THE INFLUENCES OF NATURAL ENVIRONMENT UPON THE EVOLUTION OF SAND DUNES IN TROPICAL ENVIRONMENT ALONG MEDINIPUR COASTAL AREA, INDIA

by
Sudip Dey*
Pijush Ghosh**
Amitava Nayak***

*Dept. of Geography, Women's College, Agartala-799001, Tripura (West), India.
**Dept. of Civil Engineering, North Dakota State University, U.S.A,
***Dept. of Botany and Forestry, Vidyasagar University, West Bengal, India.

ABSTRACT

This paper assesses development of coastal sand dunes particularly along tropical coast. In-depth study along on coastal dune morphology along Medinipur coastal tract shows that sea levels remained very dynamic during the Holocene period. Evidence of Holocene sea level changes are found which were responsible for the origin almost parallel distinct dune colonies through the geological past along this coastal tract. The existence of tropical-monsoon climate with its seasonal phenomena plays an important role for long-term geomorphic development along the coast. The vegetation enhances the barrier property of dunes as well. In this paper possible biological interactions between sand mass of dunes and vegetation in different stages of development has also been dealt.

Key words: Coastal dunes, sea level change, vegetation, seasonal change, Medinipur coastal tract,

INTRODUCTION

Medinipur coastal tract is a part of West Bengal coastal area of India, having a length of about 20 km from Orissa border in the west to the eastern end of Junput sector in the east within 21° 30' N latitude to 21°40' N latitude and 87°25' E to 87°45' E longitude (Fig-1). Geologically this is the coastal stretch of Indo-Gangetic plain. The present geomorphic divisions like the beach, active dunes, mudflats etc of the present study area has developed within last 6000 years (Paul, 2002, p-78) with the last sea level fall after Holocene climatic optimum through sand deposit by Subarnarekha river (Bandyopadhyay '2000, P-17). Several scientific studies show that the sea levels along the Bay of Bengal coast remained very dynamic in nature throughout geological times. Early works by Umitsu (1987,P-164-178), Chatterjee (1972, Pp-1-15), Merh (1987, Pp-235-251) etc. show that the Holocene period was marked by several phase of sea transgressions each followed by regressions. According to the records, a sharp rise of sea level along the Bay of Bengal coast occurred around 6000 years BP (Islam and Tooley 1998,Pp-1-15). After that a regression of sea along this coastal tract took place (Banerjee and Sen, 1987, P-307-320) which caused southward shifting of shoreline (Roy and Chattopadhyay, 1997, Pp-177-209). Over the last 500 years the whole Bengal basin have been sinking eastward due to heavy sediment deposition on Ganga-Brahmaputra valley (Banerjee, 1998). This causes a relative rise of sea level to the eastern part of this coastal tract while a tilting of the western part of the coast is occurred, which results relative fall of sea level in the present study area (Pethick, 1984).

The present study area falls within subtropical humid climate with three distinct seasons viz. Pre-Monsoon (March-June), Monsoon (July-Oct), and Post-Monsoon (Nov-Feb). The maximum daily temperature ranges between 26.9°C and 36.8°C while the minimum temperature lies in between 5.7°C and 24.7°C (G.S.I., 1995,P-2). The range of average annual rainfall as recorded is 1192mm-1956mm with relative humidity varying between 60% and 90%. Wind direction varies from season to season. In summer to rainy seasons wind blows generally from S-SSW direction while in winter season wind blows from NNE direction. The seasonal characteristics of tropical monsoon climate influence wave dynamics and cause significant morphological changes over the Medinipur coastal tract. The southwest monsoon brings moist wind with sinning depression that generates strong wave action during the months of July to October (Dey 1999,P-16). In the winter the dry northeast wind plays an important role in aeolion action upon the coastal geomorphology.

Medinipur coastal tract is characteristically almost flat with wave dominated sandy beach along with chains of sand dunes and mud flats. This area is a neutral museum of several types of coastal dunes, which preserve the geological history and reflect the physical environmental influences upon present landform as well. Almost parallel formation of 4 distinct dune colonies during last 6000 years indicates seaward shifting of shoreline with early sea regression or oscillation of sea level (Steers, 1937,P-205-266) along this coastal tract. A recent research by Banerjee et al (1997, Pp-492-501) shows that the dune chains of this area are entirely of aeolian origin formed during the last sea regression. Paul (2001,P-166) assessed that these dune chains are formed by aeolian sand transport over the beach ridges and vegetation interaction and related with shoreline shifting by sea level changes. Considering the geomorphic significance of the coastal dunes we decided to perform an analysis on the geomorphology of coastal dunes of this area. The primary objective of this study is to provide the reader with a better understanding about the geomorphic evolution of coastal dunes under tropical monsoon environmental conditions. The technical discussion starts with the general geomorphic classification of the dunes and their characteristics. The role of natural vegetation in different stages of development of the coastal dunes of this area has discussed. This part extends with a study of morphological changes of dunes through various seasons and their impact upon long-term development. The conclusive section discussed the present environmental hazards of this coastal area.

