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Sea Level and associated changes in the Sundarbans

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Introduction

Sundarbans, the only mangrove tiger-land of the globe is presently under threat of severe coastal erosion due to relative sea level rise. The once largest prograding delta which registers the highest species diversity in terms of mangrove and mangrove associate flora and fauna is showing evidences that suggest the rich biodiversity is under threat.
Increasingly, this deltaic island system is facing degradation due to natural and anthropogenic changes. Frequent embankment failures, submergence and flooding, beach erosion and siltation at jetties and navigational channels, cyclone and storm surges are all making this area increasingly vulnerable. In addition, alarming growth of population in this ecologically sensitive and fragile niche has posed a major threat for its very existence. Wide scale reclamation, deforestation and unsustainable resource exploitation practices have together produced changes in the physical and biological dynamics of the coastal system.

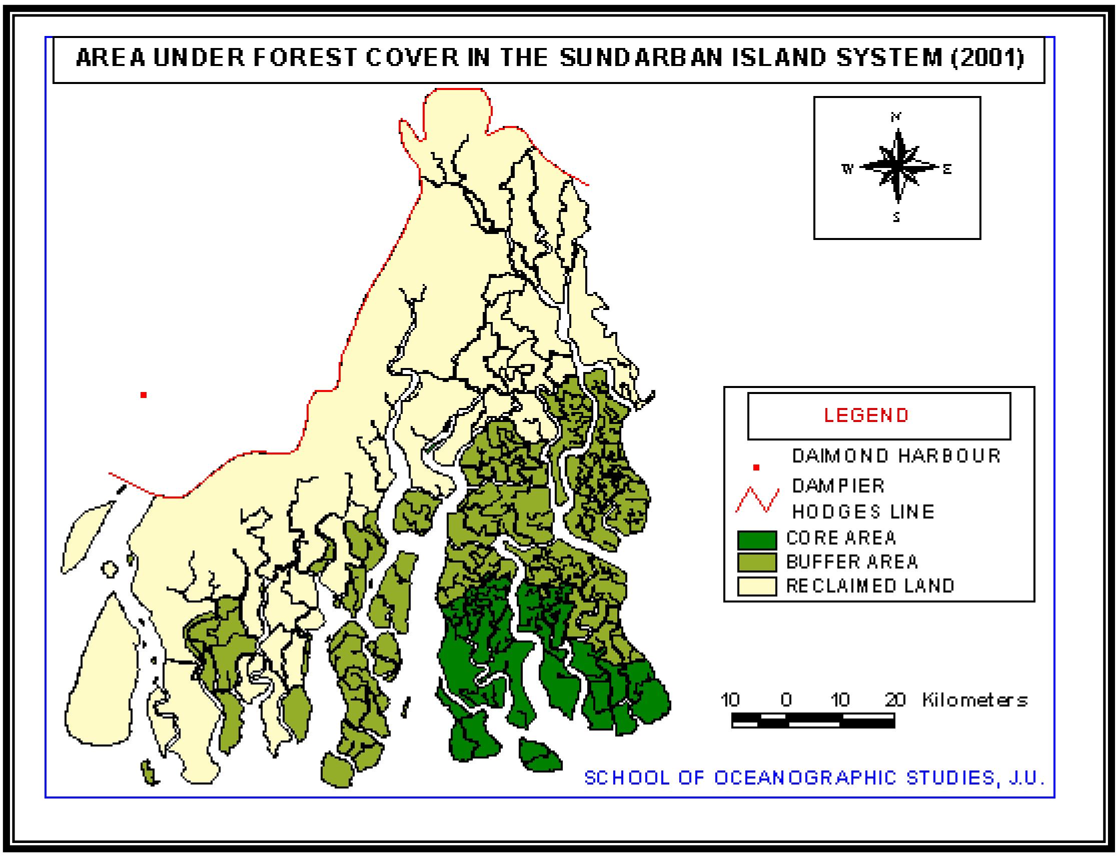
In the present research, we have tried to observe the changes if any, in the physical dimensions of this coastal ecosystem over a period of 10-20 years. For this purpose we have selected components such as i) temperature regime, ii) occurrence of high intensity climatic events like cyclones, iii) shoreline change and iv) sea level change. Simultaneously, biological and social aspects like changes in forest cover and land use patterns, food grain, fish production and population pressure have been studied to understand the vulnerability of the ecosystem with respect to possible climate change. Eventually, a mathematical model developed by the school has been applied to predict future shore line positions of the Sagar island in different sea level rise scenarios. The possible impact of such changes on the other bio-physical and socio economic dimensions of this coastal ecosystem, however, remains to be investigated further.

Geological Background

The Indian part of Sundarbans lies between $21^{0}30^{'}$ N and $22^{0}40^{'}48^{''}$ N latitude and $88^{0}1^{'}48^{''}$E and $89^{0}04^{'}48^{''}$ E longitude. It is delimited in the north by the so called 'Dampier-Hodges line' demarcating the northern extension of the intertidal zone marked by mangrove forests of 1830. This line closely corresponds to Kakdwip – Basirhat – Dhaka lineament picked up from satellite imagery (Chakraborty, 1991). In the south, the Sundarbans is bound by the Bay of Bengal. The river Hoogly (in the west) and the river Harinbhanga– Raimangal – Ichamati (in the east) demarcate the western and eastern boundaries respectively.

Up to the year 1770, the total area of Sunderbans of India and Bangladesh was estimated to be around 36,000 sq. km., which at present, stands to be 25,000 sq. km. The Indian part consists of 9630 sq. km. and the rest lies within Bangladesh. Out of the 9630 sq. km., 4264 sq. km. of Wetland / Mangrove constitutes reserve forests, which inturn comprises of 2195 sq. km. of Wetland – Mangroves and 2069 sq. km. of tidal river . This means that the reclamed area around 5,366 sq. km. (Figure 1) is used for human settlements in 19 blocks (13 in South 24 Paraganas & 6 in the North 24 Paraganas).

Fig. 1



The Sundarban island system is geologically very recent. The Delta outbuilding of Ganga-Brahmaputra system though initiated at the end of Miocene, could have reached the present location of Sundarban delta, not more than 10,000 years back (Pleistocene to Recent). The geological formation covering the island system belongs to the so called 'Bengal Alluvium'. The facies and palaeo environmental maps prepared by Raman & Neogi 1986, show an eastward prograding delta changing southward since the early Miocene, with a position of shoreline change from NE-SW to nearly E-W in the Quaternary. In the Pleistocene-Recent period, depositional trends changed significantly. The discontinuation of the eastward thickening of sedimentary formations is probably due to the reduction in the rate of subsidence of the Bengal Basin floor along the N-S axis, leading to rapid filling up of the basin. The Pleistocene eustatic sea level fall has created widespread terraces and deep erosion of valleys by lowering of base level (Alam, 1996). The sediments brought in by the Ganga-Brahmaputra system during the post-Pleistocene period probably bypassed the deltaic part for a great extent, which contributed to the rapid growth of Bengal deep sea fan (Biswas, 1993).

During the recent times the Bengal delta acquired a typical tide dominated lobate form with a tidal range varying between 3.7 to 5 m. The estuarine mouth of Hoogly and it's numerous distributaries like Saptamukhi, Jamira etc. acquired a typical seaward flaring funnel shaped pattern. Due to progressive shallowing of channels, the height of tidal bore became maximum 6.4 m and further inland this increased to 7.17 m (Tide Table of Hoogly river, 1984). The flood and ebb tides have a semi-diurnal nature (12.5 hrs interval) and occur twice daily. Within this cycle floodwater flows for 2-3 hrs duration. At the remaining 8-9 hrs, the estuary is covered by ebb tide flow of lesser velocity.

From the very begining, Sundarban with it’s numerous large and small islands remains a subsiding delta, with vertical upbuilding. Fragments of ‘ceriops’ tree obtained during excavation of George’s Dock at Kolkata below sea level (14 m bgl) justify the fact (1st Working Plan, Dept. of Forests, Govt. of West Bengal, 1962).

An intricate network of distributaries, channels and tidal creeks dissect the area forming numerous plano-convex islands made up of silt and silty clay. The islands of 3 to 8 m height, are partially/ often completely inundated by water during high tide,. The subsidence in these areas is comparatively more severe than in the open coastal parts of Digha and these are often manifested by mild earth tremors occasionally. Rarely there are instances of sudden subsidence like that during 1897, which created a series of 'Bils' instantaneously at Rangpur &

Mymansingh now at Bangladesh; (1st Working Plan, Dept. of Forests, Govt. of West Bengal, 1962).

