STUDY OF GEOMORPHOLOGY AND DYNAMICS OF SHORELINE ASSOCIATED WITH MULKY-PAVANJE RIVERMOUTH, DAKSHINA KANNADA COAST, KARNATAKA, INDIA

Thesis

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

By

GUMAGERI NAGARAJ

DEPARTMENT OF APPLIED MECHANICS AND HYDRAULIICS

NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA,

SURATHKAL, MANGALORE – 575 025

July, 2012

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July, 2012

D E C L A R A T I O N

by the Ph.D. Research Scholar

I hereby *declare* that the Research Thesis entitled **"Study of Geomorphology and Dynamics of Shoreline Associated with Mulky-Pavanje Rivermouth, Dakshina Kannada Coast, Karnataka, India"** Which is being submitted to the **National Institute of Technology Karnataka, Surathkal** in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy** in **Civil Engineering** is a *bonafide report of the research work carried out by me*. The material contained in this Research Thesis has not been submitted to any University or Institution for the award of any degree.

GUMAGERI NAGARAJ
(Register Number: **090707AM09F01**)
Department of Applied Mechanics and Hydraulics

Place: NITK-Surathkal
Date: 23 - 07 - 2012

C E R T I F I C A T E

This is to *certify* that the Research Thesis entitled **"Study of Geomorphology and Dynamics of Shoreline Associated With Mulky-Pavanje Rivermouth, Dakshina Kannada Coast, Karnataka, India"** submitted by **Gumageri Nagaraj** (Register Number: **090707AM09F01**) as the record of the research work carried out by *him, is accepted as the Research Thesis submission* in partial fulfillment of the requirements for the award of degree of **Doctor of Philosophy**.

Dr. Dwarakish G S
Research Guide
Date: 23 – 07 - 2012

Prof. Nagaraj M K
Chairman – DRPC
Date: 23 – 07 - 2012

DEDICATED

TO MY PARENTS AND BELOVED

TEACHERS...

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GUMAGERI NAGARAJ

Place: NITK

Date: 23 - 07 - 2012

ABSTRACT

The current thesis considered Mulky-Pavanje rivermouth and associated shoreline of about 12km length, lies between $13^0$00'00"-$13^0$06'00" North Latitude and $74^0$44'00"-$74^0$50'00" East Longitude of Dakshina Kannda coast, Karnataka, India for short-term (<10 years), medium-term (10–60 years) and long-term (>60 years) shoreline changes. Beach survey, beach width, wave climate (height, period and direction) and wind parameters (speed and direction) and sediment sampling are gathered from nine locations (BS 1 – BS 9) to represent total 12 km shoreline, during the period from September 2009 to December 2011 for short-term change analysis. Short-term change analysis indicated that net accretion on the beaches towards the south of the rivermouth (BS 1–BS 5), whereas the north of the rivermouth experienced net erosion (BS 6–BS 9). For medium-term shoreline change analysis, rainfall and river discharges are obtained from Indian Meteorological Department for the periods 1985-2011 and 1985-1998 respectively. The monsoonal storm directly induces rivermouth morphology to vary (BS 5–BS 6), adjacent beaches to suffer from erosion (BS1–BS 4 and BS 7–BS 9) and also leads drastic changes in wave climate and freshwater flow. During monsoon and post-monsoon periods, the rivers Mulky (North) and Pavanje (South) overflow, discharge sizeable quantities of sediments into the sea, whereas during the pre-monsoon periods, seawater enters into the rivermouth area leads sediment deposition and distribution on either side of the rivermouth. However, the discharge of the Mulky river is approximately two times more than that of Pavanje river. Because of the more flow in the Mulky river, which runs across the northern part of the rivermouth, the shoreline in the vicinity of rivermouth is predominantly shifting towards south. Additionally long-term shoreline change analyses are made through multidated satellite imageries and topomaps for the period 1912–2009. The long-term shoreline change analyses depicts that northern spit and rivermouth are shifting towards south during the period 1912–2009 and also observed that fluctuation of accretion and erosion pattern on southern side of the shoreline is highly significant as compared with northern side. The Mulky-Pavanje rivermouth being highly complex and dynamic, but it provides wide scope for developmental activities around it. Therefore Land use/Land cover changes are attempted by considering recent decade, i.e 1998–2009 with the help of topographical map and remote sensing data. Land use/Land cover change analysis indicated that, because of development of urbanization and industrialization around the rivermouth, the built-up area has been drastically increased, while the other coastal related geological features such as beach vegetation, mangroves and river sand are drastically reduced during the period 1998–2009. In addition, Artificial Neural Network (ANN) technique is used to model the very important parameters of the coastal engineering such as wave height and littoral drift, which cause coastal erosion in the study area. The developed NARX and FFBP models are evaluated using error statistics. In both cases the NARX model performed better than FFBP and proved that wave height and littoral drift are the direct responsible factors to cause erosion in the Mulky-Pavanje rivermouth and associated shoreline.

Key words: Short-term, medium-term, Long-term, beach profile, sediment sampling, beach width, river discharge, rainfall, remote sensing, ANN, wave height, NARX, littoral drift, FFBP.

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LIST OF ABBREVIATIONS

BS	:	Beach Survey
LST	:	Longshore Sediment Transport
INCOIS	:	Indian National Centre for Ocean Information Services
IMD	:	Indian Meteorological Department
NRSC	:	National Remote Sensing Center
SOI	:	Survey of India
GIS	:	Geographic Information System
GPS	:	Global Positioning System
HWL	:	High water line
ANN	:	Artificial Neural Network
FFBP	:	Feed Forward Back Propagation
NARX	:	Nonlinear Autoregressive Exogenous Inputs
RMSE	:	Root Mean Squared Error
CC	:	Correlation Coefficient
CE	:	Coefficient of Efficiency

CHAPTER 1

INTRODUCTION

1.1 General

Coastal zones represent one of the most significant and valuable ecosystems of our world, since it is being located at the meeting point of the land and sea. The coast is essentially a natural resource system, which will provide a space for living and non-living resources for human activities. As a result, the coasts attract vast human settlements from the beginning of human history and have been historically one of the most heavily exploited areas by vast human populations. They are now at a focal point in many national economies, since a large number of social and economical activities are concentrated in these areas. Actually the coastal space represents approximately 10% of the earth's surface, and at the same time coastal lowlands are inhabited by more than 50% of world population, out of which 37% lives within 100 km of the coast at a population density twice the global average (IPCC 2001; Elizabeth and Turner 2005).

The coastal zone consists of inner part of the continental shelf, the coastline and a hinterland of a few km widths. The uniqueness of the coastal space compared with other terrestrial spaces derives from the land and sea interface at the origin of very specific environments (wetlands, estuaries, open sea areas and so on), which have themselves generated multiple modes of use. At this interface, the interactions between these two ecological communities make the coast of a highly dynamic nature with frequently changing biological, chemical and geological attributes. With this dynamism, coastal systems appear to be highly productive and biologically diverse ecosystems that offer crucial habitats for many species. In normal nature, coastal systems maintain an ecological balance that assures the well functioning of the whole system including beach replenishment, shoreline stability and nutrient generation, all of them are of great ecological importance.

1.2 Coastal Processes and Shoreline Changes

Coastal zones are exposed to a series of processes that have a dynamic nature, usually cause changes on long and short-time spans. Examples of these processes include coastal erosion, sediment transport, environmental pollution and coastal development. The impacts of these coastal changes include loss of life and property, security of ports, change of the coastal socio-economic environment, and decrease in coastal resources.

The coastal erosion, as an example of coastal processes that transports soil particles from onshore to offshore and alongshore and hence they result in the loss of coastal property, which in turn affects the coastal land use practices. Among these processes, the breaking waves in the nearshore zone and the nearshore currents cause coastal erosion and shoreline change. The breaking waves in the nearshore zone and the nearshore currents transport coastal sediments from one part of a shoreline to another part resulting in shoreline changes. This process is known as littoral transport, which moves coastal sediments by the action of waves and nearshore currents causing erosion, accretion or state of balance in a given part of a shoreline (Jorge and Albert 1996; Anil et al. 2007; Rao et al. 2009).

Shorelines generally can be categorized into beach and non-beach shorelines. The dominant geological material of most of recreational beach shorelines is sand, which is not necessarily true in the case of non-beach shorelines. Most of non-beach shorelines are built-up of geological materials other than sand such as rock, silt or clay. At the same time it is obvious that sand particles are easier to move by the action of waves and nearshore currents than rocks, only the strength and the intensity of waves and nearshore currents acting on a specific area, determine the ease and the time to fracture and thereafter transport rock materials. However, silt and clay are the geological materials that composed by most of the non-beach shorelines (Omar et al. 2009).

Over short-time periods erosion may take place in a part of a beach shoreline followed by an accretion of sand in the same part by means of coastal sediment transport processes resulting in an apparent situation of no-erosion. A reduction in the build-up of sediment in a part of a shoreline creates a deficit in that part resulting in increased shoreline erosion. However, shoreline erosion takes place due to these natural causes ,i.e waves and nearshore currents, and constructing of erosion protection structures such as jetties, breakwaters, seawalls, groins etc could reduce it (Dwarakish and Natesan 2002; Antonio et al. 2010).

Monitoring of shoreline change needs a long-term commitment and is based on the temporal change. Therefore, the detailed shoreline monitoring definitely provides very useful information to develop the coastal zones in a sustainable manner. In recent years, the monitoring campaign relies on information about historic shoreline location and movement to current status of existing shoreline. Therefore, there is always increasing recognition to quantify and to understand geomorphic behaviour either at smaller or larger spatial and temporal scale (Daphne et al. 2002; Anfuso et al. 2010).

1.3 Coastal Erosion in India

Coastal erosion is a universal problem. It has been estimated about 70% of all the coastlines in the world are eroded due to natural processes and human induced activities. India has an extensive coastline of about 7517 km, in that about 5423 km in the mainland and remaining 2094 km in the Andaman and Nicobar and Lakshadweep Islands. The coastline comprises of headlands, promontories, rocky shores, sandy spits, barrier beaches, open beaches, embayments, estuaries, inlets, bays, marshy lands and offshore islands. According to Naval Hydrographical chart, the Indian mainland consists of nearly 43% sandy beaches, 11% rocky coasts with cliffs, and 46% mud flats and marshy coast. The fluctuation along the Indian shoreline is seasonal. Some of the beaches regain their original profiles during fair weather seasons. About 50% of the beaches do not regain their original shape over an annual cycle and undergo net erosion (Chandramohan et al. 1991; Chandramohan et al. 2001; Rajwath et al. 2005).

The coastal geomorphological processes along the Indian coast are influenced by a number of environmental factors, primarily due to geological, meteorological and oceanographical factors which vary from one sector of the coast to another. The primary source of the sediments deposited on the beaches is the weathering of land and the sediments are transported through rivers to the ocean. The contribution of shelf erosion to suspended sediments in the ocean is unknown and appears to be of a very low order. The quantities of materials contributed by headland erosion and aeolian transport are less than 2% of river transport. Another main source of sand for a particular region can be of an eroding upcoast cliff and/or beach. Beaches supply sand when the wave and longshore current transport capacity at a point exceeds the supply of sand from updrift sources to the point. Beach erosion occurs at an increased rate during storms (Malik et al. 1987; Onkar et al. 1995).

Many coastal zones in India are ephemeral in nature, only acting to store sediment for a short geological span before it moves further down slope. The time span for which the sediment remains in a coastal sink varies from only a few minutes or hours in the case of some tidal beaches, to several million years in the case of coastal rock formations. In many areas, sand is transported short or for a distance alongshore from its source or sources before being deposited at one or more semi-permanent locations known as sinks. Harbour, bay and estuary with tide generated flow can trap large volumes of the sediment transported alongshore. Sometimes sand may also be trapped adjacent to jetties/breakwaters constructed to stabilize the entrance channel. Lagoons and estuaries act as long-term sediment sinks for marine sand. Wind might cause a net seaward transport of sand from the dunes to the littoral zone but at most locations sand is blown predominantly to the dune field from the beach (Sanil et al. 2006).

Table.1.1 Types of coastline in different maritime states along the Indian coastline (Source: Sanil et al. 2006)

State	***Sandy beach (%)***	***Rocky coast (%)***	***Muddy flats (%)***	***Marshy flats (%)***	***Total length (km)***	***Length of coast affected by erosion (km)***	***Percentage Erosion***
Gujarat	*28*	*21*	*29*	*22*	*1214.7*	*36.4*	*3.00*
Maharashtra	*17*	*37*	*46*	-	*652.6*	*263.0*	*40.30*
Goa	*44*	*21*	*35*	-	*151.0*	*10.5*	*6.95*
Karnataka	*75*	*11*	*14*	-	*280.0*	*249.6*	*89.14*
Kerala	*80*	*5*	*15*	-	*569.7*	*480.0*	*84.25*
Tamil Nadu	*57*	*3*	*38*	*7*	*906.9*	*36.2*	*3.99*
Andra Pradesh	*38*	-	*52*	*10*	*973.7*	*9.2*	*0.94*
Orissa	*57*	-	*33*	*49*	*476.4*	*107.6*	*22.59*
West Bengal	-	-	*51*	-	*157.5*	*49.0*	*31.11*
Daman and Diu	-	-	-	-	*9.5*	-	*Not Eroded*
Pondicherry	*43*	*11*	*36*	*10*	*30.6*	*6.4*	*20.92*
Total mainland	-	-	-	-	*5422.6*	*1247.9*	*23.01*
Lakshadweep	-	-	-	-	*132.0*	*132.0*	*100.00*
Andaman and Nicobar	-	-	-	-	*1962.0*	-	*Not Eroded*
Total	**-**	**-**	**-**	**-**	***7516.6***	***1379.0***	***18.35***

Table.1.1 presents the total length of the shoreline, types of coastal geomorphological setup (percentage wise; rocky, sandy, muddy and marshy beaches) and finally the eroded shoreline in km for each coastal state. According to Sanil et al. 2006, the coastlines which belong to states like Karnataka and Kerala along the southwest coast of India are affected by tremendous and severe erosion with percentage 89.14 and 84.25 respectively. Remaining coastal areas along the Indian sub continent are not much affected by coastal erosion.

The drastic variations in the river flows appear to be major source for sediment deposition in coastal area (accretion) and offshore regions (erosion) on the Indian coast. There are about 14 major rivers, 44 medium rivers and more than 200 minor rivers along the Indian coast, which are the predominant sources for sediment transport. The annual discharge of sediments through these rivers into the sea is about 1.2 x 10^{12} kg, which accounts roughly 10% of the total global sediment flux to the world ocean. The average annual runoff from the major, medium and minor rivers of India is 1406 x10^9 m^3, 112 x10^9 m^3 and 127 x10^9 m^3 (Chandramohan et al. 1991) respectively. Next to rivers, the headlands and beach erosion also contribute significantly along the Indian coastline. In addition to this, direct runoff and rainfall contributes on the loss of sediments as rain-wash from sub aerial portion of the beach. Another minor loss is due to the mining of beaches for sand and placer deposits (Prakash et al. 2007).

1.4 Coastal Erosion in Karnataka

The coastline of Karnataka is formed at the middle part of the southwest coast of India. Karnataka’s coast stretches for about 280 km long, covers three districts, Dakshina Kannada, Udupi and Uttara Kannada. Out of these, Uttara Kannada has 160 km long coastline while 78 km is in Udupi district and the rest 42 km in Dakshina Kannada. Dakshina Kannada has three distinct agro-climatic zones ranging from coastal flatlands in the west with undulating hills and valleys in the middle and high hill ranges in the East that separates it from the peninsula. There is a narrow strip of coastal plains with varying width between the Western Ghats and the Arabian Sea, the average width being about 20 km. The average height of the hinterland is 70 – 75 m, but at some places it is as high as 150 m.

The coastline of Karnataka is characterised by 75% of long open sandy beaches, 11% rocky coast and 14% muddy flats (Sanil et al. 2006). This coastline is well known for sand bars, spits, bays and river mouths. Fourteen rivers drain their waters into the shore waters of Karnataka. The important estuaries include Netravathi-Gurpur, Mulky-Pavanje, Hangarkatta, Sharavathi, Aghanashini, Gangavali and Kalinadi. Sand bars have developed in most of the estuaries. There are a number of barrier spits at Tannirbavi, Sasihithlu, Hejamadi, Udyavar, Hoode, Hangarkatta and Kirimanjeshwara formed due to migration of coastal rivers. There are about 90 beaches with varying aesthetic potential that are suitable for beach tourism. These rivers in this region are identified as major sources of sediments along the Karnataka coast, among which the rivers Mulky and Pavanje also contribute some part of sediments into the Arebian Sea (Gangadhar Bhat 1995).

Shoreline of Karnataka is 280 km long mainly consists of open beaches, estuaries, headlands, rocky shores, sandy spits and offshore islands. Coastal erosion and submergence of land have been commonly reported along the Karnataka coast (Sanil et al. 2006). Erosion along the beaches near the rivermouth is being most common problem noticed along the Karnataka coast (Dattatri et al. 1997). The problem of erosion is relatively more severe, particularly in Dakshina Kannada and Udupi region, where about 28% of the total stretch is critical. Further, in Uttara Kannada region about 8% of total shoreline stretch is subjected to severe erosion. Most of the erosion associated with Karnataka coastline is seasonal in nature that is beaches get eroded during monsoon seasons and regain their original profiles during fair weather seasons. Only in few pockets, erosion of permanent nature has been observed by several researchers (Dattatri et al. 1997; Jayappa et al. 2003; Dwarakish et al.2009).

Rivermouth associated beaches are highly dynamic, active environments, which can respond rapidly due to change in climate, sea level, tectonic and anthropogenic drivers (Ana vila et al. 2010). This is particularly true of those on the Karnataka coast, where a mixed energy coastal environment, seasonal change in weather patterns and high sediment load from nearby coastal structures and rivermouths contribute to continual, and often rapid changes in these systems (Dwarakish et al. 1997; Dwarakish et al. 1998; Gangadhar and Subrahmanya 2000). In view of this, it is necessary to investigate the coastal environment, through that coastal regions can be managed effectively.

Coastal regions that incorporate with estuaries are some of the most densely populated zone of the world's coastlines, since these regions are ecologically productive and socioeconomically valuable. But, these regions are highly complex and dynamic environment undergo diverse spatial changes in a relatively short span of time (Graham and Ricardo 2003; Jonathan et al. 2009; Ana Vila et al 2010; Patrick and Jonathan 2010). Short term fluctuations of these regions are mainly due to seasonal episodes whereas long term variations by sea level rise, tectonic processes, variation in fluvial discharge, waves, tides etc. In addition to these factors, anthropogenic activities also influence the estuarine processes, which increase with time and development of civilization (Frihy et al. 1998; Michal et al. 2010).

Rivermouths are special environments located in the transition zone between the land and Sea. Therefore, they are affected by several processes which occur in both terrestrial and marine environments. These rivermouths are also well known as points of pollution intrusion into the sea and saltwater invasion into the coastal plains and their aquifers. Their dynamic morphology directly impact on coastal communities, coastal structures and coastal ecosystems (Michal et al. 2010; Bu-Li and Xio-Yan Li 2011). The beaches adjacent to rivermouth are also much more complex owing to site specific control of wind and wave processes (Prithviraj et al. 1995). Thus the study of rivermouth and adjacent beach morphology is found to be critical in response to the management of the coastal resources, engineering projects and zoning of nature reserves (Graham and Ricardo 2003; George et al. 2010).

