MORPHOLOGICAL ASSESSMENT OF SHORELINE CHANGES:

A case study of Mahanadi coast (North Odisha).

Dissertation submitted to Jawaharlal Nehru University in partial fulfillment of the requirement for the award of the degree of

MASTER OF PHILOSOPHY

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20 July, 2012

DECLARATION

I, MR. KAMAL NAG, hereby declare that the dissertation entitled **"MORPHOLOGICAL ASSESSMENT OF SHORELINE CHANGES: A case study of Mahanadi coast (North Odisha)"** submitted by me for the award of the degree of **MASTER OF PHILOSOPHY** is my bonafide work and that it has not been submitted so for in part or in full, for any degree or diploma of this university or any other university.

KAMAL NAG

CERTIFICATE

It is hereby recommended that the dissertation may be placed before the examiners for evaluation.

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DEDICATED

TO

GMC and Tirthankar

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CHAPTER-I

1.1 Introduction.

A coast is the interface of three primary processes, namely, terrestrial, atmospheric and marine process. It is one of the most dynamic zones and highly susceptible to changes among any parameter of the aforesaid processes. The evolution of coastal system is controlled by various factors viz., morphology and geology, climate leading to rainfall and river discharge at coastal zone, fresh water input and coastal hydrodynamics-waves, tides and currents (Albert and Jorge, 1998). Coastal areas are under various natural and human-caused threats including coastal erosion. Coastal erosion is the permanent loss of land along the shoreline and is usually the result of a combination of both natural and human-induced factors. The most important natural factors of erosion are winds and storms, near shore currents, relative sea level rise, and slope processes; on the other hand, human–induced factors include coastal engineering, construction of dam or reservoir, dredging, mining and water extraction (Coastal Engineering Manual, 2002). Coastal zones are one of the most complicated ecosystems with a large number of living and non-living resources; therefore, these are areas of major socio–economical importance worldwide (Constanza et al. 1997).

Present work intendes to deal with changes in shoreline and evolution of depositional features along the Paradip coast, Odisha, during the time period of 1973 to 2006, using geometric tools. Geometric tools are those which can be used to measure space (Geometric=Geo + metric, “Geo” means space and “metric” is used for measurement). Geometric tools include satellite images, toposheet, GIS software, and all others ground based measurement instruments like Global Positioning System (GPS), Auto level, Clinometer, Digital Distance Meter (DDM), Theodolite etc. Major secondary data based works is presented in Chapter-2 and Chapter-3, while Chapter-4 is comprised of verification of the results (which is derived through Digital Shoreline Analysis System, DSAS) and tries to find out reasons behind shoreline movement and present geomorphological situation of the study area.

Digital Shoreline Analysis System (DSAS), an extension of Arc GIS, has been used for detection of shoreline movements over the time. All types of data, generated through DSAS based on multi-dated satellite imageries, have been analyzed on the basis of general atmospheric and nearshore environmental condition.

For the convenience of the study 64 kilimeters (km) long shoreline has been divided into a number of littoral cells. Each cell is characterized by similar environmental setup and classified individually. It was still impossible to carry out a comprehensive interpretation of shoreline movements along many transects due to secondary information only. A field survey was therefore inevitable. Chapter-3 has been completed completely based on this field survey. Out of total 64 km long shoreline, only 10 km has been studied in the field. Rest of the coastline is either inaccessible or similar as what has been studied within that 10 km. To perform the field survey more meaningfully, 14 sample transects were selected as representative of both advancing and receding shorelines. Beach profiles are drawn out with the help of auto level survey to analyze beach slope and its suitability to various geomorphological processes. Photographs are being used as tools to understand ongoing process and find out their evolutionary history. Finally in Chapter-5, all results derived from Chapter-2, 3 and 4 are summarized and conclusions have been drawn.

1.2 Study Area

To perform the study successfully and satisfy the objectives, the Mahanadi delta coast (i.e., coast line along the boundary of Kendrapara and Jagatsinghapur districts) of Odisha has been selected. Northern coast of Odisha has remained as most vulnerable coastal zone since it faces cyclones of different intensity and frequency. Flooding due to heavy rainfall is a common feature in the coastal belt of Odisha. In addition to this, the urbanization, settlement expansion, construction of artificial structures, reclamation of wetlands and other activity also contribute to this. Salt-water intrusion into the agricultural lands due to flooding creates problem to the coastal agricultural which is clearly evident from Ersama area in Jagatsinghpur district and Astaranga area in Puri district during The Super Cyclone of 1999. Massive infrastructural development associated with population growth in future will cause the coastal zone under increasing pressure and result in degradation of coastal ecosystems and diminishing the coastal resources. Further exploitation of resources will make coastal communities vulnerable to sea storms and other ecological disasters.

This deltaic region is a classical arcuate type. The apex of the delta lies at Naraj about 100 km from the sea where Mahanadi divides into distributaries. These distributaries have given rise Mahanadi delta which is located in Odisha State between the confluence of Mahanadi and Debi River. Mahanadi delta coast of Odisha is diverse in terms of its overall environmental set up. Study area has been extended from 20.60N to 20.20N (figure 1.1). There are two major spit located along the north Odisha coast Odisha coast one is north of Vitorkonica reserve forest and another south of the Pradip port.

1.2.1 Tectonics and Evolution of Odisha coast

Entire east coast and offshore area of India is evolved during the Tertiary. Coastal basins show sediment thickness 2400 m as revealed by DSS profiling implying continued subsidence with the activity of growth of faults (Mohanti, 1990). Shoreline of Mahanadi delta coast has migrated seaward during the Holocene delta building (Mohanti and Swaine, 1993). Two sets of major structural / fracture trend and a number of lineaments has been identified in the delta plain area (Bharali et al., 1991). Subsurface sediments of the Mahanadi basin range in age from Late Jurassic/Early Cretaceous to Recent. The main deltaic evolution was succeeded by a major regression in Early Miocene and has been continuing till recent with minor fluctuations. Prior to that, minor delta building took place during the Late Paleocene, later interrupted by extensive carbonate deposition (Bharali et al., 1991). The major force of delta building seems to have spanned in the Late Holocene between 6000 yrs. B.P. to 800 yrs. B.P. (Mohanti, 1993). Shoreline has further shifted seaward during the last 800 years. Deltaic progradation continued in a northerly direction.

The tidal channels are commonly parallel to the ancient beach ridges and follow the intervening swales. Tidal flats and swamps are present all along the coast of the Mahanadi delta. Most of these, however, have a local extent around the mouths of distributary channels and in the swales between adjacent beach ridges. Extensive tidal flats and swamps are found near Hukitola Bay and Paradip. Widespread coastal sand bodies lie along the coast in the southern part of the Mahanadi delta, stretching from Chilika Lake on the southwest to Konark on the northeast. These are as much as 15 m high and 2 to 5 km wide. These coastal sand bodies are made up of windblown sands

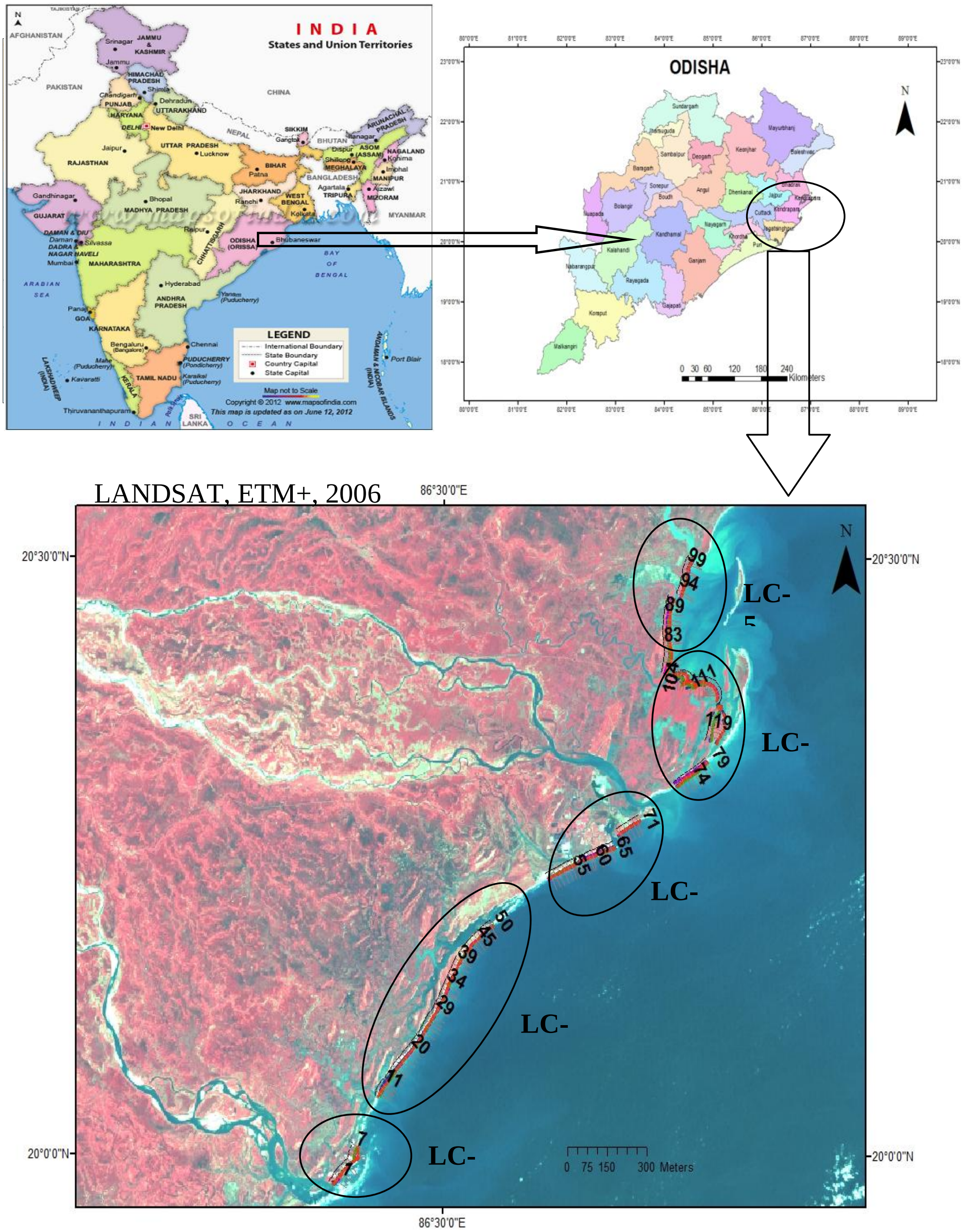

Figure 1.1 Location map of study area with five littoral cells (LC).

covering the muddy deposits of a tidal flat or swamp origin. Parabolic dunes have developed over these forms. The seaward margin of the delta plain is marked by a

Data: NOAA, U.S. Navy, NGA

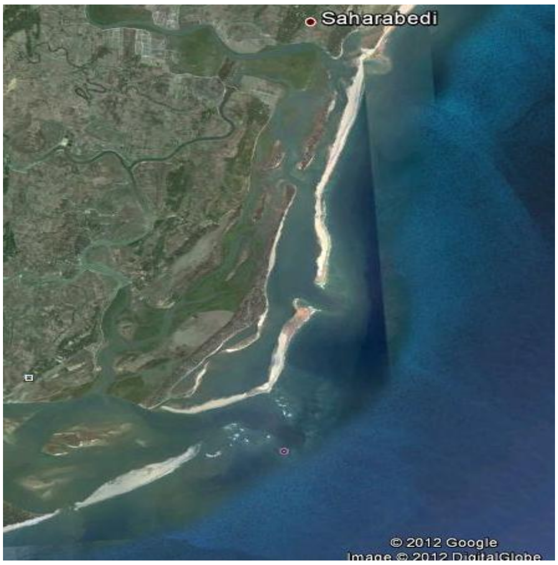

Figure 1.2 Littoral cell-1

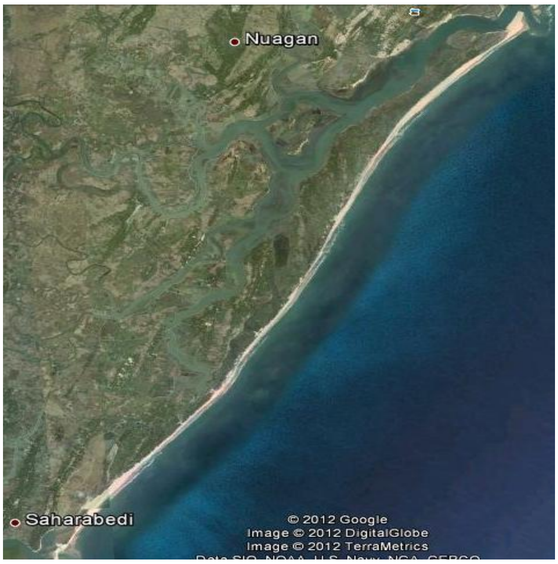

Figure 1.3 Littoral cell-2

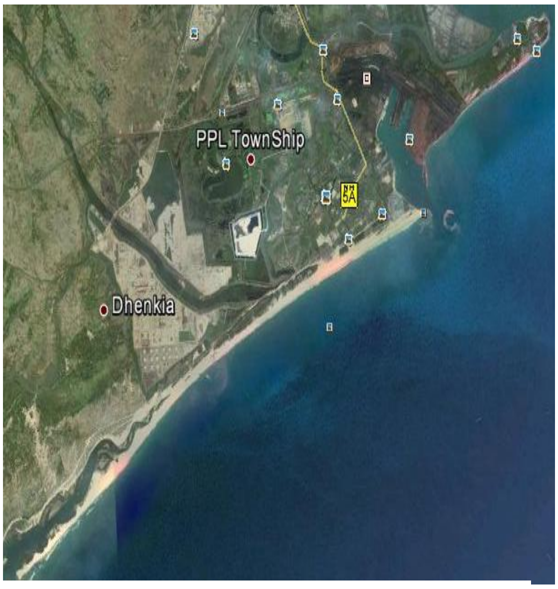

Figure 1.4 Littoral cell-3

Figure 1.5 Littoral cell-4

Figure 1.6 Littoral cell-5

Figure 1.7 Topographical representation of Odisha coast on 1:250000 scale

straight and continuously regular shoreline with a sandy beach all along it without cliffs. Prominent spits occur near the mouths of the Mahanadi and the Debi rivers. The development and extension of spits towards the north are due to northerly moving littoral drift, which has constantly pushed the mouths of rivers towards the north. Thus the rivers Mahanadi, Debi, and Kushbhadra take a northerly course parallel to the shoreline for some distance before draining into the sea. During intensive storms such spits are eroded and are cut across by rivers which thereby debouch directly into the sea.

1.2.3 Climate

The Mahanadi delta coast is bordered by the Mahanadi (north) and Debi (south) rivers, administrative boundary of Kendrapara and Jagatsinghapur districts. The region has a tropical climate, characterized by high temperature, high humidity and medium to high rainfall. There are three major seasons - summer (March-June), rainy Season (July-September) and the winter (October-February). The summer maximum temperature ranges between 35-40° C and the low temperatures are usually between 12-14° C. Winter is not very severe. The south-west monsoon sets in normally between 5th June and 10th June in the coastal plain. By 15th October south-west monsoon withdraws completely from Odisha. Direction of wind determines angle of wave approach. Wind speed determines wave energy potential which is determined by “fetch” i.e., the length of distance wind covered in an open sea. Reversal in wind direction also modifies direction of transportation in littoral cells through changes in longshore components of the cells.

The Mahanadi River deltaic coast is microtidal with a mean tidal range measuring 1.29 m. Tidal cycle is semi-diurnal. It is principally a wave-dominated coast during the southwest monsoonal season, while during the non-monsoonal period it is mixed wave as well as tide-dominated. The northeast monsoon (between Decembers - early January) is much milder in its dynamics. Southwest monsoon winds generate high waves (3 m high or more) striking the shore obliquely induces a littoral / long shore drift of sands from southwest to northeast along this coast.

Distributaries of the Mahanadi carry huge sediments and the turbid plume extends 15 km or more into the Bay of Bengal during the monsoonal months of high fluvial discharge (Mohanti, 1993). This phenomenon, coupled with seasonal change in wind direction, results in orientation and reorientation of nearshore depositional features like bars, spits, islands etc.

1.2.4 Oceanographic data

1.2.4.1 Tide

Tides are the second major marine energy which effects in shaping the coastal landform. Tides on Odisha coast are characterized by a mixed type, predominantly semidiurnal. The average spring tidal range is 2.39 metres (m) and neap tidal range is about 0.85 m. About 320 km of coastline has a medium risk rating with tidal range between 2.5 and 3.5 m. Coastal stretches of northern Puri, Jagatsinghpur, Kendrapara, Bhadrak and southern Balasore (Mohanty, 1990). About 141km of coastline has a low risk rating, recording tidal ranges of less than 2.5 m. at Ganjam, Chilica Lake and southern Puri. The Mahanadi deltaic coast is microtidal with mean tidal range 1.25 m. The Odisha coast is wave dominated during monsoon season while it is mixed wave and tidal dominated during non-monsoon period (Mohanty and Swine, 1993).

1.2.4.2 Wave

Along Odisha coast mean significant wave height ranges between 1.25 m and 1.40 m, mostly plunging during June to December and surging from January to May. However during southwest monsoons winds generate high wave of 3 m or more which strikes the shore obliquely and induce littoral or longshore drift.

1.2.4.3 Currents

Coastal waters of north Odisha indicates that the flow is towards south with speed varying from 14-29cm per second (Mohanty, 1993).

1.2.4.4 Long shore Transport

Along the coast, longshore sediment transport is southerly from November to February and northerly from April to September and variable in March and October. The longshore sediment transport rate is northward throughout the year with the maximum transport rate recorded at 19*104m^3 per month in May and June and the

Table 1.1 Temperature, rainfall and relative humidity of Jagatsinghpur and Kendrapara district.

Districts	Average Mean Monthly Temperature. Max. (*c)	Average Mean Monthly Temperature. Min. (*c)	Rainfall (mm)	Relative Humidity (%)	Years
Jagatsinghapur	30	23	1688.1	81	1993
Kendrapara	NA	NA	2013.4	NA	
Jagatsinghapur	31	25	1594.1	83	1994
Kendrapara	NA	NA	1493.4	NA	
Jagatsinghapur	31	25	1765.1	85	1995

Kendrapara	NA	NA	1906.8	NA	
Jagatsinghapur	31	24	822.8	81	1996
Kendrapara	NA	NA	935.4	NA	
Jagatsinghapur	33.3	18.9	1812.5	80	1997
Kendrapara	35.3	15.4	1463.6	NA	
Jagatsinghapur	34.1	19.3	1898.6	80	1998
Kendrapara	35.9	17.2	1287.4	NA	
Jagatsinghapur	31.1	19	1680.1	81	1999
Kendrapara	31.1	19	2072.1	NA	
Jagatsinghapur	32.7	20.3	729.1	77	2000
Kendrapara	32.7	20.3	874	NA	
Jagatsinghapur	33.3	20.5	1504.3	80.5	2001
Kendrapara	33.3	20.5	1212.5	NA	
Jagatsinghapur	31.16	24	1047.3	84	2002
Kendrapara	NA	NA	863.9	NA	
Jagatsinghapur	31.25	23.58	1702.7	79.83	2003
Kendrapara	NA	NA	1999.8		
Jagatsinghapur	30.58	23.66	1203.1	82.25	2004
Kendrapara	NA	NA	1383.2	NA	
Jagatsinghapur	31	24	1621.7	82	2005
Kendrapara	NA	NA	1782.9	NA	

Source: Indian Meteorological Department. (NA-Data not available)

minimum of 0.6*104m^3 in December to January (Hegde and Reju, 2007). The longshore current velocity exceed 0.8 m/min in May and June, 0.4m/s in March, April, July, September, and 0.3m/s during other months.

1.2.4.5 Coastal sediment

Coastal sediment of Odisha generally falls in the sand grade (0.90-2.84. mm) (Mohanty, 1990). The observed size is coarser at backshore and become progressively finer towards offshore. The sediment is generally well to moderately sorted, negatively skewed and mesokurtic. Studies of the coastal sediment of Odisha coast also indicate that the mean size of the sediments increase during monsoon in September and June, in comparison to February and April (Rajaw at et al. 2006). The coastal sediments of Odisha are rich in major minerals.

1.3 Literature Review

According to a study (Kumar, Magenta, and Radhakrishnan, 2010, “Coastal vulnerability assessment of Odisha state, east coast of India”) coastal areas of Odisha State in the northeastern part of the Indian peninsula are potentially vulnerable to accelerated erosion hazard. Along the 480 km coastline, most of the coastal areas, including tourist resorts, hotels, fishing villages, and towns, are already threatened by recurring storm flood event and severe coastal erosion. The coastal habitats, namely the large habitat in the world for Olive Ridley sea turtles (the extensive sandy beaches of Gahirmatha and Rushikulya), Asia’s largest brackish water lagoon (the‘Chilika’), an extensive mangrove cover of Bhitarkanika (the wildlife Sanctuary), the estuarine systems, and deltaic plains are no exception.

As it is widely known, a shoreline is defined as the theoretical line of contact between land and water, something easy to establish but very difficult to map because its dynamic nature and the fact that water level is continuously changing (Di et al., 2003). Hegde and Reju (2007) developed a Coastal Vulnerability Index (CVI) for the Mangalore coast using geomorphology, regional Coastal slope, shoreline change rates,and population. However, they opined that additional physical parameters like wave height, tidal range, probability of storm etc. can enhance the quality of the CVI.

Rajaw at et al. (2006) delineated the hazard line along the Indian coast using data on coast line displacement, tide, waves, and elevation. Belperio et al. (2001) considered elevation, exposure, aspect and slope as the physical parameters for assessing the coastal vulnerability to sea-level rise and concluded that coastal vulnerability is strongly correlated with elevation and exposure, and that regional scale distributed coastal process modelling may be suitable as a ‘‘first cut’’ in assessing coastal vulnerability to sea-level rise in tide-dominated, sedimentary Coastal regions.

Thieler and Hammer-Klose (1999) used coastal slope, geomorphology, relative sea-level rise rate, shoreline change rate, mean tidal range and mean wave height for assessment of coastal vulnerability of the U.S. Atlantic coast. The result showed that 28% of the U. S. Atlantic coast area of low vulnerability, 24%of the coast is of moderate vulnerability, 22% is of high vulnerability, and and26% is of very high vulnerability. Shoreline change assessment of Odisha coast by National Centre For Sustainable Coastal Management (NCSCM) , an institute under Ministry Of Forest And Environment (MoEF), Government Of India, shows that coast of Odisha is largely accreting (48.6%) and 14.4% is stable while 36.8% coast is highly vulnerable to erosion.

Pendleton, Thieler, and Jeffress (2005) assessed the coastal Vulnerability of Golden Gate National Recreation area to sea level rise by calculating a coastal vulnerability index (CVI) using both geology (shoreline-change rate, coastal geomorphology, coastal slope) and physical process variables (sea-level change rate, mean significant wave height, mean tidal range). The CVI allows the six variables to be related in a quantifiable manner that expresses the relative vulnerability of the coast to physical changes due to future sea-level rise.

In all, the above said studies on shoreline changes or displacement rate has been taken as an important parameter for assessing coastal vulnerability.

Since the 1920s, aerial photogrammetry has replaced more and more traditional ground based surveys headed up to capture beach surface by means of topographic profiling. In recent decades, new technologies have arisen for coast and shoreline mapping, including high resolution satellite imagery, kinematics GPS vehicles and, above all, airborne LiDAR surveys (Brock and Purkis, 2009).

The conventional techniques for determining the rate of change of shoreline position include: field measurement of present mean high water level, shoreline tracing from aerial photograph sand topographic sheets; comparison with the historical data using one of the several methods, (viz., End point rate (EPR) (Fensteretal., 1993), average of rates (AOR), linear regression (LR), and jackknife (JK) (Dolan et al., 1991). Methods have inherent errors that depend upon several factors, namely, accuracy in shoreline measurement, temporal variability of the shoreline, and number of data points (measured shoreline positions), non-uniform interval of time between the shoreline measurements, a total time span of shoreline data acquisition, and the method used. Linear regression(LR) method of determining shoreline position change rate is found to be important among all such techniques, as it minimizes potential random error and short term variability (cyclical changes) through the use of a statistical approach (Douglas and Crowell, 2000).

Recent advances in remote sensing and geographical information system (GIS) techniques have led to improvements in coastal geomorphological studies, such as: semi-automatic determination of shorelines (Ryu et al., 2002; Yamano et al., 2006); identification of relative changes among coastal units (Jantunen and Raitala, 1984;

Siddiqui, and Maajid, 2004); extraction of topographic and bathymetric information (Lafon et al., 2002) and providing their integrated GIS data base.

On a national level, limited research papers are available on shoreline changes which use multidated satellite data and auto regression. Maiti and Bhattacherya (2010) have performed satellite data base study on shore changes and also predicted future shoreline position based on auto regression model. They have segregated entire coastal region under observation into different littoral cells. According to them each littoral cell represents homogenous geomorphic as well as hydrologic environment.

This study has been supported by Kumar, Narayana, and Jayappa (2010) in their research on "shoreline changes and morphology of spit along southern Karnataka, west coast of India: A remote sensing and statistical based approach". They have also employed littoral cell method and cell circulation to explain shoreline changes across transects. Statistical results of this study are well fitted to the ground truth and, therefore, reliable to predict future shoreline movement. Environmental set up of the study area under this research paper is very much similar to the north Odisha coast and thus applying similar techniques might produce better results.

However, according to a study (Mahanadi River Delta, East Coast Of India: An Overview On Evolution And Dynamic Process, Mohanty and Swain, 2004) The Mahanadi delta coast of north Odisha has prograded in the seaward direction in the recent past due to abundant supply of sediments from the hinterland under favourable climatic / rainfall conditions, sea level adjustment, accommodation and tectonic subsidence. Their study also revealed that delta advance and retreat will depend on the critical factor of sediment supply to the shoreface in the future. When sediment supply to the shoreface is reduced, erosion would dominate on the shore and would be accentuated when severe storms / cyclones hit the shore. Therefore, a reliable research on the part is required for shoreline movements for integrated coastal zone management and future prediction of shoreline position.

The factors that influence long-term shoreline changes are the sediment supply, littoral transport and secular sea-level changes. Further, the shoreline undergoes frequent changes due to hydrodynamics of the near shore environment, river mouth processes, storm surges and the nature of coastal landforms (Scott, 2005; Narayana and Priju, 2006; Kumar and Jayappa, 2009).

Tidal processes, sea-level fluctuations, coastal erosion, sediment transport and deposition and flooding continuously modify the shoreline. The coastal systems have also been affected by several developmental activities such as ports, industries, aquaculture farming and other human intervention in the form of coastal defenses in the recent past. Thus, it is not possible to ascertain the complex morphodynamic pattern of any coast by hydrodynamic modeling alone. For this purpose, it is necessary to have a littoral cell wise explanation of shoreline movement and prediction of future shoreline chages (E. Bird, 2008).

Geomorphic process of the Mahanadi delta coast is complex due to, and is the net result of inland geology, shoreline configuration, tectonics, sea level rise and fall, near-shore wave climate and sediment influx. In addition to the aforesaid factors, anthropogenic activities also influence the near shore geomorphic processes, which increase with time and development of civilization (Frihy, Dewidar and El-Banna, 1998a). Thus a comprehensive study on the natural environmental process may hold good for managing development without altering the natural environmental setup.

In the tropical region, influx of sediments is highly variable with season, and sediment circulations in the near shore as well as in the vicinity of the river mouth also vary with the seasons. In response to the variation in the sediment influx, beaches in the vicinity of the river mouth and river mouth itself undergoes rapid changes and create management problems, especially, when sediment influx is modified either by damming of rivers (c.f. Bittencourt et al., 2007) or if current pattern is modified by construction activities in the mouth region (c.f. Abadie et al., 2008). North Odisha coast under the Mahanadi delta base has similar kind of environmental setup and poses identical problems.

The North Odisha coast is characterized by numerous number of spit, hook, bar and islands. These entire depositional features undergo frequent orientation and reorientation. Of the coastal geomorphic systems, spits are prominent ones and these are shaped by the accretion of sediments that occurs when alongshore drift reaches a section of headland. The sediments that make up spits are derived from a variety of sources including rivers and eroding bluffs, and changes there can have a large impact on spits and other coastal landforms. Spits can form at the ocean and bay sides of inlets are of great significance in understanding the morphodynamics of inlets and for managing navigation channels and inlets (Kraus, 1999).

The orientation of a spit is commonly used as an indicator of the direction of net littoral drift. However, spit orientation is determined by a combination of factors, including inlet channel geometry, wave refraction and tidal flow. Consequently, spit orientation may sometimes be contrary to dominant littoral drift (Hayes et al., 1970; Hubbard, 1976). Kraus (1999) developed a simple analytical model of spit extension; however, this model does not account for shoreline orientation. Petersen et al. (2001) proposed a one-contour line analytical model for spit accretion for an assumed ‘equilibrium’ spit shape and emphasized the importance of maximum evolution of spits. They also investigated the growth of spit subjected to waves from a single high angle (Petersen et al., 2002).

Recently, Ashton et al. (2007) studied the response of the spit shape to weave angle climate and suggest, through a unified model for spit extension, that distinction such as ‘drift-’ and ‘swash-alignment’ may not be of fundamental importance as swash-aligned areas may grade into the drift-aligned areas. They further demonstrate that alongshore sediment in the same wave climate alone can result in a coast where the spits trend towards an orientation dramatically different than that of a open coast. Their studies suggest that the maximizing angle for alongshore sediment transport, combined with boundary conditions, may explain many spit behaviors. Hookitola hook, located on the north of Mahanadi river mouth, is under the open coast regime and study of Temporal evolution of the hook may reveal alongshore sediment transport patterns and future orientation.