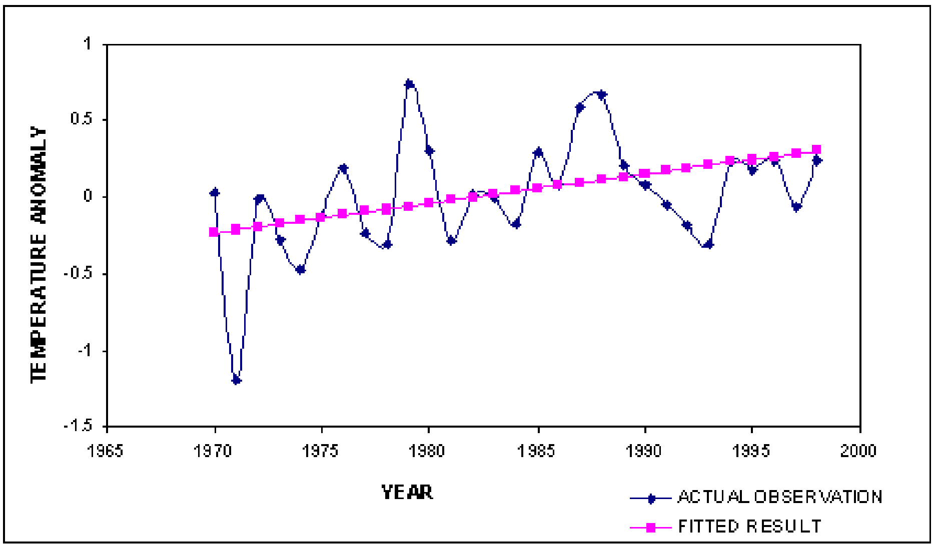
According to Morgan and McIntire (1959), the Bengal Basin, and this part of the deltaic plain is gradually tilting towards east. This has probably caused the main fresh water discharge to shift gradually eastward (through Bangladesh) imposing severe stress on freshwater budget for Hoogly-Matla estuary. According to Milliman (1989) the eastern part of the Sundarban delta is experiencing a higher rate of subsidence due to sediment loading. This subsidence rate is often close to 6 mm/year as measured at some places of Bangladesh.

The tide dominated estuarine system exhibits typical flow separation, with downstream freshwater flows along the right bank and upstream saline water tide flowing along the left bank (eastern) of the channel. The Hoogly-Matla estuary however experiences a higher rate of freshwater discharge than its eastern counterpart and therefore is less saline and comparatively well mixed. The salinity gradient increases eastward from Matla river as the erstwhile rivers have now been partially / completely cut from their freshwater source and contain tidal water only, apart from the seasonal rainwater that flows from the islands.

Recent Changes in temperature regime over Sundarbans:

Surface air temperature anomaly data over the Sundarbans and adjacent parts of the Bay of Bengal (Fig.2) has been analysed to find an increasing trend in the yearly rise in temperature. This finding corroborates with the existing global warming phenomena. Temperature increase is found out to be @ 0.019^{0}C per year (Fig.2). A similar rising trend is also observed for changes in the maximum and minimum temperature record collected from the sand head in the Sundarbans (Fig. 3a & 3b).

Fig 2.



Surface air temperature anomaly data over 20^{o}N-25^{o}N and 85^{o}E – 90^{o}E reveals an increase of Temperature @ 0.019 ^{o}C/Yr., which is correlatable with Sea Level Rise

Fig. 3a

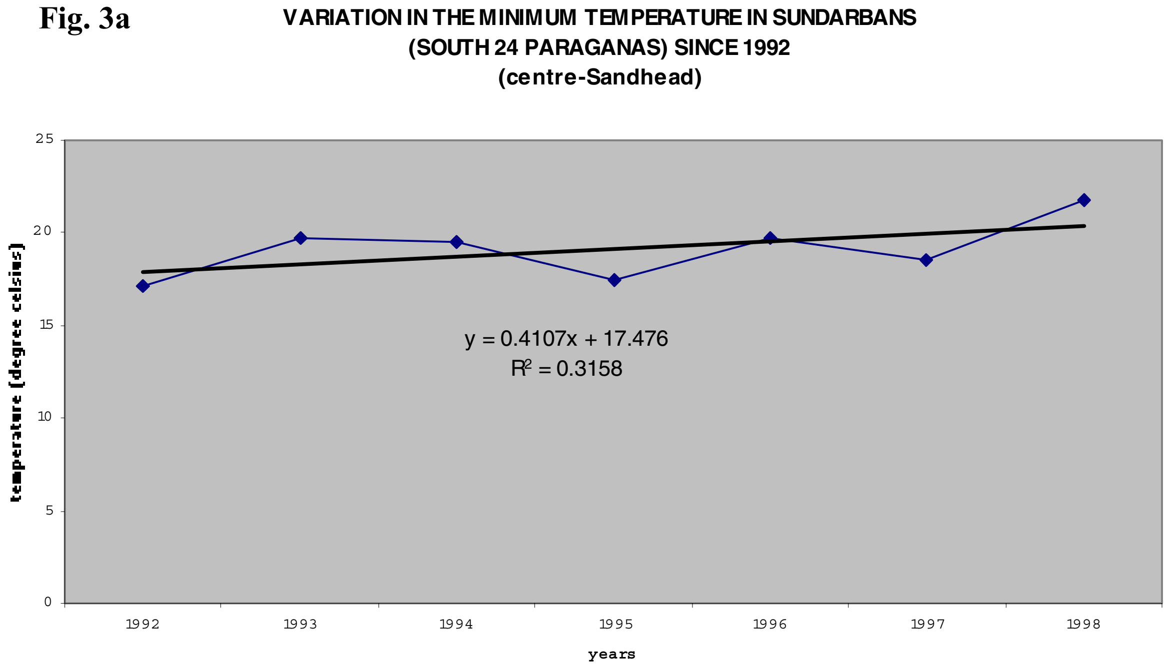
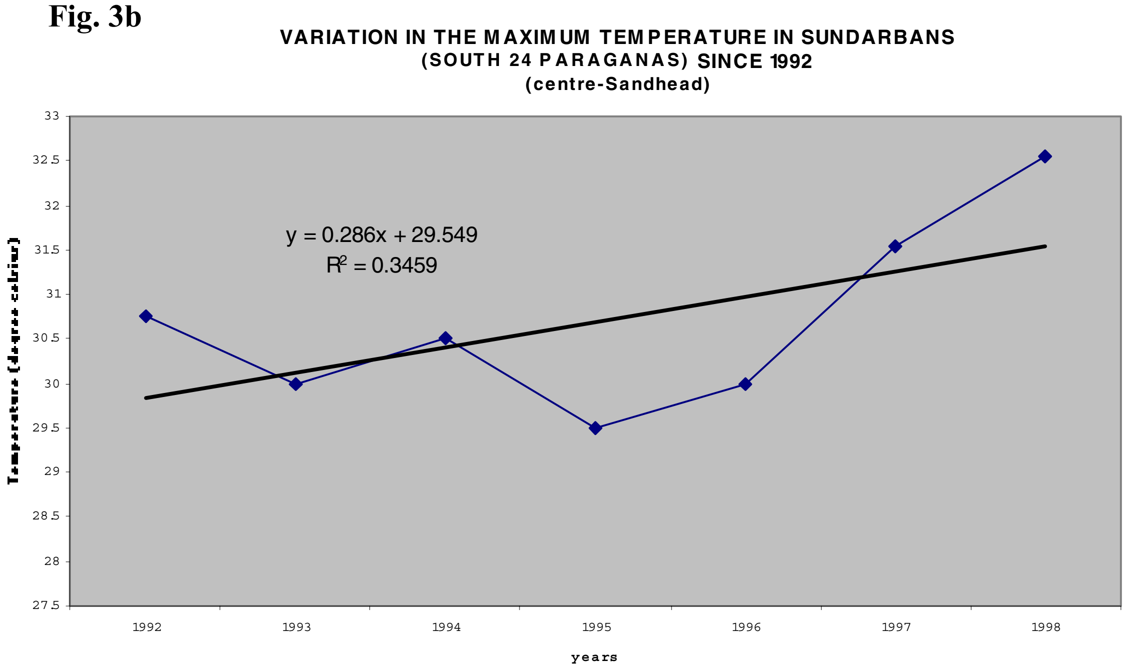


Fig. 3b



Changing pattern of cyclones over the Sundarbans:

The analysis of available records of cyclones over the Bay of Bengal adjoining the Sundarbans, exhibits an increasing trend in the degree of their intensity while showing a decrease in the frequency of occurrence (Fig. 4a & 4b). This is a striking phenomena in the perspective of warming trend discussed earlier and has significant bearing on the extent of coastal flooding, erosion and saline water intrusion due to storm surges.

The increase in the intensity also implies increase in the precipitation pattern over this part of the Bay of Bengal.