Infact there are number of rivermouths along Karnataka coast that are being developed into fishery and general harbours where sedimentation in the navigational channel is a major problem (Dattatri and Kamath 1997; Hegde et al. 2004). Dakshina Kannada is being a center of developmental activities due to its rich ocean resources and favourable conditions for the development of port based major industries like refineries, fertilizer industries, leather industries, thermal power plants, coastal irrigation, development of marine structures, etc. As a result of these anthropogenic activities natural processes are being disturbed, leading to a significant modification in the coastal configuration, particularly around the rivermouths (Dwarakish et al.1997; Hegde and Raveendra 2000; Hegde et al. 2009; Avinash et al. 2010). In addition to this, the major problems associated with rivermouths are sedimentation in the rivermouth, narrowing of rivermouths, shoreline erosion and rapid changes of the rivermouth configurations. The morphological features like tidal bar, spit formation, lagoons etc., are the main responsible factors, which lead sedimentation in the rivermouth (Bhat and Subrahmanya 2000; Raghavan et al. 2001; Santosh and Reddy 2002).

1.5 Geomorphology of Dakshina Kannada

1.5.1 Physiography

The beaches of the Dakshina Kannada coast are low open sandy beaches which are 25 to 100 m in width. The material of the beach is mainly detrital sand and the mean size of it varies from place to place. The beach material is well sorted sand. The particles are found to be within sub rounded and angular range of roundness. The shell fragments are angular and calcareous. The beaches are interrupted by natural features, river mouths and manmade features such as breakwaters at Mangalore and Panambur. Beaches are also bordered by casuarina, coconut and beach plantations which have been grown on dunes, raised berms and barrier spits.

1.5.2 Coastal Dynamics

Strong winds are observed from Southwest and West direction during monsoon period. Rest of the year, winds are mainly from North and East in the forenoons and Westerly or North-westerly in the afternoons. The coast is subjected to very strong sea breeze during the non-monsoon months. The sea breeze in the afternoons predominates over the land breezes in the early mornings. The average wind velocity during non-monsoon season varies from 0 to 18 Kmph and 8 to 26 Kmph during monsoon season (KREC Study Team 1994).

Severe waves are experienced only in the monsoon months with wave period ranging from 9 to 10 seconds. During the non-monsoon months, the maximum wave heights are less than 1 m with wide variation in wave period including the presence of long period swell waves. Predominant wave directions during the monsoon months are Southwest, West and Northwest. These deep water wave directions when approaches the coast, due to wave refraction their crest become parallel to the shoreline and hence there will be onshore and offshore sediment transport along the coast.

1.5.3 Sea Bed and Coastal Sediments

The sediment distribution in the sea bed is generally a reflection of the bathymetry of the area and the related energy domain on the sea bed. Sea bed adjoining to Dakshina Kannada coast contains medium to coarse sand with minor amounts of silt and clay upto the -5 m contour. These are the areas where waves break, the clay and silt fractions are brought into suspension to be moved offshore. Beyond the -5m contour, sea bed is composed of silt and clay. The outer shelf region comprises of fine to medium sand with clay and neritic shell fragments. Nearer to the river mouths, a widening of the sand zone along the flow direction of the rivers is invariably observed.

1.5.4 Geology

Geologically Dakshina Kannada coast is of recent origin. The major rock type is the granite gneiss which is popularly known as peninsular gneiss. Laterities are abundant in the coastal regions. The exposed laterites develop a hard crust and are devoid of vegetation as they do not retain any moisture. The area between the shoreline and Western Ghats can be broadly divided into three regions, namely the low land, the mid land and the high land.

1.6 Study Area

Dakshina Kannada is one of the coastal cities of Karnataka and densely populated zone of India, gaining economic importance due to urbanization and industrialization. It has an average elevation of 45 m with reference to Mean Sea level (MSL) and is bordering by Arabian Sea in the West and Western Ghats in the East. A broad and highly dissected seaboard terrain of Dakshina Kannada coastal zone separates the Western Ghats from more or less straight shoreline. It is characterized by long, narrow and straight open sandy beaches, spectacular spits, estuaries, barrier beaches and few scraps of Mangroves. The important rivers draining in Dakshina Kannada from South to North are Nethravthi, Gurupur, Mulky and Pavanje. These rivers originating in the Western Ghats flow westward turn almost 90^0 near the coast and then flow either southward or northward, parallel and close to the coast before joining the Arabian sea.

The rivers Mulky and Pavanje originate below the Western Ghats and are having length less than 40 km and debouch into Arebian Sea near Hejamadi Kodi. During the monsoon, these rivers flow full and discharge any kind of the sediments into the sea, whereas during the other periods seawater enters into the rivers over considerable distances and modifies sediment deposition. This variation in sediment pattern into the beach environment results a complex adjustment of sediments between the sea and the foreshore particularly in the vicinity of rivermouth (Lalu raju et al. 2008; Nayak et al. 2010). Because of this, the morphological changes of the beaches in the vicinity of rivermouth are highly complex and are more vulnerable to erosion (Kunte and Wagle 1991; KREC Study Team 1994; Dattatri et al.1997).

The study area Mulky-Pavanje rivermouth is located about 30 km north off Mangalore (Headquarter of Dakshina Kannada) and lies between $13^0$00'00"-$13^0$06'00" North latitude and $74^0$44'00"- $74^0$50'00" East longitude (Fig.1.1). The rivermouth is mainly formed by two minor rivers Mulky and Pavanje, which originate below the Western Ghats, flow westwards and then flow parallel to the coast over a distance of about 1850 m and 5400 m respectively before joining into Arabian Sea.

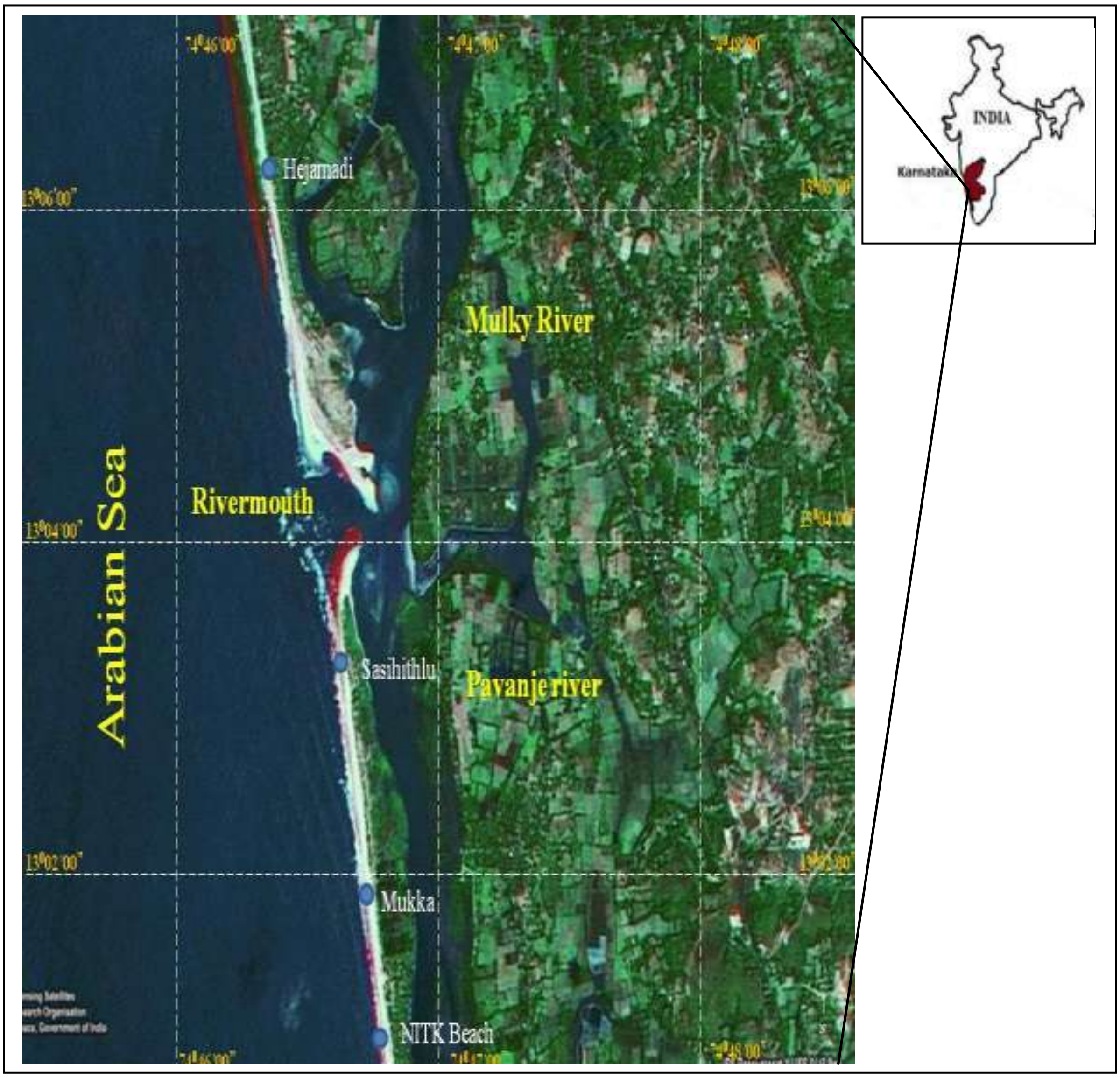


Figure 1.1 Geographical Location map of the study area, consists of Mulky-Pavanje rivermouth formed by two rivers Mulky (North) and Pavanje (South) and adjacent beaches on either side.

The annual discharge from Mulky and Pavanje rivers is 1253 Mm^3 and 619 Mm^3 respectively. The average estuarine width between these two rivers is approximately 200 m, located between the two prominent spits Sasihithlu in the south and Hejamadi in the north. The rivermouth has been unstabilized due to strong longshore sediment transport, high monsoonal river flood and sediment migrated from the shelf region.

The sediment discharge and river discharge are varying from season to season. During monsoon season (June to September), these rivers overflow and discharge sizeable quantities of sediments into the sea, whereas during non-monsoon season, seawater enters into the estuary over considerable distances and modifies the shoreline and sediment distribution subsequently. Because of high river discharge during monsoon riverine currents dominate, whereas tidal currents dominate during the non-monsoon period (October to May). However tidal currents are dominant over the year, particularly near the vicinity of rivermouth (Nayak et al. 2010).

The study area is further extended on either side of the Mulky-Pavanje rivermouth. It is total about 12 km in length; 7 km on southern side and 5 km on northern side from the rivermouth. Two submerged active spits (Sasihithlu at south and Hejamadi at north) attached to mainland developing infront of the confluence of rivermouth. In addition to this, a submerged sand bar is also being formed especially during pre-monsoon period (February to May), particularly in February, at the confluence of rivermouth.

1.6.1 Parameters instrumental in the selection of Study area

The Mulky-Pavanje rivermouth and its associated shoreline is selected as study due to the following reason;

1. Mulky-Pavanje rivermouth is free from coastal structures and hence natural phenomenon such as coastal dynamics can be studied in detail and more rivermouth changes can be expected.
2. The beaches on either side of the rivermouth are unique in a way that they have several physiographic zones for comparison.
3. The beaches on either side of the rivermouth are less disturbed by human activities compared to other beaches of Dakshina Kannda coast.
4. The beaches on either side of the rivermouth are exposed to high wave energy and hence morphological changes are dynamic in nature. Changes within the beaches are therefore dynamic and variable, making it possible to carry out short-term investigation also.

5. The study area is easily accessible from NITK Surathkal and hence helped in conducting regular field visits.

1.6.2 Oceanographic Conditions

Waves: The predominant direction of offshore waves in the vicinity of study area, during monsoon months is west and southwest while in the fair weather months it is northwest. The wave heights are more than 5 m during monsoon months and less than 0.5 m in non-monsoon months. Based on wave climate of the region the months between June and September are normally referred as monsoon period. The transition periods prior to the monsoon and after the monsoon are considered as pre-monsoon (February to May) and post-monsoon (October to January) respectively.

Wave period: During the monsoon months wave period is much less of 5 to 6 sec, whereas in fair weather period the average wave period is increased up to 10-12 seconds.

Tides: The type of tide that occurs in the study area is “Mixed Type” of predominantly semi-diurnal. Mixed tides are characterized by unequal high waters and low waters. The high water will not be of same magnitude at all the time hence called as higher high water and lower high water. Similarly the low waters are also called as higher low water and lower low water. However the mean tidal range at the study area is 0.6m.

Currents: The currents along the coast during the monsoon season are towards south. During the post-monsoon and pre-monsoon periods, the currents in general towards north. The magnitude of the currents during the monsoon season is about 1 to 1.5 knots.

Bathymetry: The sea bed in the study area has a very gentle slope in the order 1 in 500.

1.6.3 Meteorological Conditions

Winds: The winds in the study area during monsoon periods are predominantly North, South-west and West with a maximum intensity force 5 on Beaufort scale. The winds during the rest of the year are predominantly from northwest and the minimum intensity during this period is also 5 on Beaufort scale.

Rainfall: The climate is characterized by dry and wet seasons. The wet season starts in late May and ends in November. The major monsoon season lasts from June to September. The average annual rainfall is about 3954 mm, with more than 87% of it during the monsoon season (KREC Study Team 1994).

Temperature: The study area experiences moderate temperature throughout the year. The temperature varies from 22^0 C to 36^0 C. The maximum temperature recorded so far is 36^0C. Climate is isotropic with high humidity.

Due to this typical nature of the study area, a detailed investigation is necessary. In this direction, the current study is oriented towards monitoring the changes associated with rivermouth and adjacent shoreline using variety of techniques at different temporal scales. The temporal scales involved are long-term (>60 years), medium-term (10-60 years) and short-term (<10 years) (Brian and David 1996; Reeve and Spivack 2004; Anfuso et al. 2007). The techniques to monitor the changes consists of beach profile surveys, sediment sampling and analysis, rainfall and river discharge data procurement and analysis, wave and wind data procurement and analysis and finally topographical maps and remotely sensed images from different data sources and their analysis.

1.7 Land use/ Land cover changes around the rivermouth

Remotely sensed data from satellites is a reliable source for land use/land cover change detection analysis. Availability of satellite data at less cost and increasing computational power has made the application more practical for studying larger areas. Also, availability of remotely sensed data with high temporal and spatial resolution has allowed the researchers to study the dynamic changes.

Rivermouth regions are the connecting link between terrestrial and marine ecosystems, and provide a critical coastal habitat that is essential ecologically and economically to the world economy. The present study area, Mulky-Pavanje rivermouth and associated coastal region, covers approximately 36 km^2. Population in this area has been increased drastically in the last 30 years, primarily due to the growth of the cities, Sasihithlu and Hejamadi. These two cities are currently experiencing rapid urbanization and industrialization as a result of increasing population. Because of these reasons there is increasing trend to identify land use/ land cover changes around the rivermouth. In this context, the current study attempts land use/ land cover changes with the help of remotely sensed images and toposheets.

1.8 Modelling of Coastal Processes

There is need to assess the risks in coastal engineering with robust methodologies to implement proper coastal management plans. A large proportion of coastal areas depend upon the characteristics of the shoreline to protect from flooding and erosion. The move towards adopting “soft engineering” solution has changed the emphasis from prevention of flooding and erosion towards management of flood and erosion risks. As a result it is important to understand how the beaches and shorelines respond to the prevailing tide and wave regime.

From the perspective of coastal engineer, it is important to predict the coastal behaviour with some level of confidence. There are several numerical models available, but they suffer from number of drawbacks. The drawbacks include, they are difficult to operate; they require large amount of computing time to predict medium or long-term changes; they suffer instability and being relatively good for predicting coastal evolution over the period of storms; they have difficulties in predicting coastal evolution with some level of accuracy (Jose and Dominic 2010). An alternative to numerical modelling is data driven modelling, a term given statistically based analysis of patterns in observed measurements. Forecasts are made on the basis of extrapolating past patterns of behaviour into future. This approach has had some success for medium and long-term prediction, and thus provides some complementary to numerical modelling (Anurag and Deo 2003; Tsong-Lin Lee et al. 2004).

Compared to other forms of prediction, there are both advantages and disadvantages with data driven modelling. The disadvantages include, the need for long duration time series of observations and assumption that past behaviour is good indicator of future evolution. The advantages are due to improved accuracy, less complexity, smaller computational efforts and in some cases reduced data requirements.

The effects of waves in activities related to the ocean environment such as the building and maintenance of coastal and offshore structures, maritime transportation, environmental protection etc., caused the research on waves from different perspectives to extract the wave characteristics. Different methods such as empirical, numerical and soft computing approaches have been proposed for wave height prediction (Goda 2003, CEM 2003, and CEM 2006). Many forecasting schemes have been proposed for forecasting coastal processes so far. Especially, soft computing techniques such as artificial neural networks (ANN), genetic algorithms (GA), and fuzzy logic (FL) have been used for this purpose. ANN is the most used method among the soft computing methods. In this direction current study also attempted forecasting of wave heights with larger lead period with the application of ANN.

Littoral drift indicates movement of sediments parallel to a coastline caused by the breaking action of waves. Ocean waves attacking the shoreline at an angle produce a current parallel to the coast. Such longshore current is responsible for the longshore movement of the sediment (Komar, 1976). Littoral drift poses severe problems in coastal and harbour operations since it results in siltation of deeper navigation channels due to which larger ships cannot enter or leave the harbour area. An accurate estimation of the drift is needed in order to know the amount of excavation required so that corresponding budgetary provisions could be made in advance. Unfortunately this is very complex phenomenon, because the underlying physical process is too complex to model in the form of mathematical equations (Singh et al. 2008). Despite of this, workable empirical formulae that relate the drift to a set of causative variables are currently in use. They are based on collection of measurements made in the field or on a hydraulic model followed by a curve fitting exercise (Komar and Inman 1970; CERC 1984; Kamphius 1991). Thus, it is well known by now that the soft computing tools like ANN is better alternative to the numerical and empirical models (ASCE Task Committee, 2000) and hence a variety of investigators have applied the technique of ANN to solve problems in coastal engineering. Therefore the current study is oriented along this direction to determine and predict the littoral drift with application of the ANN.

1.9 Objectives of the study

By considering the actual problems in the study area and with the available data, the following objectives were framed for the present work.

1. To understand coastal geomorphological behaviour on either side of the Mulky-Pavanje rivermouth on short-term temporal scale.
2. To study the medium-term and long-term shoreline changes associated with Mulky-Pavanje rivermouth.
3. To quantify the variations in land use/ land cover change pattern around the Mulky-Pavanje rivermouth.
4. Development of ANN models, which predict wave heights for larger lead period and littoral drift using influencing parameters.

1.10 Organisation of the thesis

The present thesis is divided into five chapters.

Chapter 1 : Provides a brief introduction about coastal zones, the coastal erosion along Indian coast and Karnataka coast, followed by the objectives of the present study and finally, objectives of the current study.

Chapter 2: Reviews the literature pertaining to variety of techniques used to monitor the shoreline changes and modelling of coastal processes through ANN.

Chapter 3: Discuss the available data products and their utilization to monitor the shoreline changes and modelling of coastal processes.

Chapter 4: Discusses the results obtained from various data analyses.