Sediment deposition in the Mahanadi River deltaic environments is principally monsoon-dominated. An average annual suspended load of 27.07 million tons and bed load of 2.70 million tons are carried by the Mahanadi River at its delta head at Naraj during the monsoonal months (Delta Development Plan, 1986). Thus average annual total sediment load (suspended + bed load) amounts to 29.77 million tons. Ray (1988) and Ray and Mohanti (1989) measured suspended matter concentrations 93.8-596 mg/l during the monsoon and 0.6-40.6 mg/l during the non-monsoon period. Diffusion of effluents and sediment dispersion patterns at the river mouths have been discussed by Wright (1985).

Because of the low volumetric capacity of the Mahanadi River and high flushing velocity, the suspended load during the monsoon enters into the Bay of Bengal probably as a buoyant plume and / or friction dominated plane jet depending on the volume of fluvial discharge and the hydrodynamic conditions of the inner shelf (Ray, 1988;

Ray and Mohanti, 1989). The turbid plume may extend 15 km or more into the Bay of Bengal during the monsoonal months of high fluvial discharge (Mohanti, 1993).

Nearshore regime forms the deposition centre for sands. Delta front environment supports a complex of barrier islands, bars and spit system. Accelerated longshore transport of sands helps building and prolongation of barrier island spit system. The tendency for continued prolongation may lead to the withdrawal of material from the proximal end causing thinning and even breaching as spits have an inherent tendency to erode (Carter, 1988). Damage to the sand spits and sand barriers and breaches may occur during high episodic monsoonal floods and storms / cyclones. Storms eroding coastal dunes, beach and spits may give a feedback to the littoral drift system. This feedback mechanism can well be understood through comparison of shoreline position of multidated satellite data. Under the given conditions in the north Odisha coast of the Mahanadi delta base is appropriate to be taken as study region.

According to the study of Mohanti & Swain, 2001, delta advance and retreat will depend on the critical factor of sediment supply to the shoreface. When sediment supply to the shoreface is reduced, erosion will dominate on the shore and that will be accentuated when severe storms / cyclones hit the shore. Global climatic warming may induce frequent coastal storms/cyclones. During the last fifty years construction of a major dam (at Hirakud), a weir and barrage across the Mahanadi River have arrested sediment supply to the shoreface. Besides irregular/erratic rainfall pattern due to changes in monsoon dynamics (triggered perhaps by climatic changes and increased anthropogenic activities), involving rampant deforestation in the hinterland and also other human induced factors might have also arrested sediment supply and transport to the shoreface. An assessment of shoreline change rate, correlated with sediment supply and monsoonal rainfall hold significance for coastal zone management.

For the convenience of study on shoreline movements, whole study area should be divided into many littoral cells on the basis of movement of longshore currents. An alongshore or littoral current is developed parallel to the coast as the result of waves breaking at an angle to the shoreline. This current and the turbulence of the breaking waves, which serves to suspend the sand, are the essential factors involved in moving sand along the shoreline. As wave approaches beach at an angle, the up- rush of water, or swash, moves sand at an angle onto the shoreface. The backwash of water rushes down the shoreface perpendicular to the shoreline or a slight downcoast angle, thus creating a zigzag movement of sand. This zigzag motion effectively results in a current parallel to the shoreline. Littoral drift refers to the movement of entrained sand grains in the direction of the longshore current. Littoral drift can be thought of as a river of sand moving parallel to the shore, moving sand from one coastal location to the next and so on until the sand is eventually lost to the littoral system (Patassh and Griggs, 2006)

Littoral drift or transport in the Mahanadi deltaic coast can occur alongshore in two directions, upcoast or downcoast, dependent on the dominant angle of wave approach. Along the Mahanadi deltaic coast, southward transport is generally referred to as downcoast and northward transport is considered upcoast. If waves approach perpendicular to the shoreline, there will be no net longshore movement of sand grains, no littoral current, and thus no littoral drift. Longshore transport for a reach of coast will typically include both upcoast and downcoast transport, often varying seasonally. Under a regime of reduced fluvial sediment supply, the littoral drift system getting a potential sediment component of fluvial sand supply may be impoverished, which may hinder nearshore aggradational processes (Shorelinne Change Assessment, A Report by MoEF ,Govt. of India, 2010).

A retrograding shoreline may result under these circumstances. Looking at the depositional scenario, it can be envisioned that the Late Holocene deltaic progradation under abundant sediment supply and sea level adjustment with a net gradual seaward shifting of the shoreline, is on the critical threshold of retrogression due to reduced sediment input under natural and anthropogenic forcing and also gradual increase of sea level due to local subsidence / tectonic causes as well as eustatic causes due to global warming? If this is admitted, a staggering coastal erosion and land loss is implied (Kumar et al, 2010).

In the last two decades, remote sensing and geographical information system (GIS) techniques have been widely employed in various coastal morphodynamic studies as they are cost–effective, reduce manual error and are useful in the absence of field surveys. The applications of remote sensing and GIS have proved particularly effective in delineation of coastal configuration and coastal landforms, detection of shoreline positions, estimation of shoreline and landform changes, extraction of shallow water bathymetry (Jantunen and Raitala, 1984; Singh, 1989; White and El Asmar, 1999; Lafon et al., 2002; Ryu et al., 2002; Siddiqui and Maajid, 2004; Yamano et al., 2006; Maiti and Bhattacharya, 2009).

Rate of change in coastal landforms and shoreline position is important in development of setback planning, hazard zoning, erosion–accretion aspects, sediment budgeting, and conceptual/ predictive modeling of coastal morphodynamics (Sherman and Bauer, 1993; Al Bakri, 1996; Zuzek et al., 2003). These aspects form as basis for conceptual morphodynamic models. Rate of change of shoreline position and spit migration is estimated employing various conventional techniques viz., End point rate (Fenster et al., 1993), average rates, linear regression, and jack-knifing (Dolan et al., 1991), but is always subject to uncertainty because of inherent short changes and deficiencies in the model used to evaluate the historical shoreline position. Calculation of shoreline change rate from satellite data and computer generated linear regression model have inherent errors due to inaccuracy in shoreline estimation, variation of shoreline position with respect to time, inadequately measured shoreline data points, irregularity in shoreline measurements, and the total time span of shoreline data acquisition (Douglas et al., 1998). For estimating the rate of change in shoreline position, the linear regression (LR) method has proved to play an important role as it minimizes potential random error and short–term variability (Douglas and Crowell, 2000; Allan et al., 2003; Maiti and Bhattacharya, 2009).

This dissertation also deals with coastal sand dune and its impact on shoreline changes which is an issue of outmost importance to the coastal geomorphologist. Vast tracts of India’s coast consist of beaches and coastal sand dunes. These natural formations are among the most effective natural defenses against storms, cyclones and tsunamis. Fishing communities rely on their presence and most of the coastal tourism industry advertises them as major attractions. What is often not realised is that these are dynamic and complex habitats, many of which are under threat. Coastal sand dunes depend on a constant supply of sand, which is often obstructed by activities such as construction of seawall sand wind breaks along the coast or damming of river sand choking off their natural supply of sediment to the coast (Dilip Venugopal, Bhalla and Anbarashan, 1998).

Coastal sand dunes perform a unique ecological function as a buffering mechanism for coastal erosion and deposition and protection against wave action, wind and tides (Mascarenhas and Jayakumar, 2007, 2006; Mascarenhas, 1998; Arun et al., 1999; Dahm et al., 2005; Sanjeevi, 1996; Sridhar and Bhagya, 2007; Environmental

Protection Agency, Queensland, 2006). These include sites for boat landing; sales of fish, drying and repairing of net sand motors as well as ground water recharge (Bhalla, 2007). Additional uses of coastal sand dune vegetation are fodder, food and medicinal plants (Sridhar and Bhagya, 2007). Other functions of coastal sand dunes mentioned in literature are- Storehouse of sediments and nutrients and sources of beach nourishment, protection from storm surges, hurricanes and erosion, provide habitats for adapted plants, birds and mammals, providing nesting site for sea turtle and birds, arrest blowing sand and deflect wind upwards, assist in the retention of fresh water, obstruct the ingress of saline marine water into the hinterland, prevent looses and from advancing inland on the coastal zone etc.

Coastal dunes are among the few natural defenses against the tsunami. While the role of vegetation or bio- shields is fiercely debated, it is widely accepted that coastal sand dunes plays an important role in protecting coastal communities against both the tsunami and storm surges (Bhalla, 2007; Mascarenhas and Jayakumar, 2007; Chatenoux and Peduzzi, 2007). Despite the fact, very few studies have been performed on the coastal dunes of Odisha coast, especially dune on the Mahanadi delta coast. Thus, study of the origin and evolution of coastal sand dunes is of immense importance from geomorphological, ecological and management point of view.

1.4 Research Questions.

1. Whether multi-dated satellite imagery can be used for determining patterns of shoreline changes?
2. How coastal morphological processes influence shoreline movement?
3. To what extent shoreline configuration determines coastal erosional and depositional process.

1.5 Objectives

1. To asses and analyse shoreline changes based on secondary data, derived from multi-dated satellite imagery.
2. To analyse geomorphic processes in a specific coastal set up.
3. To analyse nature and intensity of coastal erosion.
4. To assess the degree of impact of anthropogenic activities on shoreline and coastal geomorphology.

1.6 Data Sources

1. LandSat data from United States Geological Survey (USGS) (Table: 1.2).
2. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data from USGS.
3. Survey of India (SOI) toposheet (1961).
4. Climatological data from Indian Meteorological Department.

Table: 1.2 Information on LandSat data

Satellite	Sensor	Bands	Spectral Range	Scene Size	Pixel Resolution
L 1-4	**MSS multi-spectral**	**1,2,3,4**	**0.5 - 1.1 µm**	**185 X 185 km**	**60 meters**
L 4-5	**TM multi-spectral**	**1,2,3,4,5,7**	**0.45 - 2.35 µm**		**30 meters**
L 4-5	**TM thermal**	**6**	**10.40 - 12.50 µm**		**120 meters**
L 7	**ETM+ multi-spectral**	**1,2,3,4,5,7**	**0.450 - 2.35 µm**		**30 meters**

L 7	**ETM+ thermal**	**6.1, 6.2**	**10.40 - 12.50 µm**		**60 meters**
Panchromatic	**ETM+ thermal**	**8**	**0.52 - 0.90 µm**		**15 meters**

Source: Global Land Cover Facilities (GLCF), USGS.

1.7 Methods

Morphological and shoreline change along the north Odisha coast has been analyzed using different methods which range from image processing to complex shoreline generation using ERDAS 9.1 software and ArcGIS 9.3.

The entire work on shoreline mapping and statistics generation has been worked out based on a series of multi-dated satellite data from 1973 to 2006. At the very initial stage, all required data sets were resampled to make the pixels size equal for all data sets. Resampling certainty enhances comparability among various data sets of equal pixel size. Digital Shoreline Analysis System (DSAS) (Thieler et al., 2005) is used to generate rates of change for the time series of shorelines and vegetation lines. For the convenience of study shoreline is to be divided into a number of littoral cells in such a way that each cell retains comparatively similar geomorphic characteristics. Image threshold operation has been performed on each satellite image of different dates to have binary images and then it has converted to vector format for linear features of shoreline.

Each method used to calculate rates of shoreline change is based on measured differences between shoreline positions through time. The reported rates are expressed as meters of change along transects per year. When the user-selected rate-change calculations are done, DSAS merges the individual module calculations and the output is made available as a table in ArcMap. Rate-change statistics provided with DSAS have the standardized field headings listed in the first column of the table below the end point rate (EPR) is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline. Major advantages of the EPR are the ease of computation for minimal requirement of only two shoreline dates. The major disadvantage is that in cases where more data are available, the additional information might get ignored.

The net shoreline movement (NSM) provides a distance, not a rate. The NSM is associated with the dates of only two shorelines. It gives distance between the oldest and youngest shorelines for each transect. This represents the total distance between the oldest and youngest shorelines. If this distance is divided by the number of years elapsed between the two shoreline positions, the result is the End Point Rate as described section.

A linear regression rate-of-change statistic can be determined by fitting a least-squares regression line to all shoreline points for a particular transect. The regression line is so placed that the sum of the squared residuals (determined by squaring the offset distance of each data point from the regression line and adding the squared residuals together) is minimized. The linear regression rate is the slope of the line. The method of linear regression includes these features: 1) All the data are used, regardless of changes in trend or accuracy, 2) The method is purely computational, 3) The calculation is based on accepted statistical concepts, and 4) The method is easy to employ (Dolan and others, 1991). However, the linear regression method is susceptible to outlier effects and also tends to underestimate the rate of change

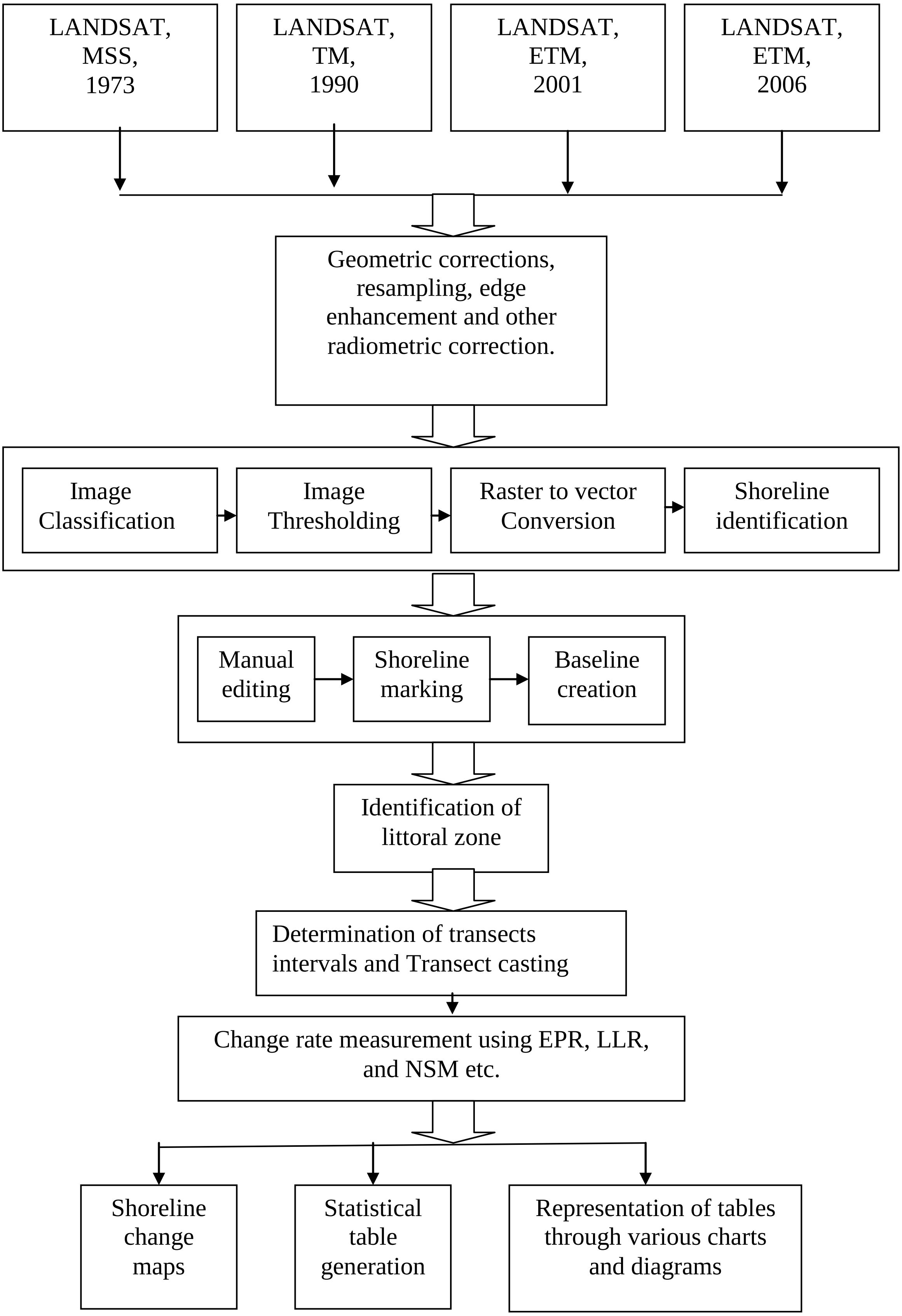

Figure 1.8 Stages of generating shoreline map and deriving statistical results (Flow chart)

relative to other statistics, such as EPR (Dolan and others, 1991; Genz et al, 2007).

Once statistics are generated on the above parameters, shoreline change maps (containing shorelines of different time along with transects and baseline) are prepared using Arc GIS 9.3. Geomorphological evolution of spit and changes of their areal extent has been determined by temporal observation through multi dated satellite imagery and simple digitization method.

Slope profile across sea beach has been drawn to find out extent of wave run-up and intensity of wave energy at which it strikes the coast. Slope profile data against each line is collected through auto level survey. While plotting data sets graphically, initial point of each profile line is assumed to be a reduced level of zero meter. Intervening distance between two consecutive points on a profile line has been taken variably to represent irregularities as it is on the ground. Dune backed beaches have been studied carefully and various stages of dune evolution captured in terrestrial photographs which also acts as a proof against all secondary data base statistics. Finally, required data sets are represented through statistical diagrams (bar graphs, line graphs etc.) for graphical representation of shoreline movement patterns.

CHAPTER-II

2.1. Introduction

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Shorelines are areas of unending interaction between land and the natural forces of wind, waves and currents. Erosion, transportation and deposition of sediments are natural processes along shorelines. There is often a net balance between the amount of shoreline eroded and the amount of new shoreline being created by sedimentation – a condition known as a dynamic equilibrium. In general, entire shoreline along the Mahanadi delta coast undergoes both erosion and accretion on a seasonal as well as yearly basis. The primary source of sediment is longshore drift and updrift eroding coast. River, especially, the Mahanadi River is a primary source of erosion within present coastal system. The source of sand thus created continues to feed the beaches within the study area comes primarily from the erosion of coastal landform (Report on shoreline changes, Dept. of Forest and Environment, Govt. of Odisha, 2011).

The Mahanadi River deltaic coast is microtidal with a mean tidal range measuring 1.29 m. Tidal cycle is semi-diurnal. It is principally a wave-dominated coast during the southwest monsoonal season, while during the non-monsoonal period it is tide-dominated mixed wave and. The northeast monsoon (between Decembers and early January) is much milder in its dynamic activity. Southwest monsoon winds generate high waves, around 3 m high or more, and waves striking the shore obliquely induces a littoral drift of sands from southwest to northeast along this coast. It annually moves around 1.5 million cubic meters of sand in the nearshore region (Mohanty and Swaine, 1990).

Shoreline along Mahanadi delta coast, thus, also shifts seasonally, tending to accrete slowly during winter months when sediment is deposited by relatively low energy wave. In addition, attempting to halt natural coastal process with seawall and other man made structure only shift the problem from one area to another. Seawall construction further leads to total restriction of sediment transport to nearshore beaches behind the wall, coastal dune, barrier beaches salt marsh and estuaries. Eventually, these entire features would disappear as the sand source that feeds and sustains these is stopped.

In order to correctly interpret the shoreline movement, entire shoreline of a different time, of the Mahanadi delta coast, has been derived from satellite data and overlaid with one another to calculate change rate. Shoreline movement has been recorded over each transect that lies perpendicular to the shoreline. Rate of movement has been calculated in respect to a baseline that is located both, in offshore and onshore position at a distance of 600m from the position of shoreline in 1990s. The intervening distance between two consecutive transects are taken as 500m.

Entire shoreline has been segmented under five littoral cells. Each littoral cell is characterised by homogeneous environmental condition with unidirectional longshore drift. Statistical results have been collected under three heads as End Point Rate (EPR), Net Shoreline Movement (NSM) and Linear Regression Rate (LRR).

2.2. Littoral Cell and transects

Based on natural and man made constructed landmarks, (such as river/Estuarine inlets and breakwaters), dominating geomorphic process, vegetation cover and the intensity of anthropogenic activity, 63.85 km-long coastal stretch of the study area has been sub-divided into five ‘littoral cells’ (see Figure 1.1). These cells exhibit similar hydrodynamics (littoral drift, rip currents etc.) and erosional as well as accretional process. Longshore currents/littoral drift patterns are generally modified at the boundaries due to tides, waves and river discharges. For detailed analysis, number of transect lines (e.g., Transect number 1 to 119) has been drawn across each littoral cell and all relevant data, regarding shoreline movement, are collected for these transects (table 2.1).

Table 2.1 Transect number and length of littoral cell.

Littoral cell	No. of Transects	Length of the cell
1	1-9	04.67 km
2	10-50	20.88 km
3	51-71	14.51 km
4	102-119	11.77 km
5	80-101	12.02 km

A baseline has been created at 600 m distance from the shoreline derived from 1990s LandSat data. Baseline has been taken as a reference line. Movement of entire shorelines, over the period 1973-2006, has been detected in reference to the baseline which is drawn both on offshore and onshore direction.

2.2.1. Shoreline change rate calculation.

With reference to the baseline, progradation of the shoreline is considered as a positive value, while recession as a negative value. The rate of change in shoreline position is calculated by the linear Regression equation ($y=\alpha+\beta t$) where y is the shoreline shift during the year t, with y=0for baseline. The regression coefficient (β) represents shoreline change rate and the coefficient of determination (R^2) is a measure of goodness of fit of the equation to the present data. Statistical significance is considered at the 80% level of confidence (instead of 95% confidence level) in view of a small number of samples, as suggested by Allan et.al. (2003).

2.2.2. Results

All statistical results derived from digital shoreline analysis system (DSAS) along the 63.85 km long shoreline for every transect has are presented in Figure 1.3 to 1.8 and Table 2.1 to 2.6, and are analysed on perspective of major determining factors of shoreline change like exposure of shoreline, wind and wave action, slope of the beach, sediment supply, transport and anthropogenic factors like sand extraction, construction of seaport etc.

2.2.2.1. Littoral Cell-1 (Transects Nos. 1-9)

All transects except 7 and 8 along the shoreline under littoral cell-1 fall within erosion regime. Average erosion rate (which is represented by end point rate) of transects 1-6 varies between 1 to 4 meters per year. Net shoreline movement during the time period of 1973 to 2006 along transect 1 to 6 varies between 30 m to 120 m. Transect number 7 and 8 are exceptions to the usual geomorphic process (recession) in this littoral zone. Erosion rate along these two transect varies between 9 m to 11 m per year and net shoreline movement over the period 344 m and 282m respectively. Southern most distributaries of Mahanadi delta (Debi River) debouches in this zone.

Littoral cell-1 is characterised by number of islands and bars. Sand bars across the mouth of Debi River results in gradual shifting of the river mouth in northern direction. This phenomenon largely responsible for eroding shoreline across transects 1 to 6. Transported sediment gets deposited along the northern end of the cell result advancement of shoreline across transect7 and 8.

Data: LandSat, ETM+, 1973, 1990, 2001 and 2006

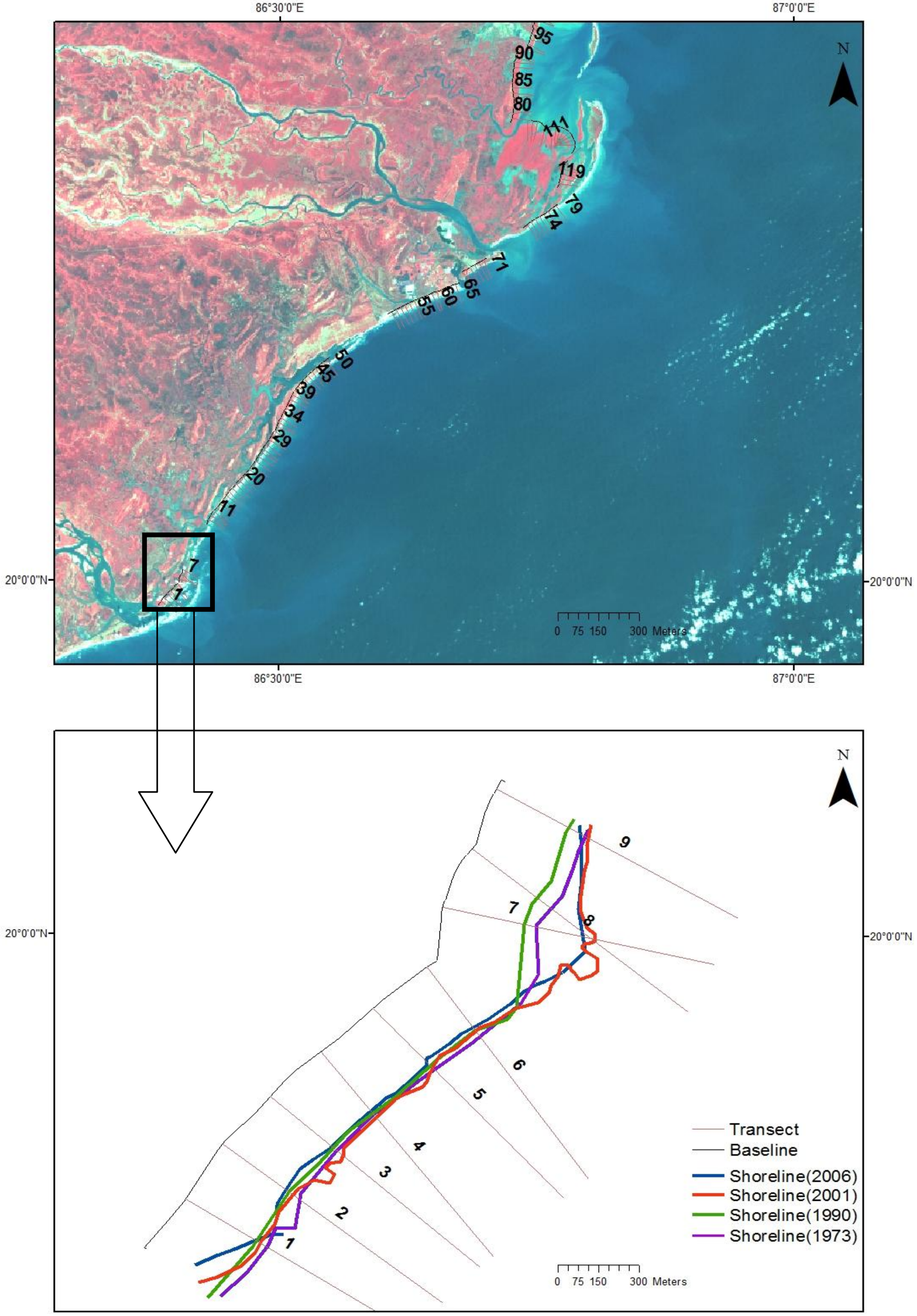


Figure 2.1 Shoreline change along transect number 1 to 6

Table 2.2 Transect number 1 to 9.

Transect Id	EPR	NSM	LRR	LR^2
1.000	-2.930	-96.560	-2.440	0.630
2.000	-3.660	-120.680	-2.950	0.670
3.000	-1.370	-45.240	-0.040	0.000
4.000	-0.940	-30.910	-0.160	0.010
5.000	-2.270	-74.870	-1.680	0.580
6.000	-2.710	-89.230	-2.410	0.890
7.000	10.460	344.650	13.370	0.580
8.000	8.580	282.930	11.800	0.490
9.000	-1.280	-42.130	-0.040	0.000

Former and present morphological setup of Debi river mouth is being represented by figure **1** and **2**. This figure depicts how the evolution of sand bar across the river mouth is resulting in gradual shifting of tidal prism. Over the time tidal prism has been shifted from east-west direction to northeast-southwest direction. Again, this changing direction is responsible for shift in tidal energy which ultimately leads to the erosion of coast and advancement of shoreline.

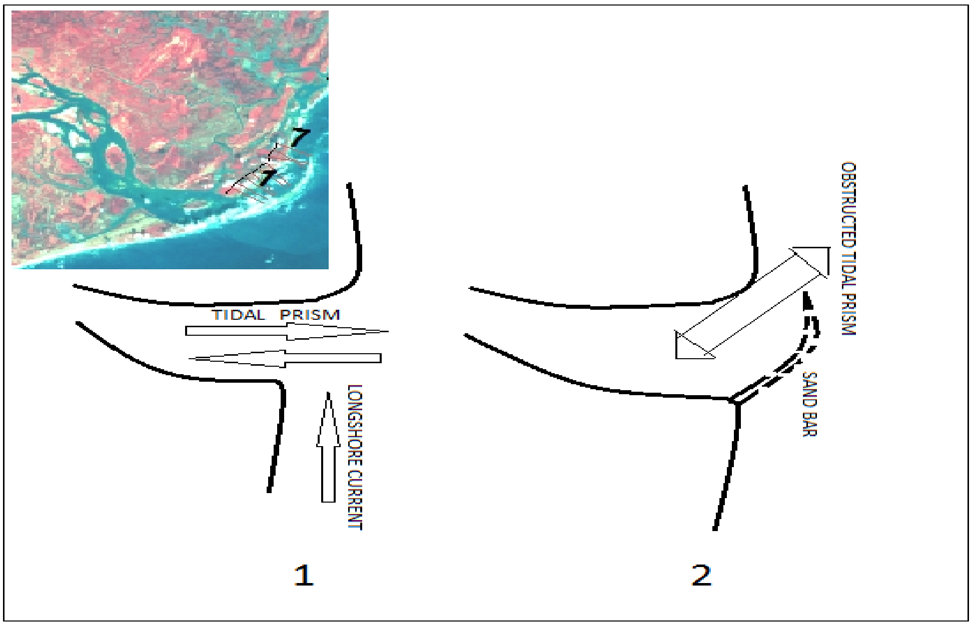


Figure 2.2 Tidal prisms.