Fig. 4a **Frequency of depressions, cyclonic storms & severe cyclonic storms in the Bay of Bengal coast (1970-2000)**

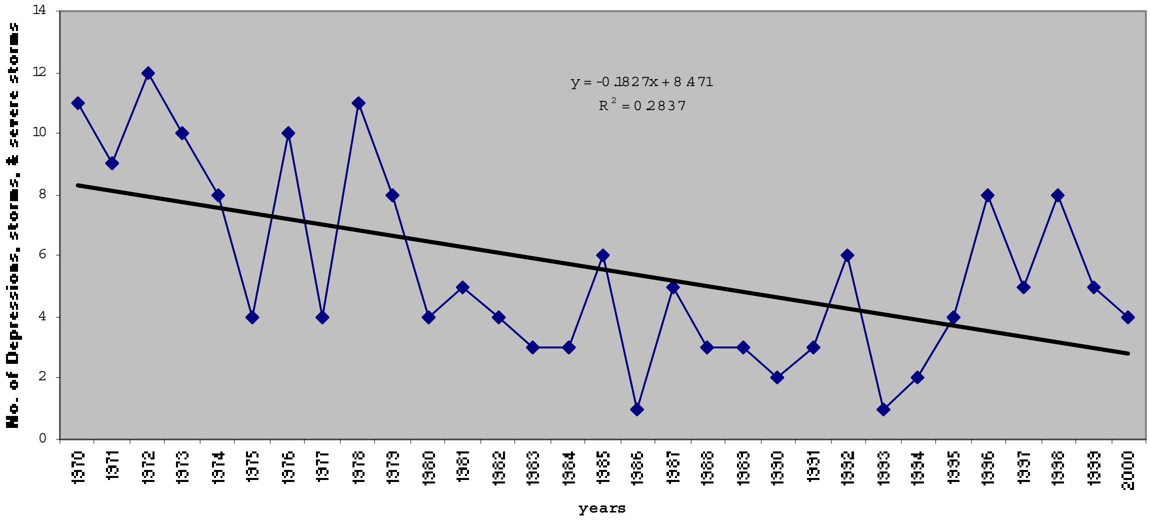
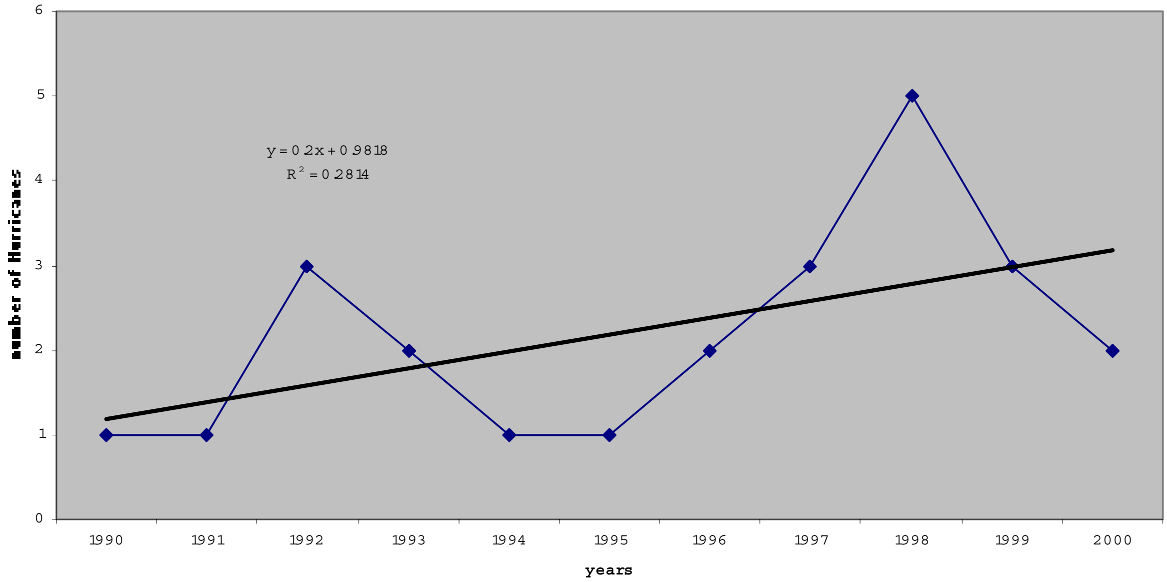


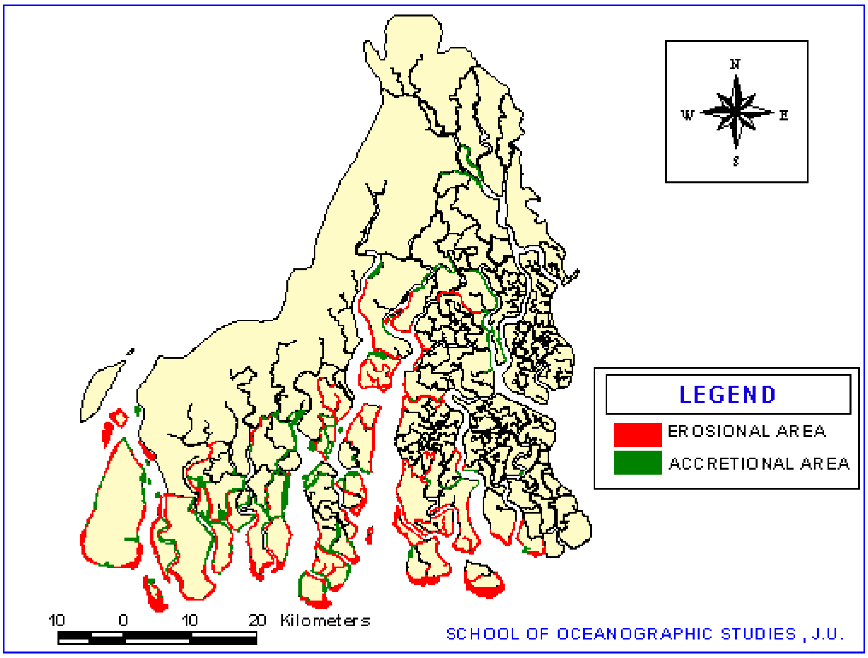
Fig. 4b **No. of Hurricanes in the Bay of Bengal Coast (1990-2000)**



Erosion –Accretion pattern in the Sundarban Island system

In order to understand the process of natural erosion – accretion of the geomorphic features in a tide dominated deltaic island system; a detailed field study was undertaken in the islands of Hugli-Matla estuary during the period 1996 to 1999. Within this four year span, the different geomorphic units generated by the complex interplay of freshwater flow of river, tidal current, wave and wave induced current and wind were studied. The specific form – process interaction in this dynamic set up is critical in understanding the response of the coastal system to any change in the external parameters of the environment like climate or sea level change. A time series analysis of the change in the shape, size and geomorphic features of the island over the past 32 years (1969-2001) has been done with the Survey of India's topographic maps and recent satellite data (Fig.5). The results show some important changes like degradation of mangrove swamp and mud flats, increase in salinisation and development of saline blanks within mangrove swamp, and overall reduction of land area inspite of feeble delta outbuilding phases.

Fig.5: <u>MAP SHOWING ZONES OF EROSION AND ACCRETION IN THE SUNDARBAN ISLAND SYSTEM</u>



The vulnerable zones identified from satellite data, were further confirmed by repeated field checks and detailed grain size analysis of sand flats and sandy beaches. Method of statistical analysis of grain size parameters (Friedman, 1961; Folk, 1957) has helped to bring out a definite pattern in erosion & accretion domains. Such analysis has also indicated the relative contribution of current, tide/wave in the process of shoreline changes in the study area. It has emerged from the analysis of remote sensing data and field mapping, that a significant reduction of land area (around $86Km^2$) has occurred in the estuarine island system over the past 3 decades. This has happened in spite of huge sedimentation by the river Hugli and increased freshwater inflow by the river after construction of Farakka barrage.

The important observations regarding the erosion accretion pattern of the island system can be summarised as follows:

- Erosional zones are most prominent among the 12 sea facing southern islands including Sagar at the west to Bhangaduni in the east.
- 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 162.879Km^2
- The western banks of the island are more vulnerable than the east and the rate is more severe indicating the role of tidal surges. Erosion is also seen along the sea facing shorelines where it is oblique.
- Marginal accretion is localised in the inner estuary particularly along eastern and northern margin of islands and along the coast where it is mostly E-W and sea facing. Amount of land accretion over the past 30 years is estimated to be 82.505Km^2.
- Emerging mud flats of 70's have suffered the maximum loss, due to not only erosion, but probably submergence as well.
- The eastern matured islands are found to be comparatively more stable due to the presence of thick mangroves and lesser anthropogenic activities. Only marginal submergence is observed.
- Within the island system, Sagar Island has suffered the bulk of erosion with an areal loss of 30 sq. km with marginal accretion.

Sea level changes in Sundarbans during recent times

During the present course of study it has been seen that the island system of the Hoogly-Matla estuary is suffering a significant amount of net land loss inspite of the reactivated delta pro gradational process. Significant beach lowering has been observed over the erosional domains of the coastal tract. It is seen from the map (Fig.5) that the erosion/submergence dominates in the southern part of the island system. This points to a possibility of relative rise in sea level in this part of the Bay of Bengal, rather than paucity of sediment supply or other anthropogenic interventions, to be the causative factor for erosion and submergence of the island system. This contention is also supported by similar observations from the open Digha– Junput coastal stretch which shows a parallel retreat of shore line with time over the last decade.