Chapter 5: Provides conclusions of the present study and suggestions for the future study.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Coastal zones encompassing the coastal planes and continental shelves, are the regions which exhibit close interaction between the hydrosphere, lithosphere and atmosphere. They are highly dynamic and diverse ecosystems that are characterised by strong environmental and geological gradients. It consists of nearshore zone, bays, inlets, creeks, tidal deltas, lagoons, coastal lakes, estuaries, coral reefs, shoals, tidal flats, mudflats, beaches, sand ridges, coastal dunes, mangroves, marshes, salt-affected land, rocks, cliffs, reclaimed lands, deltaic plains and other similar features. The developments attained through overexploitation of the resource of the coastal zone at the cost of the environmental quality would abruptly destabilize the delicate balance between the biological, geological and meteorological component of the coastal system. These resources have been plundered at an alarming rate, contributing to the loss of functional integrity and reducing the capacity to retain material such as water, sediments and organic matter. On the other hand industrial developments, climatic modifications, sea level changes and changes in land use pattern affect the coastal zone globally and further, the direct use of coastal resources has local or regional impact.

The coastal region has been the center of anthropogenic activity right from the prehistoric periods. The river valley civilisations of Egypt, Persia, India and China originated in the coast where the great rivers, the Nile, the Euphrates, the Tigris, the Indus and the Huango Ho met the oceans and flourished along the banks of these rivers. Human activity in the coastal region (e.g., agricultural production including fisheries, commercial activities including construction of buildings, ports and hotels, industrial activities including chemical processing industries, mineral exploitation and cultural activities) intervenes the natural processes active in this coastal system. The buffering capacity of the coastal system absorbs the impact of human activity and maintains the system in a state of dynamic equilibrium. However, intense human activity may bring about appreciable imbalances in the system resulting in loss of this equilibrium. Many a times, these changes bring about catastrophic effects on the current users of the system.

2.2 Glossary of the Coastal Zone

According to Costal Engineering Manual (CEM 2002; CEM 2006), coastal zone is "the transition zone where the land meets water and the region that is directly influenced by marine and coastal hydrodynamic processes. It extends from offshore to continental shelf and from onshore to the first major change in topography above the reach of major storm waves". The definition of a few terms in the coastal zone is provided in the following section and is shown in Figure 2.1.

Backshore: The zone of the shore or beach lying between the foreshore and the coastline and acted upon by waves only during severe storms, especially when combined with exceptionally high water.

Bar: A submerged or emerged embankment of sand, gravel or other unconsolidated material built on the seafloor in shallow water by means of waves and currents.

Beach: The zone of unconsolidated material extending landward from the mean low water line to the place where there is a change in material or physiographic form as examples, the zone of permanent vegetation or a zone of dunes or a sea cliff.

Berm crest: The seaward limit of berm.

Berm: A nearly horizontal part of the beach or backshore formed by the deposition of material by wave action.

Foreshore: The part of the shore lying between the crest of the seaward berm and the low water mark line. The low water line is traversed by the uprush and backrush of the waves as the tides rise and fall.

Nearshore: The region seaward of the shore (from approximately the step at the base of the surf zone) extending offshore to the toe of the shoreface. Nearshore is a general term used loosely by different authors to mean various areas of the coastal zone, ranging from the shoreline to the edge of the continental shelf.

Surf zone: The area between the outermost breaker and the limit of wave uprush.

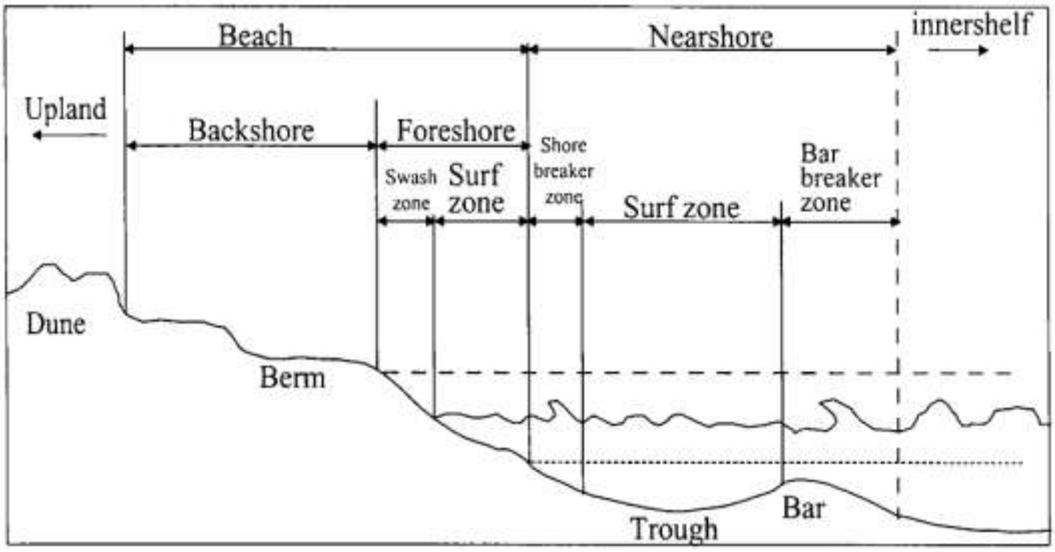


Figure. 2.1 A schematic diagram showing the different zones of the coast

Coastal areas driven by external forces, such as coastal currents, tides and tidal currents, surface waves, storm surges, tsunamis and others. Wind waves, storm surges and tsunamis bring powerful hydrodynamical forces to the shallow area of a coast. Once generated by atmospheric disturbances and submarine earthquakes, storm surges and tsunamis can release destructive effects on a coast. However, because of their infrequent occurrences, they are less important than wind waves from viewpoint of the coastal sedimentary processes. A description of a few of the important reasons for coastal erosion is given in the following sections.

2.3 Causes of Coastal Erosion

When dealing with coastal erosion problems on a regional/national scale, a profound knowledge of the geomorphological processes and causes of erosion is fundamental to a sound choice for a policy option and any related measures.

In relation to the type of erosion two components can be distinguished: structural and acute erosion. In some areas structural and acute erosion cause problems, while in other areas clearly one type of erosion is of main importance.

In case of structural erosion (i.e erosion due to dams, seawalls and breakwaters and so on), it is of importance to understand the relationship between the total availability of sediment and the forcing of the erosion (sea level, waves, tides). Sediments are delivered to the coast by the rivers due to erosion of the hinterland. Undercutting and collapse of soft coastal cliffs is another natural source of sediment for the coastal area. Coastal erosion may originate due to a reduction in the availability of sediment, instead of a change in forcing. Moreover, episodic events to the delivery of sediments (particularly at estuaries) can be of importance.

In relation to the main causes of erosion, a distinction can be made between natural and human causes. Examples of natural causes are relative sea level rise and storms and human causes are river damming, hard defences and urbanisation.

When considering causes of erosion, the dominant time and spatial scale of the underlying processes have to be taken into account. It is meaningless to discuss coastal erosion without pointing out the scale considered. When dealing the erosion problems, the coastal system to be considered is mostly larger than the area in which erosion takes place. Therefore, a coastal system should be considered with coherent and large enough time and spatial scale. The coastal erosion due to natural factors and human induced activities are shown in Figure. 2.2 and Figure. 2.3.

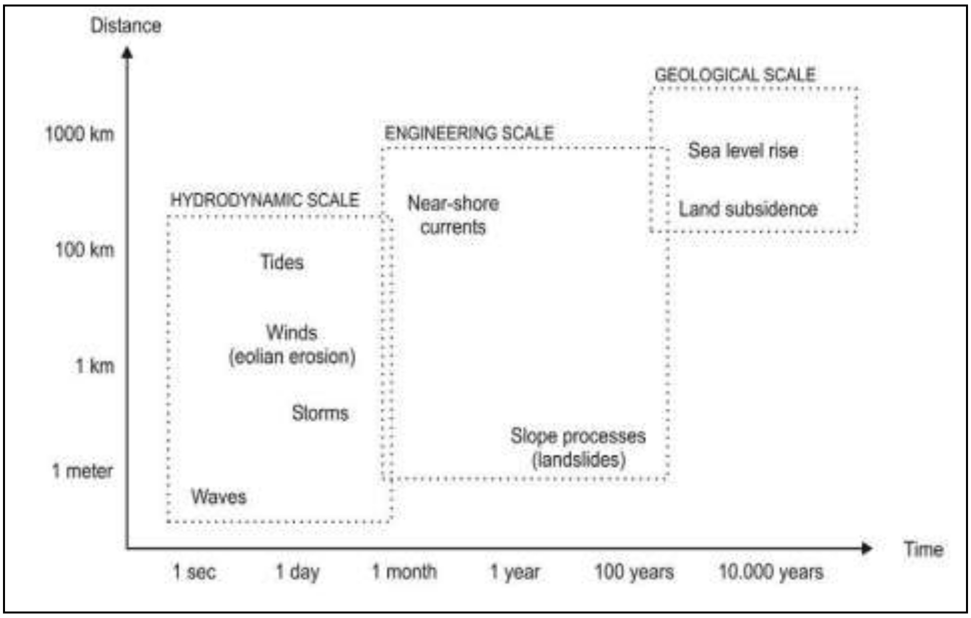


Figure 2.2. Time and space pattern of natural factors of coastal erosion

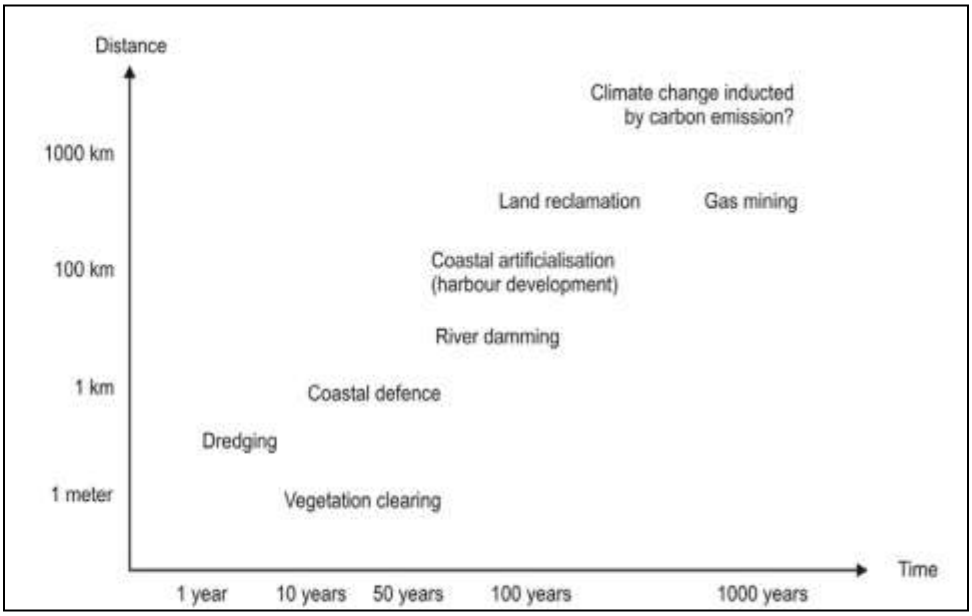


Figure 2.3 Time and space patterns of human induced factors of coastal erosion

With a few exceptions, coastal erosion can never be attributed to one single cause, may be it natural or human driven, but to a combination of various factors which all together create the conditions for erosion to take place. These factors operate on different time and spatial scales, which results in certain factors to stay "hidden" from coastal engineers for decades before there are finally evoked and their impact quantified. Some of the major factors responsible for coastal erosion are as follows.

2.3.1 Waves

Waves are generated by offshore and nearshore winds, which blow over the sea surface and transfer their energy to the water surface. As they move towards the shore, waves break and the turbulent energy released stirs up and moves the sediments deposited on the seabed. The wave energy is a function of the wave heights and the wave periods. As such the breaking wave is the mechanical cause of coastal erosion particularly along the open straight coasts.

2.3.2 Winds

Winds act not just as a generator of waves but also as a factor for sand transport, called Aeolian transport. Aeolian transport is an important process for soil erosion, dune formation and alteration, and re-deposition of soil particles. Dune formations established with dune vegetation is an important defence system for low lying sandy coasts like Karnataka, Kerala and Goa.

2.3.3 Tides

Tides result in water elevation to the attraction of water masses by the moon and the sun. During high tides, the energy of the breaking waves is released higher on the foreshore or the cliff base (cliff undercutting). Macro-tidal coasts (i.e. coasts along which the tidal range exceeds 4 m), all along the Atlantic sea are more sensitive to tide induced water elevation than meso- or micro-tidal coasts (i.e. tidal range below 1 m can be seen in India).

2.3.4 Nearshore currents

Sediments scoured from the seabed are transported away from their original location by means of currents. In turn the transport of (coarse) sediments defines the boundary of coastal sediment cells, i.e. relatively self-contained system within which (coarse) sediments stay. Currents are generated by the action of tides (ebb and flood currents), waves breaking at an oblique angle with the shore (longshore currents), and the backwash of waves on the foreshore (rip currents). All these currents contribute to coastal erosion processes in India and elsewhere.

2.3.5 Storms

Storms result from raised water levels (known as storm surge) and highly energetic waves induced by extreme winds. Combined with high tides, storms may result in catastrophic damages. Beside damages to coastal infrastructure, storms cause beaches and dunes to retreat of tenths of meters in a few hours, or may considerably undermine cliff stability. In the past 30 years, a significant number of cases have been reported, extreme historical storm events that severely damaged the coast. Most of the sediment transport in the form of crossshore or alongshore occurs along the Indian coast during storms.

2.3.6 Sea level rise

The profile of sedimentary coasts can be modelled as a parabolic function of the sediment size, the sea level, the wave heights and periods, and the tidal range. When the sea level rises, the whole parabola has to rise with it, which means that extra sand is needed to build up the profile. The rise in the sea level has been reported as a significant factor of coastal erosion in all coastal regions.

2.4 Impacts of Coastal Erosion

Natural factors and human induced activities cause erosion in any coastal region. But the human activities impact significantly the coastal erosion processes in a variety of ways. In both cases (natural and anthropogenic), changes take place whenever one or more of the above mentioned natural causes of coastal erosion are modified. From a generic point of view, a coastal management project is deemed to impact coastal erosion processes whenever it results in:

Impact 1: modification of nearshore bathymetry and wave propagation patterns, Impact 2: disruption of longshore drift,

Impact 3: removal of sediment from the sediment system,

Impact 4: reduction in river derived sediments,

Impact 5: modification of soil weathering properties and

Impact 6: land subsidence.

2.5 Monitoring Techniques for Shoreline Changes

The shoreline is a dynamic junction between ocean and land undergoes continuous geomorphologic changes in response to natural forces and human activities. Natural processes such as continental drift, tides, waves, currents etc., are always at work, but they hardly induce major morphological changes in a relatively short span of time. On the other hand, the anthropogenic activities cause immense geomorphologic changes at a rapid rate. For highly dynamic areas such as beaches, coastal inlets, lagoons, spits and rivermouths, it is necessary to gather timely information on the dynamics of coastal geomorphology for the purpose of erosion control measures, planning of the ports, navigational facilities etc.

Shoreline changes are highly dynamic, controlled by several natural processes and human induced activities. The monitoring program of shoreline is one of the important tasks in the domain of coastal engineering. The detailed shoreline change monitoring will definitely provide very useful information to construct and develop coastal zones in a sustainable manner. In recent years the monitoring campaigns relies on information about historic shoreline location and movement to current status of existing shoreline. Therefore, there is always increasing recognition to quantify and to understand geomorphic behaviour either at smaller or larger spatial and temporal scale.

Shoreline change is a result of natural causes and as well as human induced activities. Natural causes alter spatial fluctuations in the position of the shoreline, with periodicities are irregular to quasi-sinusoidal in form. The natural factors cause the shoreline to fluctuate at decadal time and associated space scales, which are more relevant in the current research. Table. 2.1 presents a variety of periodicities associated with length and temporal scales in the observations due to natural processes. On the other hand human induced factors cause shoreline to change its position substantially and trends are at larger scale and smaller scale fluctuations (Table. 2.2). Thus the mobility rate of shoreline is highly significant from the human activities rather than the natural processes. However the dominance of natural causes or anthropogenic activities vary from coastal section to coastal section.

Over the last 15 years or so the shoreline management has become one of the well established research areas. Several techniques have been used to monitor the existing shoreline at wide variety of spatial and temporal scales in order to understand coastal morphological behaviour. This monitoring in general involves field based studies and remotely observed images and their subsequent analysis. Field based surveys (particularly at significantly eroding areas) at large scale landscapes are inherently problematic and often prohibitively expensive. For this reason much of the world's coastline morphology has not been properly quantified in detail, particularly in developing countries. However, the use of remote sensing techniques allows identifying the current position of coastlines and to some extent historic origin of shoreline with relatively low cost. Further, repeated observations at the same shoreline over a time allows detailed quantification of shoreline change. In the meantime, coastal morphology can be quantified by coupling remotely sensed data with information on historic coastline position from archived sources.

In this chapter, literature pertaining to different types of techniques used to monitor the shoreline change in India and elsewhere are selected and reviewed. Details of selected papers, including name of the authors, year of publication, study area, purpose, methods used and study period are presented in Table. 2.3.