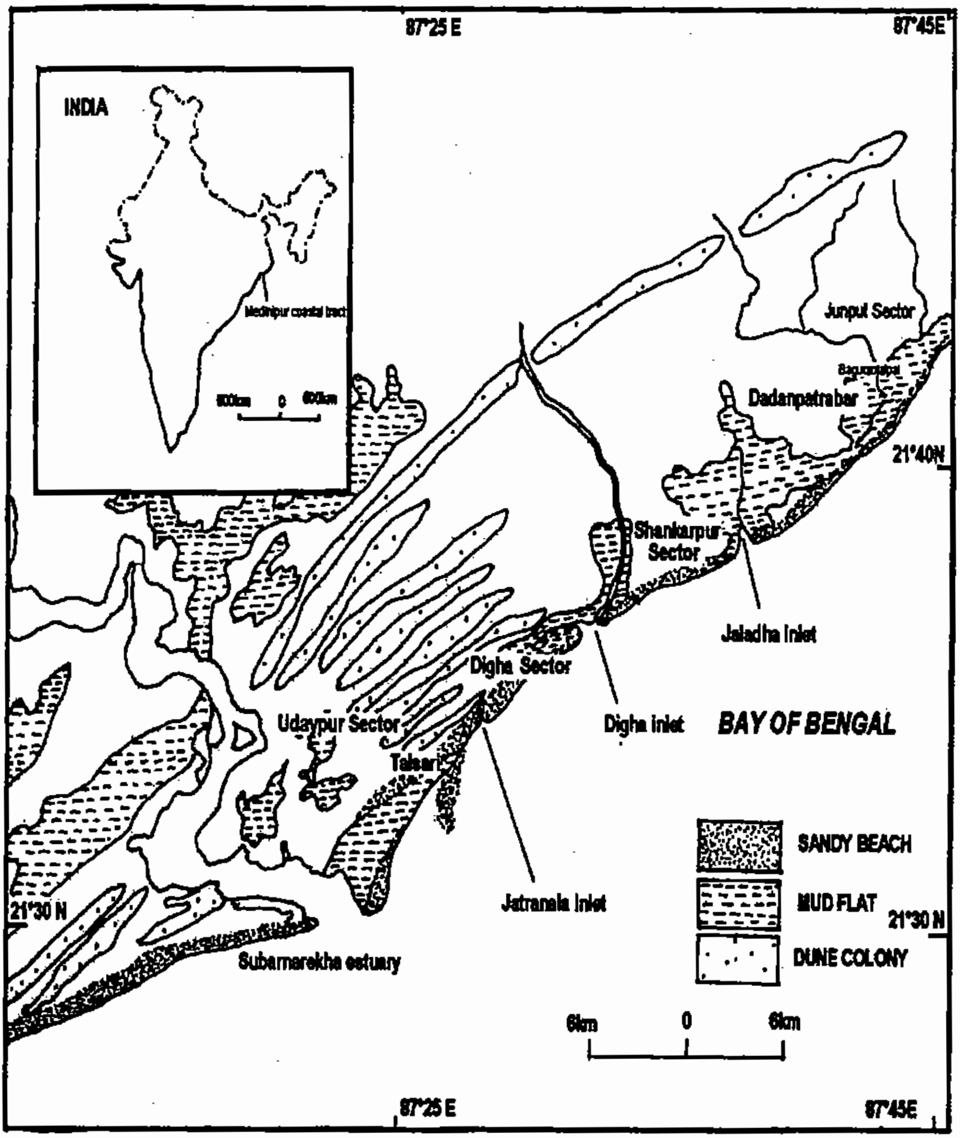


Figure 1. Location of the selected study area

METHODOLOGY

Prior to visiting the field area, an extensive study of literature was done such as reports of Geological survey of India, Digha Development Authority, Department of Environment of Government of West Bengal etc and recent research papers published in different journals and presented in different seminars, congresses etc to prepare a complete fieldwork programme. The field programmes included:

1) study of the geo-historical background of the coastal area.
2) shoreline changes during the last 6000 years
3) an examination of the climatological controls on morphologic modification of the study area.

The basic cartographic materials used to obtain better knowledge on the study area and they were used as tools of analyses (Table 1).

Table 1. Basic cartographic materials used to assess recent shoreline change

Basic materials	Year of publication	Scale	Publisher
Geological and geomorphological map of Digha area	1995	1:50.000	Geological Survey of India
Current landaus pattern and disaster management plan of Digha coast.	1995	1:50.000	Geological Survey of India
Present landuse map for Digha planning area.	1995	1:50.000	Geological Survey of India
Landuse plan for 2011along Digha planning area	1996	1:50.000	Digha Development Authority
Toposheet-73 O/06	1931-'32	1:63360	Survey of India.
Toposheet-73 O/06	1968-'69	1:50.000	Survey of India.
Toposheet-73 O/10	1931-'32	1:63360	Survey of India.
Toposheet-73 O/10	1968-'69	1:50.000	Survey of India.
Toposheet-73 O/14	1931-'32	1:63360	Survey of India.
Toposheet-73 O/14	1968-'69	1:50.000	Survey of India.
IRS-IC,WSS-3 Geocoded FCC No-7306	6.1.1997	1:50.000	National Remote Sensing Agency
IRS-IC, WSS-3 GeocodedFCC No-73010	6.1.1997	1:50.000	National Remote Sensing Agency
IRS-IC,WSS-3 Geocoded FCC No-73014	6.1.1997	1:50.000	National Remote Sensing Agency