For rapid appraisal, sea level fluctuations were estimated from the tide gauge data of Sagar island observatory (21°31'N 88°03'E) only. Based on similar analysis of tide gauge data

Warrick and Oerlemans (1990) estimated a global sea level rise in the order of 0.5-3 mm per year. In the present study, possible contributions of ocean-atmospheric effect, vertical land movement and anthropogenic activity have been carefully assessed and filtered out. Atime series analysis of the mean undisturbed sea level, free from any perturbation has alone been considered.

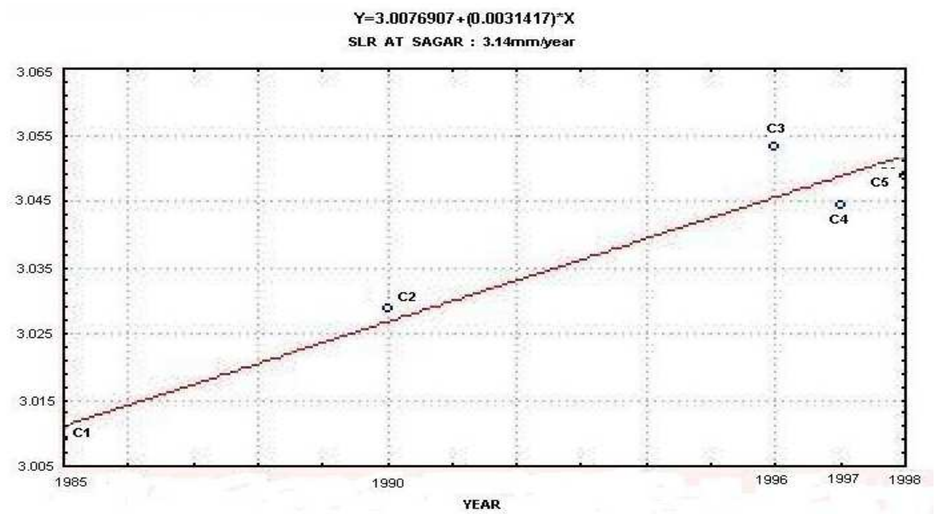
Data of 5 years, viz., 1985, 1990, 1996, 1997 & 1998 has been examined. Measurements have been taken daily on a 6 hourly basis. Monthly mean sea level has been calculated using continuous data of high and low tides for every month. Annual mean sea level of the respective years has been calculated taking the mean of the monthly data. From the least square fitting of regression line on the data of annual mean sea level, an estimation of yearly rise of annual mean sea level has been made. The 'zero' elevation has been taken for undisturbed sea surface, free from any perturbation.

Year wise variation of the mean sea level gives some impression about the involvement of excess water in the system. However, as the difference between highest and lowest monthly mean sea level of a year is found to be constant approximately, the possibility of variable contribution and influence of rainwater and other water influx/outflow from the system, on the change in relative sea level can be ruled out. So, the increase in gradual sea level definitely reflects a macro-scale global change.

Annual Change in Sea Level

From a year wise comparison of mean sea level values it is found that highest mean sea level values were found in the month of September in the year 1985, in August in the year 1990 and also in August in the year 1996. However, the occurrence of highest value shifted to July in the year 1997 and 1998. The highest annual mean sea level was observed in 1996. Excess water mass accumulation reached maxima probably due to El-Nino phenomena in 1996-97.

Fig. 6: Annual Sea Level Variation at Sagar



Comparing the annual sea level variation (Fig.6) 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 the study period (1985 - 1998) of total 14 years. Some corrections have been adopted to exclude the effect of sediment loading. Finally from a least square fitting of regression line on the data of annual mean sea level, a yearly rise of annual mean sea level has been estimated to be 3.24 mm per year. In the Ganga-Bramhaputra delta the suspended sediment lode is high. If we consider sea level rise due to sedimentation to be 0.1 mm per year, the net rate of sea level rise would be 3.14 mm per year (Fig.6). This is significantly more than the present trend of average global sea level rise of 2 mm per year.

The intercept length or C value of the regression equations for the period 1985 – 90 has been compared with that of 1990- 98. It reveals that undisturbed mean sea level without any seasonal perturbation has risen by 1.62 cm. in five years period. This also suggests a rate of increase little over 3.24 mm / year which supports our earlier findings.

Considering the present relative sea level rise @ 3.14 mm per year, it is estimated that by the year 2050, the compound sea level elevation will become close to the 1 m scenario of Broadus (1993).

The estimated rise of sea level will pose serious problems during the pre- and post-monsoon phase when most of the cyclonic storms occur.

The effect of the storm surge is likely to be more devastating in areas which were not earlier vulnerable. Even the Calcutta City is expected to be affected by inundation during monsoon instability coupled with high rainfall and high tide in the River Ganga.

Correlation Study Between Sea Level Rise and Rate of Erosion

Could there be any linkage between the erosion-accretion rate as measured in the study area with the rate of rise and fall of relative mean sea level? Or was the erosion accretion phenomena forced by some processes other than the rise of sea level independently controlling the shoreline movement? With this objective in mind, statistical analysis and mathematical correlation studies were undertaken with the available data. The analysis has been able to establish a direct correlation between the amount of erosion and submergence with the rate of relative rise and fall of sea level in different island segments. Even in the existing accretion domains it is found that not only erosion, but also the accretion rates are sensitive to the sea level rise as well. These findings and linkage establishment were essential for developing a diagnostic and predictive model of shoreline change.

This analysis has been conducted by using data from the following places (i) Sagar Island (ii) Chuksardwip (iii) Jambudwip (iv) Namkhana (vi) Mousuni island.

The correlation coefficients between rate of sea level rise and erosion rate at various locations for each of the six islands have been computed. These are elaborated in the table (Table: 1) below.

Table 1: Correlation between Sea Level Rise and Erosion - Accretion of different Islands

Name of Island	Location	Coefficient of Correlation	Impact
Sagar	North-East	0.999689	Strong Erosion
Sagar	South-East	0.994535	-Do-
Sagar	South-West	0.994258	-Do-
Sagar	South	-0.999979	Strong Accretion
Chuksardwip	North-East	0.540393	Erosion not so strong
Chuksardwip	South-East	-0.224691	Accretion but effect of SLR is least .
Chuksardwip	North-West	-0.575965	Strong Accretion
Chuksardwip	South-West	-0.465315	Moderate Accretion
Namkhana	South-East	0.983043	Strong Erosion
Namkhana	North-West	0.459758	Erosion not influenced by SLR
Mousuni	North-West	0.706928	Erosion influenced by SLR
Mousuni	South-West	0.641429	-Do-
Jambudwip	North-East	0.877821	Strong Erosion
Jambudwip	South-East	0.979289	Very strong Erosion
Jambudwip	North-West	-0.233793	Accretion but effect of SLR is least .
Jambudwip	South-West	0.994252	Strong erosion

Analysis

From the analysis it is revealed that in the NE, SE and SW part of the Sagar Island, a strong correlation exists between sea level rise and erosion. In the southern part of Sagar Island there is strong evidence of accretion. Significantly, the correlation between rate of sea level rise and accretion rate is very high.

In the North-East part of Chuksardwip only erosion effect has some correlation with sea level rise. The South-East part of Chuksardwip has registered accretion. But here the accretion rate is not strongly correlatable with sea level rise. In North-West part of Chuksardwip, strong evidence of accretion can be found. In this region we find a good correlation between sea level rise and accretion rate. This is an interesting finding, where we can conclude that accretion/siltation in someway, at least partially, is related with the phenomena of sea level rise in this part of the estuarine system. Chuksardwip being an emergent tidal ridge covered by sand flat, it is possible that the excess siltation and deposition around the island and channel floor is contributing to the relative rise of sea level, at least locally. Similar evidence is also observed on the South West part of Chuksardwip. Here sea level rise has moderate correlation with accretion rate.

In the South-East part of Namkhana, erosion rate is strongly correlatable with sea level rise, but in the North-West part correlation between sea level rise and erosion rate is moderate. In the North West part some other physical processes perhaps control erosion rate.

Influence of sea level rise on erosion rate at Mousuni Island is also significant. But this correlation is not so strong as has been observed in the case of Sagar Island.

In North-East, South-East and South-West parts of Jambudwip erosion rates are strongly correlatable with sea level rise. But in North-West part of Jambudwip, which is an accretion zone, sea level rise cannot be correlated with accretion rate. In this part it can be concluded that sea level rise has least influence on accretion.