Table. 2.1 Natural causes/factors, and associated evolutions for shore and shoreline variability (Marcel et al. 2002)

Scale	Time Scale	Space Scale	Natural causes/factors	Typical evolutions
Very Long term	Centuries to Millennia	100 km and more	• Relative Sea level changes. • Differential sea bottom changes. • Geological settings. • Longterm climate changes.	• (quasi) liner trends • Trend changes (reversal, asymptotic, damping) • Fluctuations (from cyclic to non cyclic)
Long term	Decades to centuries	10-100 km	• Relative Sea level changes. • Regional Climate variations. • Coastal inlet cycles. • Storm waves. • Extreme events.	• (quasi) liner trends • Fluctuations (from cyclic to non cyclic) • Trend changes (reversal, asymptotic, damping)
Middle term	Years to decades	1-10 km	• Wave climate variations. • Surf zone bar cycles. • Extreme events.	• Fluctuations (from cyclic to non cyclic) (quasi) liner trends • Trend changes (reversal, asymptotic, damping)
Short term	Hours to years	1-5 km	• Wave, tide and surge conditions • Seasonal climate variations	• Fluctuations (from cyclic to non cyclic) • (quasi) liner trends

Table. 2.2 Human induced causes/factors and associated evolutions for shoreline variability (Marcel et al. 2002)

Scale	Time Scale	Space Scale	Human causes/factors	Typical evolutions
Very Long term	Centuries to Millennia	100 km and more	• Human induced climate changes • Major river regulation. • Major coastal structures. • Major reclamation and closures. • Structural coastal management.	• (quasi) liner trends • Trend changes (reversal, asymptotic, damping) • Fluctuations (from cyclic to non cyclic)
Long term	Decades to centuries	10-100 km	• River regulation. • Coastal structures. • Reclamation and closures. • Coastal management. • Natural resources extraction.	• Trend changes (reversal, asymptotic, damping) • (quasi) liner trends • Fluctuations (from cyclic to non cyclic)
Middle term	Years to decades	1-10 km	• Surf zone Structures. • Shore nourishments.	• Trend changes (reversal, asymptotic, damping) • Fluctuations (from cyclic to non cyclic)
Short term	Hours to years	1-5 km	• Surf zone Structures • Shore nourishments	• Trend changes (reversal, asymptotic, damping) • Fluctuations (from cyclic to non cyclic)

Table. 2.3 Details of selected papers, including name of author(s), year of publication, study area, purpose, methods used and study period

Sl. No	Author and year	Purpose	Study area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
1	Veerayya et al. (1985)	Morphology and grain-size characteristics.	Nagway bay, India.	Examined	Examined	Wave data	Not examined	Not mentioned
2	Malik et al. (1987)	Erosion and accretion sectors.	Puvar to Manjeshwar, India.	Examined	Not examined	-	Not examined	May and September, 1984
3	Mislankar and Antao (1992)	Textural Characteristics.	Sadashivgad and Karawar, India.	Not examined	Examined	-	Not examined	Not mentioned
4	Veerayya and Muralinath (1994)	Sediment movement.	Bombay, India/280km.	Not examined	Examined	Bathymetric profiles and sonographs	Not examined	1977-1978
5	Andrew (1994)	Historical changes in rivermouth morphology.	Mvoti estuary, South Africa.	Examined	Examined	Historical records	Aerial photographs	1847-1991

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
6	Gangadhara Bhat (1995)	Long-term shoreline changes.	Mulky-Pavanje and Nethravthi-Gurupur estuaries, India/40km.	Not examined	Not examined	-	SOI Topographical maps and IRS images	1910-1993
7	Jorge and Albert (1996)	Short and medium-term grain-size changes.	Ebro Delta, NW Mediterranean.	Not examined	Examined	Fresh water discharge and wave data.	Not examined	1970-1991
8	Sajeev et al. (1996)	Beach sediment distribution and morphology.	Kerala, India/540km.	Examined	Examined	-	Not examined	March 1990-March 1991
9	Rajmanickum and Gujar (1997)	Sedimentolgical investigation.	Ambwah, Varvada Bays, Maharashtra.	Not examined	Examined	-	Not examined	Not mentioned
10	Robert Larson et al. (1997)	Sediment distribution.	Ocean city, Maryland.	Not examined	Examined	-	Not examined	Not mentioned

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
11	Jose et al. (1997)	Short- term shoreline changes.	Ebro Delta, Spain/45km.	Examined	Not examined	Water level, wave and wind, atmospheric pressure	Aerial photographs	1989-1991
12	Mohd - Lokman et al. (1998)	Sedimentological investigation.	Terengganu, south China.	Not examined	Examined	Wave characteristics	Not examined	1996
13	Sushma Prasad et al. (1998)	Geomorphology and edimentation in basin.	Gulfs of Kachchh and Khambhat.	Not examined	Examined	-	IRS images and Toposheets	Not mentioned
14	Elizabeth and John (1998)	Short-term variations.	Rhode island, USA.	Examined	Not examined	Wave, wind, sea level,	Not examined	1962-1994
15	Frihy et al. (1998)	Shoreline change, Spit evolution and erosion and accretion sectors.	Nile Delta, Egypt.	Not examined	Not examined	GPS	Landsat satellite images and topographic maps	1907-1995
16	Lacy and John (1998)	Longterm variations.	Rhode island, USA.	Examined	Not examined	Wind and sea level	Not examined	1962-1996

Sl. No	**Author and year**	**Purpose**	**Study area and length/area**	**Beach profiling**	**Sediment sampling**	**Additional data used**	**Remote sensing data used**	**Study Period**
17	*Murray Hicks et al. (1999)*	*Shoreline change.*	*Katikati inlet, New Zealand, 200km^2*	*Examined*	*Not examined*	*-*	*Not examined*	*Not mentioned*
18	*Ping Wang (1999)*	*Longshore sediment transport rate.*	*Indian Rocks Beach, Florida.*	*Examined*	*Not examined*	*Wave height and wave period*	*Not examined*	*Not mentioned*
19	*Gangadhara and Subrahmanya (2000)*	*Coastal dynamics.*	*Karnataka coastline, India/ 100km.*	*Not examined*	*Not examined*	*Naval Hydrographic charts*	*SOI maps, Aerial photographs and IRS Imageries*	*1910-1998*
20	*Hegde and Raveendra (2000)*	*Dynamics of spits.*	*Mangalore, India.*	*Not examined*	*Not examined*	*Naval Hydrographic charts*	*Toposheets and IRS satellite images*	*1912-1996*
21	*Raghavan et al. (2001)*	*Evolution of spit dynamics.*	*Nethravathi spit, India.*	*Not examined*	*Not examined*	*-*	*Toposheets and IRS satellite images*	*1910-1993*
22	*LaValle et al. (2001)*	*Sediment flux and shoreline change.*	*Point Pelee, Canada.*	*Examined*	*Not examined*	*Bathymetric data*	*Not examined*	*1978-1994*

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
23	Rogxing et al. (2001)	Shoreline change and coastal erosion.	U.S Coast.	Examined	Not examined	Bathymetry, wave, wind, temperature, water level	Aerial Photographs	1973-1990
24	Daphne van der wal et al. (2002)	Longterm morphological changes.	Ribble estuary, England.	Examined	Not examined	Bathymetry and Echo sounding and Admiralty chart.	LIDAR images and Topographic maps	1847-1994
25	Hesham and White (2002)	Shoreline change and sediment transport.	Nile Delta, Egypt.	Examined	Examined	Bathymetric surveys	Landsat Thematic Mapper data and GPS data	1984-1991
26	Jayappa et al. (2003)	Morphological changes.	Dakshina Kannada and Udupi, India.	Examined	Examined	-	Not examined	September 1985-September 1986

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
27	Bhat et al (2003)	Morphology and grainsize analysis.	Gangavalli, India.	Examined	Examined	-	Not examined	Feb 1993-Feb 1994
28	Dolan and Charles (2003)	Longshore sediment transport.	Kannapalli Beach, Hawaii.	Examined	Not examined	Wave data	Not examined	March 2000-April 2011
29	Donald and Jeffery (2003)	Monitoring the Shoreline position.	Lorida, Palm beach county, river beach county, New Jersey coast, Vero beach.	Examined	Examined	Wave and current data , MHWL positions	Aerial photographs	1988-2002
30	Tara and Charles (2003)	Short-term and long-term shoreline changes.	Waikiki beach, Hawaii.	Examined	Not examined	Wave data	Aerial photographs and topographic sheets	1925-2001
31	Don and Micha (2003)	Morphological changes.	Gaza Strip, Gaza.	Examined	Not examined	-	Aerial photographs	1970-1998
32	Ichirou Takeda (2003)	Examining stability of backshore.	Naka beach to Ibaraki prefecture, Japan.	Examined	Examined	Wave data	Not examined	1980-1982

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
33	Dov Zviely and Micha Klein (2003)	Monitoring coastal change.	Gaza coast.	Examined	Not examined	-	Photogrammetry, RS images, ground pictures	1972-1999
34	Yvonne et al. (2003)	Shoreline mobility.	Somme estuary, French.	Examined	Not examined	-	Aerial photographs	1947-2000
35	Bernabeu et al. (2003)	Beach behaviour.	Spanish Coast.	Examined	Examined	Wave and tide	Not examined	May 1990 and Jan 1991
36	Gesche Krause (2004)	Coastal morphology.	Pousada Ajuruteua, Brazil.	Examined	Not examined	-	Not examined	2000
37	Kasinath et al. (2004)	Shoreline changes and nearshore processes.	Ennore coast, India/25km.	Examined	Examined	Water samples, bathymetry survey, wave, tide and current data	IRS 1D PAN 1999 and GPS Survey,	1999-2001
38	Irene Delgado and Graham Lloyd (2004)	Beach morphology.	Coogee, Arealonga and A Farica Road, Australia.	Examined	Not examined	-	Not examined	Not mentioned

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
39	Hegde et al, (2004)	Sedimentolgical investigation.	Sharavati estuary, India	Not examined	Examined	-	Not examined	2000-2001
40	Alsharhan and El-Sammak (2004)	Grainsize analysis.	The United Arab emirates, Arebian Gulf.	Not examined	Examined	-	Not examined	Not mentioned
41	Anfuso and Martınez del Pozo (2005)	Coastal processes.	Ragusa Province, Southern Sicily, Italy/90km.	Not examined	Not examined	-	Topographic maps and Aerial Photographs	1967-1997
42	Navrajan et al, (2005)	Shoreline changes.	Gorai to Mahim, Mumbai, India.	Not examined	Not examined	-	IRS images	1966 to 2002
43	Jun-Young Park and John Wells (2005)	Littoral processes and shoreline change.	Cape Lookout, North Carolina.	Examined	Not examined	Wind climate, wave climate and bathymetry	Aerial photographs	1960-1998
44	John Rooney and Charles (2005)	Shoreline change, Longshore sediment transport	Kihei, Maui coast, Hawaii.	Examined	Not examined	Rainfall and, Wave climate	Aerial photographs and T-sheets	1900-1997

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
45	Peter et al. (2005)	Beach morphology.	Columbia river, Washington.	Examined	Examined	Wave climate and bathymetry	Not examined	1984-2002
46	Roberto et al. (2005)	Morphology and short-term changes.	Caleta Valdes, Argentina.	Not examined	Not examined	Bathymetric and seismic survey	Area photographs, satellite images and T-sheets	1971-1999
47	Giorgio and Francisco (2005)	Morphodynamic characteristics and shortterm evolution.	Chipiona, Rota and Cadiz bay, Spain/14 km.	Examined	Examined	Wave data	Not examined	1996-2002
48	Franck and Edward (2005)	Shortterm changes.	Cayenne, French Guiana.	Examined	Examined	-	Not examined	2001-2004
49	Nicholas Cooper and John Pethick (2005)	Sediment transport pathways.	St. Ouen's bay, Jersey.	Examined	Examined	Bathymetry, tides, wave climate, seismic survey,	Aerial photographs and historical maps	1812-1998

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
50	Mohamed et al. (2005)	Accretion and erosion pattern and shoreline change.	Rosetta Promontoary, Nile Delta coast.	Examined	Examined	Wave data, bathymetry	Not examined	1988-1995
51	Benavente et al. (2005)	Sediment transport pathways.	Cadiz Bay, Atlantic Spanish coast.	Examined	Examined	Wave climate (wave height and wave period)	Not examined	1994-1999
52	Schoonees et al. (2006)	Shoreline change and longshore sediment transport .	Richards Bay, South Africa.	Examined	Examined	-	Not examined	1998
53	Thampanya et al. (2006)	Coastal erosion and Mangrove progradation.	Southern Thailand.	Not examined	Not examined	reconnaissance surveys	Aerial photographs and Landsat-TM satellite data	1966-1998
54	Martin and Masselink (2006)	Morphology and sediment transport.	Slapton Sands, Devon, England/4km long.	Examined	Examined	Wave, tide and water level data	Not examined	October 2004

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
55	Ganguly et al. (2006)	Accretion and erosion.	Sundarban delta, India/ 4471 km^2	Examined	Not examined	-	Examined	1989 to 2005
56	Courtney et al. (2006)	Evolution of Longterm and shortterm shoreline change.	Outer banks of North California/ 40 km.	Examined	Examined	Bathymetry, acoustic backscatter and wave data	Not examined	1974-2002
57	Hanslow (2007)	Quantification of beach recession and accretion.	MacMasters, Australia/ 1.5km.	Not examined	Not examined	-	Aerial photography	1941 and 1993
58	Prakash et al. (2007)	Morphology, sedimentology and Mineralogy.	Chavara, India.	Examined	Examined	Current and Sediment traps	Not examined	1999-2001
59	Mahmoud (2007)	Shoreline change, Morphology, sedimentology and Mineralogy.	Nile delta, Egypt/ 12km.	Examined	Examined	-	Landsat images	1990-2002

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
60	Anfuso et al. (2007)	Morphology, and medium-term evolution.	Ceuta and Cabo Negro (Morocco).	Examined	Examined	Wave climate	Aerial photographs and satellite images	1986-2003
61	Anıl Ari (2007)	Sediment transport and long-term changes.	Karaburun coast, Black sea/4km.	Not examined	Examined	Wind and wave climate	IKONOS and IRS1C/D images	1996-2005
62	Hanamgond and Mitra (2007)	Coastal evolution.	Karwar, India.	Examined	Examined	Waves and currents	Landsat and IRSimages	1989-2003
63	Alesheikh et al. (2007)	Coastline change detection.	Urmia Lake.	Not examined	Not examined	-	Landsat imageries	1989-2001
64	Rajith et al. (2008)	Erosion and accretion pattern.	Chavara coast, India.	Examined	Not examined	Breaker wave climate and currents	Not examined	1999-2001
65	Pari et al. (2008)	Morphological changes.	Vellar estuary, India.	Examined	Not examined	GPS survey,	Toposheets and IRS images	1978-2004

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
66	Plomaritis et al. (2008)	Sediment transport.	Elmer, England.	Not examined	Examined	Hydrodynamic data	Not examined	2002
67	Dwarakish et al. (2008)	Shoreline change detection.	Surathkal to Navuda, Karnataka, India.	Not examined	Not examined	Naval Hydrographic charts and GPS Survey	Toposheets and Satellite imageries	1967-2006
68	Appeaning et al. (2008)	Historical shoreline analysis.	Accra, Ghana.	Not examined	Not examined	Bathymetry and GPS surveys, echo soundings, tides, wave climate.	Digital topographic maps, aerial photographs	1904-2005
69	Laluraj et al. (2008)	Geomorphic and geomorphology response.	Vembanad Lake, India /90 km.	Not examined	Examined	-	IRS image and topographic map	1968-2001
70	Gerd Masselink et al. (2009)	Sediment transport and morphological change.	Truc Vert, France	Examined	Examined	Tide level, wave data, current data, water levels and sediment traps	Not examined	2008

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
71	Zuo Xue et al. (2009)	Coastal erosion assessment and Longshore sediment transport.	Quinhuangdao coast, China.	Examined	Not examined	Water levels, current,	Topographic maps and satellite images	1986-2003
72	Elba and Robert (2009)	Shortterm and longterm shoreline dynamics.	Pierce inlet, Florida.	Examined	Not examined	MHW changes	Not examined	1860-2002
73	Jonathan et al. (2009)	Shoreline position and geomorphology.	Elva river delta, Washington, $831km^2$	Examined	Examined	RTK GPS	Not examined	1939-2006
74	Vousdoukas et al. (2009)	Dynamics of beaches.	Vatera, NE Mediterranean.	Examined	Examined	Wave height, wave period and rainfall	Not examined	July 2003-September 2005
75	Kaiser and Frihy (2009)	Shortterm variability.	Nile Delta, Egypt.	Examined	Examined	-	LANDSAT Images	1934-2000

Sl. No	Author (s) and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
76	Mani Murali et al. (2009)	Monitoring shoreline environment.	Paradip coast, India.	Not examined	Not examined	wave climate	Toposheet and IRS Imageries	1998-2005
77	Dwarakish et al. (2009)	Identification of coastal vulnerable areas.	Udupi, India/95km.	Not examined	Not examined	Wave, tide, bathymetric data, GPS	Toposheet and IRS Imageries	1971 to 2006
78	Ranga Rao et al. (2009)	Littoral sediment transport.	Ennore, India/ 9km.	Examined	Examined	Wave climate	Not examined	1999-2006
79	Kumar and Jayappa (2009)	Long and Short-Term Shoreline Changes.	Mangalore coast, India.	Examined	Not examined	Rainfall data	Toposheets and IRS images	1967-2005
80	Hegde et al. (2009)	Foreshore morphology.	Honnavar, India.	Examined	Examined	breaker wave climate,	Not examined	December 1999-February 2001
81	Backstrom (2009)	Shoreface morphodynamics.	Northern Ireland.	Examined	Not examined	Bathymetry, wind and wave data	Not examined	March 2005 - April 2007

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
82	Jin-Cheng Liou et al. (2009)	Shoreline evolution.	Kangnan coast, Taiwan.	Not examined	Examined	Wave height, wave period, bathymetry	SPOT images	1988-2007
83	Collen et al. (2009)	Shoreline change.	Palmyra Atoll, Hawaii/12km.	Examined	Examined	Navigational charts	Ikonos image, Historical maps and photos	1874-2000
84	Bradley et al. (2009)	Shoreline Change.	Oahu, Hawaii.	Not examined	Not examined	-	Historical shoreline maps, topographic sheets and aerial photographs	1920-2005
85	Patrick and Jonathan (2010)	Historical morphological changes.	Santa Clara Rivermouth, California.	Examined	Not examined	Bathymetry, Precipitation, River discharge, wave climate, GPS survey	LIDAR survey	1987-2008

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
86	Muñoz-Perez and Medina (2010)	Long, medium and short-term variations of beach profiles.	Victoria Beach, Spain.	Examined	Not examined	sea-level and bathymetry	Not examined	1991-1996
87	Srinivasan and Sajan (2010)	sedimentological characteristics.	Kaymukulum lake, India /24 km.	Not examined	Examined	-	Not examined	1 year period
88	Avinash Kumar et al (2010)	Shoreline positions and morphology of spits.	Karnataka coast, India.	Not examined	Not examined	Rainfall	IRS images and toposheets	1910-2005
89	Toru Tamura et al (2010)	Morphology variations.	Tra Vinh coast, China.	Examined	Examined	Wave, tide and river discharge	Topographic maps and Landsat and QuickBird images	1936-2008
90	Michal Lichter (2010)	Morphological variations and rivermouth deflations.	Gaza Strip to Haifa Bay, Israeli coast.	Not examined	Not examined	River discharge , rainfall and wave climate	Aerial photographs	1918-2005

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
91	Nayak et al. (2010)	Geomorphic processes.	Venkatapur Rivermouth, India/10km	Examined	Examined	Wave data, GPS, bathymetry	Toposheets and IRS images	1900-2005
92	Ana vila et al. (2010)	Shoreline Processes.	Port Stephens, Australia	Examined	Not examined	Wind, wave, currents and Rainfall	Not examined	March 2007 and April 2008
93	El-Asmar and Hereher (2011)	Spatial and temporal changes.	Nile Delta	Not examined	Not examined	-	Landsat Images	1973-2007
94	Anfuso et al. (2011)	Littoral morphological evolution.	Northern Tuscany, Italy/64 km	Examined	Examined	wave data, RTK GPS, bathymetric surveys	Aerial photographs and topographic maps	1938-2005
95	Gujar et al. (2011)	Morphological Variations.	Pirwadi to Sarjekot, India	Examined	Examined	Wave data	Not examined	October 2004 to December 2005
96	Mitchell et al. (2011)	Coastal monitoring.	Collaroy–Narrabeen Embayment, Australia	Examined	Not examined	GPS surveys	video cameras	1976–2008

Sl. No	Author and year	Purpose	Study area and length/area	Beach profiling	Sediment sampling	Additional data used	Remote sensing data used	Study Period
97	El-Asmar and Hereher (2010)	Quantification of shoreline Changes.	Damietta promontory and Port-Said, Nile Delta, Egypt/ 3 Km.	Not examined	Not examined	-	LANDSAT and SPOT Imageries	1973-2003
98	Gumageri et al. (2011)	Geomorphology and shoreline change.	Sasihithlu, India.	Examined	Not examined	Beachwidth and beach slope.	Toposheet and IRS images	1988-2010
99	Gumageri and Dwarakish (2011)	Shoreline change.	Mangalore, India	Not examined	Not examined	-	Toposheet and IRS images	1912-2003
100	Udhaba Dora et al. (2011)	Textural Characteristics.	Pavinkure, Kundapur and Padukure, India.	Not examined	Examined	Beach width	Not examined	March 2008- Februry 2009
101	Hegde et al. (2012)	Spit Dynamics.	Karwar to Mangalore, India.	Examined	Examined	Breaker height, wave period, and alongshore transport.	Toposheets and IRS images	1976-2006

Based on the detailed literature review, it is observed that wide variety of data sources and techniques are available to examine the position of shoreline. At the highly vulnerable coastal areas, the historical data may be limited or nonexistent. As a result, the choice of what kind of data to be used for a specific vulnerable site is generally determined by the availability of data. Infact gathering past shoreline positions seems to be opportunistic; many a times historically obtained data for the site of interest may not be available. This often leads to arrive conclusion that different sources and techniques can be used for a single study in order to achieve the desired temporal shoreline change. A number of the common techniques that are used by several researchers (Table.2.3) for shoreline change monitoring are briefly described in the following section.