Different techniques have been applied and instrumental survey works have been done during fieldwork from 2000 to 2003 to find out the geomorphologic evolution of this area. Data collected through field investigation by simple leveling survey method (using Dumpy Level, Ranging Rods, Staff and measuring tape) during various seasons have used for preparing various maps. Effects of wave action and resultant features around the beach were identified during the fieldwork.. The field study was directed towards understanding the following:

a. development of the coastal dunes through the geological past.
b. present morphological character of coastal dunes.
c. types of vegetation and their role in dune development.
d. influence of climatic condition in dune development.

SHORELINE SHIFTING

Evidences of marine coastal sediments, mangrove roots and, marine shells are found bellow 26.6m depth under the surface in Kolaghat-Tamluk region (21°55 N to 21°31 N latitudes and 87°38 E to 88°11 E longitudes), which indicate the previous position of shoreline during the Pleistocene epoch (Chanda and Hait, 1996, pp. 117-124). The Geological Survey of India (1995, P-3) has detected that shoreline positioned 5-15 km inland from the present shoreline around 6000 years BP. Around 3000 years BP the shoreline position was 2-5 km inland from the present shoreline.

Land ward shifting of shoreline due to rise of sea level and subsequent land erosion is a major environmental issue of Medinipur coastal tract in the present days. In the well-known work of O'Malley (1911), Bengal District Gazetteers, Midnapur, the possible history of recent shoreline shifting of this area has been described. Existence of a village is found in the maps of Valentijn (1664A.D.), van Der Brook (1668), James Rennel (1777) and plot chart of Thomas Bowrey (1688), which was named as "Naricool" or "Bircool". O'Malley described that in the early settlement records of British government, Bircool was known as *salt parghana*. According to report in the 18th century Birkul (Bircool) became a seaside resort for the European officers. They constructed a bungalow, which was used by Lord Warren Hastings. This bungalow was later washed away by the transgression of the sea. However today a very common myth exists among the fishermen of this area that the bungalow of Hastings often emerges from the water at the time of low tide at a distance about 5 km away from the shore. Further the Public Works Department constructed an inspection bungalow, about half of kilometre inland from that place, within mouza Digha, but with transgression of the sea this entire area has gone under sea. In 1852 Bayly described the natural beauty and fresh environment of this area (O'Malley 1911, P-5-6). But the eroding nature of this area was also found in his description as he writes "...of the three bungalows upon them, two are gone and one all but gone." These evidences suggest that erosion is not a contemporary phenomenon along this area. Evidences also suggest that over the last three centuries the problem of erosion has aggravatery along parts of Medinipur coastal tract.Goswami (1997, Pp-61-88) assessed that about 6000 m land eroded from 1775 to 1986 at and around Digha at an annual rate of 28.4m / year (Fig-2). Both Digha and Shankarpur sectors are suffering by rapid beach narrowing and lowering. From west to east Digha beach is now narrowing progressively and at the eastern end of Old Digha Township, the actual beach width remains only 5-10m.