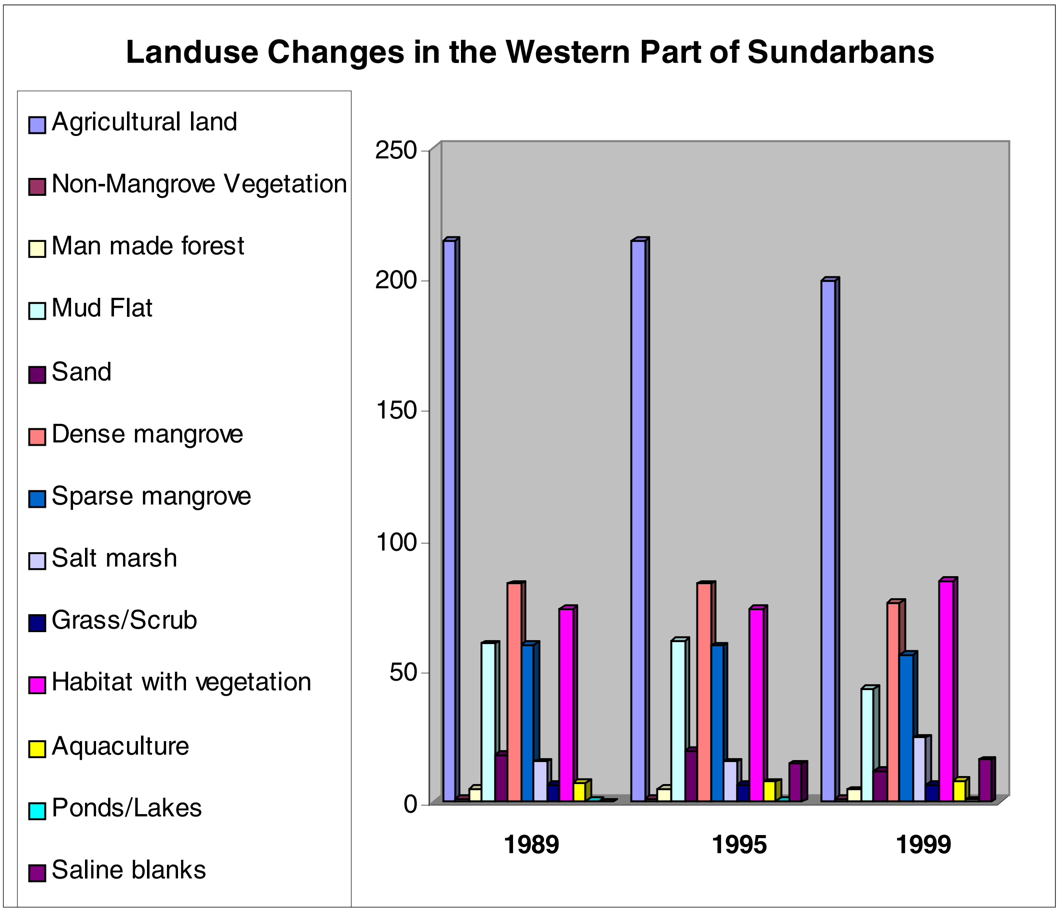
From the present analysis it is apparent that Sea level rise has a dominant influence on coastal erosion. But it is also worthnoting that at some places sea level rise has a strong influence on the processes leading to accretion and vice versa.

Land use changes

The impact of such erosion- accretion processes and sea level rise induced changes is expected to be felt mostly along the coastal zones of the island system, along the tidal creeks, and mangroves swamps and is expected to affect human activity and resource utilization patterns in the coastal zone. In order to assess the impact of such sea level rise and other anthropogenic and climatic changes on the landuse–landcover pattern of the Sundarbans, we have selected the western segment of the island system lying between the Hoogly-Matla estuary which includes an early reclamed human settlement area along with some protected reserve forests with dense mangrove forest cover. Landuse/landcover maps of the notified Coastal regulatory Zone area prepared by IWMED, in 1995 using the SPOT imagery of 1989 have been compared with the IRS-1B: LISS-II data of 1995 and IRS-1B: LISS-II data of 1999. During this study, caution has been taken to ensure that the time period of the satellite data remains the same and a thorough field checking has been done in order to make this study as comprehensive as possible.

The change of land use units over the time span of 1989 to 1995 and 1995 to 1999 has been shown with the help of a Bar chart (Fig.7)

Fig. 7



A scrutiny of the land use land cover change data in the decadal scale (Fig. 7) reveals that while the **natural** causes like erosion, accretion, submergence due to sea level rise (SLR) and corresponding geomorphic changes can account for the 66 % of land use land cover change in the study area, **anthropogenic** forces like population growth, conversion for quick economic return, urbanization and unwise exploitation of natural resources account for the rest. However there do remain some unaccounted anthropogenic changes like construction of earthen embankments, cyclone shelters or planned plantation of mangrove to prevent erosion along the coast. These changes may be classified under **nature adaptive changes**, which constitutes only 2% of landuse changes in the decadal level.

The pattern of such changes in land use pattern may be summarised as follows:

Natural Changes

From		To	Causes
Mud flat	→	increase	: Accretion
Mud flat	→	decrease	: Submergence due to SLR

Mud flat	→	Sand flat	: Flow Regime shift due to SLR
Sand flat	→	Mud flat	: Progradation
Mud flat	→	Mangrove	: Colonization in swamp
Beach	→	increase	: Accretion
Beach	→	decrease	: Erosion due to SLR
Sand dunes	→	increase	: Accretion
Sand dunes	→	decrease	: Erosion due to SLR
Salt Pans	→	increase	: Salinisation
Mangrove	→	increase density	: Colonization
Mangrove	→	decrease density/ retreat	: Degradation/ SLR
Earthen Em-bank ment	→	decrease	: Erosion/submergence due to SLR
Total available Land within CRZ	→	decrease	: Erosion due to SLR

Anthropogenic changes

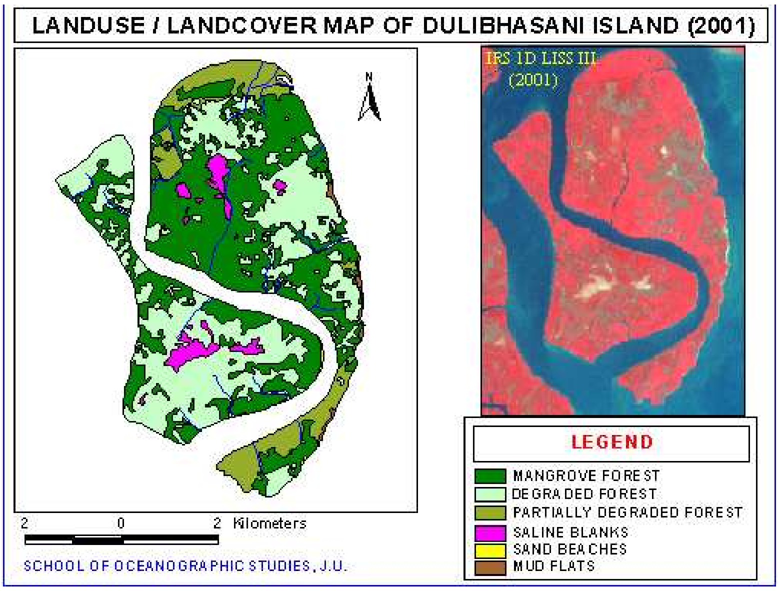
Mangrove/ Mudflat	→	Agricultural land	: Reclamation/Population
Agricultural land	→	Aquaculture	: Population Demand
Mud flat	→	Aquaculture	: Population Demand
Salt pans	→	Aquaculture	: Population Demand
Mangrove	→	Aquaculture	: Population Demand
Agricultural land	→	Brick kilns	: Urbanisation
Mudflats	→	Brick kilns	: Urbanisation
Agricultural land	→	House holding	: Population growth
Mudflats/Ag. Land	→	Ponds	: Reclamation/Population
Mangrove	→	decrease	: Deforestation

Nature Adaptive Changes

Creek banks	→	Embankment	: Natural hazard Mitigation
Dunes	→	Cyclone shelter	: Natural hazard Mitigation
Creek bank/mud flat/ Sand flat	→	mangrove forest	: Plantation to prevent erosion

In the above analysis we have included the so called saline blanks which were not mapped in detail earlier. These are small shallow pools with salt encrustation. They can be seen in many mudflats and mangrove swamps in this island system. Around these salt pools or, geomorphologically, saltpans, the mangrove vegetation gets depleted and degraded, creating a 'blank' surface, devoid of vegetation. There can be two types of such saline blanks/ saltpans, the 'primary pan' initiated as a small depression on a swamp surface and 'channel pan' or abandoned creeks with sinuous outline (Steers, 1977; Pethick, 1974, 1984). Result of initial mapping of saline blanks of Dhulibasani island is given below (Fig.8). However, the cause for the enlargement of such saline blanks with time remains to be investigated yet.