2.5.1 Historical land based photographs

Most of the land based photographs provide limited information and that can be seen at smaller scale with some ground control points, but there will not be any more information about the sea conditions (tide and waves) at the time of photograph captured. However, historical land based photographs definitely provide some background information about the presence of a site specific morphological features such as a sand spit, channel entrance, rivermouth etc. But, these photographs can be considered as reference to create actual quantitative mapping of past shorelines.

2.5.2 Aerial Photography

Aerial photography can provide a very good spatial coverage of the coast, but temporal coverage is very limited to site specific. But historical aerial photographs may also be used temporally towards pre-storm and post-storm shoreline change detection. The shoreline gathered from aerial photographs is just based on visually observed features at the interested vulnerable area. However, for aerial photographs correction must be required, before they can be used to determine shoreline change and morphology quantification (Laurel et al. 1998). Common distortions include radial distortion, relief distortion, tilt and pitch of the aircraft, and scale variation (Laura Moore 2000).

2.5.3 Beach Surveys

Beach survey can be an accurate technique to determine shoreline position. However, historical records usually will be limited both in terms of spatial and temporal scale. This is generally attributable to the high cost, since it is labour oriented method, because survey teams have to go to the field to obtain the profile data. Thus shoreline change can be compiled by interpolating between series of discrete shore normal transects. Often the alongshore distance between adjacent profiles is relatively large, so that alongshore accuracy of shoreline location is diminished accordingly (Ping Wang 1999; Dolan and Charles 2003). If sufficient beach profile data are available for a specific site, shoreline changes are easily and accurately determined.

2.5.4 GPS Survey

A more recent method of mapping the shoreline is done by using kinematic differential GPS mounted on a four wheel drive vehicle, which is driven at a constant speed along the visibly discernible line of interest and area (Baptista et al. 2008; Patrick and Jonathan 2010). The benefits of this method are: it is relatively rapid, low cost and highly accurate. On the other hand with the modern hand held GPS equipment, the greatest errors can be controlled by the visual determination of the line of interest by the operator. In this way, GPS method is more accurate than aerial photography to identify the specific shoreline features of interest.

2.5.5 Sediment Sampling

Sediment sampling provides actual knowledge towards the sediment dynamics and type of sediment accumulated in the interested area. The three common processes which most completely characterize the sediment sampling are coastal erosion and accretion and sediment transportation. With the help of aerial photographs and land based photographs, it is possible to examine these processes in the interested area. But sediment sampling and analyses provide continuous coverage of the seafloor and nearshore morphology, sediment transport pathways, sources and sinks (Robert and Larson 1997)**.** Thus, sediment sampling provides preliminary information about the site in terms of material constituents and mineral packages based on temporal and spatial scales (Rajiv et al. 2005).

2.5.6 Remote Sensing

Conventional shoreline monitoring techniques such as aerial photography and ground survey are expensive, requires trained staff and time consuming. In normal process, the preparation of these maps required month to years, and these are considered now as outdated techniques. Recently, remote sensing and geographical information system (GIS) have been widely used as another option for monitoring shoreline position and changes. Remote sensing provides the capability to monitor the shoreline in a cost effective manner. For change detection in shoreline, different spatial and temporal resolution of satellite imagery can be used.

Remote sensing is the best and most popular technique to detect shoreline changes in recent years due to its synoptic and repetitive coverage, and high resolution. This technique basically provides an insight into larger area particularly towards sediment transport and detecting long-term, medium-term and short-term changes for the entire coastline. In addition to these, nearshore erosion, deposition, sediment budget and longshore transports can also be determined. In this way accurate demarcation and monitoring of shoreline (long-term, seasonal and short-term) can be achieved for better understanding of the coastal processes.

2.5.7 Light Detection and Ranging Technology

Light Detection and Ranging (LIDAR) Technology has the capability to cover hundreds of kilometres of coast in a relatively short period (Hilary et al. 2002, Patrick and Jonathan 2010). It depends on the measurement of the time taken from a laser beam, o reach the target and back to the instrument (sensor). The speed of light allows to calculate the distance to be measured, and the use of differential GPS specifies an exact location. But the use of this technique is generally limited due to very high expenditure. However, the main advantage of LIDAR technique is that it can cover large areas very quickly.

2.5.8 Coastal Maps and Charts

Mapping and charting techniques have become more reliable in the late 18th century over global coastal research. These maps and charts are useful for shoreline change identification and investigations (Bruce et al. 1998). Maps and charts can provide good spatial coverage, but they fail to cover temporal fluctuations, and most often is very site specific. These maps in general provides detail about the position of the High Water Line (HWL) marked on site by a surveyor ‘‘by noting down the vegetation, width of the dune, approximate location of spit and rivermouth, headlands, rocky shorelines and other visible signs of coastal features’’.

The common errors associated with historical coastal maps and charts include; the errors in scale, distortions from uneven shrinkage, stretching, tears and folds, different surveying methods and partial revision. However, their advantage is to provide a historic record that is not available from other data sources. By necessity, the ‘‘shoreline’’ that is obtained from historical maps and charts is determined by the surveyor rather than the coastal engineer and it is generally assumed to have been associated with some type of visibly discernible feature.

From the extensive literature review, it is observed that coastal morphology and shoreline changes can be surveyed using a wide variety of techniques and data sets according to the study time spans. Studies on short-term shoreline dynamics are usually carried out at small spatial scales in a time span less than 10 years. The most common technique used is beach topographic surveying, sediment sampling conducted at regular intervals, in order to measure daily to annual variations in shoreline position and sediment distribution and sediment distribution. Aerial photographs, satellite images, coastal maps and charts represent a very useful techniques to understand coastline changes at short (<10 years), medium (10 to 60 years) and long (> 60 years) temporal and spatial scales (Anfuso et al. 2011). The precision and accuracy of these kinds of measurements depend on their own characteristics. Several authors studied coastal changes at different time scales and analyzed coastal evolutions at historical scale to current trend scales.

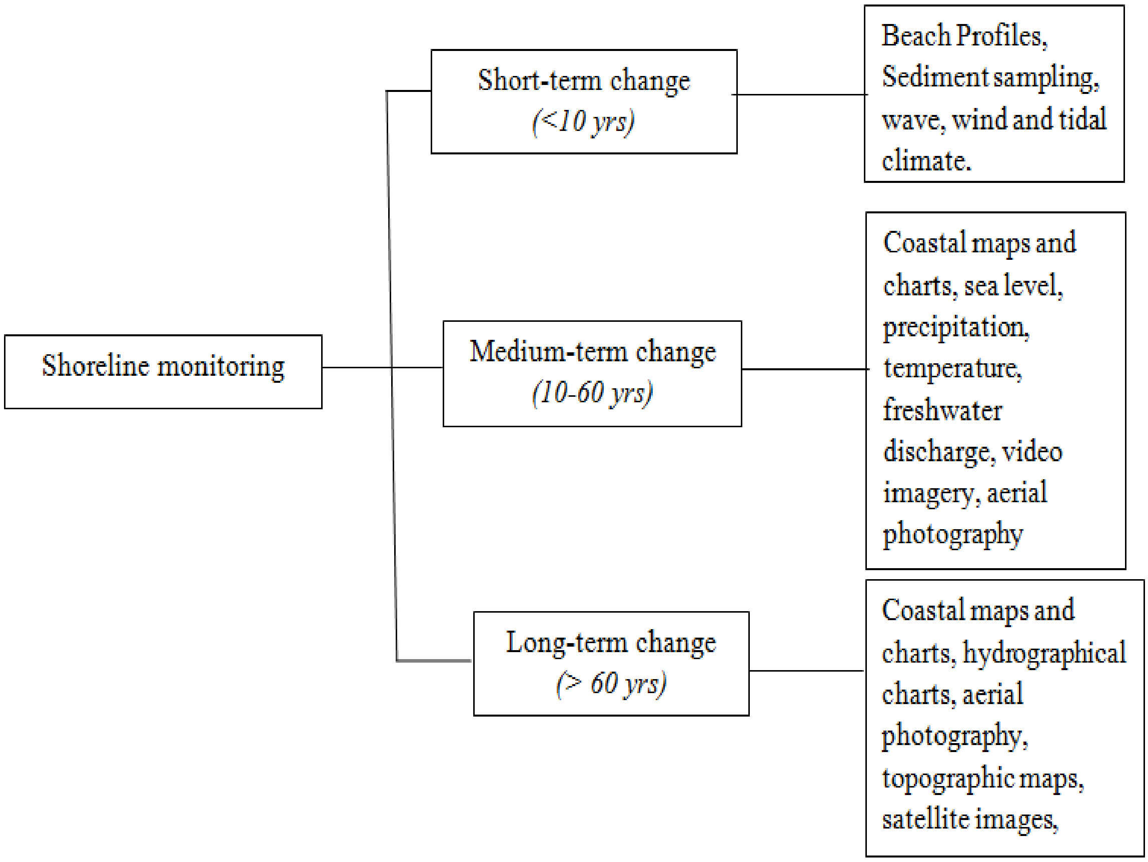


Figure.2.4 Data sources and techniques to monitor shoreline change at varying temporal scale.

Despite of high research activity in shoreline monitoring, it is pointed out that there is no independent technique addresses the entire range of coastal area and its morphological behaviour. Therefore several techniques are required for accurate coastal mapping of any stretch. The application of existing methods for many typical shoreline mapping problems is limited. Use of any particular method is influenced by the data sources and resources available. But when the several resources and techniques are available to deal the particular shoreline changes and morphology, recent few researchers have considered integrated approach in that all the possible combination of techniques and data sources are utilized efficiently and effectively

(Sandrine et al. 2000, Hegde et al. 2009, Anfuso et al. 2011). The additional data from the interested site such as wave and wind climate, tidal fluctuations, currents, freshwater discharge, bathymetry, sea-level, rainfall, temperature and water samples are collected from the interested site and analysed systematically to provide detailed information about the current status of shoreline with respect to historical position of shoreline by understanding complicated and dynamic behaviour of coast (Figure. 2.4).

2.6 Monitoring the shoreline changes using common techniques at Indian context

Most of the shoreline monitoring programs by the researchers in India has attempted with single technique or some time combination of one or two techniques, but very few research works have used combination of multiple approaches. In this direction, some of the research works carried out in India in the last two decades (1991-2011) is reviewed and described in this section. For long-term shoreline changes many of the researchers have used remote sensing techniques and for short-term changes most of the researchers used field observations.

Kunte and Wagle (1991) used satellite images and topographic maps to delineate the coastal features of the southern coastal segment of the Karnataka, situated along the west coast of India. Landsat images were used to locate the fifteen spits and coastal features, through those responsible factors for spit formation and growth are attempted to recognise. The study reveals that spit growth direction is either towards north or south depending upon monsoonal waves. The bidirectional littoral drift could be the primary agent for sediment redistribution and confinement within the region, thereby keeping the coastline straight, smooth and stable.

Manavalan et al (1993) integrated topographic sheets and satellite imageries to evaluate the migration of Mangalore and Ullal spits of Nethravathi-Gurupur rivermouth over a period of 83 years. The lateral migration of spits reduced after construction of seawall. But the rivermouth showed a tendency of shifting towards north indicates a net northward littoral drift irrespective of seasons.

Gangadhar (1995) used satellite images and aerial photographs to identify the significant morphological changes in the Nethravathi-Gurupur and Mulky-Pavanje estuaries. The study revealed that the rivermouth Nethravathi-Gurupur has slightly shifted towards North, whereas Mulky-Pavanje has shifted towards southward considerably due to swell waves during monsoon.

Dattatri et al. (1997) conducted sea sled survey along the Dakshina Kannada (D.K) coast during 1995 and 1996. It was noticed that the pre-monsoon and post-monsoon profiles were almost same. This indicates that the pre-monsoon profiles have regained their profiles during post-monsoon. The material eroded during monsoon was recovered during post-monsoon period. From this, they concluded that though there was changes during monsoon, but there was no net erosion or deposition. Hence, the portion of the beach considered in the study is in a state of dynamic equilibrium. Further they also found that, littoral drift is negligible along Mangalore coast.

Dwarakish et al. (1998) investigated Nethravthi-Gurupur rivermouth, Dakshina Kannada coast to understand the complete coastal processes, which operate in this region based on macro-level data obtained from remote sensing and micro-level data from field investigations (sediment sample analysis and sediment trend matrix analysis). The study revealed that the deposition in the vicinity of rivermouth was not due to littoral drift but it was due to discharge of sediments from the rivers into sea.

Hegde and Raveendra (2000) have investigated long-term and short-term shoreline changes at Nethravathi and Gurupur rivermouth with the help of satellite data products, topographic maps and naval hydrographic charts between 1912 and 1996. This study mainly conducted in a view to compare the dynamic changes and as well as understanding the tendency of shoreline shifting, which found to be changing during the study period near the rivermouth. They had concluded that the multidated and multi spectral data of Indian Remote Sensing (IRS) could be used effectively for monitoring of the geo-dynamics of an area.

Gangadhar and Subramanya (2000) have selected three rivermouths (Nethravathi-Gurupur, Bengre - Udyavar and Mulky - Pavanje) of Dakshina Kannada coastline to understand the coastal dynamics and influence of manmade features on shoreline changes and spit evolution within the rivermouth systems. Earliest Topographic map and high spatial resolution data of IRS were used and compared. The results obtained from the study indicated that the gradual shifting of Mulky-Pavanje rivermouth was towards north irrespective of seasons.

Subba Rao et al. (2000, 2001, 2002, and 2003) used beach profile and sediment trend matrix analysis to study the littoral drift and concluded that the sediment movement along Dakshina Kannada coast was seasonal and there was no net littoral drift along the coast. Further, the direction of sediment movement gets reversed along Dakshina Kannada coast seasonally and also observed that littoral drift did not pose any problem along Dakshina Kannada coast.

Bhat et al. (2003) discussed the morphology and sediment movement in a monsoon influenced open beach near Gangavalli river. The study was carried out at monthly intervals for one year period with the help of beach profile surveys and sediment sampling (February 1993-February 1994). The study concluded that the morphological changes are cyclic in nature; erosion during monsoon and deposition during fair-weather season.

Hegde et al. (2004) studied sediment characteristics in the vicinity of Sharavathi estuary to understand the depositional environment. They collected sediment samples in the vicinity of estuary and in the sea, (rivermouth channel) and analysed. They found that estuarine sediments were relatively fine grained during fair weather season as compared to monsoon season and further concluded that the siltation at rivermouth was mainly due to tidal currents and interference of fresh and salt water.

Hegde et al. (2009) discussed a low scale foreshore morphodynamic processes in the vicinity of the Sharavathi estuary, central west coast of India, based on wave refraction analysis, sediment characteristics and foreshore morphological changes. The study indicated two distinct trends of geomorphic process on either side of the rivermouth. The study also showed nearshore processes and wind largely control shoreface modifications of the beaches adjacent to rivermouth. The study concluded that northerly drift was the dominating factor, which made to develop a spit across the rivermouth during post-monsoon, whereas southerly drift was the clear responsible factor to erode the beaches near the vicinity of rivermouth.

Kumar and Jayappa (2009) carried out a comprehensive study between New Mangalore Port and Talapady of Mangalore region. Indian Remote Sensing Satellites IRS-1C/1D LISS-III images of January 1997 December 2001 and 2005 of the study area were analysed and beach profile surveys were carried out in order to understand long and short-term beach morphological and shoreline changes. Long and short-term shoreline changes as well as erosion/accretion patterns have been estimated by comparing topographic map of 1967 with multidated satellite images and beach profile surveys conducted between 1980 and 2005. The study concluded that the beaches adjacent to rivermouth were accreted and away from the rivermouth were suffered from erosion.

Srinivas and Sajan (2010) studied the significance of textural analysis of surface sediment samples, careful examination of granulometric parameters and their proper evaluation using standard methods in the discrimination of various depositional environments. The grain size characteristic of sediments was used to examine the depositional processes in one of the marginal lagoons parallel to south Kerala coast. The study revealed that the textural diversity on the sediments of the study area was due to the working of marine and fluvial processes and also, the morphology of the lake contributed to the textural complexity.

Nayak et al. (2010) conducted a detailed study on geomorphic processes in the vicinity of Venkatapur rivermouth, central west coast of India. Multidated satellite image analyses, wave refraction patterns, time-series beach section studies, and sediment characteristics were used to understand the geomorphic processes occurring in the rivermouth region. The beaches adjacent to rivermouth showed erosion and accretion simultaneously. It was further observed that during the pre-monsoon period, resuspension of sediments occurs, and these sediments move landward and into the estuary, particularly during the high tide. Wave refraction pattern showed wave divergence near the rivermouth and wave convergence away from the rivermouth, leading to a wave shadow area in front of the river mouth. This phenomenon leads to sedimentation in the estuary and dynamic changes in the vicinity of the river mouth.

Gujar et al. (2011) carried out detailed investigations to estimate the volumetric and morphologic variations for south Maharashtra coast. They conducted beach profiling between October 2004 and December 2005, the volumetric variations of the beach sediments, i.e. an account of accretion and/or erosion, were estimated by considering the October 2004 profile as the base reference, over which the values of other seasons were compared. Several reasons were attributed for the erosional trends. Among which the prominent reasons were rip currents, wave dynamics, variable coastal configuration, beach gradient and monsoonal seaward flowing streams.

2.7 Modelling of Coastal Processes

2.7.1. General

In analogy to the biological system, an artificial neural network is being applied to solve a wide variety of complex scientific engineering problems. Neural networks are ideally suited for such problems because of their biological counterpart and due to quick learning capability. The developed neural network models can be used to find many solutions like pattern reorganization, classify the data and forecast the future events. An artificial neural network is interconnected by a group of neurons that carries information based on connectionist approach to computation. In most of the cases a neural network is used as adoptive system that changes its structure based on the external or internal information that flows through the network. In more practical terms ANNs are non-linear modelling tools and they can be used to model complex relationship between input and output system. The networks also have a very high degree of freedom and very simple to train the system for any number of input values, which makes the network more attractive and reliable. These unique qualities made the neural network to apply in various fields.