2.2.2.2. Littoral Cell-2 (Transects Nos.10-50)

Data: LandSat 1973, 1990, 2001 and 2006

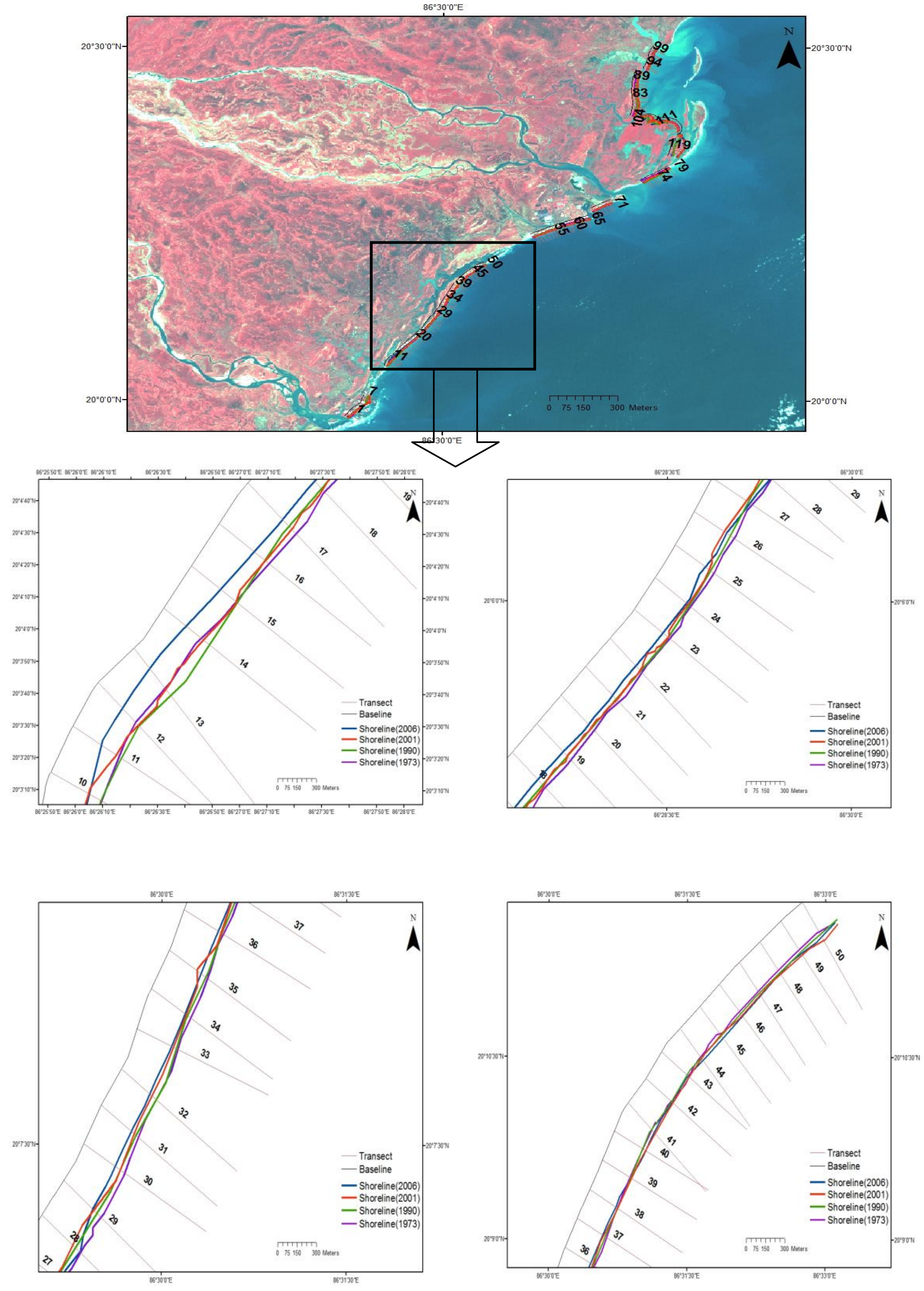


Figure 2.3 Transects numbers 10-15

Table 2.3 Transect number 10 to50.

Transect ID	EPR (m)	NSM (m)	LRR (m)	LR^2 (m)
10.000	-4.480	-147.690	-5.160	0.770
11.000	-6.710	-221.300	-5.240	0.470
12.000	-5.860	-193.300	-3.710	0.220
13.000	-7.570	-249.550	-5.450	0.290
14.000	-6.000	-197.780	-4.240	0.230
15.000	-6.150	-202.580	-4.300	0.360
16.000	-5.820	-191.930	-4.470	0.630
17.000	-5.970	-196.890	-4.620	0.670
18.000	-4.430	-146.020	-3.290	0.570
19.000	-4.570	-150.670	-3.860	0.840
20.000	-3.270	-107.730	-2.830	0.870
21.000	-3.680	-121.360	-2.900	0.700
22.000	-3.630	-119.570	-2.880	0.660
23.000	-3.690	-121.750	-2.810	0.580
24.000	-2.230	-73.600	-2.070	0.920
25.000	-4.460	-146.920	-3.910	0.880
26.000	-3.770	-124.300	-4.510	0.870
27.000	-1.180	-38.750	-1.820	0.450
28.000	-0.360	-11.920	-1.730	0.150
29.000	-4.410	-145.260	-4.490	1.000
30.000	-4.690	-154.700	-3.970	0.840
31.000	-3.640	-119.990	-3.350	0.920
32.000	-3.400	-112.080	-3.370	0.760
33.000	-2.800	-92.320	-2.750	0.890
34.000	-2.810	-92.750	-2.670	0.980
35.000	-3.170	-104.330	-4.230	0.710
36.000	-2.470	-81.290	-2.110	0.810
37.000	-2.440	-80.540	-2.400	0.950
38.000	-0.940	-30.980	-0.590	0.210
39.000	0.680	22.360	0.860	0.780
40.000	1.940	63.800	2.120	0.730
41.000	1.880	61.930	2.470	0.630
42.000	0.470	15.510	0.840	0.480
43.000	-0.490	-16.180	-0.070	0.000
44.000	2.170	71.380	1.840	0.800
45.000	2.720	89.670	2.140	0.700
46.000	2.770	91.170	2.770	0.990
47.000	2.380	78.360	2.380	0.990
48.000	1.770	58.400	2.030	0.880
49.000	2.190	72.110	2.650	0.850
50.000	2.740	90.220	3.790	0.700

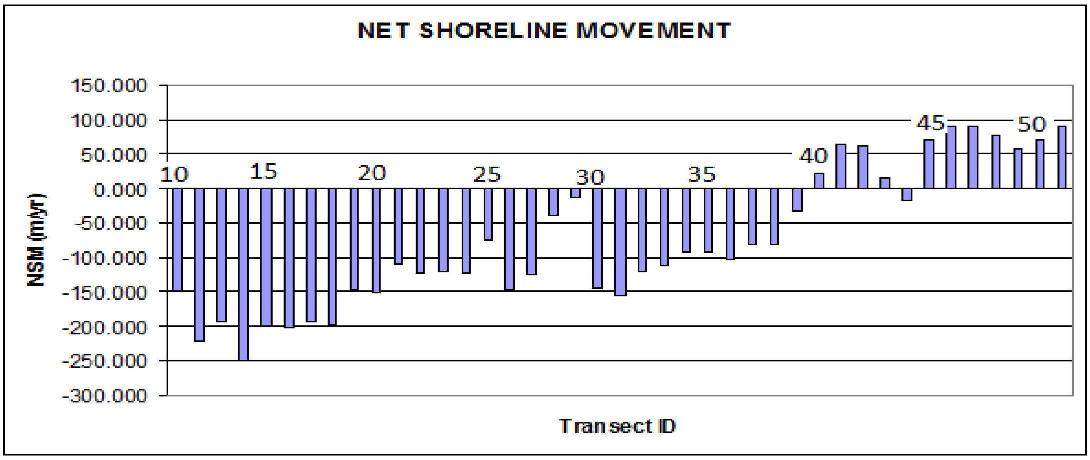


Figure 2.4 NSM along transects number 10 to 50 under littoral cell-2

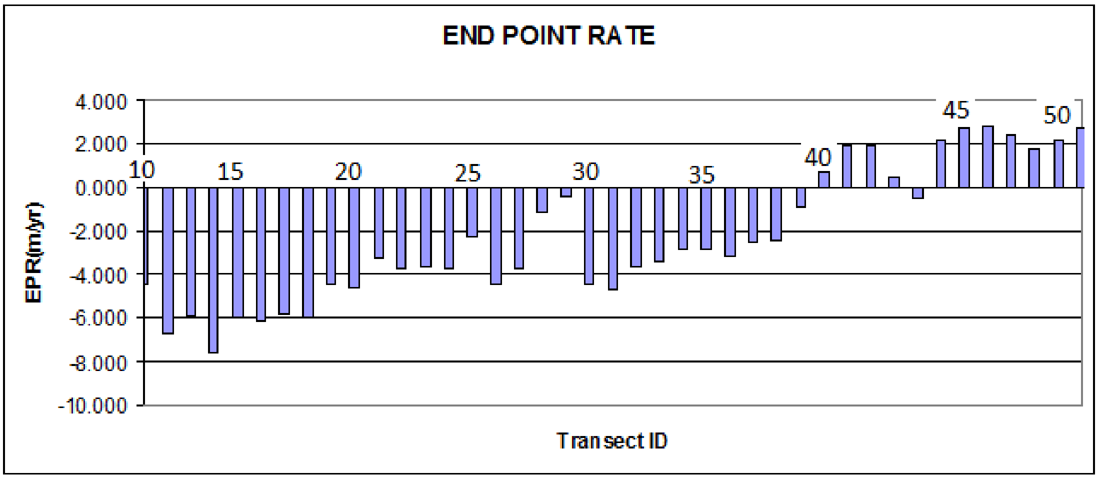


Figure 2.5 EPR along transects number 10 to 50 under littoral cell-2

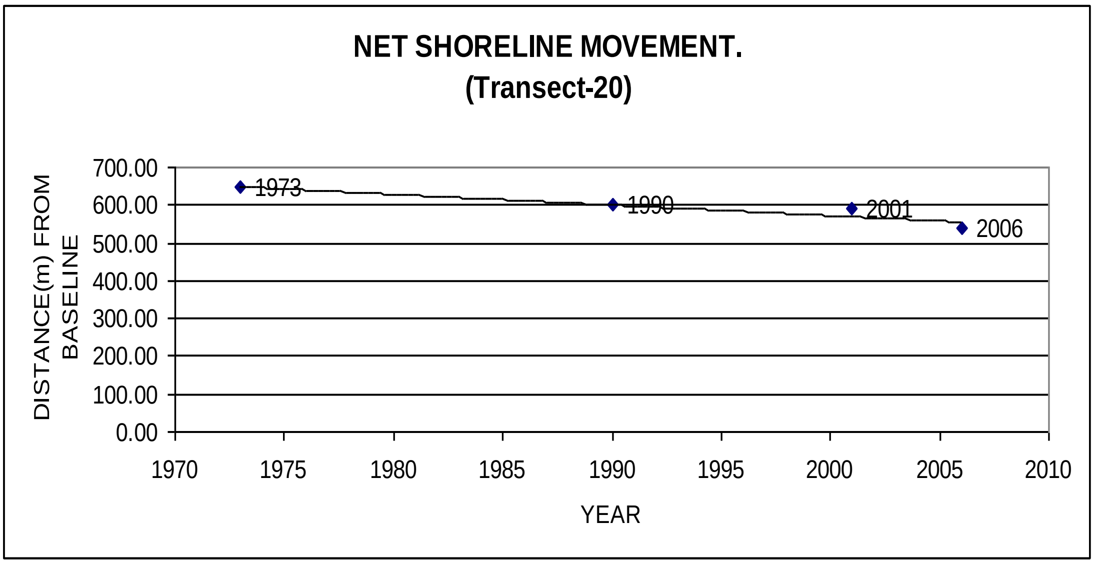


Figure 2.6 Trends of NSM along transects number 20 under Littoral Cell-2

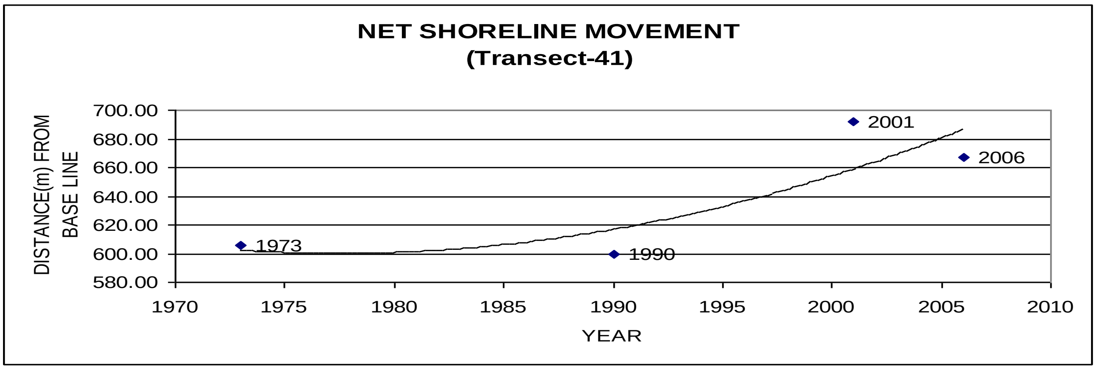


Figure 2.7 Trends of NSM along transects number 41 under Littoral Cell-2

Shoreline under littoral cell-2 is getting eroded along the Transects no.10-38 and 43 while rest of transects recorded with positive shoreline movement. On an average, southern part of this littoral cell falls within erosion regime while northern part is a depositional regime.

Table 2.3 shows that end point rate (EPR) varies between -0.49m to -7.57m per year and with net shoreline movement (NSM) of 249.55 m to 30.85 m. On the other hand, rate of shoreline recession, along northern part of this littoral cell, varies between 0.68 m to 2.77 m per year with maximum recession has been recorded as 91.17 m along transect no.-47. Graphical representation of EPR and NSM is given in Figure 2.4 and 2.5, these exhibiting a similar statistical result which signifies that shoreline movements have taken place uniformly over the years. Transect number 20 in Figure 2.6 representing average trend of shoreline movements which remained uniform between 1973 and 2006. This particular transect is also a representative of all transects between number 10 to 38, because its EPR and NSM is close to the average EPR and NSM of this group. On the other hand, transect number 41 can be taken as representative of all transects between number 40 to 51 because of the similar reason as in case of transect number 20. Figure 2.7 is showing the nature of net shoreline movement along transect 41, which remained insignificant between 1973 to 1990. After 1990, shoreline along this transect has migrated positively around 60 meters during a time period from 1990 to 2006.

Pattern of such recession and advancement of shoreline could be interpreted as the interplay of direction of shoreline lying along, wind and wave action, sediment supply through distributaries of Mahanadi, and degree of exposure to the open ocean.

The exposure of a shore unit to the erosive forces of wave action is associated with the magnitude of net potential transport rate along that shore. The magnitude of longshore transport rate is primarily a function of the offshore wave height and its angle relative to the shoreline. Areas that are exposed to equal distribution of wave energy from both directions (left and right) may have large amounts of sediment moving in the nearshore but this sediment will tend to remain in the nearshore. Northeastern monsoon could not directly hit the shoreline as the shoreline along this littoral cell littoral lying along northeast to southwest direction. On the other hand, almost every part of the shoreline directly exposed to the southwestern monsoon plays a host to strong agent of erosion. Thus total erosion and transportation of the eroded material is higher in the southern part than its northern component. This phenomenon leads to the variability of coastal geomorphic process along shoreline, under littoral cell-2, in favour of shoreline recession in southern part and advancement in the northern part.

Distributaries of Mahanadi, debouching here, are lean and the amount of sediment these being poured is less in comparison to the major distributaries located at the extreme north and south of the study area. Moreover, almost all sediment gets trapped by backshore lagoonal water, located immediate behind the barrier bar. A decrease in sediment supply, coupled with direct interaction of energy, results in net shoreline erosion within this littoral cell system.

2.2.2.3. Littoral Cell-3 (Transects Nos. 51-71)

LandSat: 1973, 1990, 2001, and 2006

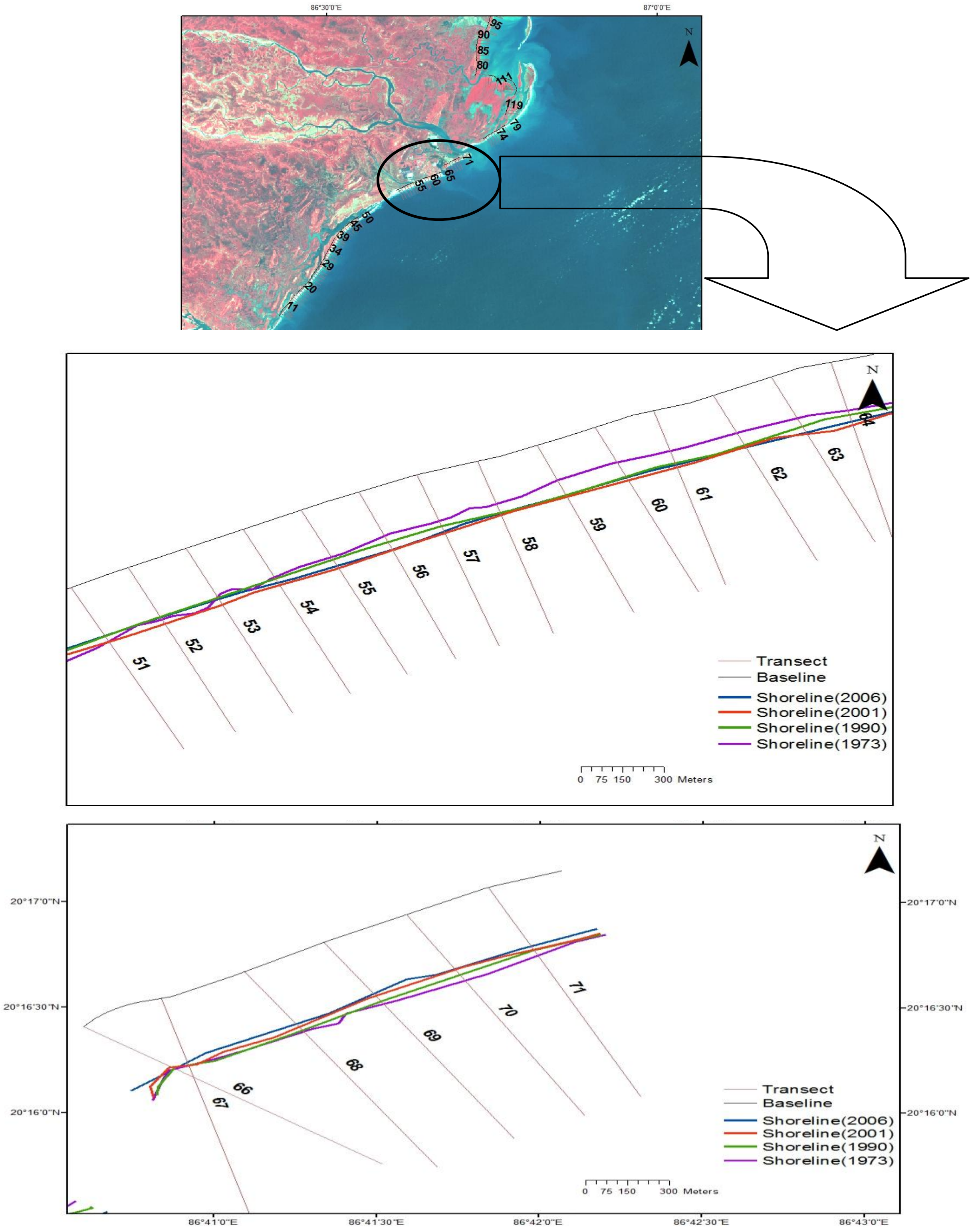


Figure 2.8 Shoreline change across transect number 51 to 71

Table 2.4 Transect numbers 51 to 71.

Transect ID	EPR	NSM	LRR	LR2
51.000	-1.940	-63.880	-1.030	0.150
52.000	-0.690	-22.800	0.350	0.020
53.000	0.690	22.800	1.650	0.340
54.000	1.980	65.180	2.600	0.720
55.000	3.180	104.940	3.870	0.810
56.000	4.950	163.080	5.400	0.960
57.000	3.610	119.140	4.130	0.920
58.000	3.190	105.140	3.480	0.810
59.000	5.260	173.400	5.540	0.780
60.000	5.540	182.590	6.070	0.810
61.000	4.840	159.510	5.310	0.860
62.000	5.310	175.060	5.330	0.890
63.000	5.270	173.740	5.790	0.950
64.000	3.860	127.350	4.700	0.840
65.000	3.100	102.020	3.700	0.860
66.000	-0.160	-5.430	-0.290	0.280
67.000	-2.360	-77.880	-2.080	0.750
68.000	-2.650	-87.290	-2.760	0.900
69.000	-3.440	-113.290	-3.570	0.990
70.000	-2.860	-94.150	-2.620	0.950
71.000	-1.850	-61.050	-1.510	0.630

Accretion is the major process of shoreline movement along this part of the study area. All transects, from number 55 to 65, in Table 2.4, are recorded with significant statistical results with positive Net Shore Line Movement (NSM). As a whole, transect number 53 to 65 have been recorded with positive NSM (shoreline recession) with a maximum of 175m and minimum of 22m during the time period of 1973 to 2006. Transect number 51, 52 and from 66 to 77 has been recorded with negative NSM. Among transects which is recorded with negative NSM (shoreline advancement), statistical results is significant only on Transect number 68, 69 and 70, while rest of the transects appeared with insignificant results and thus are highly unpredictable in nature. Transect number. 70 has been appearing as representative of all transects that recorded negative NSM. It has an EPR of 2.86m/yr and a LRR of 2.

62m/yr with statistically significant results. End Point Rate (EPR) along transects which are recorded with positive NSM, varies from 3 m to 5 m/yr

Considering EPR, NSM and LRR, transect number 57,63 and 65 can be taken as representative of all transects between 54 to 65. Net shoreline movement along these transects in Figure 2.11, 2.12 and 2.13 shows a similar pattern of steady advancement during 1973 to 2001. After that, shoreline has shown slight retreat between 2001 and 2006. Human activities seem to affect the stability of both dune-backed and bluff-backed shorelines. At a longer time and larger space scales, jetty construction and maintenance dredging are factors that can affect shoreline stability.

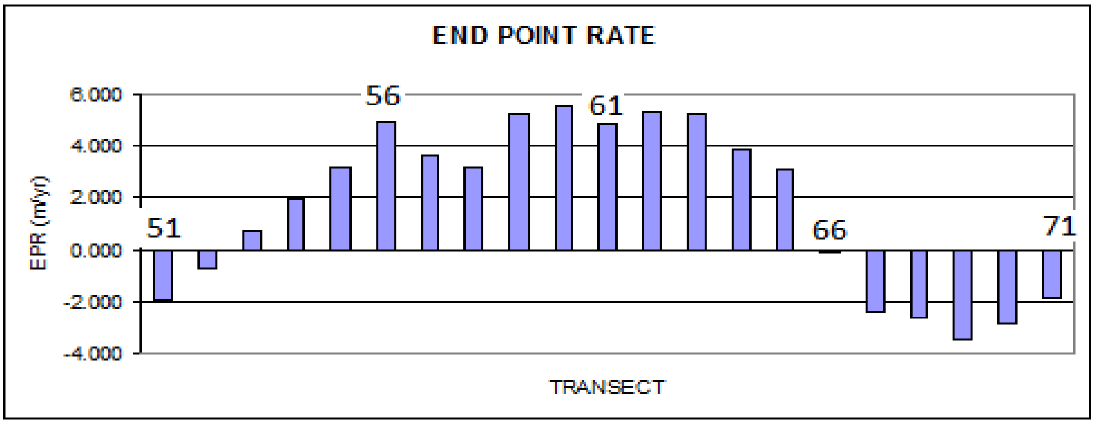


Figure: 2.9 EPR across transect number 51 to 71

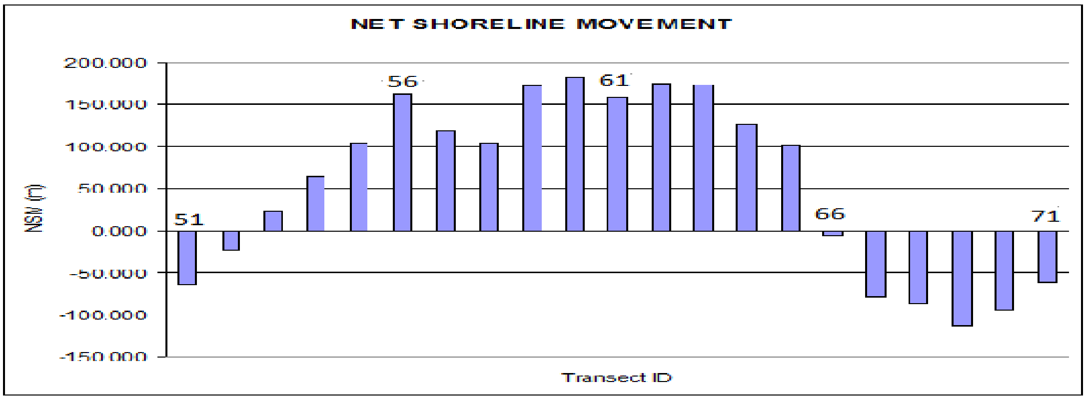


Figure: 2.10 NSM across transect number 51 to 71

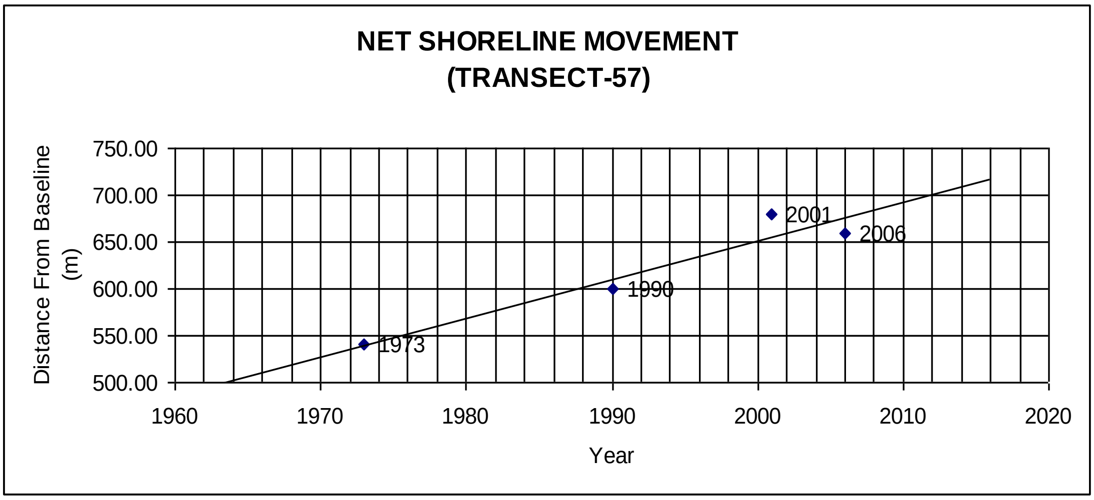


Figure 2.11 Trends of NSM along transect number 57.

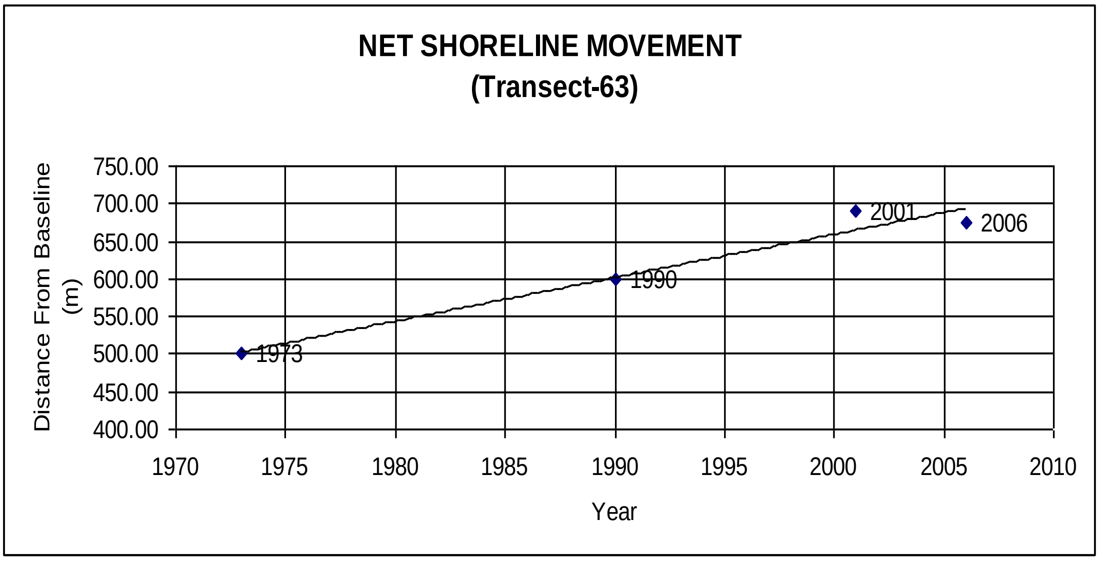


Figure 2.12 Trends of NSM along transect number 63.

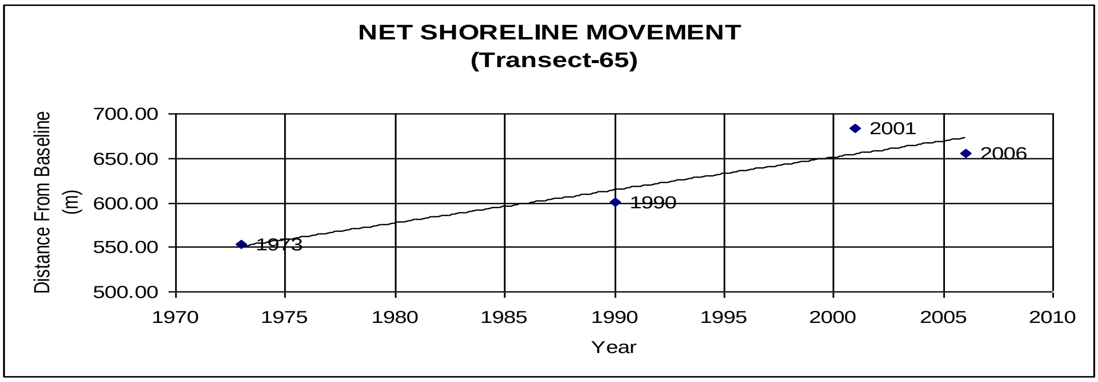


Figure 2.13 Trends of NSM along transect number 65.