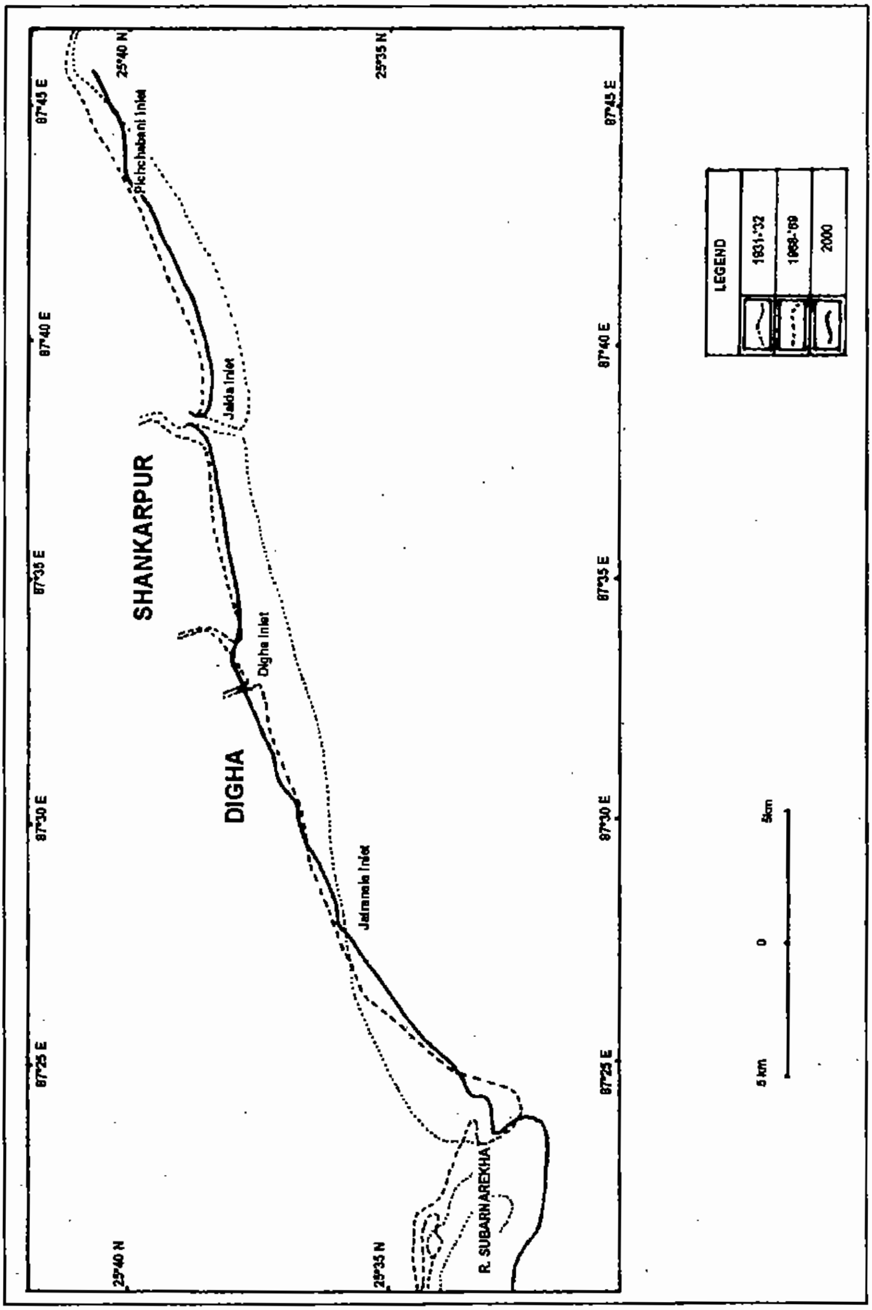


Figure 2. Recent change in shoreline along Medinipur coastal tract

From the recorded data and comparative study with Survey of India toposheets, satellite images and field data it is found that during 1931-32 to 1968-'69 the westward part of Medinipur coastal tract (from Subarnarekha river estuary to Jatranala inlet, length: 13 Km) was under prominent accretion. Rest of the area, from Jatranala to Pichhabani inlet (length: 28.5 Km) was under erosion. Though from Jalda inlet to Pichhabani inlet there was a little accretion during this period, net positive change of shoreline was landward during that time.

During 1968-'69 to 1997 a remarkable change is found along the coast. During this period a new zone of accretion has emerged towards the east, from Jaladha inlet to Pichhabani inlet (length 13.5 Km). But from Jatranala inlet to Jaladha inlet (length 15 Km) rapid erosion took place. This creates a big problem of land loss with registration of many environmental refugees in this area (Department of Environment, 1996,Pp-17-19).

This study shows that erosion and accretion of occur side by side along this coastal area. But it is also observed that during 1931 to 1967 the general tendency of shoreline change was to shift landward. It indicates a sharp rise of sea level during 1931 to 1967. By contrast in recent years accretion occurs in western and eastern parts of this coastal tract. But Digha and Shankarpur sectors are still under serious wave erosion (Mukherjee & Chatterjee, 1997 Pp2-4; Bhandari, 2001, Pp38-53).

RESULTS AND DISCUSSIONS

1. Origin and morphology of dunes along Medinipur coastal tract

Coastal dunes morphology consists of distinct parallel dune chains and depressions (Pethick, 1984) which have a significance of geomorphic evolution throughout geological time (Dey and Haque, 2003). In the light of the recent hypothesis the following two models of coastal dune formation have been suggested (Viles and Spencer1995, p-68-69):

1) Dune formation associated with rising sea level condition (transgression) - as sediments are pushed onshore from continental shelves.
2) Dune formation in association with falling sea level as exposed offshore sandy accumulation become prone to wind deflection.

For practical understanding of the above-mentioned hypothesis, we conducted a study along the selected field area. On the basis of the field study, two main geomorphic classes of the dunes of this area are observed, they are Paleo-dunes and Neo-dunes. Between these two dune colonies, inter-dunal depression is existed.

Paleo-dunes

These are older dune chain with 2 to 10 m heights which indicates the early shoreline positions during 2920±60 Years B.P. Banerjee and Sen (1987, P-307-320) accorded that regression of sea along this coastal tract around 6000 years BP resulted seaward shifting of shoreline and formation of paleo-dunes. These dunes got maturity by the growth of natural vegetation under stabilised environmental condition during last 3000 years B.P. Aeolion action is responsible for the slowly decrease of dune heights.