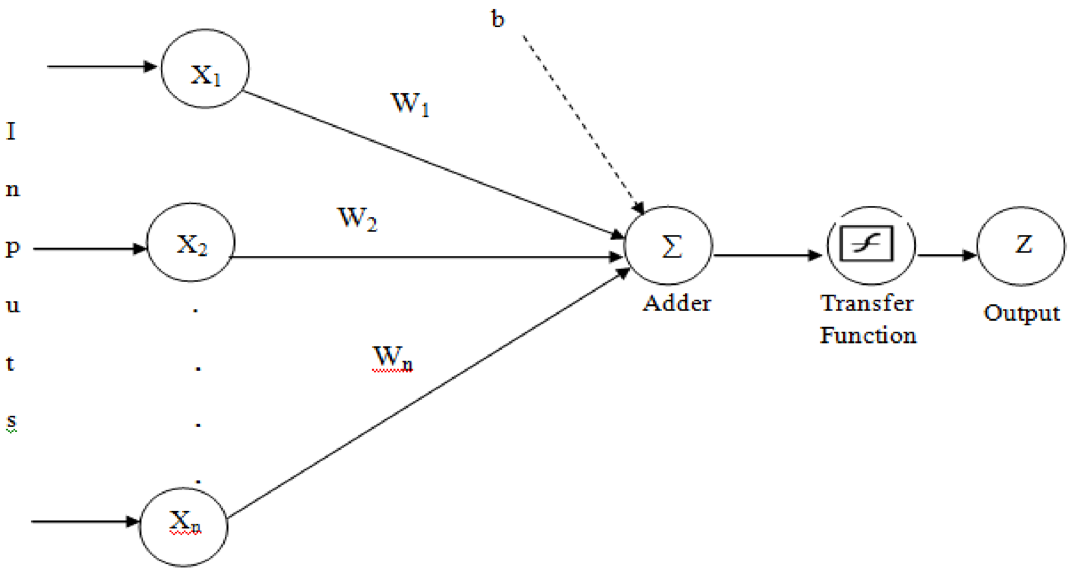


Figure.2.5 Structure of single neuron network model

2.7.2. Artificial Neural Network

An Artificial Neural Network (ANN) is an information processing system modelled on the structure similarity to that of human brain. The biggest merit of ANN is that its ability to deal with fuzzy information whose interrelation is ambiguous or whose functional relation is not clear. The ANN has the capability of learning and adjusting with the outside environment. Training the network with specified examples called network learning. During training process network calculates the weight and bias values with respect to the output values. The testing is done for unknown input values so that network predicts the new output, so in other words neural network learn from outside environment. Either humans or other computer techniques can use neural networks, with their remarkable ability to derive meaningful information from complicated or imprecise data, to extract patterns and detect trends that are too complex.

A single Neuron model is as shown in Figure. 2.5. A network model consists of an input layer, adder, single hidden node and single output node. The input parameters are fed at input layer and then these input parameter gets multiplied with the weights and added with the bias values. The total value passes through the transfer function at hidden layer and then output is obtained.

2.7.3 Applications of ANN in coastal and ocean engineering

ANNs have been used to solve wide variety of problems related to the coastal and ocean areas over the period of last one and half decades. Most of the studies have been involved in estimation or forecasting of coastal and ocean parameters. In most of the studies ANN models have outperformed than the traditional empirical, statistical or numerical models to a smaller and larger extent.

The problems in the field of coastal and ocean engineering can be attempted either on the basis of knowledge based schemes or through data driven methods. The former depends on known physical processes through analytical, empirical or numerical schemes while the latter essentially analyzes data with little knowledge of the process and incorporates conventional statistical, stochastic schemes or recent approaches of soft computing, artificial intelligence, machine learning and data mining. The ANN is one such modern data driven methods that has been successfully applied in oceanic problems for estimation or forecasting of coastal parameters.

In coastal and ocean applications the ANN's have been used mainly to evaluate or forecast some random parameter. These are wave height, wave period, wave direction, tidal levels, sea levels, water temperature, wind speeds, estuarine characteristics, coastal currents and rate of sediment movement and so on. Additionally forces on structures, including wind and wave loads, structural damage indicators, ship design parameters, barge motions, and scour depth and soil liquefaction have also been evaluated with ANN. Therefore, it is found that apart from improving the accuracy of the outcome, the ANN's have significantly reduced the computational effort as well as time when compared with other traditional methods.

Several researchers have used the ANN to solve various problems related to coastal engineering. It is the most widely used method among the soft computing methods, since it is not defined as specific equation form. In the past few decades the ANN approach, which is non linear black box model, was applied for many types of work, oriented towards the estimating or predicting of various parameters. In this section nearly about 50 technical papers are selected and reviewed to support the effective utilization of ANN in the domain of coastal engineering. Most of the typical ANN research works include (a) wave height predictions (Deo and Naidu 1999; Agrawal and Deo 2002; Makarynskyy 2004; Makarynskyy et al. 2005; Mandal and Prabaharan 2006; Jain and Deo 2007; Kemal Gunaydın 2008; Londhe 2008; Mahjoobi and Mosabbeb 2009; Mehmet Ozger 2010), (b) wave parameters estimation (Agarawal and Deo 2004; Mandal et al. 2005; Mahjoobi et al. 2008), (c) wave tranquillity studies (Londhe and Deo 2003), (d) Littoral drift prediction (Singh et al. 2007; Singh et al. 2008), (e) Sediment estimation (Ozagur kisi 2008), (f) tidal levels prediction (Leea et al. 2002; Tsong 2004; Hsein-Kuo Chang 2006; Bang-Fah chen et al. 2007), (g) wind wave forecasts (Subbarao and Mandal 2005; Makarynsky et al. 2007; Ahamadreza Zamini 2008), (h) predicting coastal currents (Charhate et al. 2007), (i) beach profile predictions (Hashemi et al. 2010 ; Gunawardena et al. 2009), (j) Sand bar behaviour (Leo Pape 2007) and (k) Design and reliability analysis of coastal structures (Dong Hyacen Kim 2005; Dookie Kim 2000).

During the last decade, the ANN approach was usually applied for wave and tide predictions. Some of these applications are as follows: Deo and Chaudhari (1998) used ANN techniques to predict tides at three different locations around the east as well as the west coast of India. Tsai and Lee (1999) applied the ANN with back-propagation procedures to forecast the time series of tidal levels using a learning process based on a set of previous data. Deo and Kumar (2000) studied on weekly mean significant wave height derivation from their monthly mean observations. Mandal (2001) studied back propagated neural network for tide prediction. Deo et al. (2001) used ANN having wind speeds at the current and one previous time step as input to obtain 3-hourly values of significant wave height and average zero cross period. They also further predicted weekly mean significant wave heights based on 4 input nodes pertaining to weekly wind speeds in a month. Lee and Jeng (2002) studied the prediction of tidal level using short-term tidal data. Tsai et al. (2002) performed an investigation to obtain significant wave heights at a station based on wave records at the neighbouring stations. Makarynskyy (2004) applied the ANN technique to predict significant wave heights and zero-up-crossing wave periods made over 1–24hr time interval. Kalra et al. (2005a) obtained daily significant wave heights at a specified coastal site situated along the west coast of India, using Radial Basis Function (RBF) and Feed Forward Back-Propagation (FFBP) methods. The daily significant wave height, average wave period and the wind speed sensed by a satellite at nine deeper offshore locations were given as input to the network. Kalra et al. (2005b) determined daily significant wave heights at a nearshore location based on wave heights sensed by a satellite at 21 deeper offshore locations with RBF, FFBP, and adaptive neuro-fuzzy inference system (ANFIS) methods. Subbarao and Mandal (2005) hindcasted wave heights and periods of cyclone generated waves using two input configurations of ANN. The first input configuration included radius of maximum wind speed, speed of forward motion of cyclone and central pressure while the second input configuration included fetch and wind speed. Makarynskyy et al. (2005) forecasted wave heights and periods 3, 6, 12, and 24 hr in advance at the west coast of Portugal using ANN. Lee (2006) predicted storm tidal level during the typhoon at Jiangjyun station in Taiwan. Four input factors including the wind velocity, wind direction, pressure and harmonic analysis tidal level at this station were used during the application of ANN. The recurrent neural network of 3, 6, 12, and 24 hourly wave height estimation was carried out by Mandal and Prabaharan (2006). They compared their results with Deo and Naidu (1999) and Rao et al. (2001), Kalra and Deo (2007) estimated significant wave heights, average wave period and wind speed at the coastal site based on values of these parameters collected by TOPEX satellite at 19 offshore locations with the help of ANN.

Since wave heights vary rapidly close to coasts, the hourly significant wave heights (H_s) in the offshore region provide seasonal wave climatology. Knowing these H_s become useful for ocean engineering applications such as transport activities, including optimal ship routing (Padhy et al. 2008). The hourly wave heights can also be used to derive shorter time interval wave heights such as weekly wave heights which are useful for short-term applications like determining clear weather window to carry out some construction or repair activities (Deo and Kumar 2000).

From the literature review, it is observed that with the application of ANN, majority of the research works in the domain of coastal engineering have selected only wave heights to forecast some extent. On the other hand a very few research works attempted to predict littoral drift. Therefore two coastal parameters such as forecasting of wave heights and prediction of littoral drift are attempted in the present study.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 General

Coastal processes are complex and dynamic components, dependent on large number of influencing factors such as wind velocity, storm (frequency and intensity), tidal range, nearshore currents, wave climate, water level, river discharge and so on. These components would interact with each other and produce large amount of variations in coastal morphology. Therefore, it is difficult to isolate specific factors causing shoreline changes, for instance changes in vegetation line can be seen more easily, but large variation cannot be easily analysed without considering several factors. Therefore, in order to evaluate the various factors and their inter-relationship, it is necessary to discuss not only major influencing factors but also minor factors need to be considered.

This chapter describes a wide variety of techniques/methods used, and reasons for collecting the data from different sources and analysing the same in order to monitor the changes associated with Mulky-Pavanje rivermouth at different temporal scales (short, medium and long-term) (Table. 3.1). In this chapter, each section describes a justification for data gathering and their utilization at different phases of the research work.

3.2 Data from Field visit

3.2.1 Beach Profiles

One of the most oblivious features in the coastal zone is represented by beaches, which are basically deposits of sediment. Beaches are constantly changing due to wind, waves, tides, storm activity and interference of human beings.

Table. 3.1 Details of data and data sources used in the present study

Type of Data	Data source	Data period	Data scale
Short-term Data			
Beach profile Survey	Field visit/ Monthly	Sept 2009 to Dec 2011	12 km length
Beach width Measurements	Field visit/ Weekly	Sept 2009 to Dec 2011	--Do--
Foreshore Sediment Data	Field visit/ Monthly	Sept 2009 to Dec 2011	--Do--
Wave climate data (height, period and direction) and wind data (speed, direction)	Field visit and INCOIS Hyderabad and IMD Pune	Jan 2007 to Dec 2010	--Do--
Medium-term Data			
Precipitation Data	IMD Panambur and IMD Kateel	1985-2011	--Do--
River Discharge data	IMD Kateel	1985-1998	--Do--
Long-term Data			
Toposheet	SOI	1912	1:25,000
Toposheet	SOI	1988	1:25,000
IRS – 1D LISS III	NRSC	1998	23.5 m resolution
IRS – 1D LISS III	NRSC	2003	23.5 m resolution
IRS – P6 LISS III	NRSC	2006	23.5 m resolution
IRS –P6 LISS IV (MX)	NRSC	2009	5.8 m resolution

A typical sandy beach is composed of the following areas: the foreshore and the backshore, the foreshore is mainly the beach face, from the lowest part of the low tide to the highest part of the berm closest to the beach face. The backshore consists of the berms. A berm is created by wave action and represents the highest area on the beach, where waves can carry and deposit the sand. A principal aspect of the beach is its dynamic behaviour, due to the loose grain sediments that respond to the waves and currents. The beach profile studies give ample information on cyclic or seasonal changes of the beach area. The beach profile studies are very much essential to understand the erosional and depositional features, which in turn help to understand the changes in oceanographic processes in the coastal areas.

The most common form to determine changes in the shoreline is beach profile survey. For this, a dumpy level with tripod, a measuring staff, a prismatic compass and bundle of string are used for profiling. The starting point of beach profile is marked on the landward edge of the beach where there is permanent vegetation covers or at toe of seawall or no appreciable change in elevation. The starting reference point is fixed in such a way that the reference point should not be affected by any wind or wave. From which succeeding surveys were carried out along the length of study area. Further at each station, on the landward side of starting point, two reference points are setup to ensure reestablishment of the starting point even if disturbed. A prismatic compass is used to maintain the profile line in perpendicular direction to the shoreline. In order to help the staff holder, a string is used to assist the straight alignment. Crossshore beach elevations are taken at every 4 m interval. The elevation beach profiles covered the area between the land and water line at the time of measurement from the starting reference point.

Total of about five beach survey (BS) profiles were selected on southern side of the Mulky-Pavanje rivermouth based on a reconnaissance survey and change in morphology, covering a length of about 7 km and four more additional profiles were chosen on northern side of the rivermouth with equal spacing (1000 m each) covering a distance of about 4 km. The profiles of southern part are designated as BS 1, BS 2, BS 3, BS 4 and BS 5 and at the northern part are represented as BS 6, BS 7, BS 8 and BS 9, and the profile number increasing from South to North direction (Figure. 3.1). From the backshore reference points, the profiles were taken from September 2009 to December 2011 at monthly intervals. A total of about 252 shore normal transects were obtained from the study area during the study period on either side of the rivermouth (BS 1 to BS 9). The Geographical details and site specific features of location of nine beach profile survey are presented in Table.3.2.

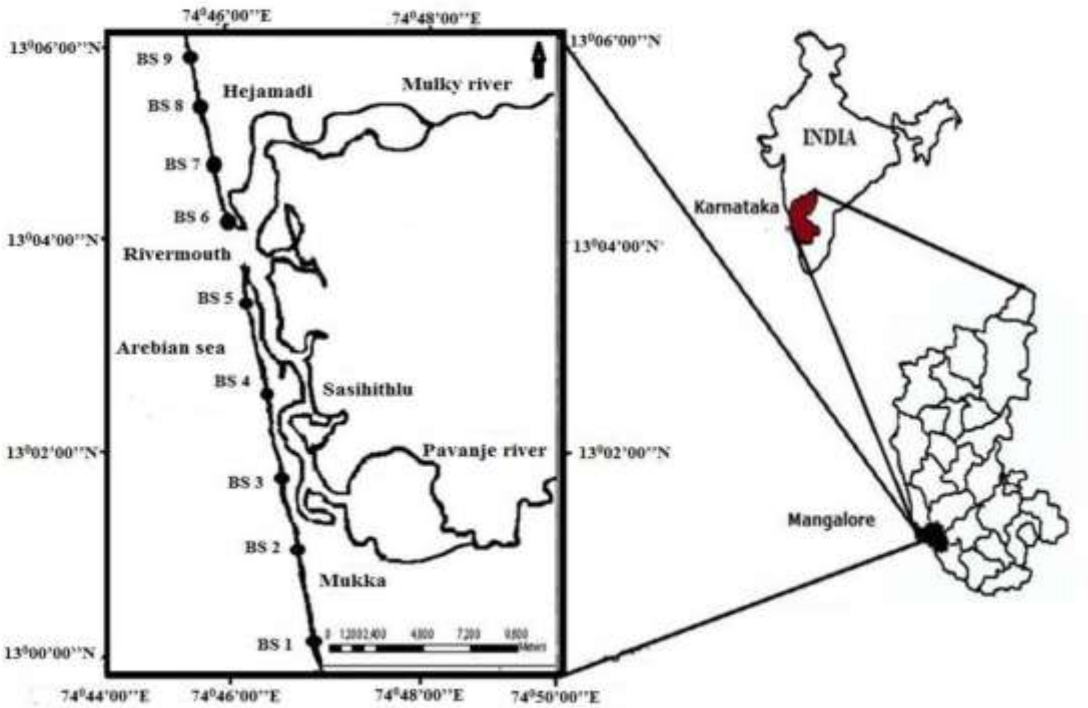


Figure 3.1 Locations of beach profiling, sediment sampling and beachwidth measurements (BS 1to BS 9)

Short-term field data obtained by beach survey are converted into X- Y co-ordinates to represent the actual beach profile. Successive profiles can be plotted (as shown in Figure.3.2A) and the changes in cross sectional area for time period between measurements were determined. Based on profiles, the beach volume is computed to quantify crossshore and alongshore sediment transports (Dolan and Charles 2003).

Table.3.2 Geographical locations, location of beach profiling, sediment sampling and beach width measurements

Area and Profile No	Position		Beach Profiling, Beachwidth Measurement and Sediment Sampling	Site specific characteristics
	Latitude	Longitude		
NITK Beach (BS1)	$13^0$00'48"	$74^0$47'15"	Base point location on the southern side of the rivermouth	Open Beach
Mukka Beach (BS 2)	$13^0$01'21"	$74^0$46'10"	500m from BS 1	Infront of seawall
Mukka Beach (BS 3)	$13^0$02'03"	$74^0$46'47"	500m from BS 2	Infront of seawall
Sasihithlu Beach (BS 4)	$13^0$03'25"	$74^0$46'47"	5000m from BS 3	Adjacent to rivermouth
Sasihithlu Beach (BS 5)	$13^0$04'10"	$74^0$46'37"	1000m from BS 4	In the vicinity of rivermouth, southern side
Hejamadi Beach (BS 6)	$13^0$04'43"	$74^0$46'30"	Base point location on northern side of the rivermouth	In the vicinity of rivermouth, northern side
Hejamadi Beach (BS 7)	$13^0$05'12"	$74^0$46'24"	1000m from BS 6	Adjacent to rivermouth
Hejamadi Beach (BS 8)	$13^0$05'41"	$74^0$46'10"	1000m from BS 7	Infront of seawall
Hejamadi Beach (BS 9)	$13^0$06'16"	$74^0$46'05"	1000m from BS 8	Infront of seawall

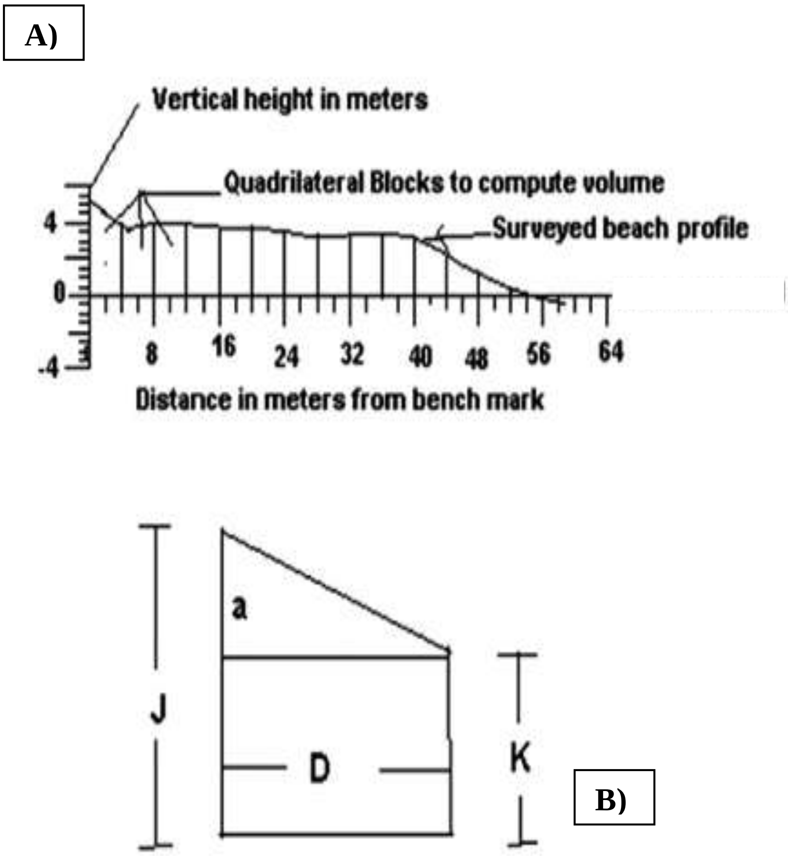


Figure.3.2 (A) Representation of beach elevation profile in X-Y co-ordinate system. The profile is split into quadrilateral blocks of 5 m length (along the profile), for computing the volume of sand for 1 m length of the beach. (B) Cross sectional view of one quadrilateral block of "*D*" meters length (5 m in this case) of the profile. "*J*" and "*K*" are the vertical heights of sand from fixed reference point at every "*D*" meters interval. "*a*" shows the difference in vertical heights of every successive data point (Gujar et al. 2011).