Fig. 8



From the foregoing discussion it is apparent that there is a significant impact of SLR induced erosion-accretion process on the land use change dynamics of the area. The conversion of agricultural land, mangrove or mudflats into aquaculture farms, reclamation can obviously be attributed to increasing population pressure, and growing human need leading to unwise utilisation of natural resources. The other changes, like reduction of land area within the coastal regulatory zones, degradation of mangrove and increasing salinisation, erosion and submergence of beaches/mud flats and artificial embankments, on the other hand, points to the natural stress developing within this system due to the erosion accretion process linked with sea level rise. These two independent forces finally make the island ecology extremely vulnerable to any future changes in the environment.

It will be prudent to review the changing population pressure on this fragile ecosystem.

Population Pressure

At present (2001) the Indian part of Sundarbans hosts a population of around 4.1 million, living in the high risk zone of cyclone and storm surges. Sundarban, one of the least developed areas of West Bengal, has been experiencing a tremendous pressure of population over the years. There are 6 Community Blocks of North 24 Parganas-Haroa, Minakhan, Hasnabad, Hingalganj, Sandeshkhali-I, Sandeshkhali-II and 13 community blocks of South 24 Parganas- Jaynagar-I, Jaynagar-II, Kultali, Canning-I, Canning-II, Basanti, Gosaba, Kakdwip, Namkhana, Mathurapur-I, Mathurapur-II & Patharpratima that fall within the Sundarbans. All these blocks are densely populated with an average density of 690 persons per sq. km. (according to 1991 Census). The population of each block varies from 120,000 to 250,000 (1991 Census). The total population of the area in 1991 was 3154910. The overall change in the population density of each block since 1961 has been depicted (Fig.9) below:

The first census in 1872 of these blocks showed a population of 296,045. In 1901, by the turn of the century, it became 487,377, a rise by 65%. By 1931, the population became 754,421 a rise of 55% over 1901. After the partition, in 1951, the population was 11,59,559 which rose to 3154910 in 1991, a rise of over 160% just after the Independence (Kanjilal, 2000). It is estimated that in 2020, the total population of the region will grow to 4.6 millions or even more. This steady rise in the population size is alarming and if this continues, it would certainly have far reaching effects on the overall ecosystem of the area. Table- 2 shows the overall change in the growth rate of population under each block since 1961.

Fig. 9 Density of Population in Sunderban Area since 1961

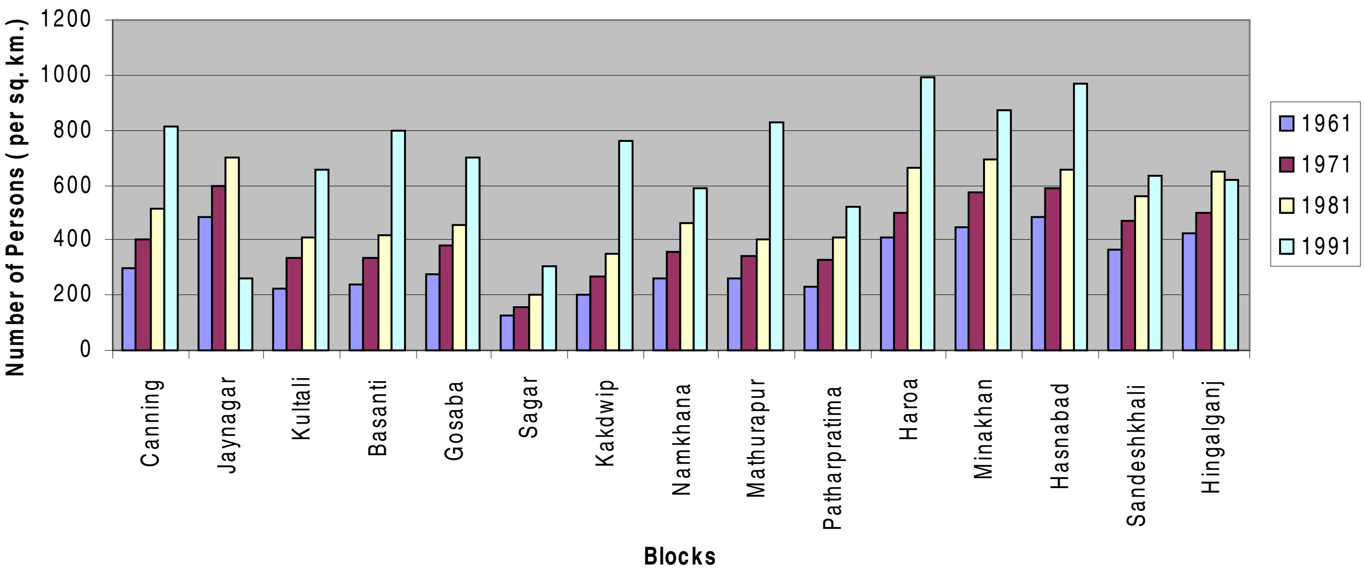
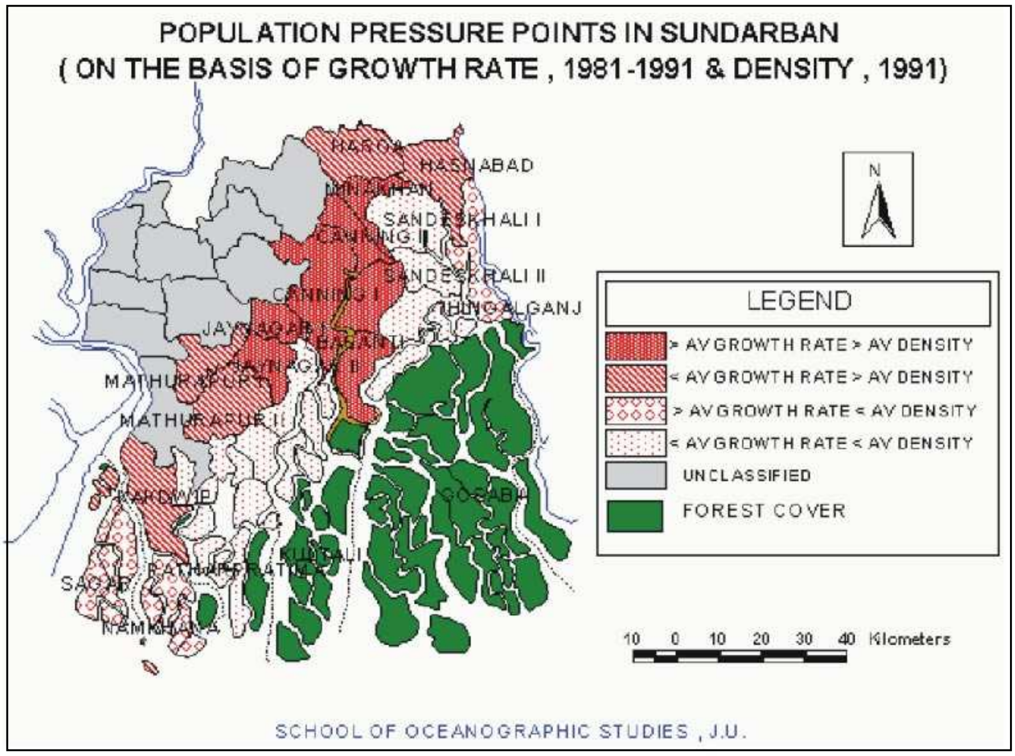


Table 2: Growth of Population (in percentage) in different Blocks of Sundarban since 1961

Blocks	1961-'71	1971-'81	1981-'91
Canning	33.85	27.73	39.87
Jaynagar	23.70	17.40	42.49
Kultali	47.46	22.82	6.32
Basanti	41.17	26.69	31.69
Gosaba	36.16	19.52	19.12
Sagar	23.90	26.29	33.82
Kakdwip	31.07	30.60	13.98
Namkhana	36.22	30.84	81.18
Mathurapur	28.96	17.36	28.72
Patharpratima	41.92	23.17	24.24
Haroa	21.37	31.84	12.64
Minakhan	38.80	11.99	29.14
Hasnabad	21.46	11.78	5.12
Sandeshkhali	29.90	18.43	25.31
Hingalganj	19.15	28.72	35.78

Population pressure points have been delineated on the basis of average growth & average density change rate (Fig. 10).

Fig. 10



In 1981, the figure for the proportion of rural population to urban population was 97.30%. Hence, Sundarban is predominantly a rural region where most of the people eke out a living from agriculture & allied activities. About 89% of the total population of the region are agriculture dependent on reclamed lands that bear the single crop of paddy (Aman- a monsoon dependent paddy). The poverty level of the agricultural labourers can be assessed in the region where about 50% of the cultivators are landless and the number is on the increase. Other than agriculture, fisheries provide the major source of employment and income for the people. Other occupations are fuel-wood cutting & honey collection. A slow pace of socio-economic development and lack of infrastructure for the building up of industries both have largely accounted for the majority of the inhabitants to depend on land and water for their livelihood in the Sundarbans.

Agricultural pattern in Sundarban:

Agriculture forms the backbone of the economy of Sundarban, where almost the whole area is dependent on a single crop, the rain-fed paddy *aman*. Though during 1992-'93, Sundarban was predominantly a two crop region where aman paddy was grown in association with wheat, (Fig. 11), in the year 1999-2000, - it turned totally into a monocrop region producing rain fed aman paddy only (Fig. 12).