The older sand ridges are actually situated almost parallel to the active dune chain beyond 3 km from the beach and complex in form. These are nearly 0.5-1 m in elevation. This area is characterised by thin soil profile. The sandy terrain of beach and dunes is found without any soil cover. At some places very thin clayey soil profile is found which is entisol to inseptisol in character and composed of very thin clayey loam with a maximum 1.00 mm in size (G.S.I, 1995). In this part some agricultural activities are found.

Inter-dunal depression mud flat

Inter-dunal mud flats are found beyond 200 m nearly parallel to the sea from Orissa border to Old Digha in between neo-dunes and paleo-dunes. These occur between the front dunes and the older dune tracts, which are marked by high tide level and storm-tide level. Thin layers of mud with remobilised sands from the dunes are found covered by grasses and bushes.

Neo-dunes

This type is found on the upper face of the beach. Some seasonal small dunes normally form during the drier seasons by sand drifts (1.5-4.5 m high). It is accepted that further regression of sea and sea-ward shifting occurred after 3000 Years BP (GIS, 95) which resulted a new platform for the development of another dune chain in front of the paleo-dunes. The fore dunes of present day started to form with initial sand deposition. Growth of vegetation plays an important role for stabilisation of dunes. Recent rise of sea level along this coastal tract causes landward shifting of dune belt. In Udaypur sector as the shoreline is shifting southward due to accretion the some front dunes of this part are now gradually stabilising by free growth of vegetation. In the other sectors the neo-dune belts have a tendency to shift landward and readjusting their position with recent rise of sea level, which result a negative condition of maturity.

These dunes collapse and get decayed during the monsoon season. Vegetation cover on these dunes is rare or little. Foredunes are found on the margin of beach. These dome shaped sand dunes are 12 to 19 m high with steep slopes >45°. Front dunes are very common along the study area. The erosion-marks on the front dunes indicate the present high tide level as the dunes are situated on the upper front of the beach. No soil formation is observed on these dunes.

2. Influence of vegetation in dune formation in different stages

Vegetation in sand dunes alters the performance of a dune by leaving a contribution in the form of checking dune erosion, causing accretion of sand mass and enhancing the dune stability. The sand mass with vegetation dispersed in it forms a complex system with high degree of heterogeneity. The fibers physically present close to the surface of a composite behave different from the one present in the bulk Drawing similar concept, vegetation of sand dunes can also be classified into two main types, one close to or exposed to the dune surface and the other inside the mass. The surface vegetation gives rise to pseudo-coating effect and the interspersed or the vegetation in the bulk mainly causes reinforcement effect. The main functions of these two types are:

Surface Vegetation

1) checks the velocity of wind and causes drop in wind load (as natural sand fence).
2) absorbs wave impact.
3) prevents sand mass beyond a certain part from undergoing abrupt change in properties (like gaining water content etc.).

Bulk Vegetation

1) shares different external stresses incumbent on the dune.
2) checks crack propagation.
3) enhances the barrier property of the sand mass.
4) controls the erosion susceptibility of swelling clays and sands by some adhesion mainly rising out of biological interactions.

Biotic influence in dune formation has observed during the fieldwork (Figure 3, Plate-1).

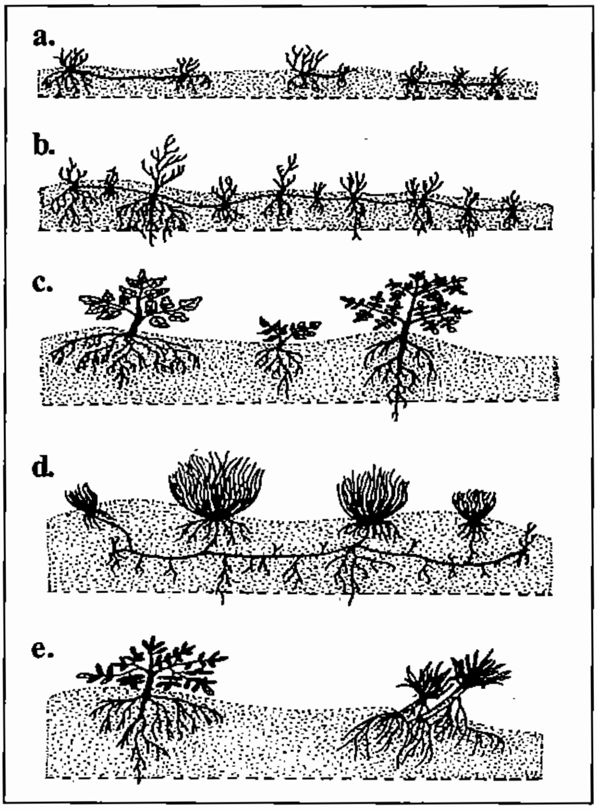


Figure 3. Penetration of vegetation roots and their influence on sand accumulation in different stages of dune development