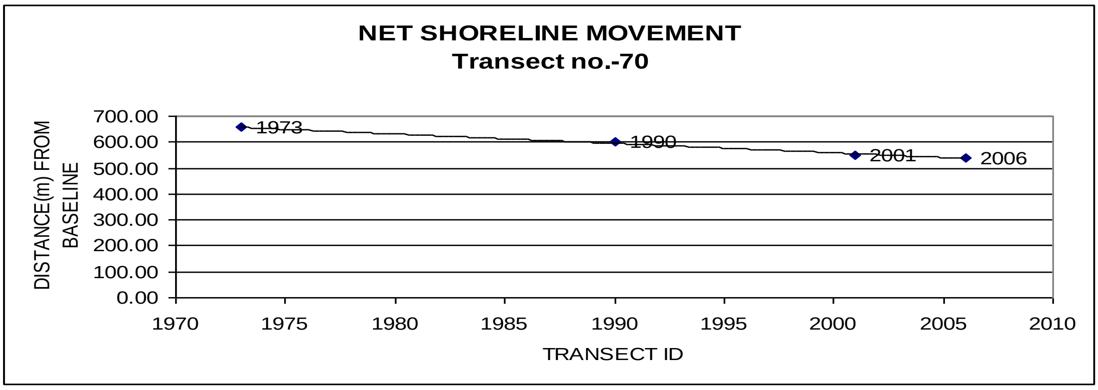


Figure 2.14 Trends of NSM along transect number 70.

On the other hand, shoreline across transect number 66 to 71 has been eroded over the time, which is essentially against the usual nature of this littoral cell. Figure 2.14 is representing the average trend of shoreline movements along transects number 70, which can be taken as representative of the transect group comprising transect number 66 to 71. Similar shore zone process has developed different nature of shoreline movement only because of anthropogenic activity. There are a variety of human activities like sand extraction and seaport construction etc. which affects shoreline stability over a shorter time and smaller space scales.

As a whole, it can be said that this littoral cell system is under depositional regime. Wave run-up is weak because much of the incoming wave energy is expended in breaking before it reaches shoreline. On narrow and steeply-sloping, reflective beaches run-up is strong because incoming waves break right at the shoreline with little prior loss of energy.

Shorelines are nourished under extensive protection of sand dunes which prolong wave run-up. The interaction of dunes with the adjacent beach and nearshore, thus, provides the essential basis of a stable shoreline or shoreline with positive movement towards ocean. Field study carried out along the shoreline and beach profiles, drawn from the data collected by auto level survey, reveal that this part of the study area is characterised by gentle slope (3° to 5 Degree). Incidentally entire shoreline in the southern part of the study area is receding. Maximum shoreline recession has been recorded along the transect number 60, whereas minimum along transect number 53. Net shoreline movement varies between 182 m to 22 m over the time period of 1973 to 2006.

2.2.2.4. Littoral Cell-4 (Transects Nos. 102-119)

LandSat 1973, 1990, 2001 and 2006

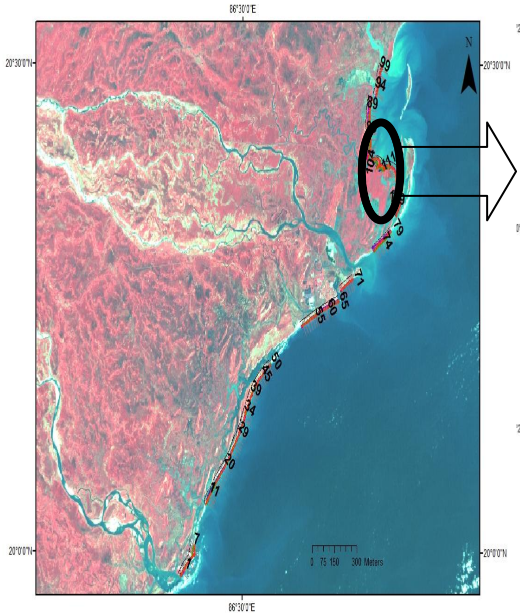


Figure: 2.15 Littoral Cell-4

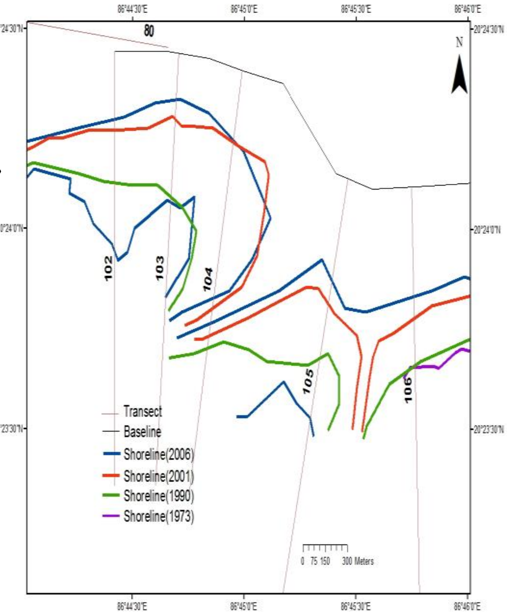
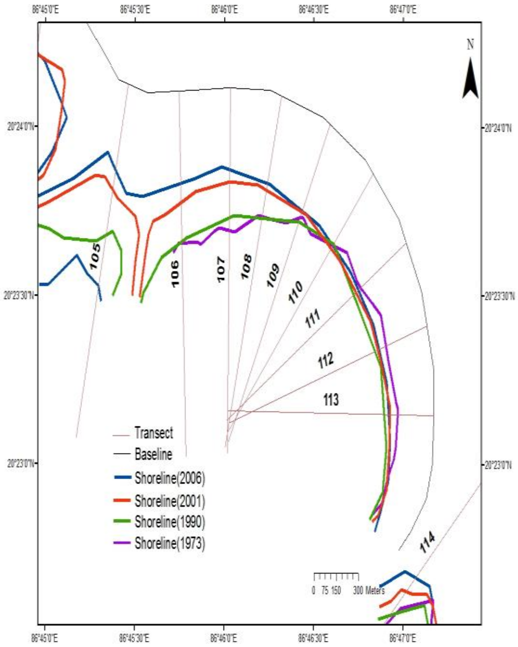


Figure: 2.16 Transect No. 102 to 106



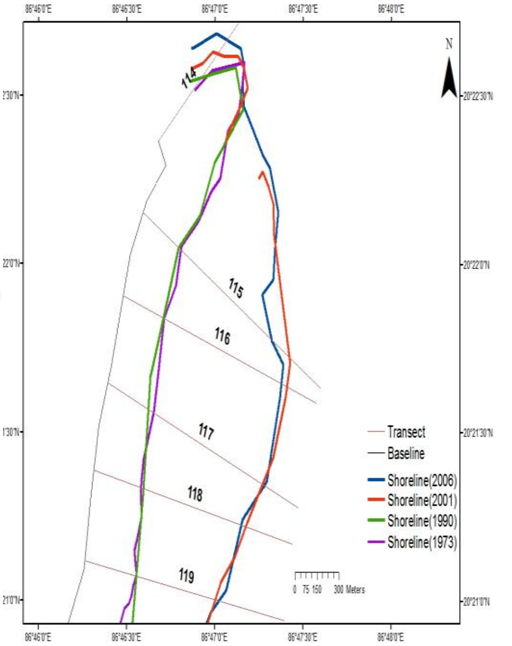


Figure 2.17 Transect No. 107 to 114

Figure 2.18 Transect No. 115 to 119

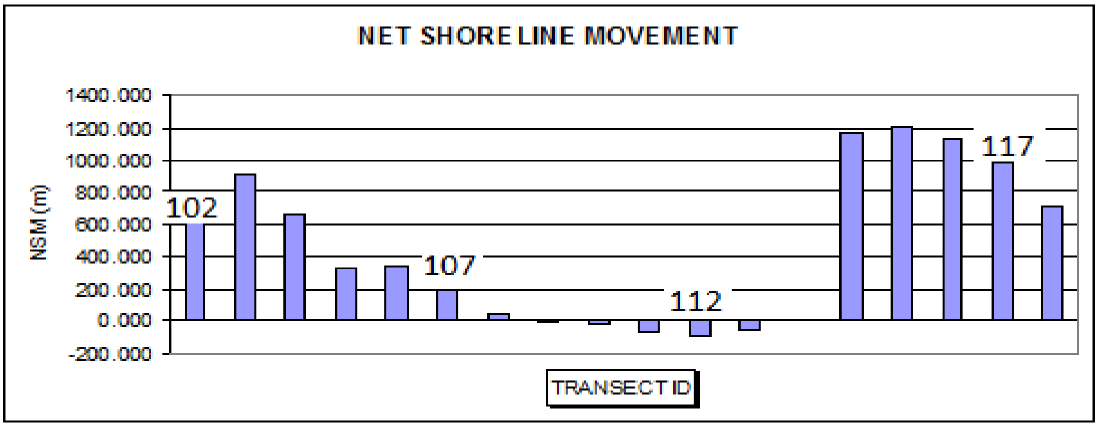


Figure 2.19 NSM across transect number 102 to 118.

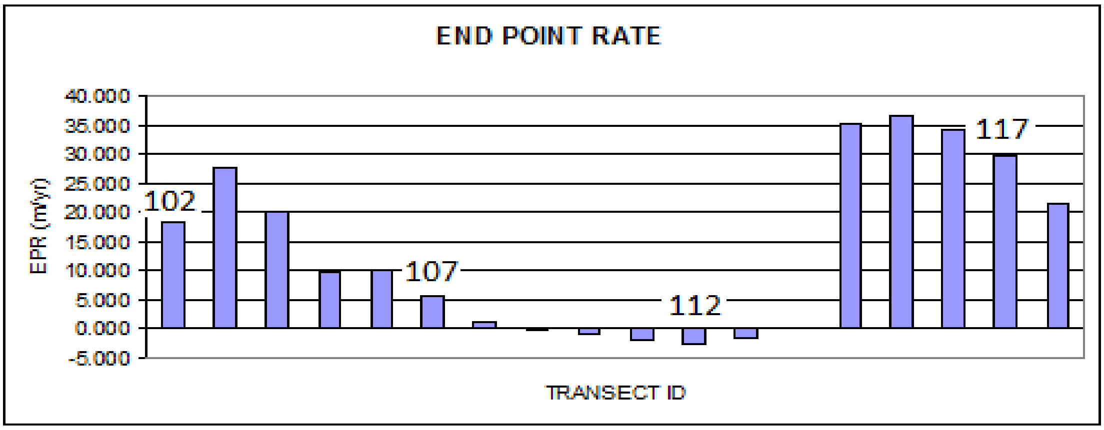


Figure 2.20 EPR across transect number 102 to 118.

Net shoreline movement along the transect Nos. 102 to 107, in Figure 2.16, shows high positive value with a minimum of 39 m along transect 108 and a maximum of 911 m along transect 103. Transect number 109 to 113, in Figure 2.17, shows minimal erosion during 1973 to 2006. On the other hand, a completely new island has been emerging over the area under transects 115 to 118 in figure number 2.18. This has been manifested as unusual advancement of shoreline with maximum advancement rate of 1211 m per year along transects number 116 in the Table 2.5. Graphical representation of NSM and EPR in Figure number 2.19 and 2.20 shows that nature of shoreline movement in this littoral cell is prominently of two types i.e., either stable or accretional in nature.

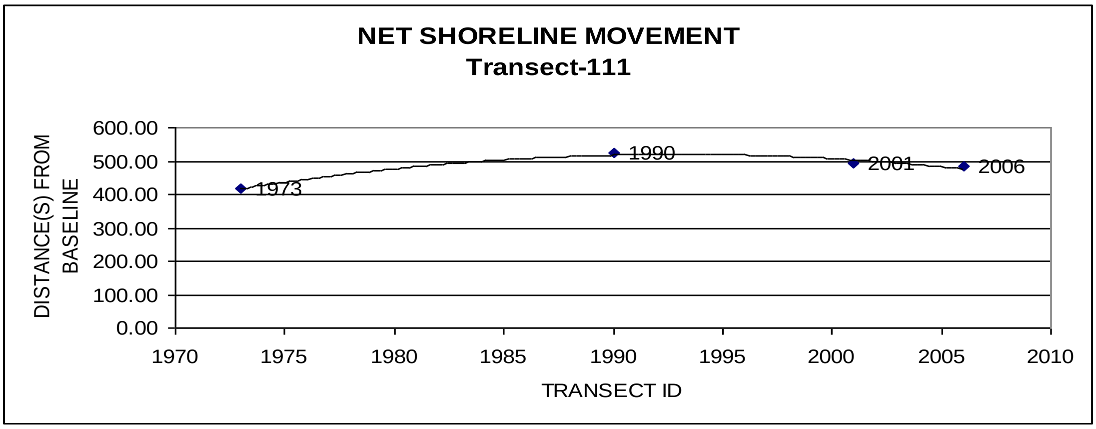


Figure 2.21 Trends of NSM along transect number 111.

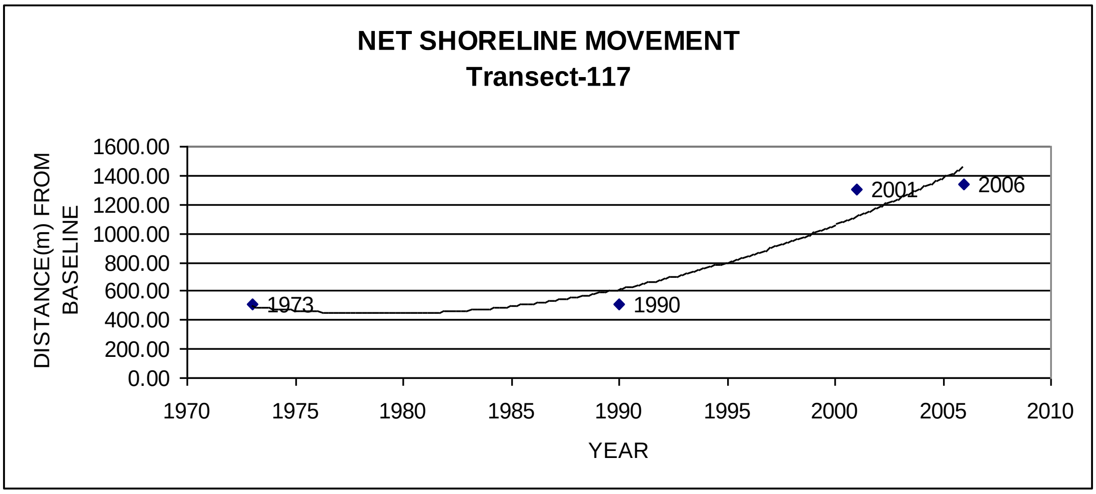


Figure 2.22 Trends of NSM along transect number 117.

Transect number 111, in Figure 2.21, has an EPR and NSM which are very similar to average EPR and NSM of all transects between 108 and 113. Thus it can be taken as representative of this group. Shoreline along this transect has remained almost stable during the time period of 1973 to 2006. A movement of around 100 m has taken place from 1973 to 1990. From 1990 to 2001, shoreline has eroded slightly but after 2001 shoreline has largely remained stable in nature. On the other hand, transect number 117, on behalf of its EPR and NSM, can be taken as representative of all transects between number 102 to 107 and number 114 in 118. Figure 2.22 shows that shoreline along these transects has moved positively with a rapid pace during the time period from 1990 to 2006.

2.2.2.5. Littoral Cell-5 (Transects Nos. 80-101)

LandSat 1973, 1990, 2001 and 2006

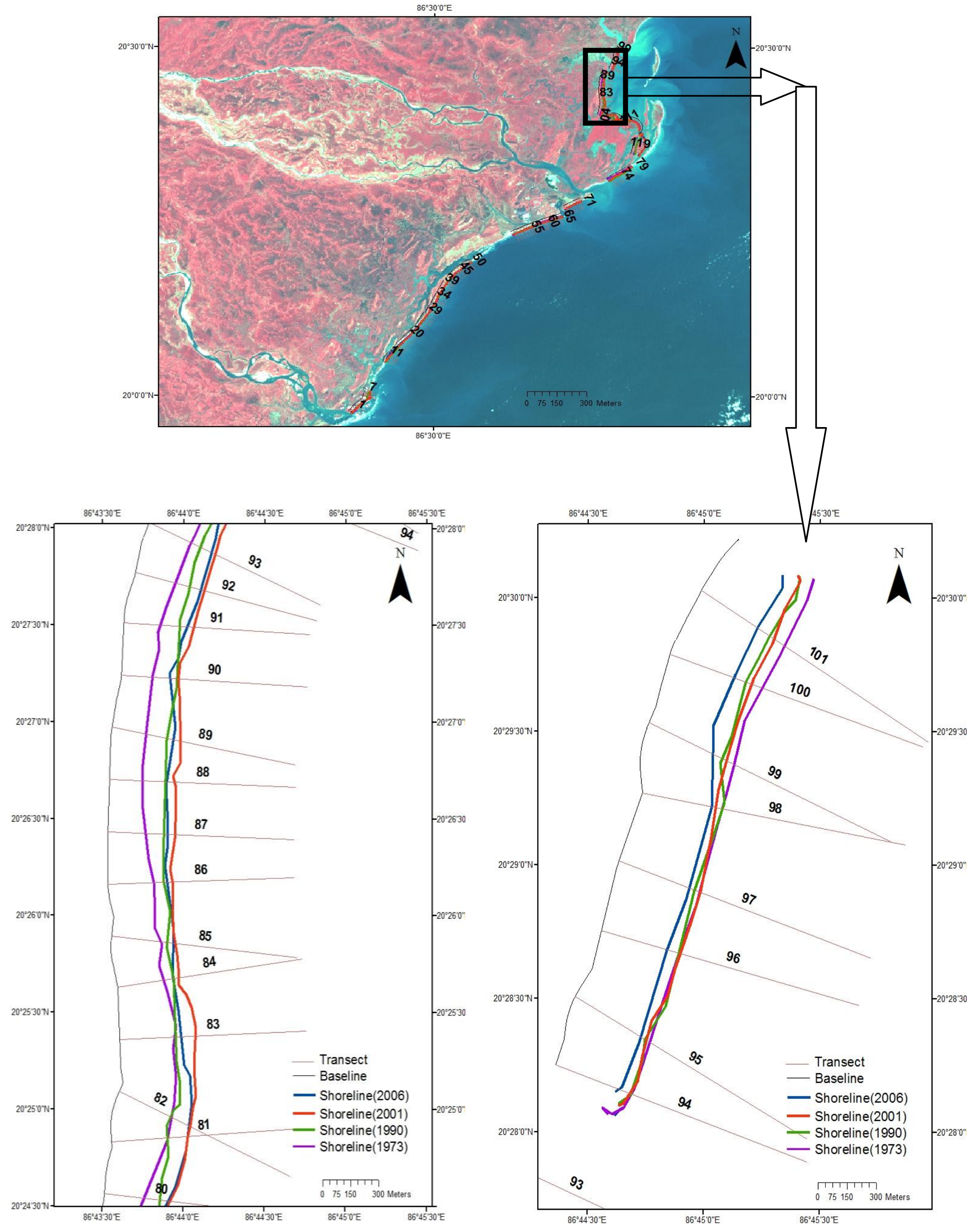


Figure 2.23 Shoreline change across transect number 51 to 71

Table 2.5 Transect numbers 80 to 101.

Transect ID	EPR (m)	NSM (m)	LRR (m)	LR2 (m)
80.000	7.770	256.160	8.430	0.950
81.000	6.380	210.390	7.280	0.730
82.000	6.140	202.540	7.150	0.710
83.000	2.230	73.550	4.510	0.400
84.000	2.990	98.400	3.840	0.690
85.000	4.060	133.920	4.620	0.920
86.000	4.320	142.450	5.270	0.830
87.000	7.240	238.560	8.490	0.840
88.000	7.830	257.980	9.010	0.810
89.000	9.000	296.570	10.390	0.870
90.000	5.720	188.570	6.670	0.570
91.000	8.760	288.680	10.060	0.890
92.000	8.530	281.240	9.570	0.940
93.000	7.280	240.010	8.370	0.910
94.000	-3.120	-102.900	-2.370	0.510
95.000	-2.270	-74.750	-1.750	0.660
96.000	-2.810	-92.510	-1.820	0.310
97.000	-2.550	-84.070	-1.580	0.320
98.000	-2.390	-78.870	-2.290	0.720
99.000	-5.190	-171.150	-4.060	0.690
100.000	-6.800	-224.040	-5.330	0.690
101.000	-7.170	-236.310	-5.680	0.720

Shoreline under littoral cell-5 has changed both positively and negatively. Protected coast along the southern part is advancing along transect no.80-93. North Hookitola barrier is protecting southern part from wave energy generated by north-eastern wind, while Hookitola barrier protects coast from south-western wind and consequent wave action.

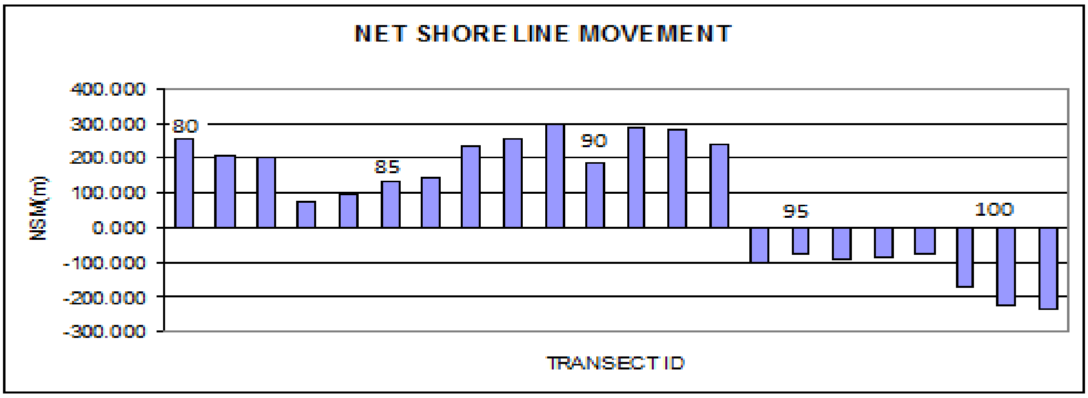


Figure 2.24 NSM across transect numbers 80 to 101

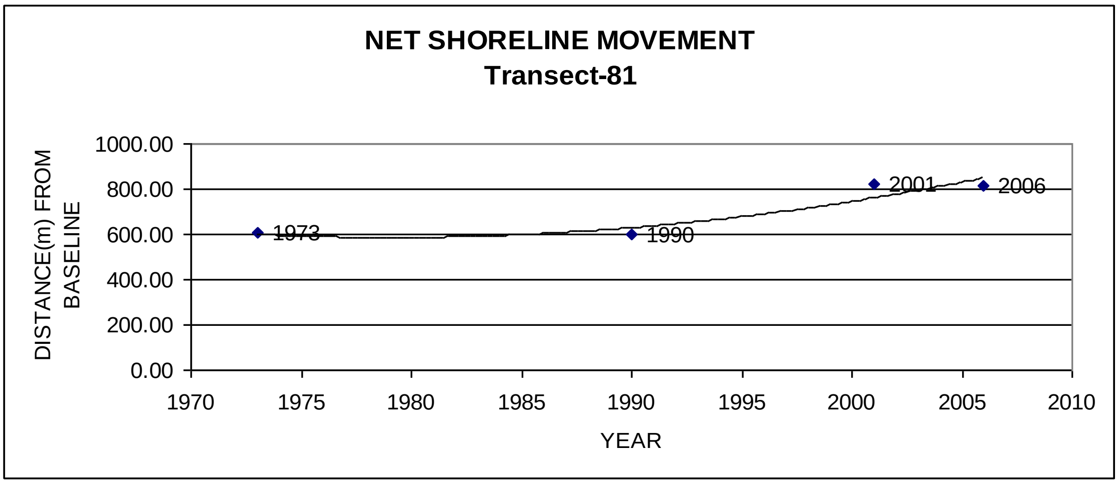


Figure 2.25 Trends of NSM along transects 81.

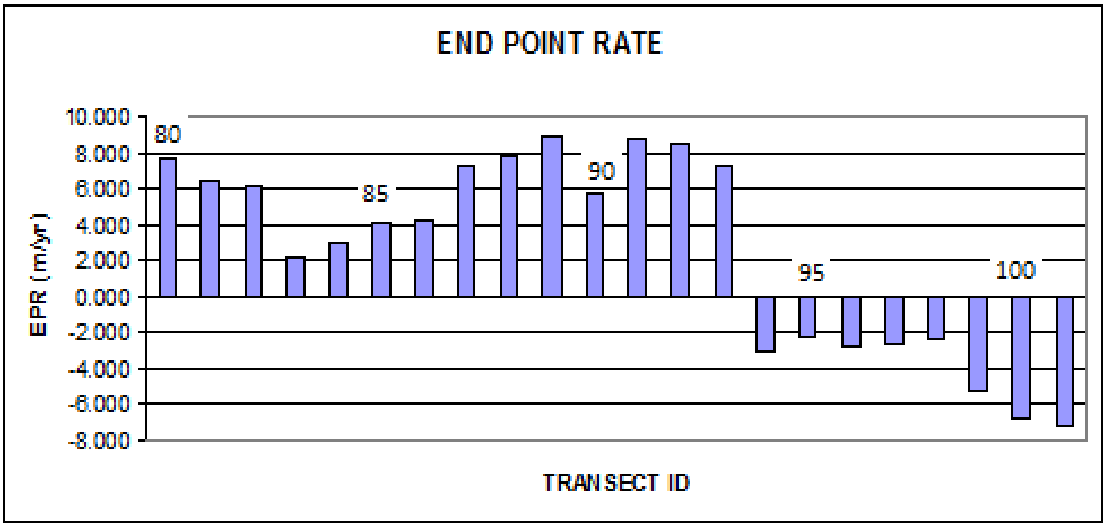


Figure 2.26 EPR across transect Nos. 80 to 101.

The NSM along Transect number 80-82 and 87-93, in Figure 2.24, shows 250 m during 1973 to 2006. Such a rapid advancement of shoreline is not only for protecting location but also due to continuous sediment supply through numerous distributaries of Mahanadi. On the other hand, the northern part of the littoral cell is facing estuarine erosion which is detected in the statistical results along transect number 94 to 101. Maximum erosion has been noted along the transect no.101 which is located along the immediate south of the estuary (Figure 2.23) and subsequently rate of erosion decreases as distance from estuary increases.

Graphical representation of EPR (Figure 2.25) shows that deposition has taken place at a faster rate along transect number 89 and 91 (Figure 2.23). These two transects are also more predictable because of higher levels of goodness of fit (R^2) which are 87 and 89 percent (table 2.26) respectively.

NSM and EPR along transect number 81 are similar to average of all transects between 80 and 93. Thus, it can be taken as representative of this group. Figure 2.26 shows that the rate of shoreline movement was higher during 1990 to 2001, while shoreline remained almost stable between the time period of 1973 to 1990 and 2001 to 2006.

2.4. Summary

Environmental process of the Mahanadi delta coast is a complex and difficult to understand with its numerous erosional and accretional features. Dozens of factors that influence shoreline movements along the delta coast are-wind and wave energy, tidal force, sediment supply, degree of protection from natural barriers, location of river mouth, mangrove vegetation, construction of port and seawall etc.

Longshore bar under littoral cell 2 protects shoreline behind it and stimulates accretion process, which in turn, results in shoreline recession. Ocean front of the longshore bar is subjected to face direct action of tide and wave energy while it acts as a dissipater of this geomorphic agent for the sheltered shore behind it. That is why entire ocean front of longshore bar recodes very low to moderate erosion

Erosion and accretion pattern reveals that the accretion is dominant in littoral cell 2 and 4 while, both accretion and erosion in littoral cell 5 and maximum erosion in littoral cell 1. Further, erosion is observed in the coastal area where engineering structures such as sea walls, groynes and jetties are built.

Morphological orientation, tidal prism and direction of debouching water and sediment are changing at a faster rate near river mouth. The mouth of the Debi and Mahanadi rivers have migrated into the north and southward directions respectively during 1973 to 2006. Mouth of the Debi River has shifted towards north at the rate of 2-4m/year between 1973 and 2006.

An overall analysis of the delta coast can be summarized under following points-

1. Direction of shoreline with respect to angle of wave approach is important to determine type of geomorphic process.
2. Shoreline along the northern part of the study area is advancing towards the sea while the southern part is receding.
3. Exposed shoreline coupled with less sediment supply through distributaries is more vulnerable to erosion.
4. Protected shorelines with mangrove are advancing rapidly due to the emergence of new islands.
5. Longshore bar attached to the mainland leads to unusual nature of positive shoreline movement.
6. Shifting of river mouth, direction of longshore movement and openness of the coast are major factors for shoreline movement along the Mahanadi delta coast.

CHAPTER-III

3.1 Introduction.

Coastal depositional features (offshore barrier bar, longshore bar, islands, spit and hook) are closely related to beaches and shaped by coastal a geomorphic process which includes direction of wave propagation, effectiveness of tidal energy and longshore drift. Weathering and transportation of weathered material at nearshore are major processes which in turn influence coastal accretion. Nearshore zone of north Odisha coast (Mahanadi delta coast) is characterised by number of barrier bars, islands, spit, hook etc. These entire depositional features have been orienting and reorienting over the period. Such rapid reorientation is mainly because of combined wind and wave action. Beside these, configuration of the river mouth and direction of debouching water and sediment plays a vital role in the evolution of such depositional features.

