivity and Red-NIR spectral space Ray *et al*., 2013 attempted to assess the mangrove forest cover dynamics by designing an object oriented enhancement algorithm using mathematical operators, which is supervised in nature and expressing the characteristics of plant chlorophyll 'a'.

Two considerations that were taken in this respect include pixel value having chlorophyll influence which remains greater in near-infrared band than red band and pixel value having no chlorophyll influence which tends to be greater in red band than near-infrared band. On the basis of these considerations, following supervised enhancement algorithm has been developed and is named as Modified Advance Vegetation Index (MAVI)which can be calculated by the following equation (Ray *et al*., 2013)

$$[\{(\rho NIR+L) * (256-\rho RED)\} * (\rho NIR - \rho RED)](1/3)$$

(Where, ρRED = Reflectance value of Red band of TM5 Sen-sor, ρNIR = Reflectance value of Near-infrared band of TM5 Sensor, L= Coefficient which varies with the vegetation cover, Where L represents the slope factor of Red and NIR relationship.

In the second phase, the vegetation density (VD) has been calculated for both of images of year 2000 and 2010 by synthesizing the outcome of MAVI and Bareness index (BI) on Principle Component (PCA) basis.

The BI is calculated by the undermentioned formula--

[(Band5+Band3)–(Band 4+Band1) / (Band 5+Band 3) + (Band 4+Band 1)]

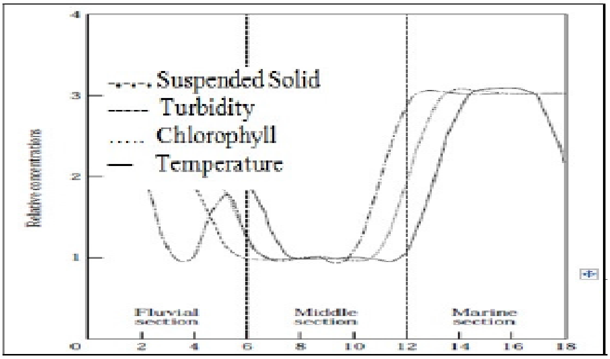

Fig. 9: Correlation Among Various Environmental Indicators

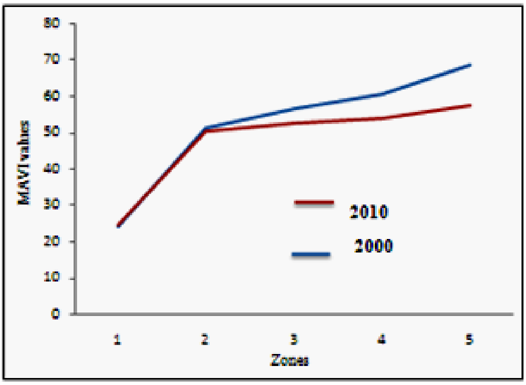

Fig. 10: Vegetation Status from Year 2000 to 2010

If the vegetation wise compartments, derived from the sliced MAVI rasters are compared, the deteriorating status of vegetation health can be evaluated (Fig. 12).This dynamicity in the vegetation health vis-à-vis forest cover between the time period of 2000 and 2010 has been assessed as per the information being presented in the Fig. 13 and Table 1. Although vegetation cover has been deteriorating steadily, 7% vegetal area understudy has been upgraded to class 5 health category(Advantageous for the ecosystem) and only 0.9% area has been deteriorated to class 1 (Harmful for the ecosystem). After comparing the areas of each vegetation density zone, it has been seen that the area of the highest vegetation density zone (noted as zone 5) has been increased considerably for the year of 2010, which represents 20% of the total area and rate of such increase for the zone with respect to the year of 2000 is approximately 2%. On the other hand, in the zone 3, a considerable decrease (approximately 2.5%) in vegetation area has been occurred for the year of 2010 in comparison to the year of 2000. A positive relationship between vegetation density and vegetation health has always been existed during the period of the study. If the results on MAVI and vegetation density (VD) are compared, most healthy vegetations have been found to be concentrated within the high density zones (Table 2 and Fig. 13) (Ray *et al.,* 2013).