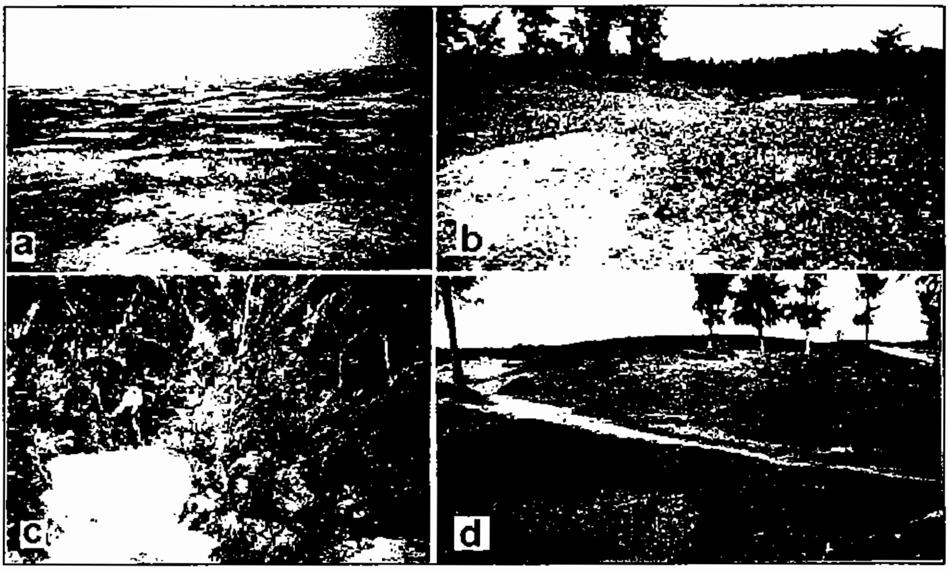


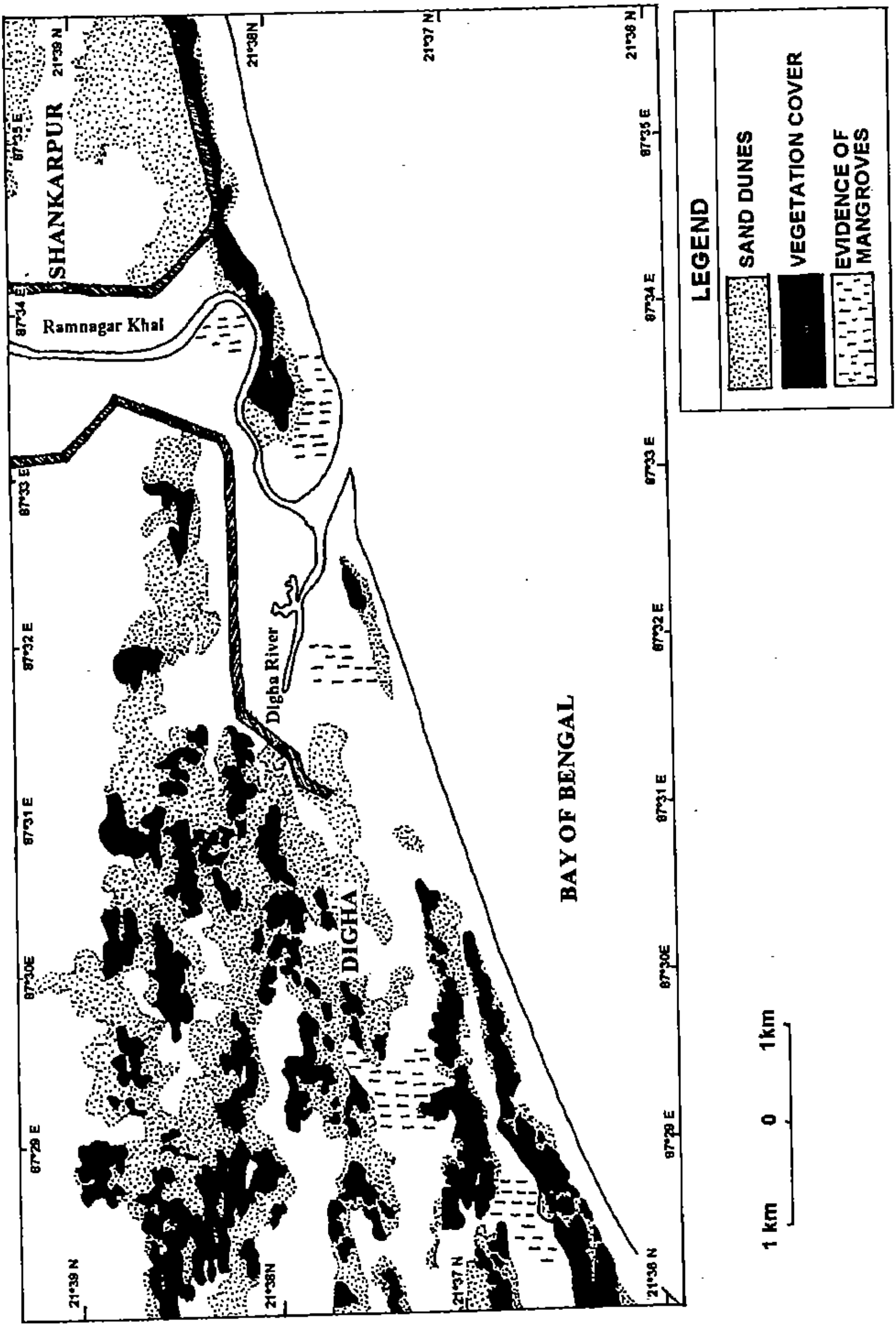
Plate-1: Stages of dune development a) Initial growth of salt tolerance grasses with extension of beach by accretion at Baguranjalpi, b) Stabilisation of dunes by growth of Ipomonia Sp at Baguranjalpi, c) Growth of trees on extensive dune belts Shankarpur, d) Rear end of mature paleo-dunes near Digha