Delta front provides suitable nearshore depth of an extensive submarine platform over which complex barrier islands, bars, spit system can be evolved easily. Accelerated longshore transport of sand helps in building and prolongation of barrier island spit system. The tendency for continued prolongation of a spit may lead to the withdrawal of material from the proximal end causing thinning and even breaching, as spits have an inherent tendency to erode (Carter, 1988). Damage to the sand spits and sand barriers and beaches in them may occur during high episodic monsoonal floods and storms/cyclones. Storms eroding coastal dunes, beach and spits may give a feedback to the littoral drift system. The complex and interrelated factors of the catchment area, variable monsoonal precipitation influence sediment supply and transport to the details depocentre determine the evolution of the coastal depositional features spit, hook, bar, islands etc. Tectonics, eustatic changes and episodic catastrophic events (floods, storms/cyclones) are judged as controlling factors in the Mahanadi River delta building in time and space in the tropical setting on the east coast of India (Mohanti, 2006).

However, recent development of depositional features can be described as follows-

3.2 Spit.

A spit is one type of depositional barrier that forms at the downdrift end of a littoral cell. Spits are typically attached to the mainland at the proximal end and have a “free” distal end. As with other barrier systems, spits have a subaqueous platform and a subaerial environment consisting of beach, dune, and marsh deposits (Meistrell, 1966). The form and location of spits change rapidly in response to changes in a number of controlling processes such as water level, sediment supply and wave climate.

It is a type of bar or beach that develops where a re-entrant occurs by the process of longshore drift longshore drift. Longshore drift (also called littoral drift) occurs due to waves meeting the beach at an oblique angle, and backwashing perpendicular to the shore, moving sediment down the beach in a zigzag pattern. Longshore drifting is accompanied by longshore currents which transport sediment along the shore.

Shape of a spit is influenced by the space available for its growth, formation of curvatures and by the adjacent sea floor topography as demonstrated by Schou (1945) in the Danish archipelago. Spit grows more rapidly across shallow nearshore areas than in deep water and their configuration is related to the variation in fetch (exposure to wave action) which is determined by the nearby headlands, islands and reef. Its size and shape depends on the space available on the inner side of growing spit.

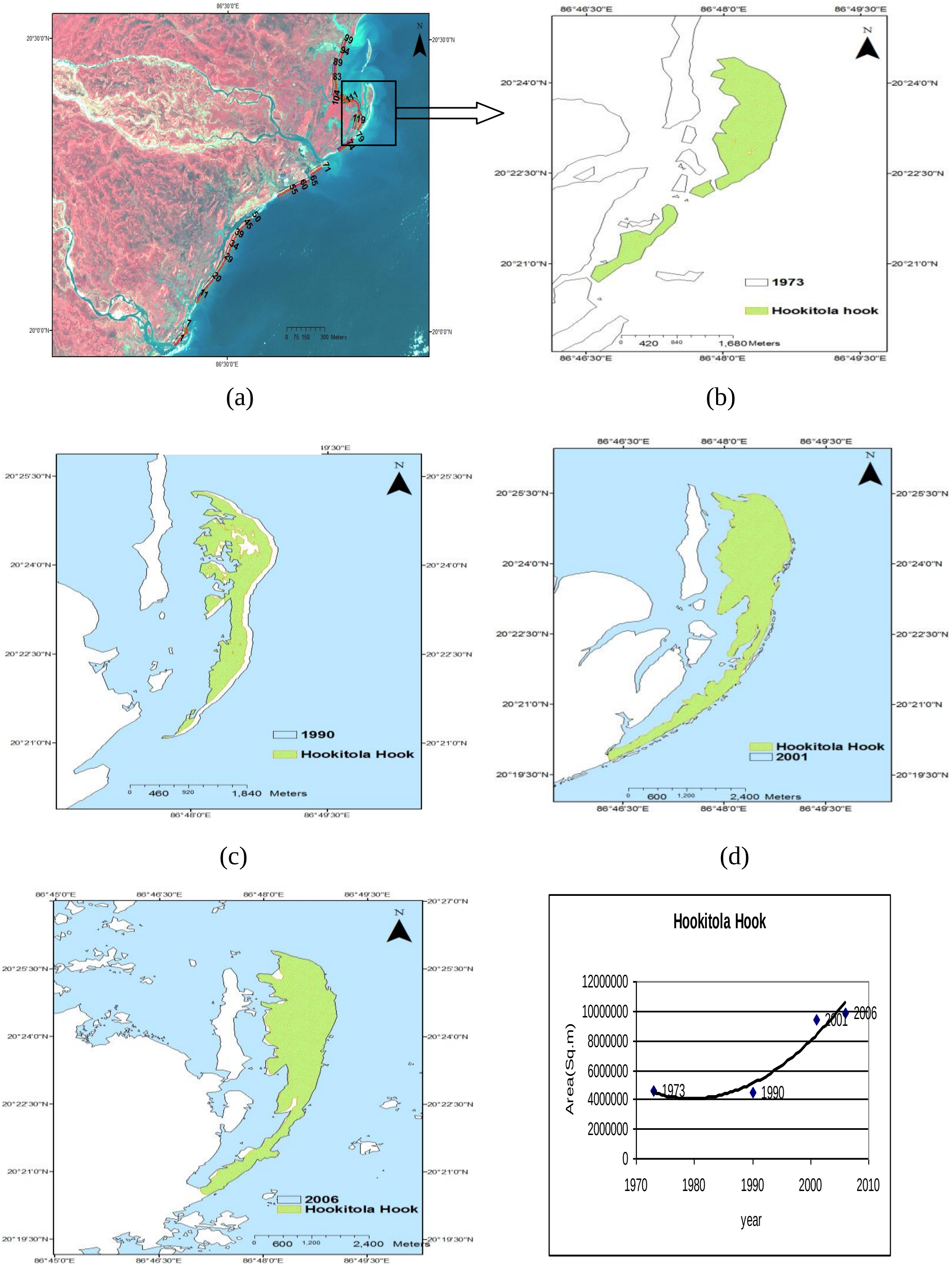
Table 3.1 Changes in area coverage of the hook.

Hookitola hook	
Year	Area (Sq. m)
1973	4548785
1990	4459893
2001	9416520
2006	9883269

Hookitola spit is located to the north of Mahanadi river mouth. It has been continuously growing in an open sea under shallows nearshore areas as revealed in Table 3.1 and figure 3.1. Configuration of the spit has largely been controlled by wind and wave action. Seasonal change in wind direction and wave propagation has resulted in the developing hook's shape (figure 3.2). North-eastern monsoon, during Winter season generates sea waves which directly hit on the distal end. Thus, continuous unidirectional wave energy causes south-west ward bending of the distal end of the hook. On the other hand, southwestern monsoon during summer generates waves that directly hit ocean front of the spit. Both, the southwestern and the northeastern wind and the consequent direction of wave energy propagation are largely responsible for the land ward development of the sport and its overall configuration.

Spit has been widened by increasing volume of beach material. Stages of spit development are marked by successive beach ridges (Figure 3.3). In the study of cape code Davis (1996) showed that sand eroded from the cliff had been built into a spit with beach ridges marking stages in progradation.

LandSat 1973, 1990, 2001 and 2006



(a) (b)

(c) (d)

(e) (f)

Figure 3.1 Hookitola Spit (a), successive stages of spit evolution (b) (c) (d) and (e), changes in area coverage of the hook (f).

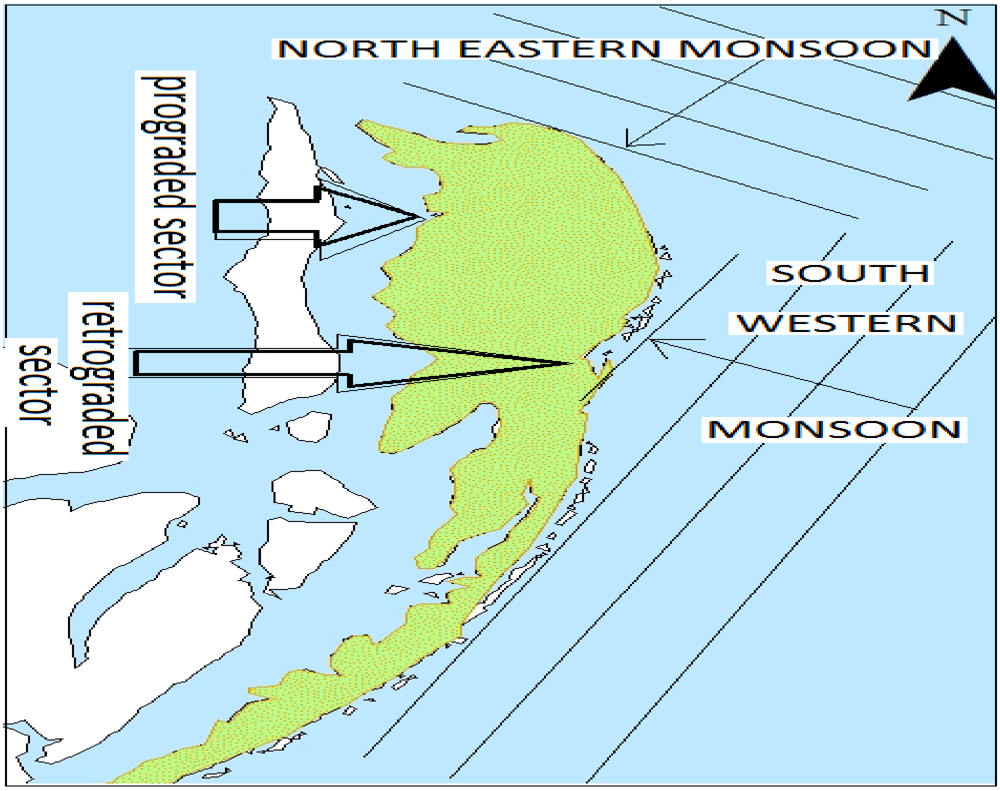


Figure 3.2 Seasonal change in direction of wave propagation and resultant progradation and retrogradation on Hookitola hook.

Data: NOAA, U.S. Navy, NGA

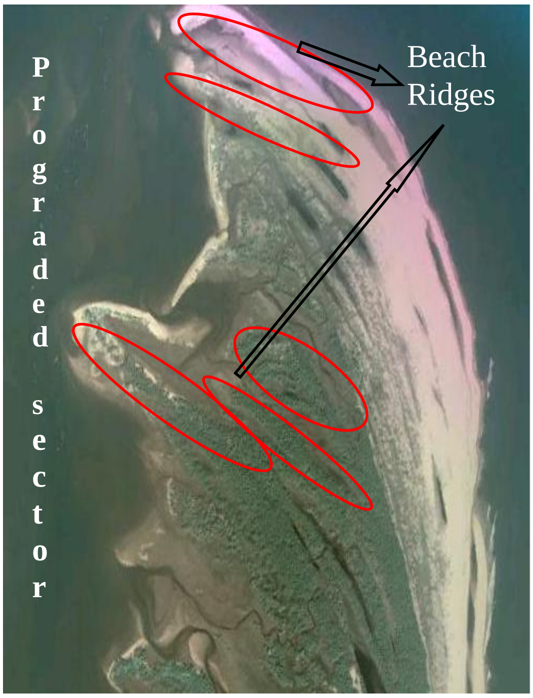


Figure 3.3 Prograded sector

Figure 3.4 Retrograded sector

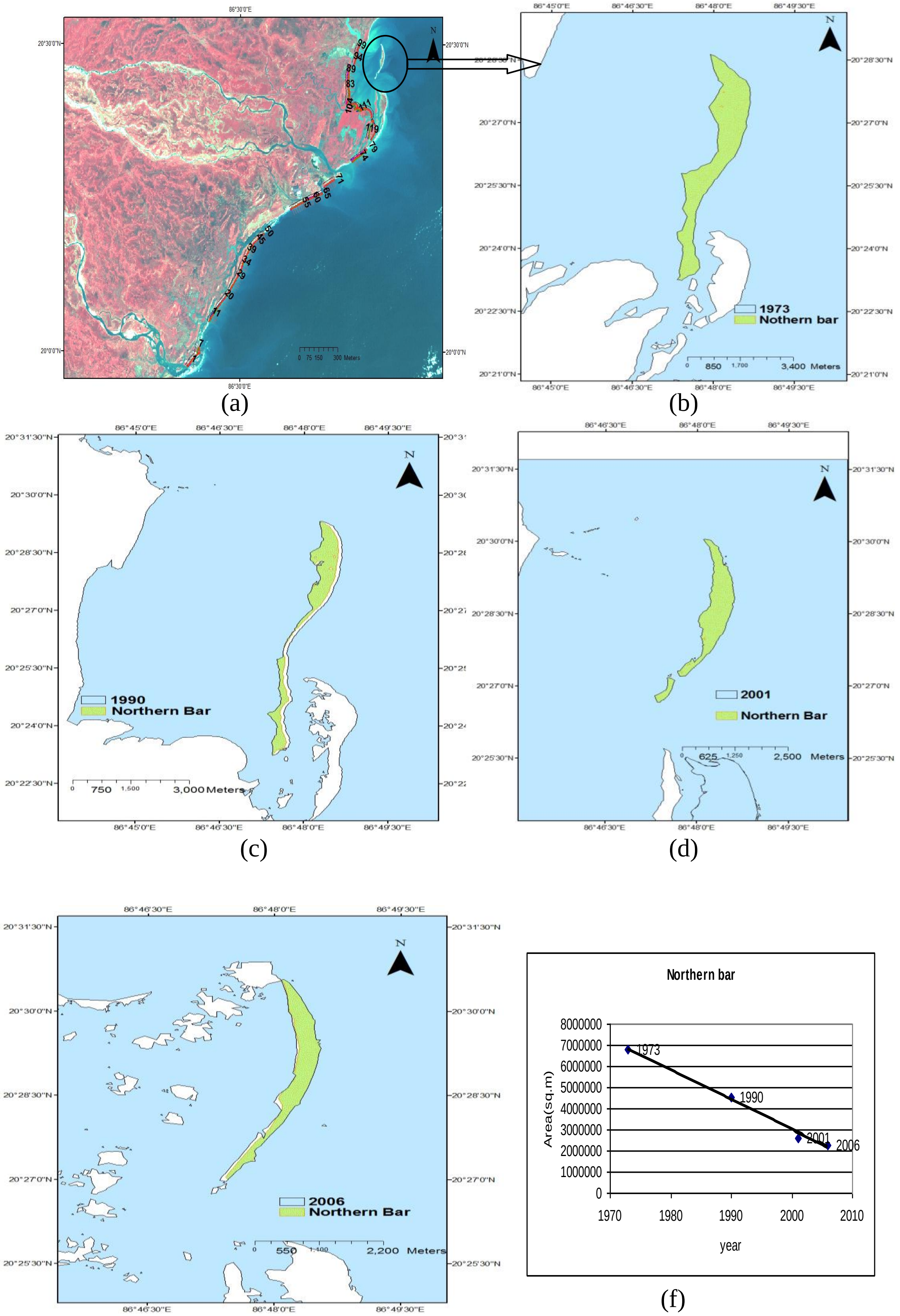
Beach ridge pattern of the Hookitola spit shows that the spit has been reshaped and truncated in formerly prograded sector by coastal geomorphic processes (Figure3.4). Truncation of former prograded sector indicates that the spit has been eroding along its outer shore yielding sediment that drift along shore to prograde its distal end (Figure 3.3).

Deposited sediment on the spit has been coming from many channels and distributaries of Mahanadi delta. A northward extension of the hook provides shelter to the vast mangrove swamp from direct wave action. Mangrove acts as a stimulus to the siltation process. Under well sheltered condition, mangrove swamps advances at a faster rate and consequently shoreline (under mean sea level condition) advanced more than 1200 m in places as revealed in statistical analysis. Such unusual nature of shoreline advancement is usually accompanied with newly emerged mangrove covered swampy land.

3.3 Coastal Barriers.

Sandbar or coastal barriers are linear landform features within or extending into a body of water, typically composed of sand, silt or small pebbles. Offshore bars are characteristically long and narrow (linear). It develops where a stream or ocean current promotes deposition of granular material, resulting in localized shallowing of the water. Offshore bars are typically composed of sand, although, it could be of any granular matters that are capable of shifting around (for example, soil, silt, gravel, cobble, shingle, or even boulders) with moving water. Grain size of the material comprising a bar is related to the intensity of the waves

LandSat 1973, 1990, 2001 and 2006



(a) (b)

(c) (d)

(e) (f)

Figure 3.5 Offshore Bar (a), successive stages of evolution of offshore bar (b) (c) (d) and (e), changes in area coverage of the bar (f).

Table 3.2 Changes in areal coverage of the offshore bar

Ofshore bar	
Year	Area (sq.m)
1973	6768296
1990	4536043
2001	2627451
2006	2298417

or the strength of the currents moving materials. Availability of types of material to be to be transported by waves and currents is also important in the current context (Bird, 1990).

Barriers bars and islands exemplify multiple casualty in that they have originated in a variety of ways and no single explanation will account for all of these features (Schwartz, 1971). Offshore bar in Figure 3.5, located at the north of Hookitola spit, has originated by an abundant supply of sand, transported through numerous distributaries of Mahanadi and shallowness of the near shore coastal zone which provides suitable basement for the growth of northern bar.

Erosion, fragmentation (Figure 3.5, d) and consequent decrease in area coverage (Table 3.2 and Figure 3.5f) of the bar has been exerting its direct impact on the sheltered shore. In Table 2.6 of the second chapter, transect 94 to 100 has recorded that the part of shoreline behind this offshore bar are strongly under erosive regime. Erosive agent becomes more effective in response to the deceasing length and fragmentation of the discrete barrier. Erosion of the barrier may be in response of a number of causes, like increased wave action, deceasing sediment supply due to shifting in of river mouth etc.

3.4. Longshore Bar

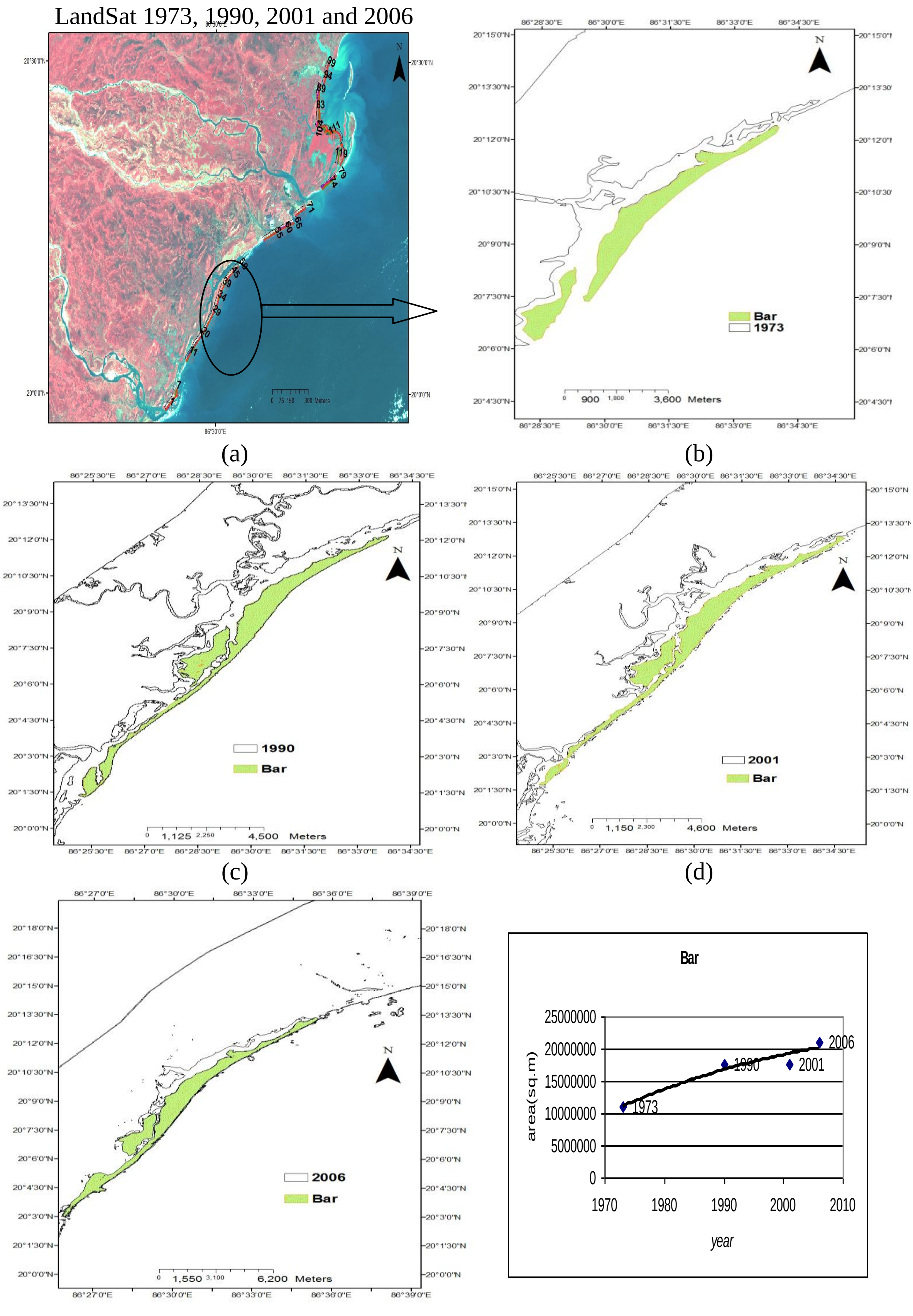
Longshore barriers to the south of Paradip coast is relatively nearer to the mainland, backed by a lagoon. Transect number 10 to 50 has been drawn across the ocean front of this longshore bar which shows that shoreline across transect number 10 to 38 are receding while shoreline across transect 39 to 50 are advancing towards the ocean. Again, overall area under the barrier has increased considerably during 1973 to 2006, impliying that areal expansion is largely inwardly. On the other hand, while most of the islands, spit and barriers are receding at the northern end, longshore bar at the south of Paradip has remained protected from direct interaction with north-eastern wind and wave energy due to coastal configuration. Continuous inward growth is bringing the region closer to the mainland through shrinking of lagoon water.

Table 3.3 Changes in areal coverage of Longshore bar

Longshore Bar	
Year	Area (sq.m)
1973	10926950
1990	17563841
2001	17644700
2006	21054153

3.5 Estuarine Islands and Bars.

Coastal environmental setup has largely been affected due to faster growth in number and areal coverage of islands and barriers. Accretion processes, across the mouth of Debi River, are effectively changing the configuration of the river mouth and direction of debouching water. These changes again are responsible for erosion of coastal land which is manifested in the statistical results of transect 1 to 5 in Table 2.2.



(a) (b)

(c) (d)

(e)

Figure 3.6 Longshore Bar (a), successive stages of evolution of longshore bar (b) (c) (d) and (e), changes in area coverage of the bar (f).

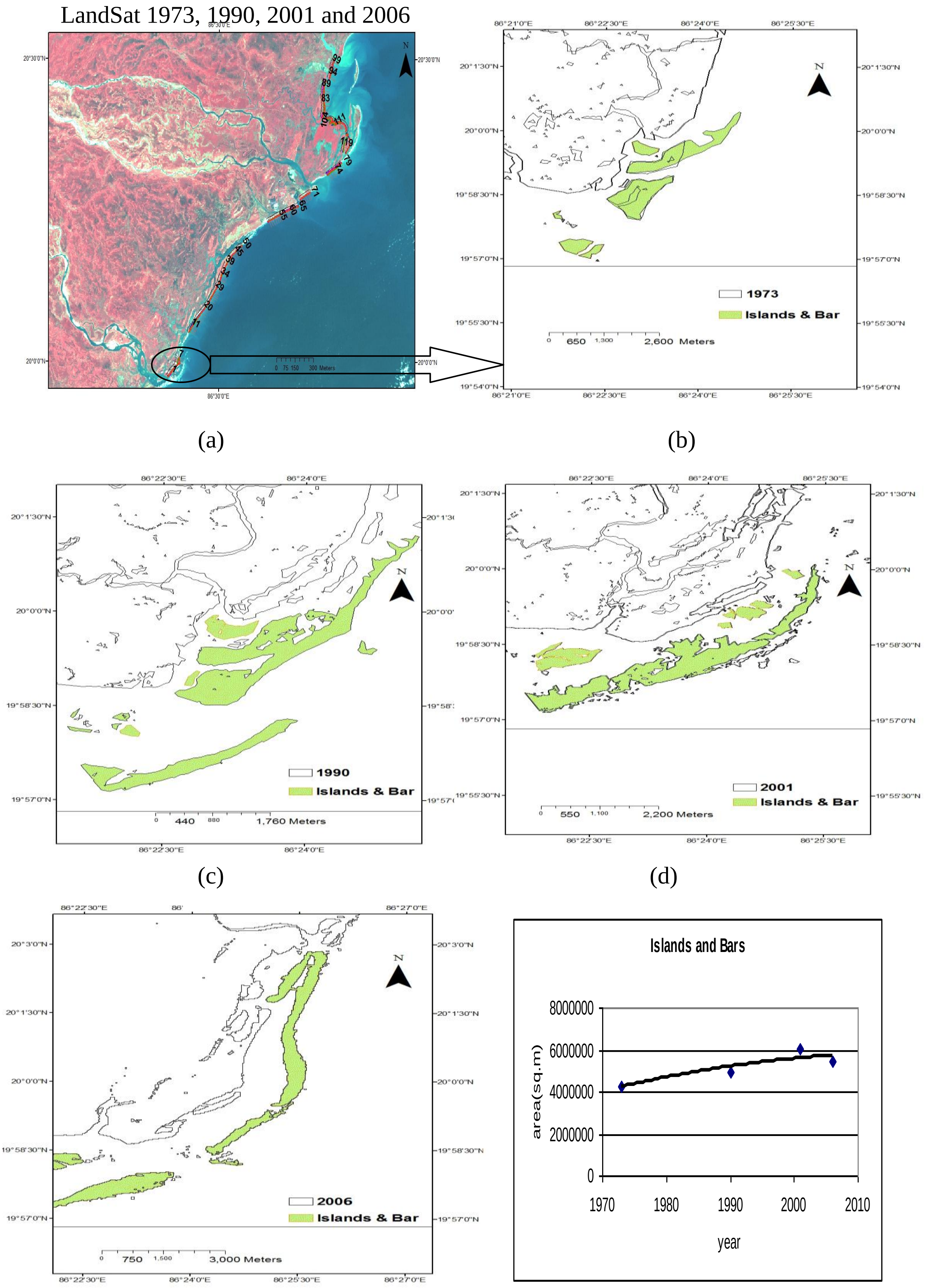
Table 3.4 Changes in areal coverage of the estuarine islands and bar

Estuarine islands and bar	
Year	Area (sq.m)
1973	4282162
1990	4966907
2001	6072613
2006	5464500

An increase in number and areal coverage of estuarine islands and bars is an indicative of increasing amount of sediment supply by Debi River. Morphological development of entire barriers, bars and islands are positive except offshore bar located at the north of Hookitola spit. Increasing dimensions of depositional features are indicative of youth stage of marine cycle of erosion (on shoreline of emergence) which is characterised by appearance of submarine bars above sea level, numerous independent small bars and locked sea water between the coast and offshore bars.

3.6 Evolution of marine bars under micro and mesotidal settings of Mahanadi delta coast

Ebb tidal delta of Mahanadi in micro and mesotidal settings commonly exhibits swash bars ranging in length from 300 m to several kilometres (Oertel,1972; Hayes, 1975) that are built by wave induced accumulation of sand (Hine,1975). Although ebb delta bars are a major component of the morphology of tidal inlets and of the shore line sediment budget (Oertel, 1977), albeit with patterns of development that vary considerably along wave and tide range gradients (Davis, 2004).



(a) (b)

(c) (d)

(e) (f)

Figure 3.7 Estuarine islands and bars (a), successive stages of evolution of estuarine islands and bars (b) (c) (d) and (e), changes in area coverage of islands and bars (f).

Swash bars tend to migrate landward under surf bores and swash processes at rates that can be quite high, but extremely variable, ranging from 64 to 86 m/yr (Smith and Fitzgerald, 1994) to1 33–327 m/yr (FitzGerald, 1984; GaudianoandKana, 2001), but an exceptional rate of 46m/month, has also been reported (Balouin et al., 2001,2004). Its migration and welding on to the adjacent beaches generally result in rapid, localized shoreline movements.

Shoreward migration process (in such wave dominated to mixed energy settings) of longshore bar under the Mahanadi delta coast involves coalescence of individual bars to form large complex bars (300m to several km long) just before welding on to the shoreline (Hine, 1975; Aubrey and Speer, 1984; Fitz Gerald, 1984, 1988, Fitz Gerald et al., 1984, 2000; Kana et al., 1999; Borrelli and Wells, 2003). Such welding sometimes results in the formation of large hook spits (Fitz Gerald, 1984; Gaudiano and Kana, 2001). Bar welding mechanism can, thus, be an extremely important form of natural beach nourishment, attaining, in some cases, several millions of qubic metres in the course of a single welding event (Kana et al., 1999). Where the ebb delta is devoid of swash bars, Shoreline erosion can be observed on the downdrift side of the inlet (Fitz Gerald, 1984). The pattern of shoreline erosion and deposition in the vicinity of such inlets is controlled by cycles of ebb tidal delta growth (swash bar formation) and decay (bar welding) that last from 4 to 8 years on the east coast of the Mahanadi delta.

The conceptual model proposed by Kana et al. (1999) comprises three stages. Stage one depicts an offshore bar isolated from the rest of the swash platform near the downdrift limits of the ebb-tidal delta. In second stage, bar migrates landward and initiates the process of getting attached to the beach face. Beach erosion typically occurs at the ocean front of the bar and accretion continues on its lee side. The third and final stage involves a longshore spreading of the bar in either direction from the point of attachment. Typically, a bulge in the shore line persists where the bar is attached.

Understanding of the magnitude of swash bar induced beach change and how such change varies along shore is extremely sparse. Furthermore, aspects relating to the morphology and dynamics of these bars, and to the impact of these features on the coastline in very large tidal range settings (spring tidal ranges >8m) are unknown.

3.7 Stages of Evolution of Longshore Bar

As per the conceptual model of shoreline changes (proposed by Kana et al, 1999), inter activity between an ebb-tidal swash bar and the beach in a microtidal environment involves three stages of evolution. Lognshore bar located south to the Paradeep coast, along the near shore zone, indicates subsequent stages of their evolution.