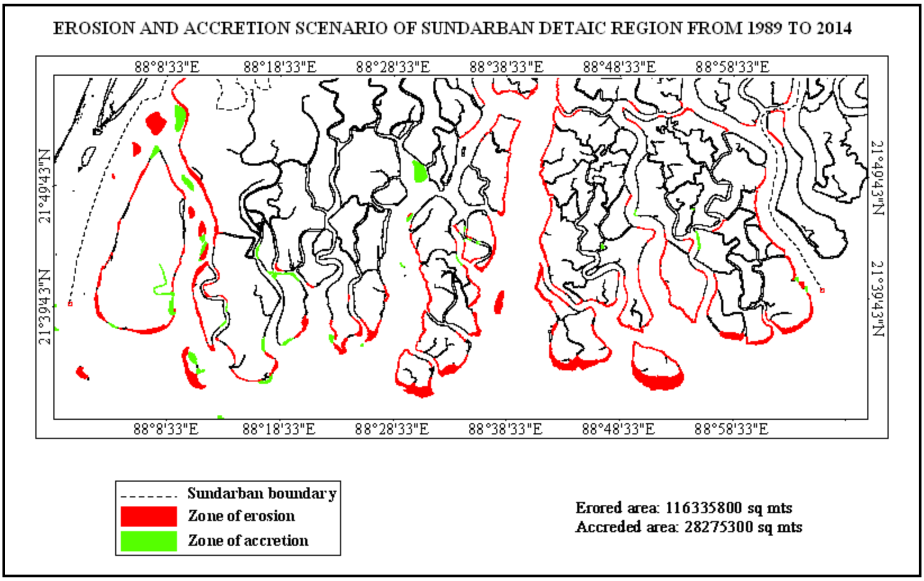

Fig. 11: Trend of Erosion-Accretion in the Sundarbans Deltaic Systems from 1989 to 2014

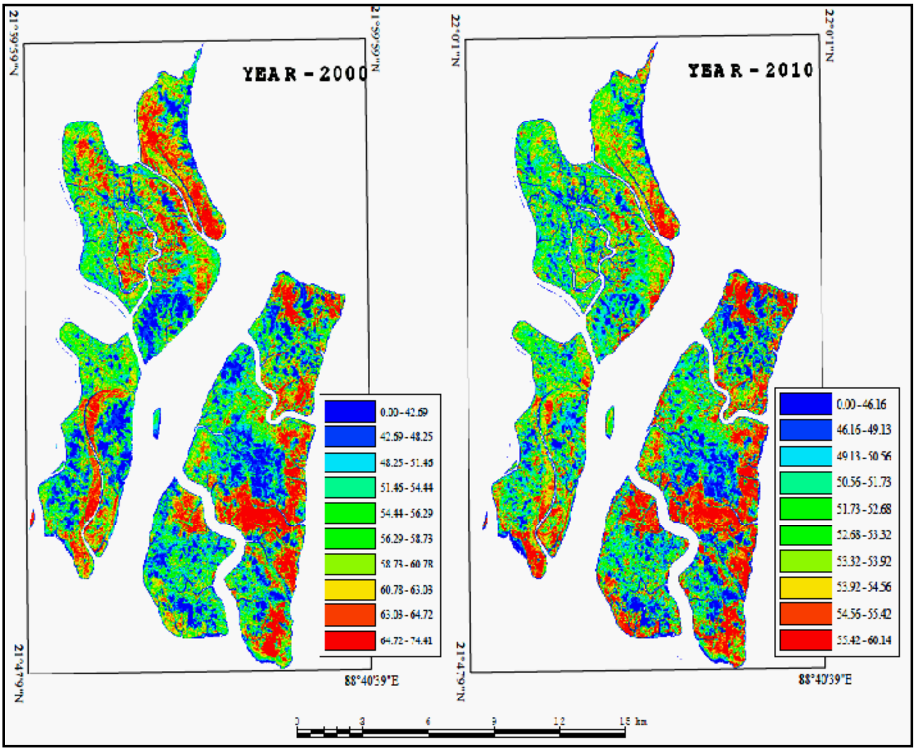

Fig. 12: MAVI of the Forest Cover (Health Status)

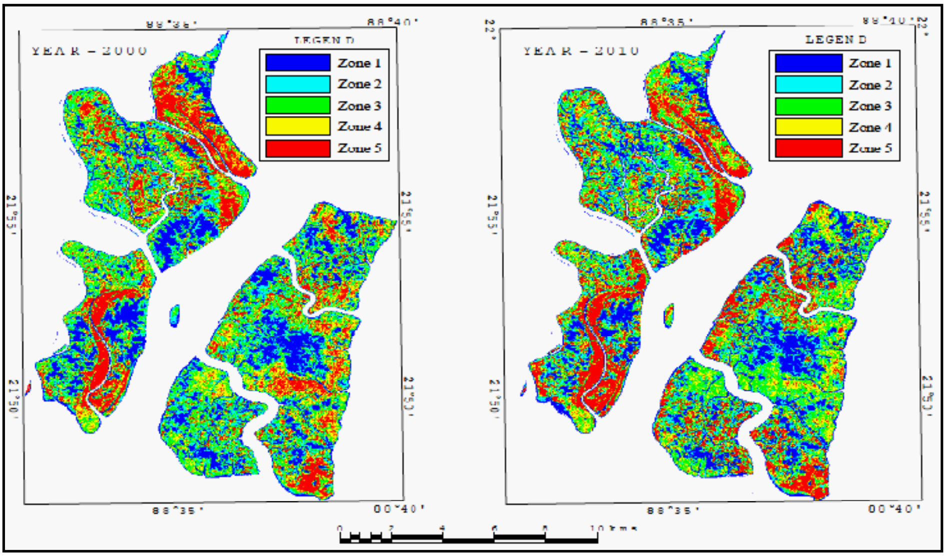

Fig. 13: Vegetation Density Map

Table 1: MAVI Values According to Zone

Zone	Year 2000	Year 2010
Very low	0.00 – 48.25	0.00 – 49.13
Low	48.25 – 54.44	49.13 – 51.73
Moderate	54.44 – 58.73	51.73 – 53.32
High	58.73 – 63.03	53.32 – 54.56
Very high	63.03 – 74.41	54.56 – 60.14