Numbers of important features of the morphological development of coastal dunes of Medinipur coastal tract falling within the tropical environment have emerged through the field study, which can be stated as follows:

1) At the initial stage of the dune development, formation and extinction of long-shore spits along the coastal margin are the main platforms. Catastrophic cyclones break the spits into disconnected barrier islands. Marshlands trap silts and prograde the mud flat towards the barrier margin at high tide. Beach ridge feature occurs along the upper slope of the beach face by the naked sea wave energy. The dune formation begins above the beach ridge feature by wind- blown sands from the open and dry foreshore at low tide. Vegetation cover makes the nucleus of dune development. Grasses like *Aleuropus lagopoids*, *Leersia hexendra, Paspalum distichum* can only tolerate the over wash process and sand accumulation in this area.
2) In the next stage accumulation of sands and transformation of vegetation occurs which continues dune developing process. Through strong wind velocity fine sand particles being lifted and thrown-up from the seaward slope of dune ridge before being deposited at the back-bar in pre-monsoon time. This process causes inland movement of the dune ridges.

3) The dune ridge become detached from active shoreline and separated from the coastal inland and this inland dune ridge will stabilise the surface with complete vegetative cover in the form of distinct topography known as a chainer sand ridge (Paul, 1996). In this stage the colonisation process is going on with the vegetative growth. As the coast is very exposed, the unconsolidated substratum of the shorefront is in constant movement. To stabilise the unstabilised conditions only low growing "*Spinifex litttorieus*" deeply penetrating root system survives (Bhakat, 2001). This confirms the vegetative succession installation. The tuff spiny leaves of 'Spinifex" helps in deposition of fine sands transported by aeolion process.
4) The unstable sands with very low fertility status discourage plant's colonisation. In this developing dune sparse vegetation going in a scattered way. The pre-dominating species of this developing dune are: *Lantana camara,, Eleusine indica, Cyndon dactylon, Sida corcordifolia, Euphorbia thymifolia, Borreria articularis, Tephrosia perpurea*. The hard and deep penetrating roots of the herbaceous species can survive in this less fertile sandy soils and gradually cover 30-75% of the neo-dunes.
5) In this semi-fixed dunes the herbaceous species invites some shruby plants which can also survive in this semi-arid and semi-fertile sandy soils. The next species to colonise are *Glycosmis pentaphylla, Cyperus exaltatus, Pandanus tectorius, Opunita dillenii,. Calotropis giganate.* Among these species, *Pandanus* stabilise the shoreline and act as a buffer against the erosion of loose sands. With *Pandanus, Anacardium occidentale,* also dominate the dune slopes in this stage. Gradually dunes becomes lower with age by the process of erosion.

So, in the stabilised dunes all types of plants (herbs, shrubs and trees) present which complete the succession and finally stabilised the dunes (Figure 4) as well as makes the soil impregnate with nutrients gradually, thus facilitates the full vegetative growth.


SHANKARPUR
Ramnagar Khal
Digha River
DIGHA
BAY OF BENGAL
LEGEND
SAND DUNES
VEGETATION COVER
EVIDENCE OF MANGROVES
1 km
0
1km
21°39 N
21°38N
21°37 N
21°36 N
87°29 E
87°30E
87°31 E
87°32 E
87°33 E
87°34 E
87°35 E

3. Influences of vegetation cover on dune movements along the study area

Dune movements have been found to depend not only upon the sand and wind speed, pattern and thickness of vegetation cover play a very important role (Dey, 1999; Bhakat, 2001). Here the authors have made a scheme of dune classification according to their pattern vegetation cover and rate of migration on the basis of field study along the Subarnarekha delta plain. This is presented in the table below:

Table 2. Types of dunes, estimated percentage of vegetation cover and characteristics along Digha-Sankarpur coastal tract

Types of dunes	Estimated percentage of vegetation cover	Characteristics	Vegetation **
Mobile sand dunes	0 to <30% vegetation cover. Mainly covered by the grasses and casuarina plants	Geologically known as 'beach front dune complex'; mostly affected by wind in dry season and by wave in rainy season.	*Cyndon dactylon, Borreria articularis, Eleusine indica, Euphorbia thymifolia, Ipomonia pes-caprae, Launaea sermentosa, Sida corcordifolia etc.*
Semi-stable sand dunes	30% to 75% vegetation cover	Geologically known as 'Older dune complex'; found beyond 2km from the sea to 15km inward	*Calotropis giganatea, Cassia sophera, Cyperus sp., Glycosmis pentaphylla, Lantana camara, Opunita sp., Pandanus sp. etc.*
Stable sand dunes.	More than 75% vegetation covers	Beyond 10-15km from sea; lower height (2m or less)	