Stage-1: Detached Offshore Bar.

Longshore bar in 1973 is located at a distant position from the mainland. A wide channel, well connected to the open sea, separates the bar from the mainland. Sediment, carried out by the distributaries easily find outlet to move into the open ocean. Evolution of the bar in subsequent stages also provides a glimpse of its former position. It can be assumed that in the past, prior to 1973, it was located at further distant with the wider passage separating the bar from the mainland. In this stage longshore bar acts as a dissipater of waves from the east and northeast. It also promotes stability and accretion of the shoreline in its shelter.

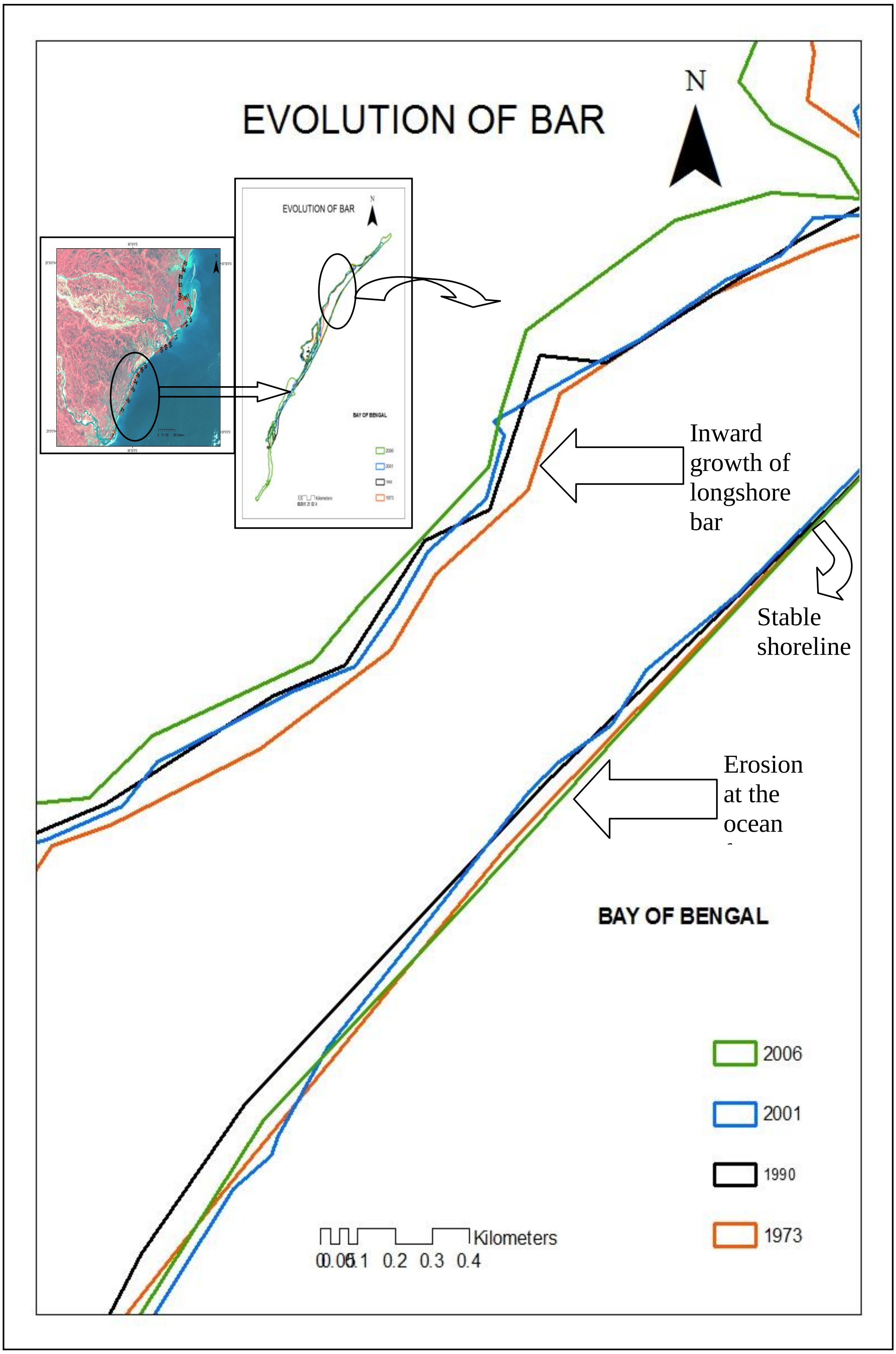


Figure 3.8 Evolution of longshore bar.

Stage-2: Proximity of Longshore Bar with Shoreline.

With time, longshore bar increases in its length along the direction of long shore movement. Longshore movement is largely seasonal and completely reversed in winter. As a result of this phenomenon, it increases at its both ends. An increment in length augments sediment trapping process through the closure of passage to open sea. Closure motion stimulates two major processes of the bar

attachment to the mainland; one is absolute stability of the shoreline behind the bar and the other is infilling of lagoon water. Open ocean front of the bar becomes less nourished and subjected to face wave and tide energy. Thus, open ocean front is attributed by negligible to moderate erosion.

Stage-3: Bar Integration and Redistribution of the Sediment in Littoral Cell System.

In this stage, longshore bar become fully integrated to the sheltered beaches, lagoon get filled up and the ocean front of the bar present high tide beaches. Almost entire distributaries behind the bar shifted out to find out new outlet to the open ocean.

3.8 Summary

Temporal analysis of the satellite data, combined with short term field observation highlights the original nature of relationship of longshore bar, spit hook etc to the shore in a microtidal to mesotidal environment. Conclusions can be drawn from these studies are as follows-

1. Configuration of longshore bar, spit, hook etc are largely determined by direction of the propagation of wave energy.

2. Offshore bar protects shoreline behind it, which in turn stimulate the process of accretion along the shoreline and consequently its recession.
3. Shifting of river mouth and variability of sediment supply are the determining factors for the formation, evolution, orientation, reorientation and contraction of the coastal accretional landform.
4. Unusual rate of shoreline recession in a natural environmental setup is necessarily accompanied with newly emerged land, bar attachment to the main land etc.
5. Merging and increase in length along the direction of longshore movement are the two major process of evolution of longshore bar, spit, hook, and islands.
6. Entire depositional landform grew at a faster rate between 1990 and 2000.
7. Rate of increase in areal expansion has decreased since 2000.

CHAPTER-IV

4.1. Introduction

In the land ocean interaction zone, river deltas are formed due to dynamic interaction of fluvial and marine agents on the coastal margin. Shoreline is always subjected to change as a result of coastal processes which are controlled by the nature of wave action and its resultant nearshore circulation, sediment characteristics, beach form, etc. Shoreline near the coastal region of Paradip is characterised by two major geomorphic process i.e., coastal dune formation and wave induced erosion. Anthropogenic causes like sand extraction, seaport and seawall construction are also responsible for the shoreline changes at the immediate south and north of Paradip port.

Current chapter deals with the ongoing geomorphic process and their effects on shoreline changes. Extensive field measurement and ground truth verification has been performed along 22 km shoreline to find out the reason of shoreline changes and to verify the statistical results deducted from LandSat data with the help of Digital Shoreline Analysis System (DSAS).

Coastal geomorphology is the outcome of prevailing geomorphic processes. Hence each geomorphic unit itself is an indicator of a specific coastal process. Shoreline along this region has been divided into three segments on the basis of their nature of evolution and present geomorphic process as (1) dune backed shoreline (2) shoreline under wave induced erosion and (3) shoreline under anthropogenic effects. Slope of the beach, angle of the wave approach, coastal configuration has been studied through auto level survey, clinometer, prismatic compass, digital distance meter etc. Visual interpretation of the photograph has also been used as useful tool to determine angle of wave approach. Cross section profile, drawn across the beach, has been used as a major step to find out nature

4.2. Dune evolution and Shoreline changes

LandSat 1973, 1990, 2001 and 2006

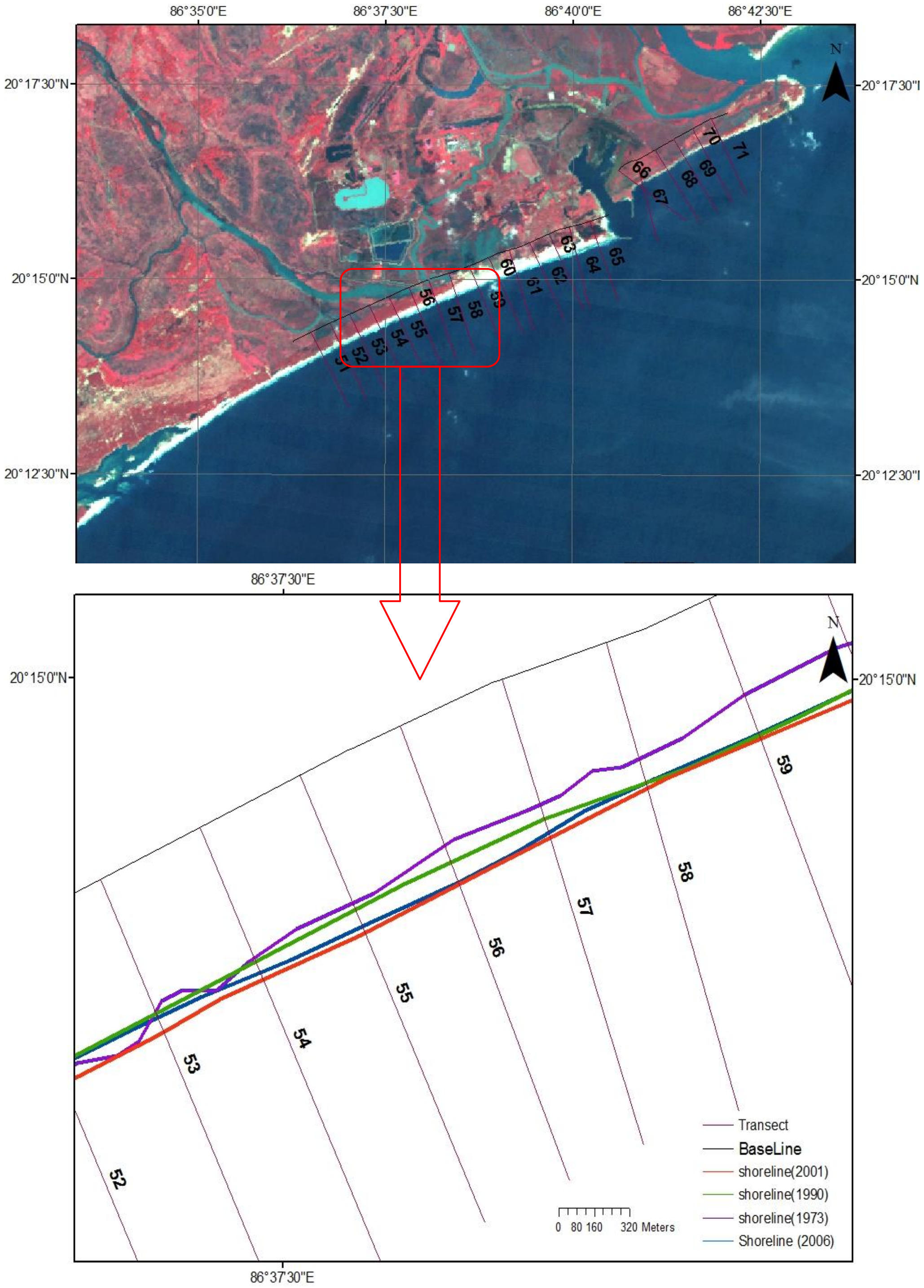


Figure 4.1 Shoreline change along transect number 53 to 60

Table: 4.1 Transect number 53 to 60.

Transect Id	EPR (m)	NSM (m)	LRR (m)
53.000	0.560	18.280	1.730
54.000	1.810	59.360	3.110
55.000	3.060	100.440	4.490
56.000	4.310	141.520	5.870
57.000	5.560	182.600	7.250
58.000	6.810	223.680	8.630
59.000	5.260	173.400	5.540
60.000	5.540	182.590	6.070

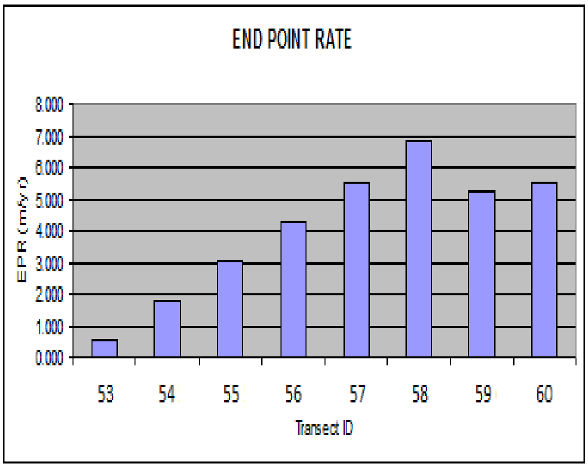


Figure 4.2 EPR across transect number 53 to 60.

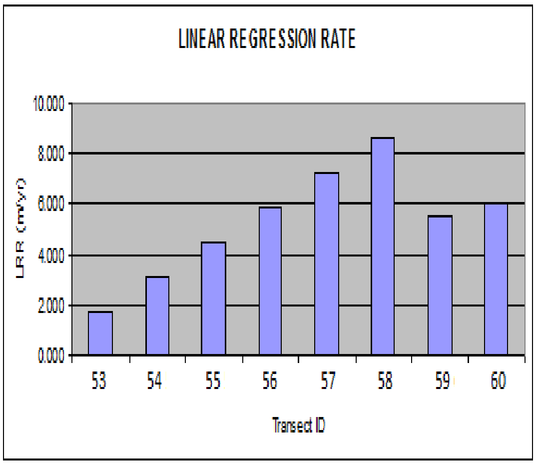


Figure 4.3 LRR across transect number 53 to 60.

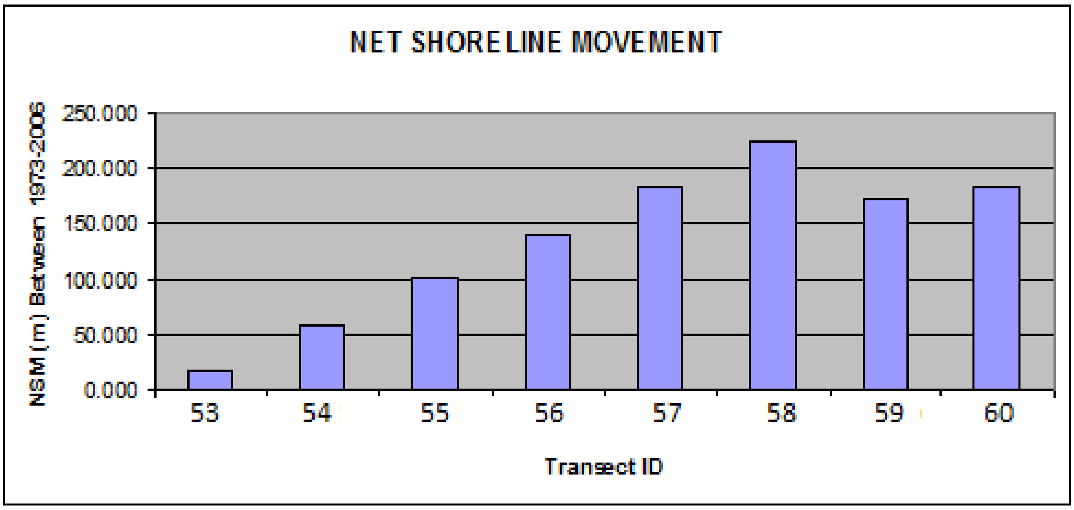


Figure 4.4 NSM across transect number 53 to 60.

of slope, different stages of slope evolution and the scale of anthropogenic effects on beaches. Finally, field study report has been linked with the Digital Shoreline Analysis

System (DSAS) generated statistical results to testify and satisfy validity of secondary data based result and explain the results.

Shoreline, across transects numbetr-53 to 60 (Figure 4.1), is backed by coastal dune. Statistical results of all transects, in Table 4.1, are showing positive movement of shoreline. Net shoreline movement along transects varies between 20 to 225 m for the time period of 1973 to 2006. Field study performed in this region has found out different component as well as various stage of sand dune evolution and rightly explain nature of shoreline movement against each selected transect.

Graphical representation of EPR and LRR (Figure 4.2 and 4.3 respectively) resemble similar rate of deposition. It certainly indicates that depositional process remained highly uniform throughout the time period between 1973 and 2006. Transect number 53 and 58 are detected with maximum and minimum rate of erosion. Net Shoreline Movement (NSM) (Figure 4.4) is highly consistant with LRR and EPR. Such consistency provide strong base for better prediction of shoreline movement.

Transect number 53 to 60 have been taken as sample transects to verify statistical results (derived against these transects) and find out why such changes are taking place. However, the field measurement revealed that entire sea beach under these transects are backed by coastal dune, these are also developing positively through different stages of evolution. Evolution of coastal sand dunes in relation to shoreline changes are studied as follows-

4.2.1. Coastal dune

A sand dune is a mount, hill or ridge of sand that lies behind the part of the beach affected by tides. Theese are formed over many years when windblown sand is trapped by beach grass or other stationary objects. Dune grasses anchor the dunes with their roots, holding them temporarily in place, while their leaves trap sand promoting dune expansion (Pethic, 1989).

Without vegetation, wind and waves regularly change the form and location of dunes. Dunes are not permanent structures. Sand dunes provide sand storage and supply for adjacent beaches. It protects inland areas from storm surges, hurricanes, flood-water, and wind and wave action that can damage property and also augment the process of shoreline advancement towards the sea. Sand dune in this part of the study area is in different stages of their evolution.

Coastal sand dunes provide extensive protection to many of the world's shorelines. The interaction of dunes with the adjacent beach and nearshore provides the essential basis of a stable shoreline, through the regular exchange of nutrients and minerals. Dunes are often regarded as relatively fragile environments, yet a more pragmatic assessment might focus on their adaptability and responsiveness to environmental change (Nordstrom et al.1990).

Coastal sand dunes are one manifestation of a suite of landforms associated with varying water levels. Given an adequate sediment supply, material may accumulate at various locations within a coastal system. Favoured sites include river or estuary mouths which attract sediment in order to achieve hydraulic equilibrium, within shore caustics (or shadow zones), and at the downdrift ends of transport cells. Under certain conditions marine sediment may accumulate sub-aerially as coastal dunes. Such developments may be triggered by sea level fall, or domain shifts within the reflective/dissipative continuum (Hesp, 1880).

The latter occurs when the beach and shoreface angle alters, becoming flatter or steeper, perhaps due to fluctuations in sediment supply or the opening or closing of a nearby tidal inlet. Such secular variation in beach slope imparts a strong control over the mode (or domain in terms of area) of the form of the breaking waves. Profile steepening leads to more reflective condition while profile flattening to more dissipative ones, which in turn are associated with types of dune morphology and development (Short and Hesp, 1982).

On all time scales, sub-aerial storage should be viewed only as an ephemeral process; sediment is constantly exchanged with adjacent environments as energy conditions fluctuate. Thus dunes are eroded during storm surges to replenish the nearshore profile, material is pumped through spit estuary complexes to retain a hydraulic balance, or over washed to rebuild barrier islands further inland. The rate of change varies from site to site, but in all cases such processes form part of natural environment within self-compensating coastal systems. The role of vegetation within these episodic but largely cyclic systems is thought to be important (Carter, 1991).

Very extensive dune systems have formed at various times in the geological past. Perhaps the most favourable conditions for the development of coastal dunes include an abundance of sediment, a variable climatic and/or wave regime (Carter, 1991).

Coastal dune along the south of Paradip exerts enormous influence on shoreline and its movements over the time. Dune evolution changes beach slope and consequent wave run-up which in turn determine at what intensity wave energy would strike the coast. Various components of beaches and dunes (Figure 4.5), which controls shoreline position, could be explained under following head-

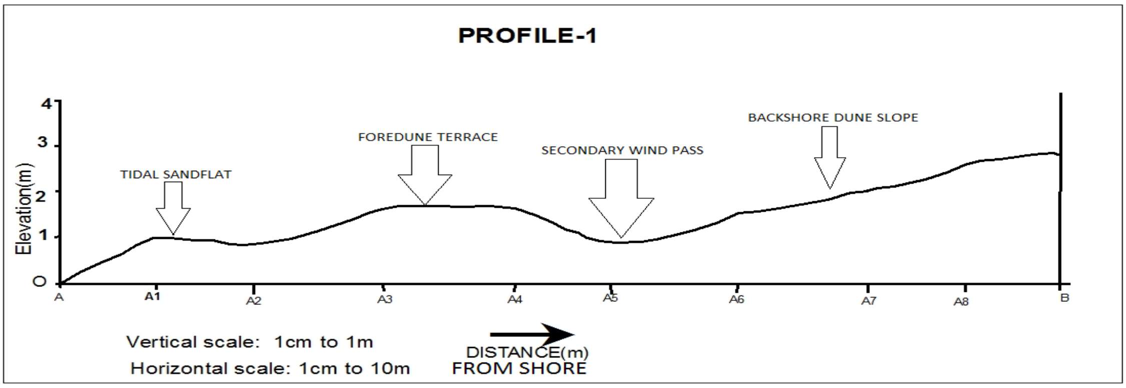


Figure 4.5 Components of dune-backed shoreline.

Figure 4.6 Tidal sandflat at south of Paradip coast

Figure 4.7 Foreshore dune terrace. at south of Paradip coast

Figure 4.8 Intermediate depression between fore and backshore dune at south of Paradip coast

Figure 4.9 Secondary dune pass. at south of Paradip coast

4.2.2. Tidal sand flat

Many coastal cliffs are bordered by shore platform that extend across the intertidal zone. Shore platform mainly composed of coastal sand is called as tidal sand flat (Figure 4.5 and 4.10). These have been shaped by various process like duration and intensity of wave run-up, wind action etc. It is different from the wave cut platform which is entirely shaped by hydraulic action of wave. Tidal sand flat (Figure 4.6) along the Paradip coast is 40 m to 60 m long at places with gentle slope that varies from 3 to 5 degrees.

4.2.3. Foredune terrace

Foredunes (Figure 4.7) are the frontal or most seaward dunes. These develop in the backshore or upper shore area beyond the reach of ordinary wave and tide action. Foredunes consist mainly of loose and exposed sand with intermittent patches of vegetation. For the most part, the material is unconsolidated and readily moved by wind; plants found are usually well adapted to periodic burial. Foredunes represent an early succession stage in the development of a transverse dune field. Foredune with flat surface is termed as foredune terrace. Plants that endure partial burial are considered dune building species. These provide the barrier against which wind-blown sand can accumulate. To survive in this dry, nutrient poor environment, pioneer sand dune plants have specialized root systems. Some have roots that spread for considerable distances horizontally.

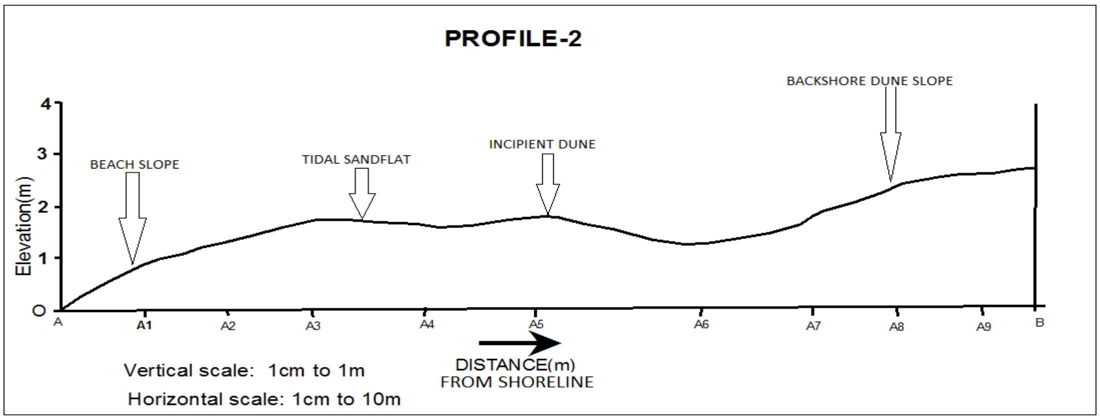


Figure: 4.10 Beach profile with different component of sand dunes.

4.2.4. Secondary dune pass

Secondary dune pass (Figure 4.9) is the intermittent depression between fore and backdune. Paradip coast is well deloped with recognisable secondary dune pass.

4.2.5. Incipient dune

Incipient dune (Figure 4.11) is the very initial stage of dune development. As the time passes wind blown sand get deposited at the junction of strandline deposition and lead to the formation of incipient dune which is a heap of sand with 10 to 20cm in height and 4 and 2 to 5m in perimeter, are frequent along the south Paradip beach.

4.2.6. Backshore dune ridge

Backshore dune ridges (Figure 4.12 and 4.13) are the second phase of primary dune formation. These usually form continuous ridges along the shore at a distant location. Backshore dunes along the south Paradip coast are 10m-20m in height with slope varies from 40 to 70 degree. Backshore dune ridge acts as a guard wall against geoclimatic extremes like tsunamis, cyclone etc. Seaward face of the dune ridges usually lack vegetal cover with bare surface but lee side is characterised by well developed vegetal cover.

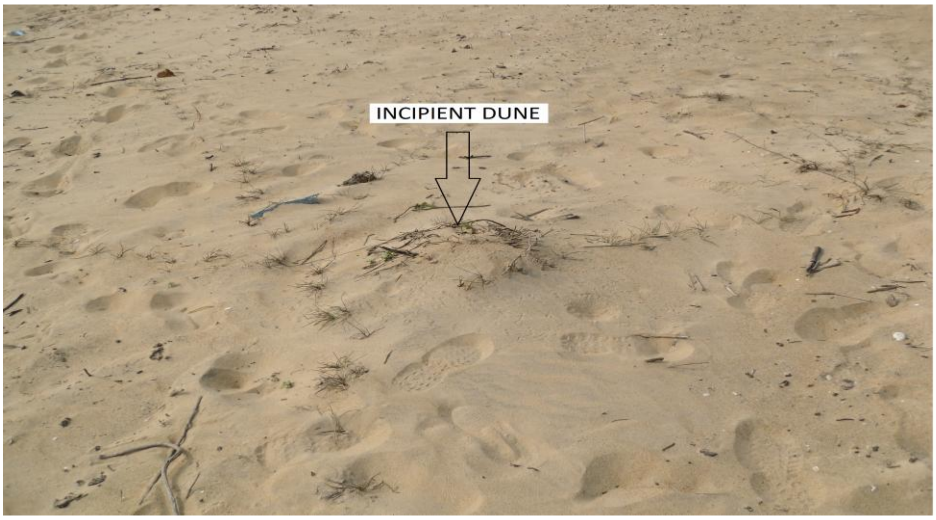


Figure 4.11 Incipient dune located at the cross junction of strandline deposition.

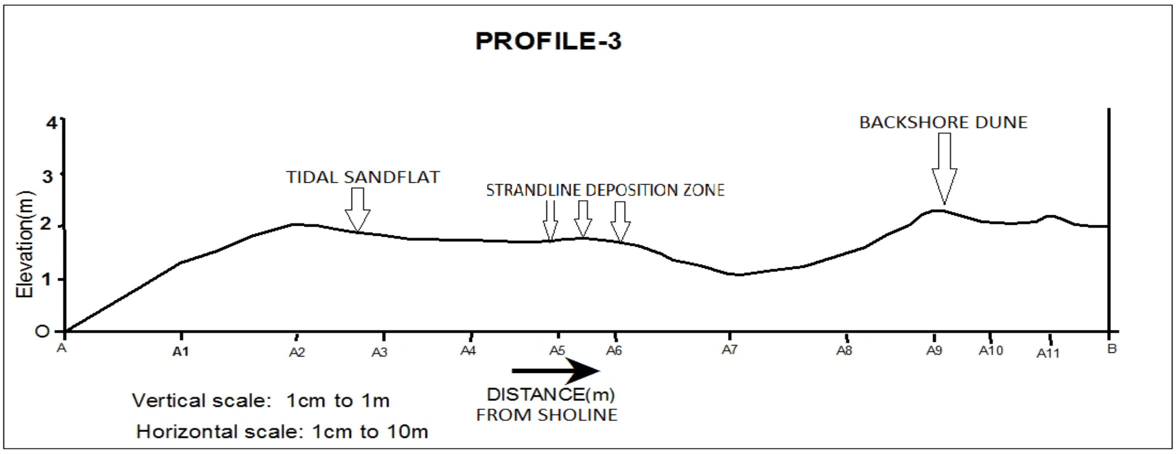
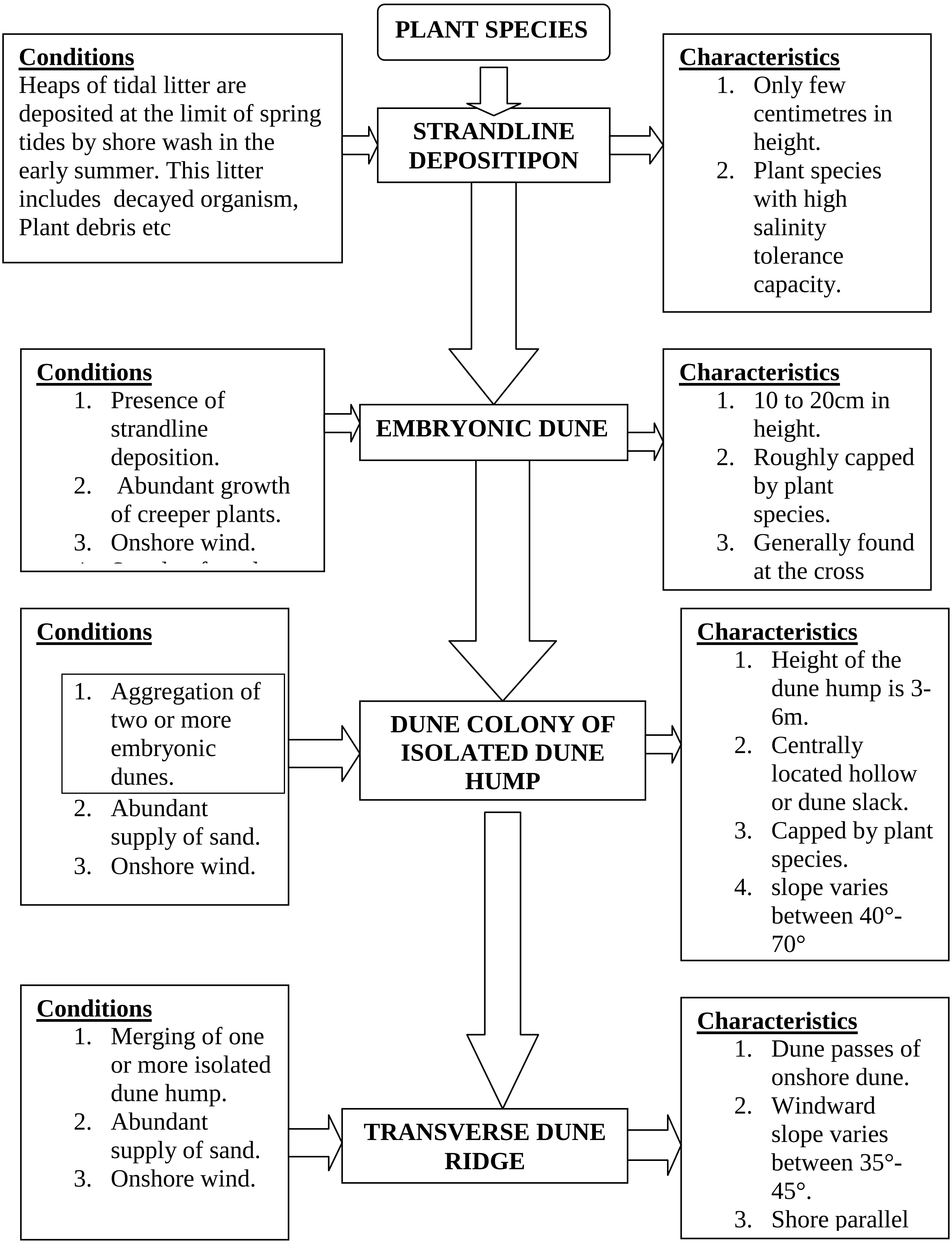


Figure 4.12 Tidal sand flat backed by strandline deposition backshore dune at south of Paradip coast

Figure 4.13 Backshore dune ridge at south of Paradip coast

Figure 4.14 Strandline depositions along the linear growth of plant

EVOLUTION OF COASTAL SAND DUNES



PLANT SPECIES

Conditions
Heaps of tidal litter are deposited at the limit of spring tides by shore wash in the early summer. This litter includes decayed organism, Plant debris etc

STRANDLINE DEPOSITIPON

Characteristics
1. Only few centimetres in height.
2. Plant species with high salinity tolerance capacity.