Table 2: Areas of Different Density Zones

Grade	Area in sq.mts. (2000)	Area in sq.mts. (2010)
Very low	2958100	21929400
Low	29231100	29788200
Moderate	32892300	30710700
High	31274100	30200400
Very high	25605000	29274300

DISCUSSION

Global warming vis-à-vis climate change is not an alteration of temperature profiles in the atmosphere leading to the melting of glaciers and rising of sea level but should be considered as the occurrence of chain of reactions jeopardizing the basic fabric of ecosystem functioning, especially in the aquatic systems by increasing the frequency of hydro-geo-biochemical-physical-meteorological events. Unpredictable occurrence of different natural disasters (flood, tropical cyclones etc.) are being increased by Sea-Surface-Temperature rising (CSE, 2009).The increasing frequency of tropical cyclones is generally attributed to rise in sea–surface temperature (CSE, 2009). Temperature is one of the most important physical factors that determine distribution, abundance and survival of species. Thermal adaptation is largely dependent on the physiology. Cells exposed to elevated temperatures (heat shock) first activate the expression of heat shock genes and reduce the expression of "house-keeping" genes. During continued exposure to elevated temperature within tolerance range, cells adapt and return to a state of gene expression closer to normal, a state called "General Adaptation Syndrome". This is one of the important adaptive responses to changes in the ambient temperature and contributes to cell's homeostasis under different condition. Mangroves are an important bulkhead against climate change: they afford protection for coastal areas from tidal waves and cyclones, and are among the most carbon-rich forests in the tropics(Archer and Rahmsterf 2010). Anthropogenic activities and their consequences, including climate change, are negatively impacting biodiversity and ecosystem services, with ecosystem loss and degradation occurring at an alarming rate (Millennium Ecosystem Assessment).The low global cover and high sensitivity of mangroves to environmental change, including climate change has been established (Macintosh and Ashton, 2002; Ellison *et al.*, 2010). It has been recently reported that as much as 11 of the 70 known species of mangroves (16%) have been assigned as the species under threat of extinction. Future predictions suggest that 30–40% of coastal wetlands, and 100% of mangrove forests could be lost in the next 100 years if current rates of decline continue (Duke *et al.*, 2007; International Panel for Climate Change (IPCC, 2000) also has suggested rapid changes in mangrove dynamics for Bangladesh and India, highlighting an overall decrease in mangrove health in the east side of the Sundarbans, and an overall increase in this parameter for the west side. How different threats being experienced by mangroves can be detected and mapped using radar-based information appear to be pre-requisite to guide management action. The present study has highlighted the prospective physical-biological-geological-chemical changes in the mangrove–estuarine-complex of Sundarbans, India in view of global warming by ground survey, laboratory analysis and remote sensing technology. Reviewing existing literatures, applicability of molecular markers and remote sensing in global warming mediated Sea-Level-Rise (SLR) which has imparted considerable impact on the biogeography and species richness of flora and fauna, salinity invasion, decreasing of pH and dissolved oxygen, unpredictable availability of nutrients, sudden occurrences of tropical cyclones having higher intensity and other related environmental consequences, increased erosion, unwanted accretion, higher sedimentation, turbidity, and declining of biological productivity in different parts of Sundarbans Mangrove Ecosystem of India, experiencing seasonal and spatial variabilities.Two approaches one at molecular level by estimating biochemical markers, Heat Shock Proteins (HSPs) has revealed that although HSP is highly thermal tolerant (Volemmy 1992), it exhibited variability in respect of structure and function in different degrees of temperature stresses. Other factors such as industrial effluents, heavy metals (Regoli *et al.,* 1995) in conjunction with temperature rise have resulted in increasing HSP level in fishes (Das *et al.,* 2004). Application of remote sensing has found to contribute significant roles in identifying the problems and also to record the trend of changes of different structural components starting from vegetational health, temperature chlorophyll content, turbidity, and erosion-accretion patterns which are being used to design proper conservation strategies (Fig. 9). In a time span of 34 years, a considerable portions of mud-sandflats of Sundarbans have been eroded followed mostly unwanted accretion during this period which need immediate attention for eco-management.

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