Fig. 11

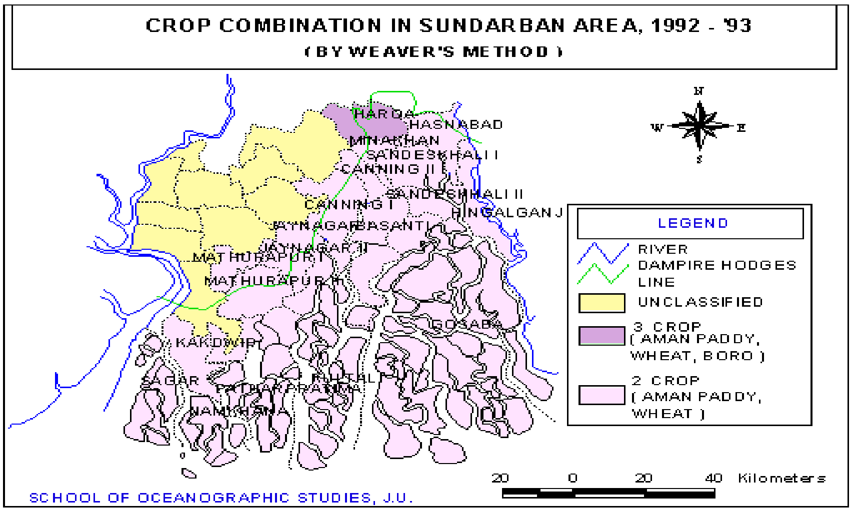
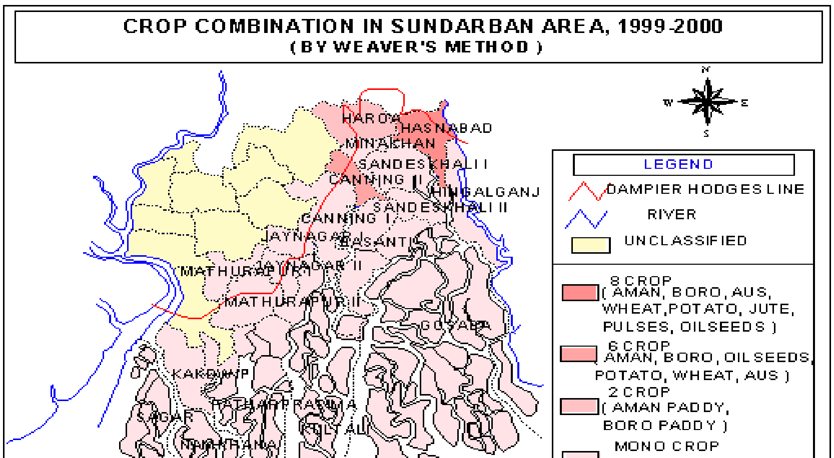


Fig. 12



However, a preliminary investigation indicates that both production and productivity of aman has a negative relation with rainfall that is in the eventuality of further excess rainfall in this region in response to a climate change phenomena, the aman production will show a decline. The winter paddy Boro on the other hand, is not very responsive to rainfall, but shows a decline with increase in temperature. Therefore in the likely hood of increase in temperature and rainfall in future, the agricultural productivity and subsistence in the Sundarbans will come under serious threat.

In the Sundarbans, the problem of agriculture is intimately related to salinity and water logging. The yield of Paddy crop is adversely affected by inadequate drainage during the monsoons. In the dry season, huge portions of land remain fallow for want of irrigation facilities. Additionally, withdrawal of subterranean water is cost prohibitive.

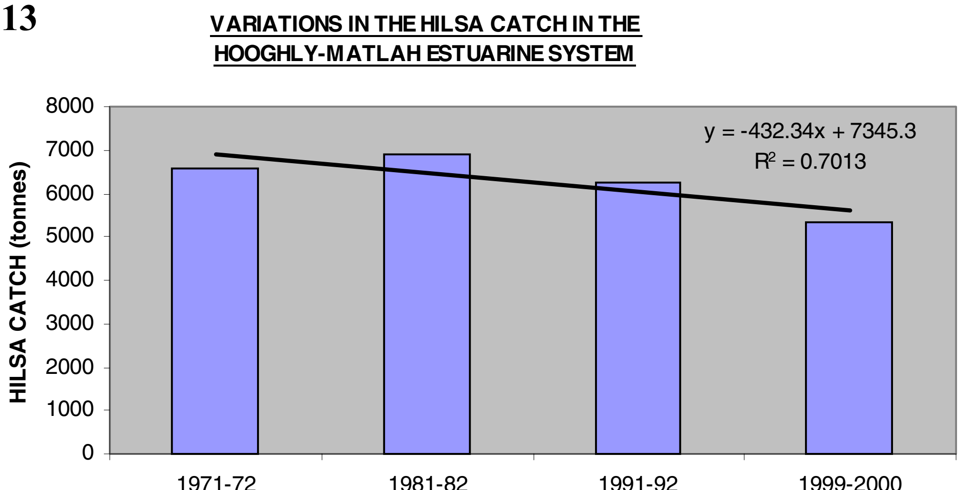
Decline in Fisheries resources

Next to agriculture, fisheries is the dominant productive activity providing employment in the region. Availability of skilled manpower is conducive to fishing. Nearly 42% population belongs to the scheduled caste & tribe, most of them are engaged in fishing.

However a critical appraisal of the major catch of Hilsa (Tenulosa Ilisha) in the Hoogly-Matla estuary of the Sundarbans shows a declining trend since the 80s. This coincides eventually with the construction of Farakka barrage on the upstream of river Ganga.

The details of catch during last 4 decades for Hilsa (Tenulosa Ilisha) is furnished below (Fig.13):

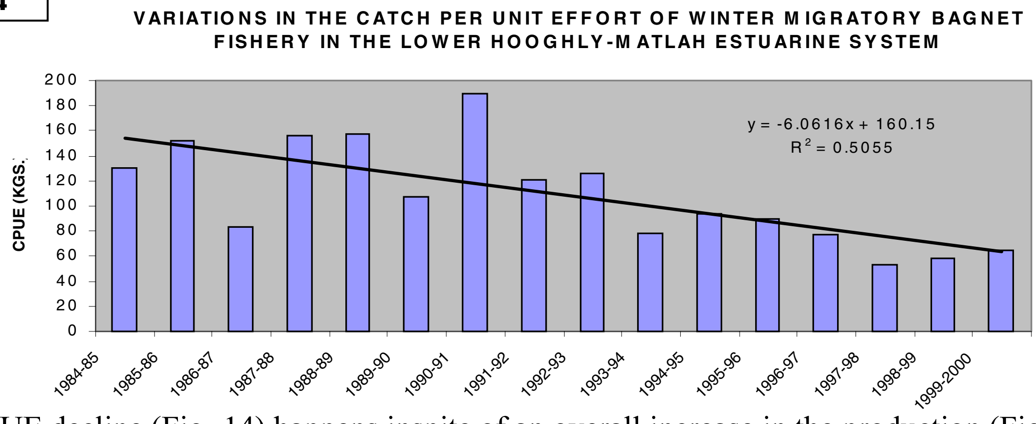
Fig. 13



Fish catch of 81.9% takes place during November to January while 3.6% the lowest catch takes place during March to June.

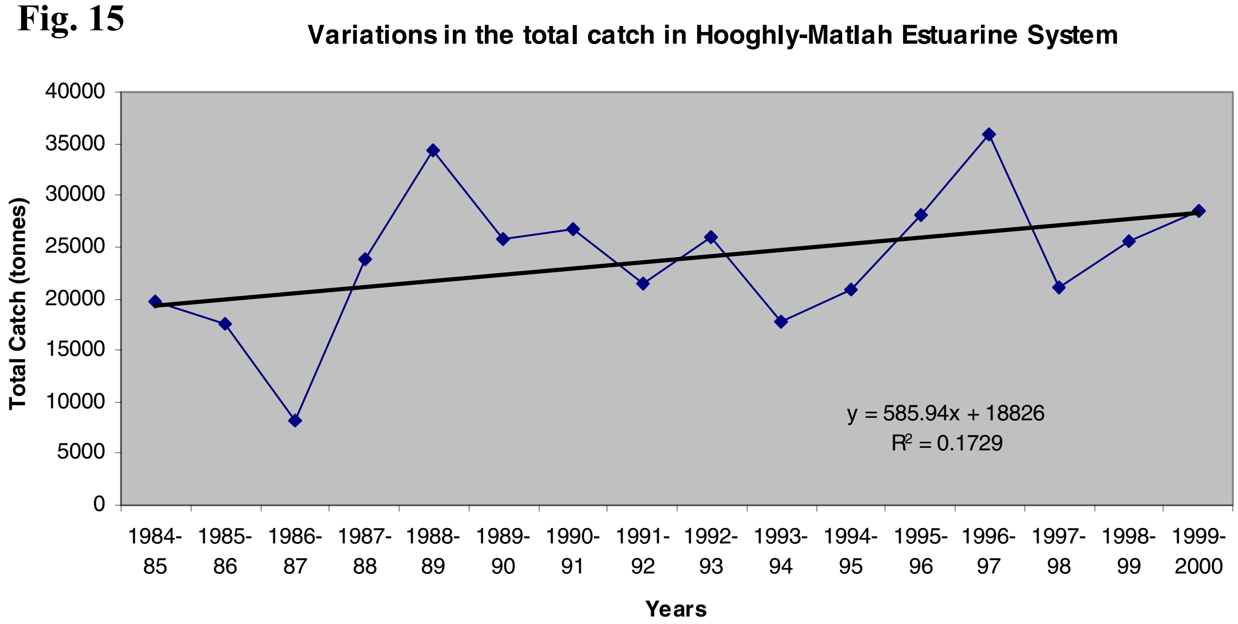
The catch statistics collected by Central Inland Captured Fisheries Institute, Barrackpore (Mitra, 1997) & (Annual Report 2000), however shows a steady decrease in the catch-per-unit effort (Fig. 14):