The logic of computation of beach volume is that along the profile from the reference benchmark, quadrilateral blocks are made at 5 m interval (Figure.3.2B). Consequently it will produce two vertical heights and one distance between two successive locations along the profile. This becomes a quadrilateral, whose area can be computed by splitting the quadrilateral into a rectangle and a right-angled triangle. The area of the rectangle, $(K \times D)$ or $(J \times D)$, where "K" or "J" are vertical heights. The area of the right angled triangle $= 1/2\ (a \times D)$, where "a" is the vertical side of the triangle (obtained by getting the difference from the two vertical sides of the quadrilateral $(J \times K)$ and "D" is the distance between data points. The total of the above two components would give the actual area of the quadrilateral. Further the volume is computed by multiplying the area of the quadrilateral by 1m width of the beach, which gives volume in cubic meters per meter (m^3/m) length of the beach.

From the shore normal transects, monthly, seasonal and annual volumetric changes per unit length of beach (m^3/m) were calculated as per the descriptions given by Mallik et al. (1987) and Gujar et al. (2011). These volumetric estimations would give the actual morphological variations at each location over a short-term evolution scale. Further, alongshore sediment movement was also calculated from the crossshore profile volumes by multiplying the alongshore distance between profiles from BS 1 to BS 9 in order to provide clear picture of alongshore sediment accumulation changes over seasonal and annual cycles (Dolan et al. 2003).

To compare the sediment volume variation between southern side and northern side of the rivermouth, the southern side and northern side volumes are computed by considering 4 km distance on both sides. To obtain the sediment volume for south and north, the average of cross-sectional volume between two profiles is multiplied with alongshore distance. For Example, AV= $\frac{X_1+X_2}{2} x D$; Here X_1 and X_2 represents the volume at two profiles, D indicates the alongshore length between the same two profiles and AV is the alongshore volume in m^3/m. In the similar way, the alongshore volume is computed for 4 km distance on both sides of the rivermouth, which would give the actual variation in sediment accumulation between southern and northern side of the rivermouth at short-term scale.

3.2.2 Beach width Measurements

Beach width is an important parameter indicates the 'health' of the beach. Understanding of how the beach width changes over varying temporal scale and spatial scale will definitely provide a proper management plan. Therefore, measuring the beachwidth is important for future shoreline management and planning (Mwakumanya et al. 2009). For instance, while planning the beach nourishment program, construction of seawall, defining hazard setbacks, identifying ‘hot spots’ (locations of enhanced erosion) and the threat that pose to coastline due to human structures and/or recreational activities (Smith et al. 1992). Thus, it is found that analyzing beach width change characteristics are very important for assessing the beach erosion vulnerability and recommending the appropriate management strategies.

The beach width was measured on either side of the rivermouth at selected locations (from BS 1 to BS 9) on weekly basis and also while carrying out beach profile survey during the study period (September 2009 to December 2011). The beachwidth measurement was made by using standard tape of 30 m length from reference point on the backshore to low waterline, where the sea water and land meets. The measured total beach width data from each station was analysed on monthly basis to see the short-term change due to oceanographic features (waves, winds and tides) and meteorological characteristics (storm and storm frequency) over seasonal time scale (season to season) and spatial scale (BS 1 to BS 9).

3.2.3 Sediment Sampling

The purpose of collecting sediment samples is to estimate sedimentary properties of beach sediment population. Therefore, the sampling must be unbiased and able to yield deposition and erosion sectors without an excessive expenditure of time. Sediment sample analysis includes the measurement of grain size distribution in samples of sedimentary materials and subsequent transformation of these measurements into descriptive statistics (mean, standard deviation, skewness and kurtosis). These statistics help to make direct comparison of one or more sample sites or sedimentary environments. Scholarship of grain size analysis has a link between the depositional environment and the sediment grain size distribution.

Total of five sampling locations were established on southern side (BS 1 to BS 5) and four on northern side (BS 6-BS 9) of the rivermouth (Figure.3.1). After determining the location of sampling site, a composite sediment sample of about 1000 grams is collected from the foreshore region, at a depth of about 10 cm deep by hand-grab method. The sediment samples are collected at the specified nine locations on monthly interval during the beach survey.

The collected samples were dried and sieved in accordance with recognized standards in a bank of phi scale sieves at 0.25 phi interval. The weights measured from each sieve are used to generate descriptive statistics. The proportion of the sample retained in each sieve is weighed and expressed as a percentage of the weight of the total sample. The weighted data is then plotted as a cumulative frequency curve from which the statistics such as mean, standard deviation, skewness and kurtosis are determined by following Folk and Ward (1957).

3.3 Data from National Data Centres

3.3.1 Wave parameters

The Indian National Centre for Ocean Information Services (INCOIS) being the central repository for marine data in the country receives voluminous oceanographic data in real time, from a variety of in-situ and remote sensing observing systems. The offshore wave climate of the NMPT region is measured by deploying wave rider buoy in the year 2007 at NMPT area, which is obtained from INCOIS, Hyderabad and the same data used for the present study.

The Indian Meteorological Department (IMD) compiles the daily synoptic observations over the Indian region and makes it available to users in the form of Indian Daily Weather Reports (IDWR). The IDWR information includes visual wave observations reported every day by merchant ships passing along the Indian region. This wave information is reported by codes of wave heights from 0 to 4.5 metres, periods in classes of one second from 5 to 19 seconds and direction in ten degree interval from 10 to 360 degrees. From IMD Pune, the grid bounded by 12° N to 14°

North latitudes 73° E to 75° East longitudes of wave data procured for the period January 2007 to December 2010. About 800 data points were thus obtained, each one representing a particular wave height, wave period and wave direction. As most ship reports are from deep water, the obtained wave data were considered as deep water waves. The direct use of visually or ship observed wave heights can be considered as significant wave heights and the same opinion is justified for most applications (Jardine, 1979; Chandamohan et al. 1988). It would be important to mention here that the ship reported wave data are in general biased towards unequal weather and the observations are made with simple means leading to only a fair estimate. Since the instrumentally recorded waves are sparse and discontinuous along the Indian coast, the use of such ship reported waves compiled for a longer duration would satisfy for wave climate analysis (Chandamohan et al. 1988).

These two data sets (INCOIS and IMD) represent wave clime for the study region. In addition, wave data from the site (breaker wave heights and breaker wave directions) were visually observed from September 2009 to December 2011 while carrying out beach survey and corresponding directions were noted down. The dataset thus obtained from these three sources is used for analysing major oceanographic characteristics such as variation in seasonal wave period, wave height and wave approaching angles. Further, the same wave climate data (INCOIS and IMD) was used as an input to estimate Longshore Sediment Transport Rate (LSTR) for the study area as per SPM (1984).

3.3.2 Wind Parameters

The wind parameters such as wind speed and wind directions are obtained from National Data centres (INCOIS and IMD) for the period from January 2007 to December 2010. These parameters would give indirect influence on shoreline over large temporal and spatial scale. Further, these parameters directly induce changes in sea and swell waves to generate waves from generating area to nearshore. As a whole wind parameters have indirect influence on shoreline change. Therefore, the wind and wave parameters are used to correlate the seasonal morphology on estuarine associated shoreline in terms of accretion and erosion.

3.3.3 River Discharge Data

The river's freshwater discharge and sediment flow into the sea are the predominant factors that control the coastal evolution, i.e. the landform shape of river mouth, the beach process and the coastal zone ecological environment (Jorge and Albert 1996; John and Charles 2005; Vousdoukas et al. 2009; Patrick and Jonathan 2010). The connection between freshwater discharge and evolution of estuarine shoreline has not yet been extensively investigated so for, for the study area.

The rivers Mulky and Pavanje are the minor rivers in Dakshina Kannada district. Among these two rivers Mulky is larger with approximate catchment area of about 1400 km^2 and Pavanje catchment is about 400 km^2. Because of the variation in catchment area, the discharge of the river also tends to vary from river to river with respect to seasons. The river discharge data are obtained from IMD substations for a period of about 14 years. The river discharge data is continues and daily basis, and it is from January 1985 to December 1998. This fourteen years dataset would give the actual effect of freshwater discharge on adjacent beaches (Mukka and Sasihithlu on southern side and Hejamadi on northern side of the rivermouth) in recent years (during last two decades). The analysis of river discharge in turn helps to see the fluctuations and trend of flow in different seasons and further provides a clear estimate of shoreline change between two important years 1988 and 1998. In addition to this, utilization of discharge data provides information about the status of Mulky-Pavanje coastline at medium-term scale.

3.3.4 Rainfall Data

The impact of storms in the coastal zone induces a series of processes. In the coastal environments, the impact of the storm induces a significant coastal response in such a way that the intensity of the storm could be affected by enhancing or reducing longshore sediment movement or crossshore sediment dynamics. For instance, the longshore dynamics do exist during high energetic storm periods but the cross-shore transport is of a greater magnitude.

Some of the effects directly related to storm characteristics such as wave height, wave period, river discharge, water level whilst others are related to the coast subjected to the impact, for instance: coastal sediment material movement or morphology, relative shoreline orientation and associated nearshore circulation and other relevant factors.

The rainfall data was procured from two different sub stations of IMD (Panambur and Kateel). The rainfall data from these two sources is continues and daily basis, confined to very recent precipitation of the region ranging from January 1985 to December 2011. These two datasets were analysed for seasonal variations and annual fluctuations on coastal processes.

3.3.5 Shoreline Change Detection

One of the most important research subjects of coastal geomorphology studies is to quantify erosion/accretion pattern and shifting of shoreline. There are several factors affecting shoreline change such as bathymetry, shoreface, sea level fluctuations, sediment budget, longshore sediment transport and tectonic activity. In order to ensure sustainable development of coastal zone, it is necessary to develop accurate, up-to-date and comprehensive scientific analysis for the selected region.

Generally short-term variation is induced over periods ranging from days to seasons whereas long-term variations (the rise in sea level, the shift in natural sediment supply) occur over a period of decades to centuries. Hence, the shoreline changes directly affect the economic development and land-use management. Because of this reason, long-term trend of the shoreline and short-term impacts on shoreline needs to be studied in detailed manner.

In order to establish the time series analysis of shoreline of Mulky-Pavanje rivermouth different data sets have been used to extract the shorelines of five different periods. They are basically topographic maps and satellite images. Two different sets

of five different periods of maps and images are gathered from two different sources. Details of data products and their purposes are provided in Table 3.3.
The common techniques involved in analysing the shoreline changes are as follows.

1. Base map preparation, scanning and geo-referencing of satellite data,
2. Visual interpretation and on-screen digitisation,
3. Change detection, and
4. Shoreline changes.

Table. 3.3 Details of data products and their purposes in the present study

Remote Sensing Data				
Year	**Type of the data**	**Source**	**Approximate scale**	**Purpose**
1912	Toposheet	Survey of India	1:25, 000	1. To compare the rivermouth configurations over short-term, medium-term and long term scales. 2. To see the spit dynamics on either side of the rivermouth. 3. To understand the long-term, medium-term and short-term shoreline changes.
1988	Toposheet	Survey of India	1:50,000	
1998	IRS – 1D LISS III	NRSC	23.5 m resolution	
2003	IRS – 1D LISS III	NRSC	23.5 m resolution	
2006	IRS – P6 LISS III	NRSC	23.5 m resolution	
2009	IRS –P6 LISS IV (MX)	NRSC	5.8 m resolution	
2009-2011	GPS survey	Field visit/ Monthly	Covering a distance of about 12 km on either side of the rivermouth	To quantity the erosion and deposition pattern.

3.3.5.1 Remote Sensing Data

Remote sensing is the technology of acquiring data through a device which is located at a distance away from the object without any physical contact, and analysis of the data for interpreting the physical attribute of the object. Both these aspects are intimately linked to each other.

Remote sensing data could be either analog or digital form, representing in the real world. Data may be acquired through a variety of devices depending upon the object or phenomena being observed. Most of the remote sensing techniques make use of emitted or reflected electromagnetic radiation of the object of interest in a certain frequency domain (infrared, visible light, microwaves). This is possible due to the fact that the examined objects (vegetation, houses, water body and so on) reflect or emit radiation in different wavelengths and in different intensity according to their current condition.

Four remotely sensed imageries were obtained from National Remote Sensing Center (NRSC), Hyderabad. In addition, two topomaps were obtained from Survey of India (SOI) in order to asses the changes in the shoreline, since 1912, and the details are presented in Table 3.3.

3.3.5.2 Geographic Information System (GIS)

Geographic Information System (GIS) is an automated tool for assisting the capture, storage, management, analysis, display and retrieval of spatially displaced information. GIS is defined as an information system that is used to input, store, retrieve, manipulate, analyze geographically referenced data or geospatial data, in order to support decision making for planning and management of shoreline, natural resources, environment, transportation, land use/land cover, oceanography, and other coastal administrative records.

3.3.5.3 Software used

In order to assess the changes in shoreline at five temporal conditions, ERDAS Imagine 9.2 and ArcGIS 8.2 are used for digital image processing and for the creation of maps respectively.

3.3.5.3.1 ERDAS Imagine

ERDAS (Earth Resources Data Analysis System) Imagine Version 9.2 is designed specifically for satellite image processing. ERDAS Imagine is a suite of software tools designed specifically to process geospatial imagery. With its large and easy to use selection of image processing tools, ERDAS Imagine both simplifies and streamlines the workflow.

3.3.5.3.2 ArcGIS 8.2

ArcGIS is the name of group of desktop Geographic Information System (GIS) software product lines produced by ESRI. ArcGIS includes: ArcReader, which allows to view query maps created with the other Arc Products; ArcView allows one to view spatial data, create maps, and perform basic spatial analysis; ArcEditor which includes all the functionality of ArcView and consists of more advanced tools for manipulation of shape files and geodatabases.

3.4 Long-term and short-term shoreline changes

To understand the long-term shoreline change configurations in the vicinity of Mulky-Pavanje rivermouth, data are acquired from topographic maps and multidated remote sensing imageries. For the longterm shoreline change analyses, multidated temporal and spatial data analyses are made using ERDAS imagine software, 9.2 version; observation of the rivermouth configuration and associated shoreline changes are monitored using Global Positioning System (GPS). Survey of India Toposheets (1912 and 1988) on a scale of 1:25,000, IRS-1D LISS III Imageries of January 1998 and December 2003 and May 2006 and IRS–P6 LISS IV (MX) of April 2009 and Google Earth 2006 constitute the database for the analyses of long-term changes in the configuration of the estuarine beach. Based on the changes observed from Survey of India Toposheet (1912), the changes in shoreline and rivermouth configuration around the Mulky Pavanje rivermouth are assessed over a period of 97 years, from 1912 to 2009.

The shoreline obtained from the Survey of India Toposheet of 1912 and 1988, and data obtained from satellite are kept in different coverages in the same projection and map coordinates. These five coverages were overlaid through ArcGIS 8.2. Shoreline change map of 1912-1988, 1988-1998, 1998-2003, 2003-2006 and 2006-2009 are generated. Finally, accretion/recession of shoreline is measured at every 250 m interval to evaluate long-term changes (1912-1988) and short-term (1988-1998, 1998-2003, 2003-2006 and 2006-2009) changes.

3.5 Land use/ Land cover changes

Remote sensing satellite data provides a synoptic view of the coastal zones. The modern scientific technologies of remote sensing and digital image processing are extremely useful in periodic assessment of the coastal land use/land cover changes and analyze them to formulate better management plan. There are many case studies that used satellite imagery and digital image processing techniques to map coastal zones, coastal landforms and shoreline conditions (Chauhan et al. 2005; Yagoub et al. 2006; Mani Murali et al. 2007).

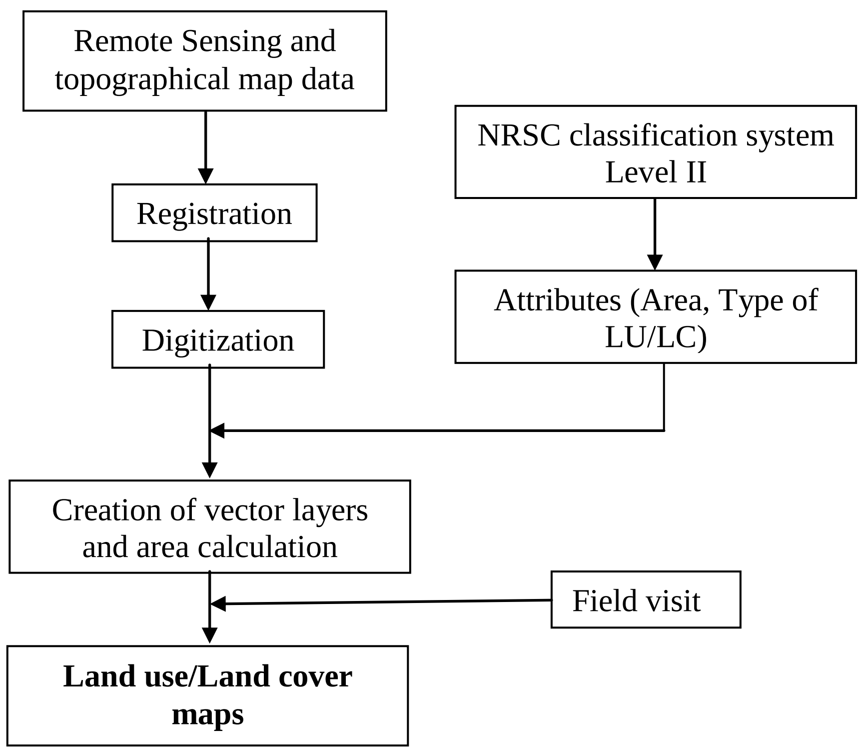


Figure.3.3 Flowchart showing methodology for Land use/Land cover map preparation.

The Land use/ Land cover (LU/LC) map represents the spatial distribution of various land use/ land cover categories like built-up land, agricultural land, water bodies, mangroves etc. Information on the existing LU/LC pattern and its spatial distribution studies is required for planning, utilization and formulation of developmental activities.

Due to large special coverage of satellite images, the region around the Mulky-Pavanje rivermouth is selected and analysed for Land use/ Land cover change detection in recent years**.** For land use/ land cover changes recent satellite imageries, IRS – 1C LISS III (1998) and IRS-P5 LISS IV (2009) imageries are used to detect the changes in land use pattern. These images are geometrically corrected using a Survey of India Toposheet 1988. The change detection is carried out upto level II classification based on standard NRSC classification system. The ERDAS Imagine 9.2 is used to register images, then the vector layers of various land use/land cover features and attributes of these areas such as area, type of land use/land cover are detailed and then the final map was composed using ArcGIS 8.2. The flow chart shown in Figure.3.3 represents methodology for preparation of LU/LC maps.