*Source: Field Investigation Report and **Bhakat (2001)*

4. Seasonal influences upon long-term geomorphic changes

It is accepted that seasonal changes of sea level is one of the remarkable features of tropical-monsoon areas which influences geomorphology of coastal areas (Dey, 2000: Dey, 2003) such as beach (width and angle) dune (height and angle) and mud flats. Seasonal changes in wind direction and wave action also influence the variations supply of sand along the study area. The nature of sand supply through the seasons are as follows (here WE indicates the west to east direction of littoral drift and EW indicates east to west littoral sand drift).

Table 3. Seasonal nature of sand supply along Subarnarekha delta plain

Area	Length (in Km)	Geomorphic significance	Seasons	Sand drift ($x10^4$ Cum/ month)	
				Along shore	On shore/ Off shore
Udaypur sector	13.0	Accretion zone	Pre-monsoon	148.2 (WE)	18.83 (Off shore)
			Monsoon	142.0 (WE)	18.66 (Off shore)
			Post-monsoon	82.2 (EW)	10.49 (On shore)
Digha sector	5.5	Erosion zone	Pre-monsoon	223.9 (WE)	28.41 (Off shore)
			Monsoon	278.9 (WE)	36.14 (Off shore)
			Post-monsoon	137.8 (EW)	17.46 (On shore)
Shankarpur sector	9.5	Erosion zone	Pre-monsoon	132.9 (WE)	16.79 (Off shore)
			Monsoon	198.1 (WE)	25.71 (Off shore)
			Post-monsoon	98.7 (EW)	12.49 (On shore)

Table based on Bhandari (2002).

Seasonal changes of the sand dunes are also very important for the geomorphology of the study area. Local sea level rise during the monsoon season wave erodes the upper front dunes (Plate-2/a & 2/b). In this period the dune belts shift slightly landward, storm wave action often destroys parts of the dunes, breaking the continuity of the dune belt. Moreover, in the pre monsoon season the strong south-west wind triggers the landward dune encroachment, which causes the loss of fertility of the agricultural lands.

In the post-monsoon season the reconstruction of sand dunes starts under the impact of north-east wind (Plate-2/c and 2/d). The angles of the dune slopes, which were steep and relatively high-angled in monsoon seasons, get reduced in height and slope-gradient. The angles of front dunes are maximum in late post monsoon (January-February) and minimum in the last part of monsoon (August-September).

Height of the dunes also varies with the changes of seasons. Seasonal change of front dunes ultimately results a landward shifting at a yearly rate of 2m to 5 m along this coastal tract which is a strong evidence of gradual increase wave action along Medinipur coastal tract.

Plate-2: a) Eroded foredunes during monsoon season at Shankarpur sector b) Marks of wave erosion on foredunes at Udaypur sectors, c) Developing neo-dunes in post monsoon season at Junput-Dadanpatrabar sector, d) Social forestry during post-monsoon season at Shankarp

Table 4. The seasonal change of dune morphology

Situation of dunes (in between)	Pre-monsoon		Monsoon		Post-monsoon	
	Angle	Height	Angle	Height	Angle	Height
Udaypur sector	35°	18m	31°	17.65m	38°	17.77m
Digha sector	33°	12m	31°	11m	37°	12m
Shankarpur sector	37°	7m	32°	6m	39°	6.5m

Source: Field investigation 2001-2002

CONCLUSIONS

Formations distinct dune belts of in this area clearly indicate the dynamic nature of natural environment during the Holocene epoch. Seasonal character of this tropical coastal area plays very vital role in developing the sand dunes along with the natural vegetation. Vegetation cover control movement of dunes and morphological modification along the coasts. The vegetation dispersed in sand mass increases the stability of a dune to resist wind and wave action by many folds. The contribution of vegetation results from both structural and biological interaction of itself with sand mass.

Besides this, it is observed that there is a tendency of sea level rise at a remarkable rate during the last 300-500 years along Medinipur coastal tract (Niyogi, 1970, Pp-1–36). There is ample evidence (Hazra *et al.* 200, Pp-25-37) of sea level rise at a considerable rate (>2 mm per year) in this part during recent years. Prominent landward encroachment of dunes alongwith the shoreline changes strongly support that sea level rise is now at an alarming stage in this area. Human intervention, particularly over the last three decades has also been very significant for the change in coastal environment. Construction of fishing harbour, covering a large area at Shankarpur sector, development of tourism and associated industries (mainly ice and fishing ship/boat-building industries) along the coast have aggravated environmental hazards. Recently social forestry has been introduced by the Department of Forestry, Government of West Bengal to protect the beach and dunes from wave erosion (Plate-2/d). Under these circumstances study of both long-term and short-term environmental influences on the geomorphology of the coast would be very important for sustainable development scheme for the future.

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