Fig. 14



The CPUE decline (Fig.-14) happens inspite of an overall increase in the production (Fig. 15).

Fig. 15



In Sundarbans, the major livelihood of the people is fishing in the tidal water or in the deep sea. Nearly 90% of the people are engaged either in agriculture and fishing , crab collection or honey collection. But the secondary data of catch per unit effort in the Sundarbans for the last 15 years shows an overall negative trend along with decline in the major catch Hilsa. This points to the un sustainability of such efforts in a future climate change scenario. Again, intense prawn seed collection during the 80s and 90s has resulted in a major damage to the other fish juveniles. This may endanger the livelihood of the fishermen community in near future.

Environmental migrants from the vanishing island

The rate of relative Sea level rise is presently approaching 3.14 mm per year near Sagar Island and this could increase to 3.5 mm per year over the next few decades due to global warming, including the other global and local factors. At Bangladesh the rate is more than double due to higher rate of deltaic subsidence. All over the world, the sea level rise is threatening a large number of coastal communities, 'environmental refugees' are increasing in number, may it be in Chesapeake Bay, Marshall Island or in Maldives. In India, thousands of people are being displaced from their original habitats from islands like Lohachara, Bedford or Ghoramara forming a new, vulnerable community of 'environmental migrants'. More over, the ecological community of Sundarbans, which depends upon the resource of mangrove forests for it's livelihood, is also being threatened by rapid degradation of mangrove forest. Post partition refugee influx, proliferation of aquaculture farms and other anthropogenic activities leading to large scale reclamation are all causing further environmental stress. The resource depletion and environmental stress build up can trigger large scale migration in the Sundarban island system in near future.

The island Sagar itself has registered a net loss of 30 km^2 area over the past 30 years. The entire population of the villages of Khasimara, Baisnabpara, Khasimara Char and Baghpara or Ghoramara Island has had to leave its original habitat and seek refuge in the nearby island of Sagar.

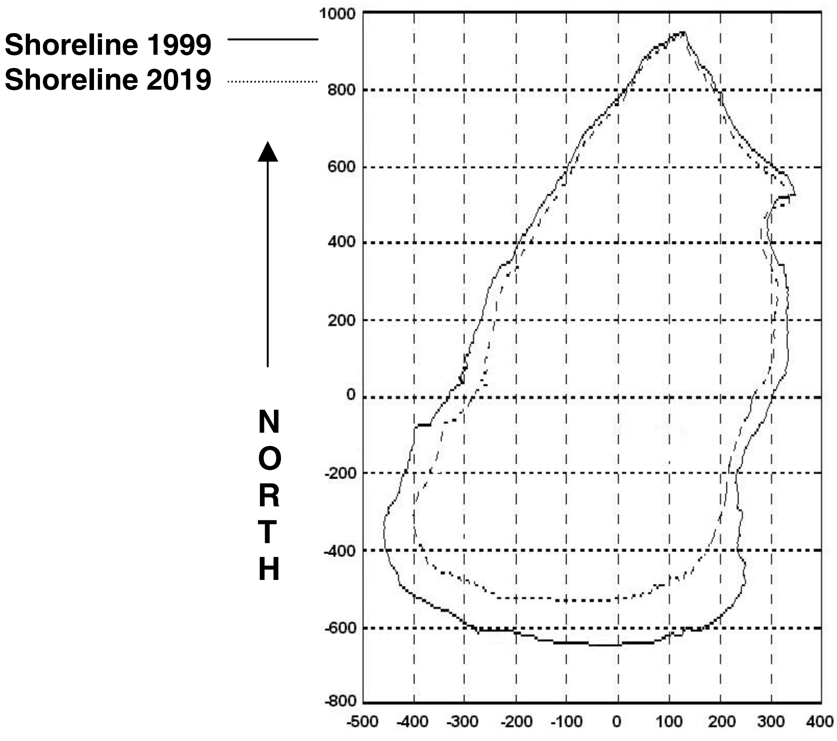
Apart from the sea level rise, the island system is also vulnerable due to recurrent coastal flooding, embankment failure and severe cyclones and storm surges, which may be termed as 'rapid onset' type of environmental disaster. An earthen embankment of 3520 Km. in length was erected in the early twentieth century to protect the agricultural land from saline water flooding and loss of crop. However with time, the embankment has been worn out and the river beds have been raised by siltation. Some of the rivers like Muringanga are even flowing above the level of island coasts. This has created conditions for breach of embankment and total wash out during cyclone and storm surges. Over the last two decades crop and forest property worth 950 million Rupees has been damaged or lost and over 0.4 million people have been affected out of which around 600 families have had to migrate and settle elsewhere as environmental migrants due to storm surges and coastal flooding. As discussed earlier, the extent and intensity of coastal flooding is likely to increase in future over this part of the Sundarbans. The islands of Ghoramara, Dublat G.P. of Sagar Island, G-Plot and Mousuni are extremely vulnerable in this respect.

Future changes:

The review of the recent changes in Sundarban indicate that among the changing environmental parameters like temperature, sea level, coastal configuration, salinity, forest cover, landuse, population, agricultural and fish productivity, the changes in shore line of the island system vis a vis sea level appears to be of prime importance in assessing the vulnerability of the fragile eco system in a climate change scenario. The other parameters like population or land use, biological production of the ecosystem may later be linked with the analysis .In order to simulate the shoreline changes with incremental rise or fall of sea level, a mathematical model considering suitable algorithm linking rate of coastal erosion/ accretion with rate of rise in sea level has been developed (JUCOAST 2002,Sen & Hazra) at the School of Oceanographic Studies Jadavpur University. In the present work, this model has been applied to study the shoreline behaviour of Sagar Island only. The impact of erosion accretion and sea level rise has been tested and validated within a time window of 1969 to 1999. A future prediction of shoreline positions at different rates of sea level rise with probable shifting, accentuation or retardation of erosion –accretion regimes has been made. This indicates, that with a little (1 mm/y) fall in the rate of sea level rise, the area as a whole shows accretion/emergence with a pronounced pro gradation in the southern part. However even with a 1 mm/yr more rise than the existing rate, the southern loab continues to prograde with reduction of the overall area from west and east. But in case of any further rise in the rate of SLR) the sea enters from all sides of the island and exhibits a typical feature of submergence.

With continuance of existing rate of SLR, the model demonstrates (Fig. 16) that the island will lose around 15% of its existing land area by the year 2020.

Fig. 16 **Shoreline Position Predicted for 20 Years with Current Sea Level Rise**



Conclusions

The important conclusions which may be arrived at from this study are:

1. Surface air temperature over this part of the Bay of Bengal is rising @ .019^{o}C/year which is correlatable with the rate of relative sea level rise@ 3.14mm/ year, near Sagar island.
2. Rate of coastal erosion and land loss in the Sundarbans is fairly correlatable with the rate of sea level rise.
3. Though the frequency of high intensity events like hurricane and cyclonic storms is likely to reduce, the intensity along with surge height may increase in future. This implies threat to the coastal population with increased risk of coastal erosion and destruction of life and property.
4. Due to coastal erosion and flooding, around 30,000 people are feared to be rendered homeless from Sagar Island alone, turning in to a kind of environmental refugees. Considering the whole of Sundarbans with the existing trend of population rise and reclamation, this number may touch 0.1 million mark by 2020.
5. Mangrove forest cover is predicted to diminish further along with degradation of the existing species combination. Some fresher water species like Heritiera, Nypa or Zylocurpus may show a trend of migrating northward, but might not get enough space due to the advancing human habitation front and may thus get extinct unless appropriate adaptation strategies are taken.
6. Agriculture and fish production may face a serious threat making livelihood and sustenance of the ecological community of Sundarbans difficult.

Acknowledgements

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