Conditions
1. Presence of strandline deposition.
2. Abundant growth of creeper plants.
3. Onshore wind.

EMBRYONIC DUNE

Characteristics
1. 10 to 20cm in height.
2. Roughly capped by plant species.
3. Generally found at the cross

Conditions
1. Aggregation of two or more embryonic dunes.
2. Abundant supply of sand.
3. Onshore wind.

DUNE COLONY OF ISOLATED DUNE HUMP

Characteristics
1. Height of the dune hump is 3-6m.
2. Centrally located hollow or dune slack.
3. Capped by plant species.
4. slope varies between 40°-70°

Conditions
1. Merging of one or more isolated dune hump.
2. Abundant supply of sand.
3. Onshore wind.

TRANSVERSE DUNE RIDGE

Characteristics
1. Dune passes of onshore dune.
2. Windward slope varies between 35°-45°.
3. Shore parallel

Figure 4.15 Stages of evolution of coastal sand dunes (Pethick, 1990).

Figure 4.16 Initial Plant species at south of Paradip coast

Figure 4.17 strandline deposition at south of Paradip coast

Figure 4.18 Embryonic dune at south of Paradip coast

Figure 4.19 Isolated dune hump at south of Paradip coast

Figure 4.20 Transverse dune ridges at south of Paradip coast

Figure 4.21 Centrally located dune slack at south of Paradip coast

4.2.7. Strandline deposition

Highly salt tolerating creeper act as an initial interceptor of wind blown sand. Sand deposition along the creeper plant over tidal sand flat is responsible for the development of strandline deposition. Strandline deposition (Figure 4.14) is primary condition for the evolution of incipient dune at the successive stages.

Fully developed dune is sometimes known as the first dune ridge (Figure 4.20). Older dunes which extend in a sequence inland from the first ridge are thus numbered second third and so on. These are each temporal stages of development of the system estimates of the absolute time of interval between each ridge which vary from area to area but may be between 70 to 200 years (Pethick, 1984).

Dune morphology is a result of the relationship between the sand transport rate and the pattern of the wind streamline as it passes over considerable obstruction created by the dune ridge. The higher wind velocities approach the dune surface on its windward face and crest but a flow separation occurs on the lee slope where the high velocity streamlines climb away from the surface leaving an area of dead air. The effect of this pattern on sand transport is, by easy to predict (Pethic 1984).

On the leeside of the dune, the wind velocities suddenly drop and saltation rate with it, so that the rapid deposition takes place. The effect of this is to cause steepening of windward slope and a gradual rolling over of the entire dune which consequently advances landward.

Very initiation of sand dune starts with the formation of highly salt tolerating creeper plant which leads to the strandline deposition. Incipient dune or embryonic dunes are the subsequent phase of dune development and other phase of dune development like individual dune ridge, dune slacks etc comes on later stage.

4.2.8. Dune slacks

Dune slacks or centrally located hollow (Figure 4.21 and 4.23) is formed among the individual ridges. Initial stages of dune slacks development has been shown in the figure. At the subsequent stages dune slacks retain moisture content which provides favourable condition to plant species growth.

Figure 4.22 Dune pass

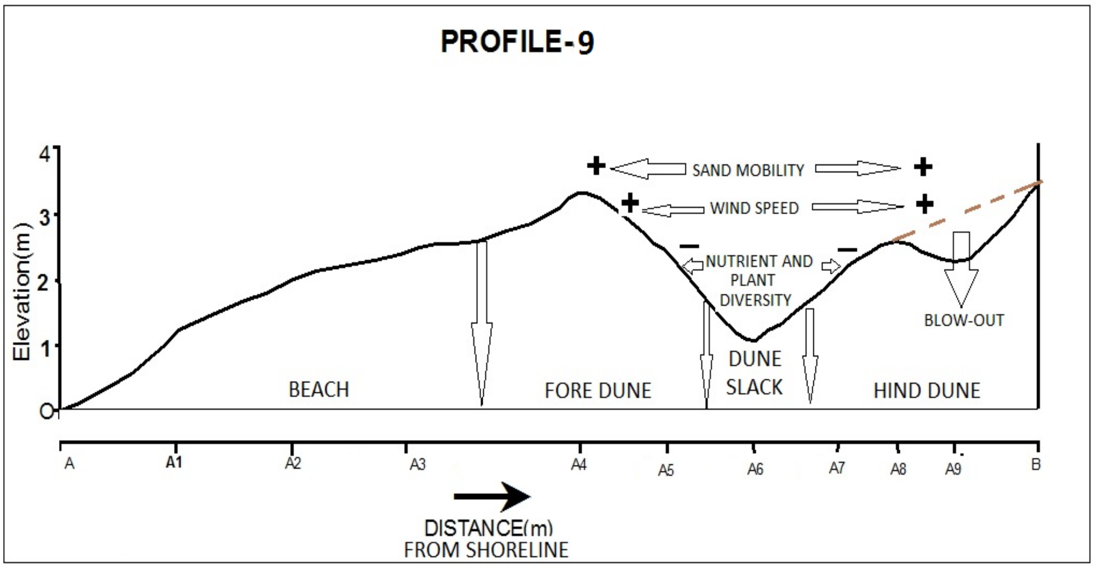


Figure 4.23 Dune slacks with intensity of wind speed variation and sand stability with altitude

4.2.9. Dune colony

As the time passes embryonic dune or incipient dune grow in its overall dimension and develop further phase which is called isolated dune ridge or dune hump

(Figure 4.19). A group of isolated dune ridge leads to the development of dune colony. Dune colony is very picturesque landscape. Each individual dune of dune colony is 2m to 5 m in height, with slope ranging 45 to 70 degree.

4.2.10. Transverse dune ridge

Transverse dune ridge (Figure 4.20) is the subsequent stage of isolated dune hump. It is the linear ridge like formation parallel to the shore. Transverse dune ridge is characterised by step windward slope and gentle lee slope with height that ranges between 3 m to 5 m for transverse dune ridge of foredune is indicative of first phase of primary dune development.

After analysing these entire components of sanddune, it is evident that shorelines along this part of the study area are backed by coastal dunes which are under different stages of evolution. Dunes are growing over the time positively in its dimension which in turn responsible for near stability or positive movement of shoreline. Statistical results of all transects is, thus, supported by the field study and certainly be taken as a proof in favour of LandSat data based results, derived by Digital Shoreline Analysis System (DSAS).

4.3. Wave induced erosion and shoreline changes.

Coastal cliff recession, an outcome of wave induced erosion, is a major process which forms shore platforms. It becomes the main subject when we consider formative processes of shore platforms and wave-cut terraces as a responsible factor to shoreline movement. In a dynamic treatment of these problems, it is necessary to clarify the mechanism of sea cliff erosion by waves and consecutive shoreline movement.

Data: LandSat 1973, 1990, 2001 and 2000

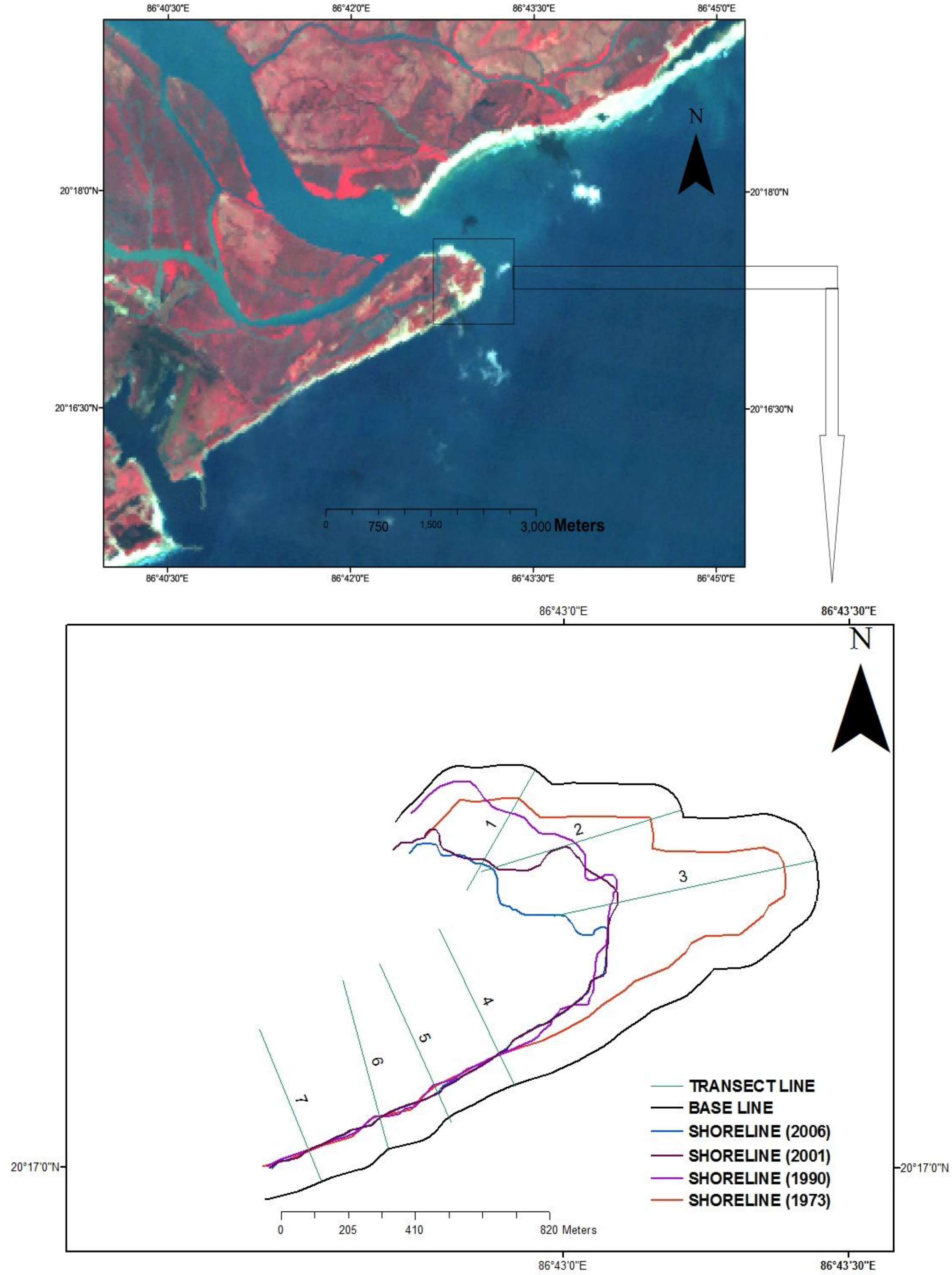


Figure 4.24 Shoreline changes along transect number 1 to 7.

Table: 4.6 Transect number 1 to 7.

TRANSECT ID	EPR(m/yr)	NSM(m/yr)	LRR(m/yr)	LR2
1	-6.64	-224.10	-7.13	0.88
2	-507.63	-507.63	-15.95	0.98
3	-20.67	-698.10	-19.12	0.89
4	-0.11	-3.88	-0.14	0.60
5	0.58	19.63	0.72	0.55
6	0.16	5.46	0.19	0.78
7	-0.11	-3.59	-0.09	0.72

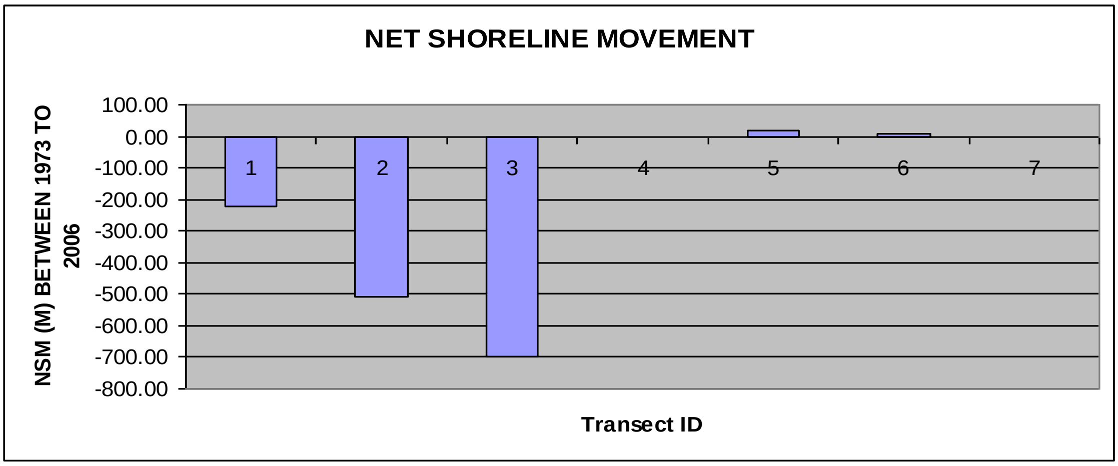


Figure 4.25 NSM along transect number 1 to 7.

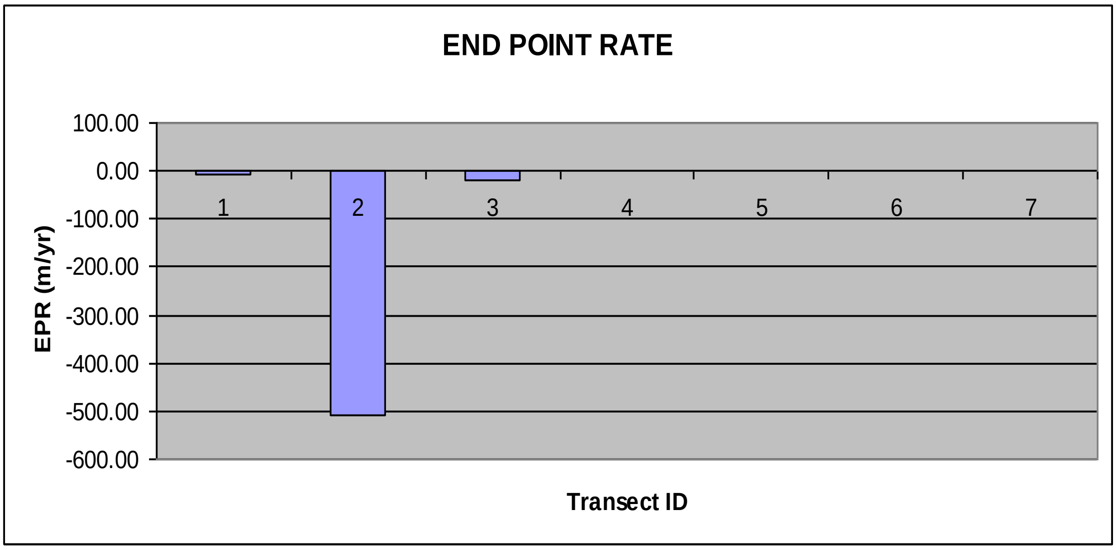


Figure 4.26 EPR along transect number 1 to 7.

Shoreline along the north of Paradip has been continuing to face wave induced erosion on behalf of its configuration and concentration of refracted wave energy. A total of seven transects has been plotted across the projected head land and shoreline movement has been cleared against direction of wave propagation, wave refraction and shoreline configuration.

Nature of shoreline movement (Figure 4.25) along the north of Paradip port is different from rest of the study area. Seaward projection of the land and consequent configuration of shoreline (Figure 4.24) makes it vulnerable to wave induced erosion. Shorelinealong the immediate south of Mahanadi is subjected to both the riverine

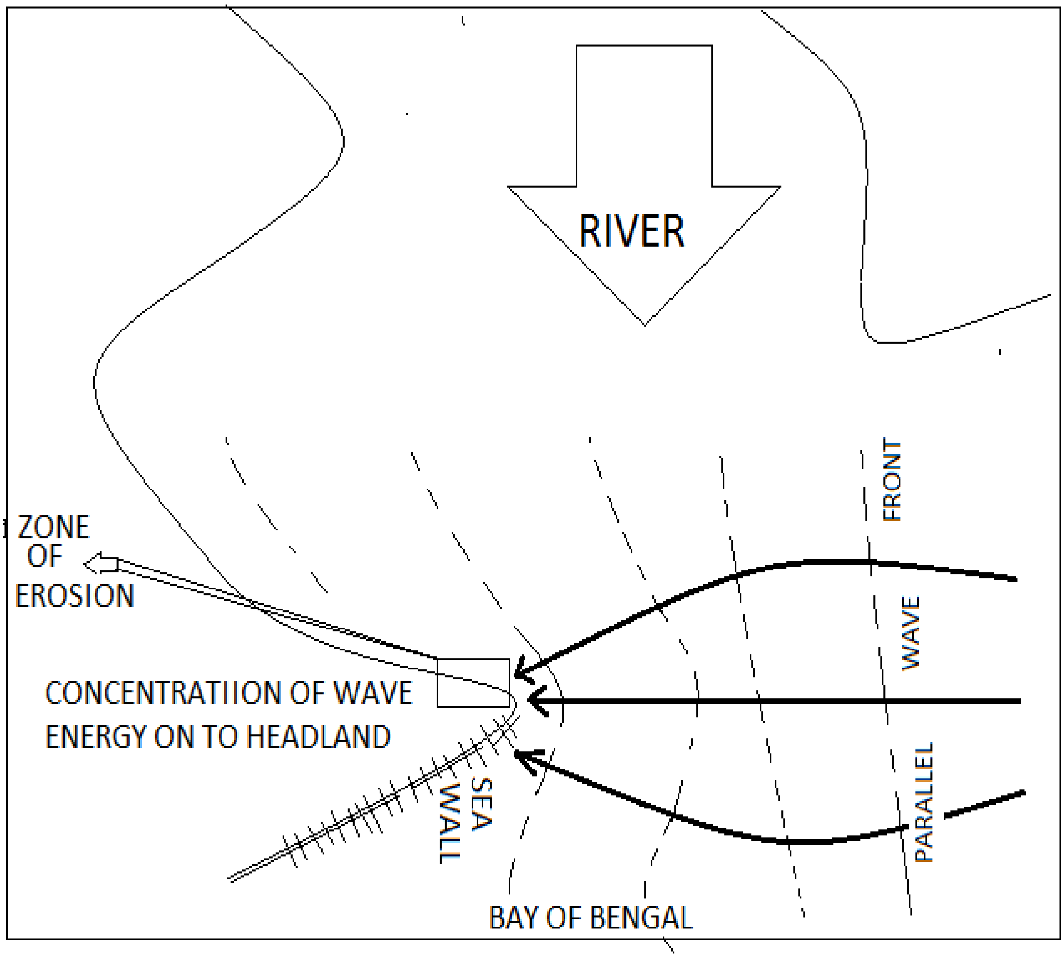


Figure 4.27 Environmental setup of erosion prone projected headland. Diffracted wave energy gets concentrated on the headland during winter season (northwest monsoon regime).

and marine erosion. End Point Rate (EPR) of transects number-1, 2 and 3 (Table 4.6) are respectively 6.64m, 507.63m and 20.67m per year. Such a strange variation of the nature of erosion is not the actual phenomenon as EPR used only the extreme position of shoreline. If one look at the Linear Regression Rate (LRR) in Table 4.6, actual nature of the erosion can be understood because LRR calculates shoreline movement on year on year basis. LRR of the transects no. 1, 2 and 3 are respectively 7.13 m, 15.95 m and 1912 m. Total recession of the shoreline along transects number-1, 2and 3 are 224 m, 507 and 698 m.

Projected headland is most vulnerable to erosion during winter season. It is the north-eastern monsoon wind generated wave energy which affects mostly to this part. During winter season waves coming from the north-eastern direction directly hit on the part. Wave refraction is the process by which the wave crests are bent until they become parallel to the submarine contour-a process fundamental to the coastal geomorphology (pethic, 1984).

Figure 4.27 illustrates unusual nature of shoreline erosion within a single cell. A wave train which is sweeping down a coastline with its crest at an oblique angle to both shore and bed contour will, at any given instance, have the shoreward portion of its crests in shallow water and seaward portion in deeper water. Since the wave phase velocity is directly related to water depth this means that the shoreward part of the wave crest will be moving more slowly than the same crest further out to sea. The result is that the seaward portion swings forward and the wave crest become curved. This process continues until all part of the crest is parallel to bed contour and shoreline. This process results in a spreading out, or divergence of the wave rays (lines drawn at the right angle to the wave crest) in bays and their convergence at the distal end. Thus concentration of energy results in coastal erosion dung winter season.

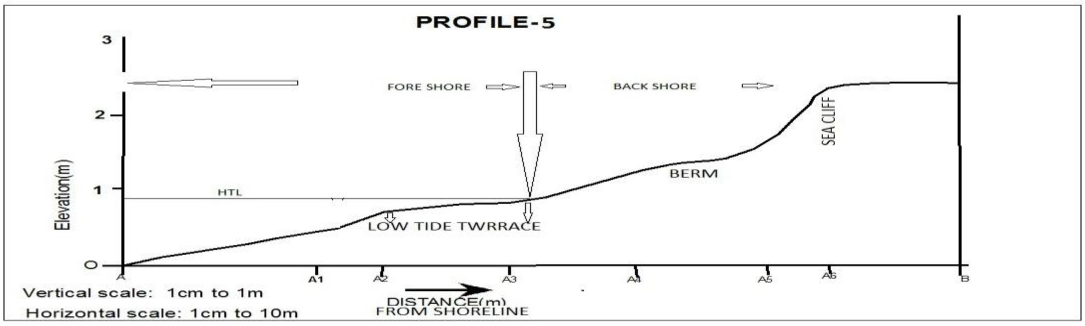


Figure 4.28 Beach profile showing different part of the eroded coast.

Figure 4.29 A part of projected headland exposed to erosion at Mahanadi confluence.

Figure 4.30 Eroded tidal creeks at Mahanadi confluence.

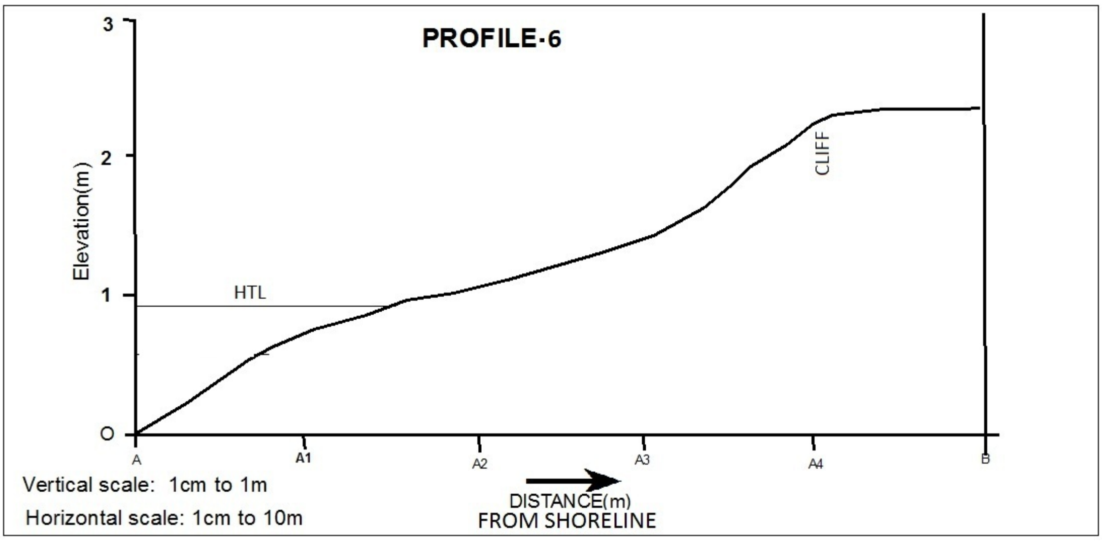


Figure 4.31 High tide level and cliff.

Coastal erosion and accretion are complex processes that need to be investigated from the angles of sediment motion under wind, wave and tidal current action; beach dynamics within a sediment/littoral cell; and human activities along the coast, within river catchments and watersheds and offshore, both at spatial and temporal scales (Pethic, 1984). This segment of the coast is characterized by fine-grained sedimentary deposits, predominantly silt and clay that come from rivers; it can be classified as a “soft” coast. Different types of landform which has been evolved under present geomorphic process here are as follows-

4.3.1. Wave cut platform

Wave-cut surfaces in front of cliffs are called wave cut platform (Figure 4.31) which are slightly concave upward. The origin and development of the wave cut platform is related to cliff recession. It is also called wave cut benches. Shore platform is formed because of active cliff recession from powerful wave action at the cliff base by uprushing breaker wave and effective removal of eroded material by backwash.

4.3.2. Cliff

Steep slope of the cross beach profile rises almost vertically above the seawater is called cliff (Figure 4.34, a). It is the result of gradual extension of wave cut platform due to toe erosion. If the marine erosion at the base of cliff is much faster than the sub aerial weathering of cliff face and crest, overhanging cliff with steep vertical face is formed.

4.3.3. Beach berm

Beach berm (Figure 4.28) is a semi permanent ridge which stands well above the high tide level. In case of erosional beach, berm gets eroded over the time. Beach berm is a diminishing feature.

Cross profile drawn on different part of the eroding beach are also representative of different stages of erosion. Profile number 5 in figure 4.30, has more irregular slope than the slope of profile number 6 in Figure 4.33. It becomes therefore more regular in profile number7 (Figure 4.39). Absence of cliff accompanied with very gentle slope in places, indicates that process of erosion is about to complete and beach profile becomes semi-permanently stable. Gentle slope developed over the time increases wave runup and diminishes swash energy as well as backwash energy when it becomes unable to modify beach profile significantly.

4.3.4. Mechanism of wave induced cliff erosion

Cliff erosion is determined by the relative intensity of two forces, i.e., the assailing forces versus the resisting force. The assailing forces consist of hydraulic actions such as compression, tension, cavitation, and wear, abrasive and artillery action due to wave-moved pebbles and boulders and wedge action due to the air compressed in fissures by waves. The resisting force of the rocks is controlled by their mechanical roperties such as compressive strength, tensile strength, and wear resistance. If the former are greater than the latter, then waves can attain the erosive force, which is defined here as the "force to cause erosion." There have been few studies which attempted to explore this basic problem in the field. One reason for an absence of such studies is the difficulty of making precise measurement of phenomena in complicated natural environment.

However, wave induced cliff recession along shoreline to the north of Paradip, can be divided into certain stages. Each stage is characterised by specific geomorphic features, beach slope and wave properties (Figure 4.35).

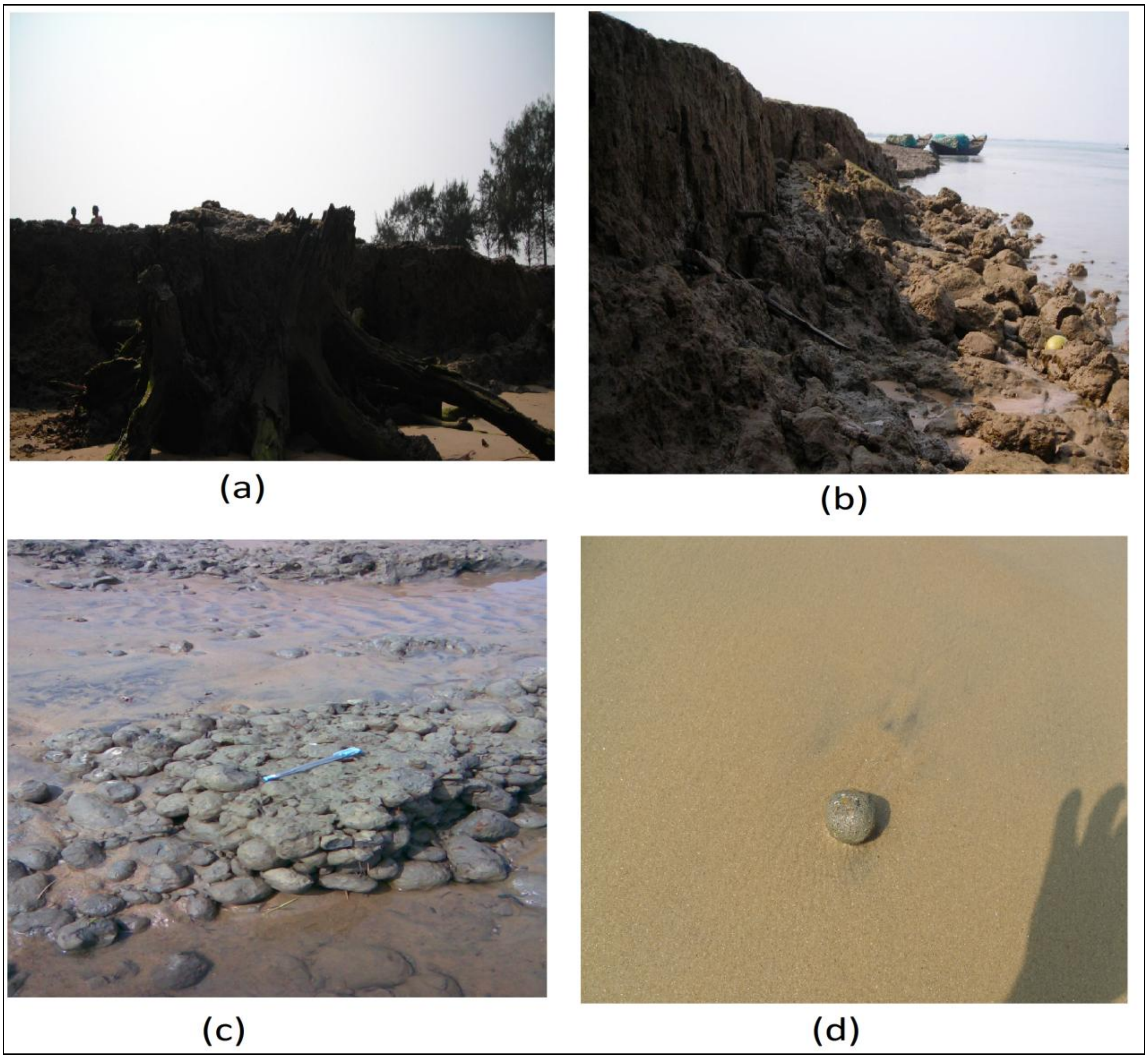

(a)
(b)
(c)
(d)

Figure 4.32 Wave induced erosion through mud ball creation. (a) Sea cliff (b) basal erosion and consequent slumping (c) oval round and near round shaped mud balls. (d) Final stage of mud ball. Continuous rolling over the beach slope resulted in round

Figure 4.33 Semi permanent regular beach slope. All irregularities have been wiped out through wave action.

Figure 4.34 Eroded beach slope with an angle between 8 and 15 degree.

shaped

- **Stage-1:** Initially cliff base (Figure 4.32, a) is eroded by wave action. Basal erosion and transportation of eroded material creates cavity at the base of cliff. With time basal cavity leads to slumping and toppling of cliff material.
- **Stage-2:** Toppled and slumped material (Figure 4.32, b) starts to roll over the beach. Continuous rolling over beach slope resulted in to round shaping of slumped block which now called mudball (Figure 4.32, c).
- **Stage-3:** Further rolling over beaches (by swash and backwash) leads to reduction in their size and finally mudballs disappear from the beach slope.

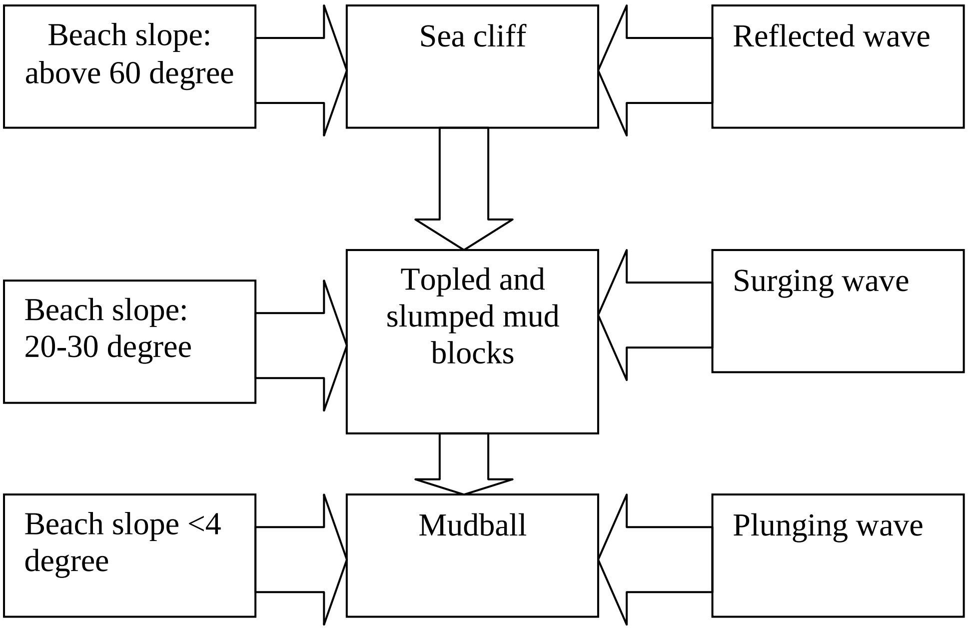


Figure 4.35 Mechanism of cliff erosion in relation to beach slope and wave types.

4.3.5. Shoreline movements along seawall

Shoreline along transects number-4, 5, 6 ant 7 (Figure 4.24) shows almost stable condition during the time period of 1973 to 2006. Net shore line movement (NSM) and

Figure 4.36 Mechanism of cliff erosion in relation to beach slope and wave type.

Figure 4.37 Beach slope <4* with very low wave energy component at Mahanadi confluence

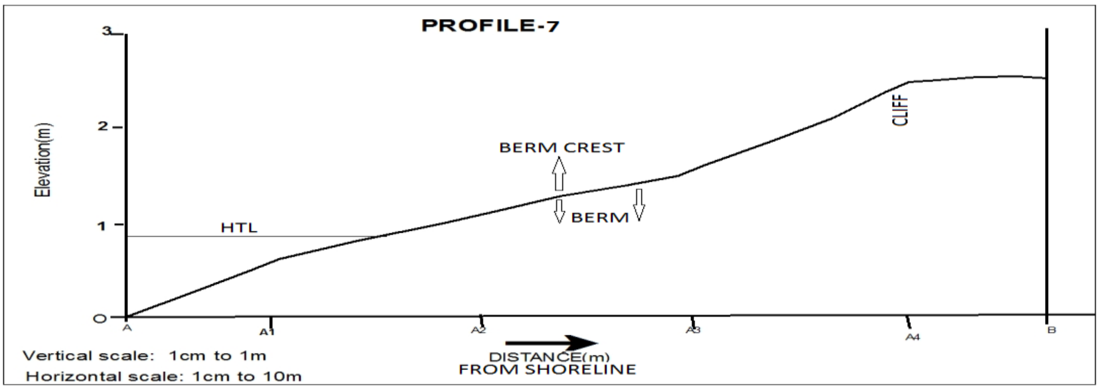


Figure 4.38 regular slope profiles with almost diminished beach berm and cliff

Figure 4.39 Sea wall protecting eastern side of projected head land. Sea wall construction results in near constant situation of shoreline after 1990's, which also responsible for insignificant net shoreline movement along transect 4, 5, 6 and 7.

Linear Regression Rate (LRR) along transect no.4, 5, 6 and 7 are exceptionally lower than its contiguous part. Such consistency of shoreline position is attributed to construction of sea wall (Figure 4.41) along shoreline, which made it protected from the wave action since 1989, when it was construed.

Almost entire statistical results of these transects are indicative of near-stable nature of shoreline and correctly matched to the ground truth. This again provides profound base for satellite data to be used as a tool to monitor shoreline change.

4.4. Anthropogenic effect on coastal environmental setup

Human activities affect the stability of both dune-backed and bluff-backed shorelines. At longer time and larger space scales jetty construction and maintenance, dredging etc. are factors that can affect shoreline stability. This is specifically true along dune-backed shorelines where shoreline is very much susceptible to even minute alteration of sand dune. There are a variety of human activities that affect shoreline stability over shorter time and smaller spatial scales. Examples of activities typically associated with residential and commercial development which include grading and excavation, surface and subsurface drainage alterations, vegetation removal and shoreline stabilization by sea wall construction.

4.4.1. Sand mining near Paradip coast.

Coastal and nearshore marine environment, sea sand in particular, is a source for a variety of minerals of geological and biological origin that have been extracted and utilized by the human for centuries. In general, marine sand used for building and construction are utilized locally, whereas those products that have a world market, such as jewellery and industrial metals, may be largely exported in one form or the other. The mining or extraction of these minerals, however, tends to be unplanned and unmanaged causing severe and long lasting detrimental impact to the environment.

Sea beaches are dynamic landforms and are constantly subjected to erosion and/or accretion. The sand on the beach is subject to storms, waves, and buffeting from the force of sea waves. This in turn results in the movement of sand from one part of the beach, by erosion and accretion to another. The condition of a sea beach is the reflection of the local balanced or unbalanced gain due to deposition or loss due to erosion. While natural beachfront and sea erosions do occur, anthropogenic alteration of the beach has significantly contributed to beachfront erosion.

Coastal sand mining can change the entire beach geomorphology and restoration of the beach often takes years resulting in loss of available habitat for marine flora, fauna and sea turtles, in addition to large change of beaches.

While beach nourishment is one solution for what has been lost due to sand mining, it can negatively impact beach fauna especially sea turtles which is an important species of coastal biodiversity along entire east coast of India. If the sand imported is drastically different from native beach sediments, it may affect nest site selection, digging behaviour, incubation temperature, gas exchange and the moisture content of nests, all of which can ultimately impact the reproductive fitness of sea turtles and other fauna resides on the beaches (A GOI – UNDP PROJECT MANUAL, 2003).

In India, there is severe damage to the nesting beaches of olive ridley turtles. Odisha coast near Paradip has been altered severely due to sand mining for rare earth metals and constructional activities. Such alteration holds negative potential nesting beaches of olive ridley turtles and ingress coastal fresh water under ground reservoir and shoreline erosion.

Figure 4.40: Commercial sand extraction at Mahanadi confluence.

Figure 4.41 Deformation of natural shoreline at Mahanadi confluence.

Figure 4.42 Stagnation of salt water in depression created by commercial sand extraction at Mahanadi confluence.

Figure 4.43 Salt water intrusion during high tide at Mahanadi confluence.

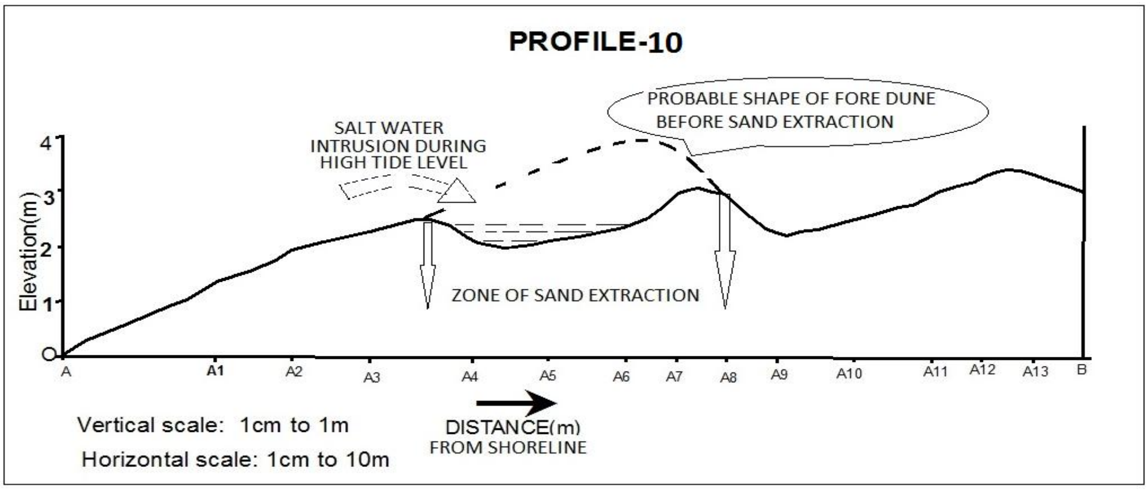


Figure 4.44 Sand extraction and deformation of beach profile.

Southern segment of the Paradip coast has been affected by the sand extraction and removal of sand dune (Figure 4.40 and 4.41). It has largely been altering the natural environmental set up of the region. Extensive sand extraction from the beach leads to the irregularities of the beach profile. Excavation created depression at the backshore zone which holds spring tide water (Figure 4.42 and 4.43). Such stagnation of water may contaminate fresh water aquifer behind the backshore (Figure 4.44). On the other hand removal of sand dunes damages natural ecosystem of the region. Irregularities, created by excavation on beach profile, also change the extent of wave runup and consequent wave energy interacting with the coast.

4.4.2 Storm facies as an evidence of shoreline accretion.

At places of the Paradip coast backshore natural environmental set up has been altered through road construction, fisheries etc. to such an extent that it becomes difficult

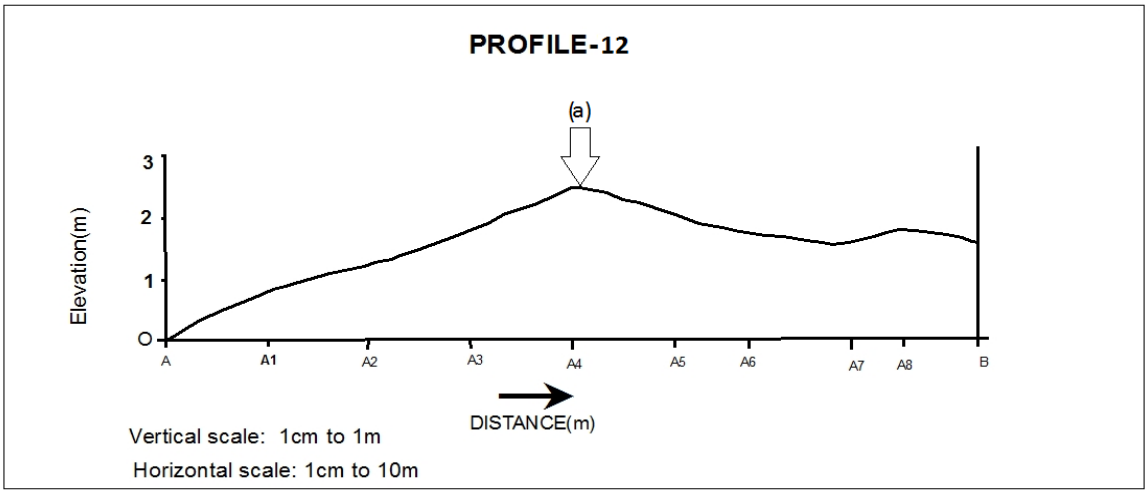


Figure 4.45 Beach berm with human induced flat backshore zone

Figure 4.46 Beach berm

Figure 4.47 Storm facies

to understand the actual nature of coastal process. Shoreline on transect number 65 is showing that it is under depositional regime and advancing since 1973 but there was no visual proof against the statistical results. It has been found that there is a dark coloured sand strata (Figure 4.47) located at a depth of around 18cm depth of the beach. A closed investigation revealed that the layer is composed mainly of organic litter and illmenite. Literatures on the part describes that such deposits can only be deposited during extreme climatic condition. If we look at the climatic history of immediate past, it is 1999 Super Cyclone which strikes the shore as extreme climatic phenomenon. Thus, it can be inferred that this layer deposited in 1999 and the subsequent deposition has taken place thereafter. This phenomenon is also supporting statistical results derived from Digital Shoreline Analysis System (DSAS), indicating accretion along shoreline and consequently its positive movement.

3.5. Summary

The primary objective of the study of this chapter was to find out reasons of shoreline changes and to verify the secondary data based statistical results. Digital Shoreline Analysis system (DSAS) generated statistical results with above 80 percent goodness of fit has been taken as significant. All significant results directly match with ground truth and favour applicability of satellite data to be used as a useful tool for shoreline change analysis.

The littoral zone based analysis shows that shoreline under transect number- 1, 2, 3 and 4 is undergoing intensive erosion. Geomorphic features of eroded shoreline like wave cut platform, cliff, mud balls etc, are well recognised in this coastal zone. Shoreline erosion occurs due to wave induced seasonal erosion under north-eastern wind regime. As the field study was performed in mid December, shoreline erosion has effectively been captured in photographs which can be taken as proofs against statistical results derived from satellite data. Almost stable nature of shoreline across transects 5, 6, 7 and 8, resulted from sea wall construction, and is also matches to the actual ground truth of the corresponding shoreline.

Dune backed shoreline across transects number 53 to 60 (under littoral cell-3 in second chapter) are of advancing nature. Field study performed in this segment shows different stages of sand dune evolution. Sand dunes are developing positively under the favourable conditions and such development again acts as an agent of shoreline movements in positive direction. In spite of having favourable condition for sand dune development under the same littoral cell-3, erosive nature of shoreline movement, along transects no. 62 to 71, has resulted from the anthropogenic modification of nearshore zone.

Thus, significant statistical results of selected transects are well matched to the ongoing geomorphic process. However, to detect the pattern of shoreline movement more accurately and its prediction of future movement through this method requires more data set with better resolution so that goodness of fit of statistical results would be taken at much higher level and effective result could be deduced.

CHAPTER-V

5. Conclusions

Coastal geomorphological processes of the Mahanadi delta coast are complex and multifaceted. Numerous geomorphic and anthropogenic factors are acting together to influence the shoreline position as well as entire environment set up. Natural processes on the part are largely seasonal. Such seasonal process in long run leads to the semi permanent changes which are being captured in the current study through a temporal analysis of some selected aspects of coastal environment.

Shoreline in the northern part of the delta coast has been found highly depositional while in southern part it is erosive in nature. Sediment supply, long shore drift of sediment, direction and intensity of wave propagation are playing a major role in shoreline evolution and entire depositional features. Nature of shoreline changes in places is highly arbitrary and thus, it is difficult to predict future shoreline position. Out of total 119 only 52 transects has been recorded with statistically significant results. It implies that in majority of cases movement is not predictable.

As revealed in the study entire shoreline has undergone significant changes during the last 40 years. Shifting of river mouth on account of siltation and formation of islands and bars affects tidal prism. Shifting position of tidal prism in turn augments shoreline erosion under suitable condition. Entire accretional features in the southern part of the

Mahanadi delta coast are in the line of positive evolution. Areal expansion and merging are two major processes of evolution of these features.

Longshore bar under the littoral cell-2 is at the final stage of bar attachment process with negligible ocean front erosion. Increasing length of the bar is expected to lead to complete blockage of sediment passage to the open ocean. Closing of sediment process and siltation would further accentuate infilling of lagoon water. On the other hand, once sediment supply is completely blocked, it would create a situation of input deficit in the littoral cell system. Constant energy level coupled with an input deficit in the system would further stimulate shoreline erosion in the near future.

Littoral cell-4 is highly depositional with almost all transect recorded positive movement of shoreline. Some transects recorded unusually high rate of shoreline advancement and is essentially related to the emergence of new land owing to adequate sediment supply faster sediment trapping by mangroves. Over this entire littoral cell is distinguished with faster shoreline movements and rapid orientation and reorientation of all depositional features.

Accretion and erosion are both active processes in littoral cell-5. Accretion is an active process along the southern part. This is because of its sheltered location and adequate sediment supply. Northern part of the littoral cell is increasingly exposed by decreasing length of an offshore bar located at the north of Hookitola spit. On the other hand shifting river mouth and consequent decrease in sediment supply provides impetus to the erosion along northern part of the littoral cell-5.

The Mahanadi delta coast provides an ideal environment for the development of depositional features. Owing to extensive submarine platform, numerous depositional features have been grown up. Entire geomorphic features acts as a dissipater of marine energy. Shoreline behind longshore bar, spit, islands etc., are highly accreting in nature.

On the other hand entire open shore is detected with negative NSM (Net Shoreline Movement).

Coastal dynamics, especially in respects to the evolution of the near shore features, are complex and outcomes of many interactive processes. During the last 40 years almost all bars, spit, islands etc. , has undergone rapid changes. Longshore bars and islands, located at the to the south of Paradip are in the process of attachment to the mainland. Entire depositional features to the north of mahanadi river are undergoing changes changes at a much faster rate. Mangrove swamps and near enclosed sea provide an ideal environment for accretion.

Field study performed along 22km long stretches of Paradip coast has revealed many reasons behind shoreline changes. Shoreline along the south of Paradip is essentially is dune backed. Strand line deposition, isolated dune hump, dune colony and dune slacks, foredune terrace,backshore dune ridge etc., are all together representing different stages of dune evolution. All profiles, drawn across the beaches are showing gentle slope which effectively increases wave run-up. As wave run-up is inversely proportional to the wave energy, later is less effective to modify shoreline along the south of Paradip. On the other hand, extensive tidal sand flat across the beach is provided an ideal environment for further advancement of strandline deposition towards ocean front. Merging of dune hump gives rise to foreign terrace which act as a dissipate of extreme climatic event. Backshore dune ridges are thickly covered with salt tolerating vegetation which protects it from wind forces that otherwise blows away dune sand. However, these entire depositional features are manifesting the nature of shoreline which is stabilised or slowly moving toward offshore. Transects line across the beach are also recorded with positive movement of shoreline and all statistical results derived against these transects are well matched to the ground truth. This phenomenon is strongly advocating authenticity and usefulness of satellite data in determining patterns of shoreline movement in the past and predicting future changes.

Shoreline configuration with respect to the direction of propagation of wave energy has proved to be a determining factor of shoreline changes. Diffraction and convergence of wave energy lead to the variable nature of coastal process in contagious places. Contraction of wave energy is major responsible factor for intensive coastal erosion and consequently faster shoreline movement. Wave-cut platform, cliff, diminishing height of beach berm etc are indicating negative shoreline movement. Moreover, all three transects lying across eastern part of projected headland are recorded with highly negative EPR and NSM which gives a glimpse of intensity of erosion by wave action.

Natural movement of shoreline is largely obstructed by seawall construction and sand mining. Seawall effectively stabilizes shoreline movements while sand mining alters beach profiles, wave run-up and salt water stagnation.

Appendix

1. **Table: 4.2** Reduced levels (RL) on cross beach profile-1.

PROFILE NO-1								
stations	BS(m)	IS(m)	FS(m)	HC(m)	RL(m)	Interval Distance (m)	LAT/LONG	Remarks
A	4.65			4.65	0	0	20*14.621'N/ 86*38.004'N	BM= sea level(0m)
A1		3.65		4.65	1	15		
A2		3.79		4.65	0.86	15		
A3		3.01		4.65	1.64	20		
A4		3		4.65	1.65	20		
A5		3.77		4.65	0.88	15		
A6		3.12		4.65	1.53	20		
A7		2.63		4.65	2.02	20		
A8		2.05		4.65	2.6	15		
B			1.82	4.65	2.83	15	20*14.615'N /86*37.656'N	

2. **Table: 4.3** Reduced levels (RL) on cross beach profile-2

PROFILE NO-2								
stations	BS(m)	IS(m)	FS(m)	HC(m)	RL(m)	Interval Distance (m)	LAT/LONG	Remarks
A	4.7			4.7	0	0	20*14.355'N/ 86*37.650'N	BM= sea level (0m)
A1		3.81		4.7	0.89	15		
A2		3.38		4.7	1.32	15		
A3		2.93		4.7	1.77	15		
A4		3.08		4.7	1.62	20		
A5		2.9		4.7	1.8	20		
A6		3.36		4.7	1.34	30		
A7		2.89		4.7	1.81	20		
A8		2.31		4.7	2.39	15		
A9		2.06		4.7	2.64	15		
B			2.02	4.7	2.68	10	20*14.005'N/ 86*37.355'N	
Total length of the profile=175m								

3. **Table: 4.4** Reduced levels (RL) on cross beach profile-3

PROFILE NO-3								
stations	BS(m)	IS(m)	FS(m)	HC(m)	RL(m)	Interval Distance(m)	LAT/LONG	Remarks
A	4.85			4.85	0	0	20*13.445'N/ 86*37.650'N	BM= sea level (0m)
A1		3.54		4.85	1.31	20		
A2		3.53		4.85	1.32	20		
A3		3.08		4.85	1.77	15		
A4		3.23		4.85	1.62	15		
A5		3.05		4.85	1.8	10		
A6		3.51		4.85	1.34	20		
A7		3.04		4.85	1.81	15		
A8		2.46		4.85	2.39	15		
A9		2.21		4.85	2.64	15		
A10		2.3		4.85	2.55	10		
A11		2.29		4.85	2.56	10		
B			2.17	4.85	2.68	10	20*13.205'N/ 86*37.355'N	
Total length of the profile=180m								

4. Table: 4.5 Reduced levels (RL) on cross beach profile-9

PROFILE NO-9								
stations	BS(m)	IS(m)	FS(m)	HC(m)	RL(m)	Interval Distance(m)	LAT/LONG	Remarks
A	3.655			3.655	0	0	20*15.226'/ 86*39.686'	BM= sea level (0m)
A1		2.45		3.655	1.205	20		
A2		1.62		3.655	2.035	20		
A3		1.245		3.655	2.41	20		
A4		0.32		3.655	3.335	30		
A5		1.24		3.655	2.415	15		
A6		2.555		3.655	1.1	15		
A7		1.55		3.655	2.105	15		
A8		1.15		3.655	2.505	10		
A9		1.45		3.655	2.205	10		
B			0.19	3.655	3.465	15	20*15.296'/ 86*39.653'	
Total length of the profile=170m								

5. Table: 4.7 Reduced levels (RL) on cross beach profile-5.

PROFILE NO-5								
stations	BS(m)	IS(m)	FS(m)	HC(m)	RL(m)	Interval Distance (m)	LAT/LONG	Remarks
A	4.12			4.12	0	0	20*17.506'/ 86*42.890'	BM= sea level (0m)

A1		3.69		4.12	0.43	15		
A2		3.41		4.12	0.71	5		
A3		3.3		4.12	0.82	10		
A4		2.86		4.12	1.26	10		
A5		2.62		4.12	1.5	10		
A6		1.79		4.12	2.33	5		
B			1.73	4.12	2.39	10	20*17.465'/ 86*42.880'	

6. **Table 4.8**. Reduced Levels on cross beach profile-6.

PROFILE NO-6								
stations	BS(m)	IS(m)	FS(m)	HC(m)	RL(m)	Interval Distance(m)	LAT/LONG	Remarks
A	4.04			4.04	0	0	20*17.514'/ 86*42.940"	BM=sea Level (0m)
A1		3.3		4.04	0.74	10		
A2		3.02		4.04	1.02	10		
A3		2.67		4.04	1.37	10		
A4		1.76		4.04	2.28	10		
B			1.69	4.04	2.35	10	20*17.440'/ 86*42.945"	
Total length of the profile=65m								

7. **Table 4.9** Reduced Levels (7) on cross beach profile-7.

PROFILE NO-7								
stations	BS(m)	IS(m)	FS(m)	HC(m)	RL(m)	Interval Distance(m)	LAT/LONG	Remarks
A	3.92			3.92	0	0	20*17.660'/ 86*42.670'	BM=sea level(0m)
A1		3.33		3.92	0.59	10		
A2		2.84		3.92	1.08	15		
A3		2.36		3.92	1.56	15		
A4		1.48		3.92	2.44	15		
B			1.44	3.92	2.48	10	20*17.555'/ 86*42.960'	
Total length of the profile=65m								

Table 4.10 Reduced Level (RL) on cross beach profile-10.

PROFILE NO-10								
stations	BS(m)	IS(m)	FS(m)	HC(m)	RL(m)	Interval Distance(m)	LAT/LONG	Remarks
A	3.825			3.825	0	0	20*15.254/ 86*39.906	BM= sea level (0m)
A1		2.485		3.825	1.34	30		
A2		1.905		3.825	1.92	15		
A3		1.545		3.825	2.28	15		
A4		1.725		3.825	2.1	20		
A5		1.725		3.825	2.1	15		
A6		1.475		3.825	2.35	15		

A7		0.885		3.825	2.94	10		
A8		0.905		3.825	2.92	10		
A9		1.555		3.825	2.27	10		
A10		1.325		3.825	2.5	15		
A11		0.835		3.825	2.99	15		
A12		0.545		3.825	3.28	10		
A13		0.515		3.825	3.31	10		
B			0.765	3.825	3.06	10	20*15.315/ 86*39.860	
Total length of the profile=200m								

Table 4.11 Reduced Level (RL) on cross beach profile-12

PROFILE NO-12								
stations	BS(m)	IS(m)	FS(m)	HC(m)	RL(m)	Interval Distance(m)	LAT/LONG	Remarks
A	3.25			3.25	0	0	20*14.934'/ 86*38.910	BM= sea level (0m)
A1		2.43		3.25	0.82	20		
A2		2.04		3.25	1.21	20		
A3		1.48		3.25	1.77	20		
A4		0.81		3.25	2.44	20		
A5		1.27		3.25	1.98	20		
A6		1.57		3.25	1.68	15		
A7		1.7		3.25	1.55	20		
A8		1.53		3.25	1.72	10		
B			1.72	3.25	1.53	15	20*14.928'/ 86*38.822	
Total length of the profile=160m								

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