A 3 km X 3 km area was considered around the rivermouth for classification, since dynamic changes occur mostly around in this region. The changes in the land features have been identified and assigned classes based on visual interpretation.

3.6 Modelling of coastal processes with ANN

The use of Artificial Neural Network (ANN) to model the coastal processes has achieved increased reorganisation. Most of the researchers have used ANN to model their process rather than conventional methods. Among the research works, most of the researchers have concentrated on wave height prediction and very few researchers oriented towards estimation and prediction of littoral drift. By keeping these views in mind, the current research work also attempted to model aforementioned parameters with the application of ANN.

3.6.1 Working Principle of ANN

Artificial neural networks (ANNs) are inspired by biological neurons of the human brain. In this method, every input vector is related with the corresponding output vector (Figure. 3.4). It consists of three layered neural network with input, output and hidden layers and the relation between the neurons. The neural network contains computational elements called nodes or neurons, which undertake the task of combination of inputs and estimation of their weights. Then the values of all nodes are applied on the transfer function. For example, for a sigmoid transfer function, the relation between inputs and output is shown as follows:

Mathematically ANN can be represented as,

$$O=1/(1+e^{-S}) \quad \text{..........................(3.1)}$$

$$\text{where } S=(x_1w_1+x_2w_2+x_3w_3+........)+b \quad \text{......................... (3.2)}$$

In which, O = output from the network; x_1,x_2,x_3...........= input values; w_1,w_2,w_3..........= weight values ; b= bias value. Equation (3.1) indicates a transfer function of sigmoid in nature, which is commonly used.

Basically the objective of training is to reduce the global error E, defined below

$$E = \frac{1}{n}\sum E_p \quad \text{...........................(3.3)}$$

where p is the total number of training patterns, E_p is the error at p^{th} training pattern is given by

$$Ep = 0.5\sum(T_k - O_k)^2 \quad \text{.......................... (3.4)}$$

where n is the total number of output nodes, O_k is the output at the k^{th} output node and T_k is the target output at the k^{th} output nodes.

In every training algorithm, an attempt is made to reduce this global error by adjusting the weights and biases.

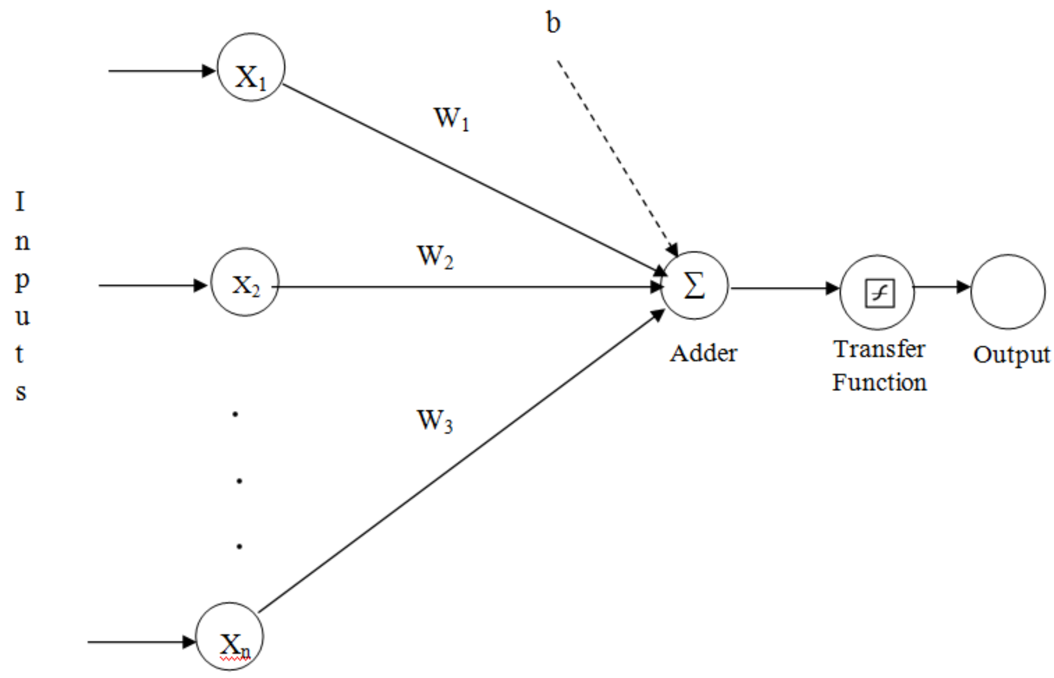


Figure.3.4 A typical sketch of Artificial Neural Network

The time series wave data obtained from INCOIS and IMD are used to model the coastal processes. Two different neural network models such as FFBP (Feed Forward Back Propagation) and NARX (Nonlinear Autoregressive Exogenous Inputs) are used to predict the significant wave height with lead period from 3hr to 120hr with varying time intervals 3hr, 6hr, 12hr, 24hr, 48hr, 72hr, 96hr and 120hr. The period of data is 48 months, ranging from 1st January 2007 to 31st December 2010. The time series significant wave height over the period is considered for analysis. Further the wave climate data obtained from INCOIS (January 2007 to December 2010) and the same neural networks (FFBP and NARX) are used to predict littoral drift for the study area.

3.6.2 Feed Forward Back Propagation (FFBP)

A Feed Forward Back Propagation Network (FFBP) is one of the most commonly used neural network type, which is composed of a set of nodes and connections. The nodes are arranged in layers, the connections are typically formed by connecting each of the nodes in a given layer to all neurons in next layer. In this way every node in a given layer is connected to every node in the next layer. Typically a feed forward network consists of three layers like input layer, hidden layer and output layer as shown in Figure. 3.5. The multi-layered neural network trained by back-propagation algorithm, consists of a three-layered neural network with an input layer, a hidden layer and an output layer, and is utilized for wave height and littoral drift prediction. Each layer consists of several neurons and the layers are interconnected by sets of correlation weights. The neurons receive inputs from the initial inputs and produce outputs by transformation using an adequate nonlinear transfer function. In the back-propagation neural network, the error at the output layer propagates backwards to the input layer through a hidden layer to obtain the desired outputs.

In Figure 3.5, where X_i (i= 1, 2,…, M) represents the input parameters: Y_i (i = 1, 2,…,N) represents the output of neurons in the hidden layer and Z_i (i= 1, 2,…,O) represents the outputs of the neural network. The weight matrix connected to the inputs is called input weights (W_{ij}) matrix, while the weight matrices coming from hidden layer are called hidden weights (W_{jk}).

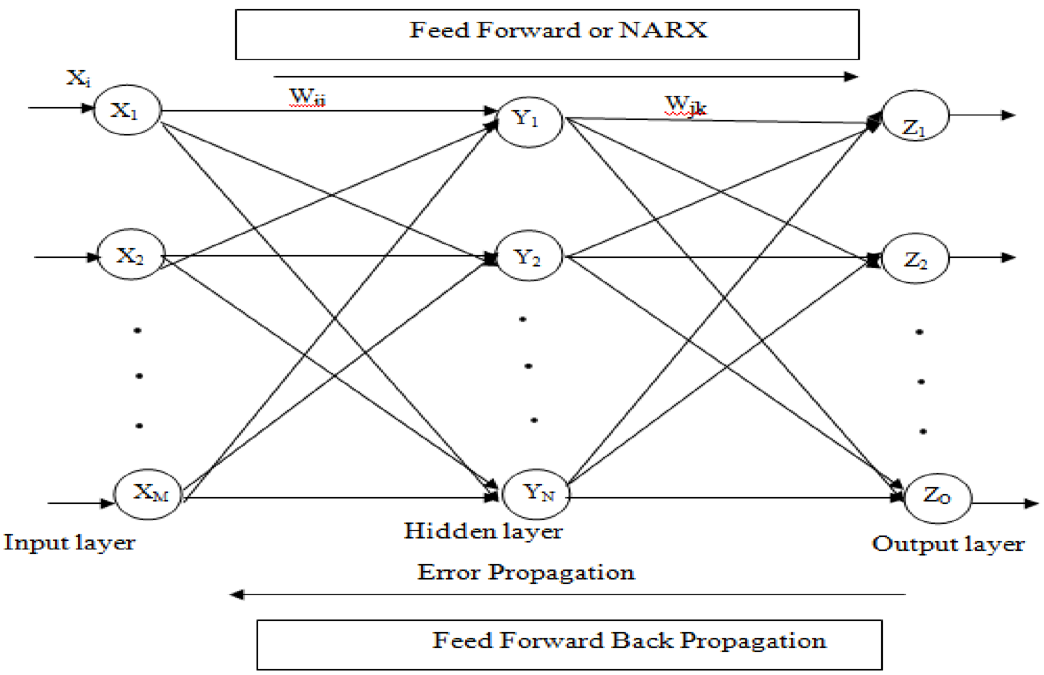


Figure.3.5 Three- layered feed forward back propagation neural network

3.6.3 Nonlinear Autoregressive Exogenous Inputs (NARX)

The Nonlinear Autoregressive model with Exogenous inputs (NARX) model is the other network system in ANN characterized by the non-linear relations between the past inputs, past outputs and the predicted process output and it can be delineated by the high order differential equation, as follows,

$$y\ (t) = g\left(y(t-1), \ldots, y(t-n_y), x(t), \ldots, x(t-n_x)\right) \qquad \text{.........................(3.5)}$$

where x and y are the system input and output vectors, respectively; n_x and n_y are the maximum lags in the input and output, respectively; g is a linear or nonlinear function. The inputs of the NARX neural network are $y(t-1)$, …, $y(t-n_y)$, and $x(t)$, …, $x(t-n_x)$ and the output of the NARX neural network is $y\ (t)$. (Mandal et al.2005). In this case, error form the output layer will not propagate backward, instead it produces directly desired output by minimizing the error (Figure.3.5). To compare the performance of FFBP with NARX, additionally NARX model is utilized to predict wave height and littoral drift.

Neural Network Toolbox of version 7.8.0 of MATLAB is used to model the neural network. The basic steps involved in modelling the network are: collection of input/output datasets; modelling of the neural network; training and testing of the neural network; simulation and prediction with new input data sets; and analysis and post-processing of predicted results.

3.6.4 Model Development for Wave Height Forecasting

For the wave height forecasting, total available data were divided into two parts, with the first 70% portion used for training and the remaining 30% employed for testing the network. To begin with a large number of input and output combinations are tried so as to obtain best training and testing performance. The trails included providing the input with significant wave height values of the preceding 1-8 time steps one by one (i.e 3hr, 6hr, 9hr, 12hr, 18hr, 21hr and 24hr) and forecasted output consisting of the significant wave height value for the lead time of 3hr, 6hr, 9hr 12hr, 24hr, 48hr, 72hr and 120hr. The number of hidden neurons is tried from 1 to 30 to check the best performance of various networks. Two different networks such as FFBP and NARX are used to predict the significant wave height with lead period from 3hr to 120hr.

3.6.5 Model Development for Littoral Drift Prediction

The phenomenon of littoral drift is influenced by a variety of causative factors; some of which could be very important while some others may not be so influential in determining the rate of littoral drift. The Shore Protection Manual (1984) as well as the Coastal Engineering Manual (2002) list following variables as influencing parameters to cause littoral drift in any region. They are, significant wave height (H_s), significant or zero crossing wave period (T_z), breaking wave height (H_b), angle of wave at the time of breaking (α_b) width of breaking (surf) zone (W), sediment size (D_{50}) and longshore current (V) (Singh et al., 2008).

Here the data (wave data) obtained from INCOIS for a period ranging from January 2007 to December 2007 used to obtain H_s, H_b, α_b, and T_z, since INCOIS dataset provide continues records. Due to non availability of width of the surf zone data for the selected site, the parameter width of the surf zone is replaced with beach width, assuming that width of the surf zone is more or less same with beach width. The set of all these parameters are used as input to the model and the estimated longshore sediment transport rate (Q) through SPM (1984) is considered as output to the model.

For the sake of littoral drift prediction, total available data were divided into two parts, with the first 70% portion used for training and the remaining 30% employed for testing the network. Here also networks FFBP and NARX are used to predict littoral drift. Further the prediction accuracy of the developed models is checked by calculating the performance indices/error statistics.

3.6.6 Network Performance Analysis

The performance of the neural network model depends on the optimised neural network structure. In general, the factors affecting the neural network structures include the number of hidden layers, the learning factors, the number of training iterations and the number of neurons in each layer. In order to assess the performance of the neural network with these parameters, the performance indices such as the root mean squared error (RMSE), correlation coefficient (CC) and coefficient of efficiency (CE) are calculated. They are given in the following equations.

Root Mean Square Error (RMSE)

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{n}} \qquad \text{.........................(3.6)}$$

The prediction accuracy of the network was judged by calculating the correlation coefficient (CC) between the predicted and observed wave heights. Hence, the correlation coefficient (CC) of predicted data over observed values is calculated using the formula

$$\mathrm{CC} = \frac{\sum_{i=1}^{n} x_i y_i}{\sqrt{\sum_{i=1}^{n} {x_i}^2 \sum_{i=1}^{n} {y_i}^2}} \qquad \text{......................... (3.7)}$$

Addition to these, the coefficient of efficiency (CE) is used as scores to evaluate the model performances. Hence CE is defined as one minus the ratio of mean square error to observation variance and is given by

$$\mathrm{CE} = 1 - \frac{\sum_{i=1}^{n}(X_i - y_i)^2}{\sum_{i=1}^{n}(X_i - \bar{X})^2} \qquad \text{......................... (3.8)}$$

where $x_i = X_i - \bar{X}$ and $y_i = Y_i - \bar{Y}$ Xi is the ith observed values, $\bar{X}$ is the mean of X: Y_i is i^{th} predicted values, $\bar{Y}$ is mean of Y: n is the total number of observations.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

Monitoring of shoreline changes is one the very important necessities in the domain of coastal engineering in order to provide proper plan and management of coastal zones in a sustainable manner. The monitoring processes usually involve three types of temporal scales such as long-term (>60 years), medium-term (10-60 years) and short-term (<10 years) with varying spatial scales. For the sake of short-term shoreline monitoring conventional data such as shore normal profiles (beach profile), sediment sampling, beach width measurements and wave and wind parameters pertaining to selected study area were obtained from field visit and national data centers. The data period comprises about 28 months, i.e September 2009 to December 2011. In addition, precipitation and freshwater discharge for two catchments were obtained from Indian Meteorological Department (IMD) for the periods 1985-2011 and 1985-1998 respectively, that were analysed for medium-term changes. Also long-term and short-term shoreline change analyses were made through multidated satellite imageries, procured from National Remote Sensing Center and topographical maps from Survey of India. From this database, short-term and long-term changes and morphological variations, and their interdependency were analyzed and discussed in the following sections.

4.2 Short-term Shoreline Changes

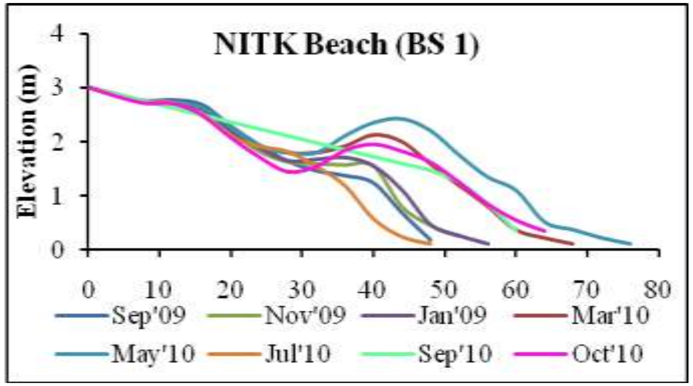
4.2.1 Beach Profile Analysis

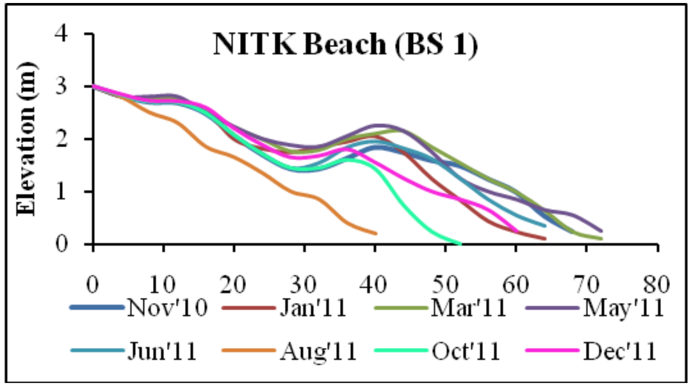
The analyses of beach profiles were initially aimed for seasonal changes and later for short-term changes. Therefore, this section begins with seasonal variations and later part describes short-term changes by considering complete study period. Here, the seasons are classified based on coastal wave and wind conditions of the region. Based on wave climate of the region, the months between June and September are normally referred as monsoon period. The transition periods prior to the monsoon and after the monsoon are considered as pre-monsoon (February to May) and post-monsoon (October to January) seasons respectively.

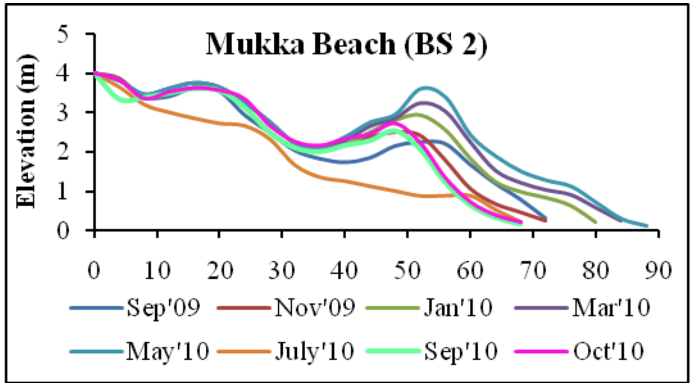
The monthly and seasonal variation in the beach profiles and computation of volume changes of the beaches in the vicinity of the Mulky-Pavanje rivermouth are presented in Figure. 4.1 and Table. 4.1. The monthly profiles showed a gradual accretion from post-monsoon to pre-monsoon and high rate of erosion during monsoon. The seasonal profiles in general showed net erosion on the beaches towards the north of the rivermouth whereas the south of the rivermouth experienced net accretion during the study period.

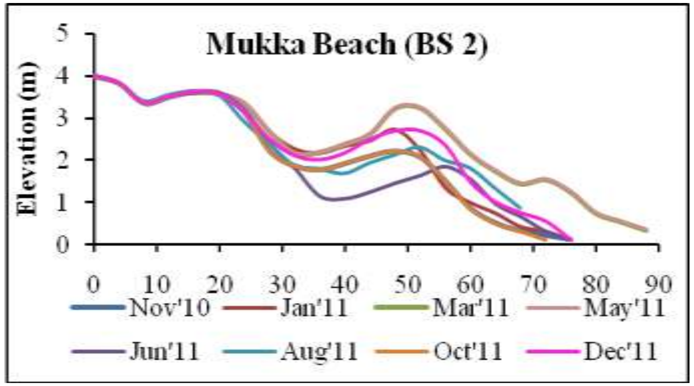
4.2.1.1 Pre-monsoon Period (Feb 2010-May 2010, Feb 2011-May 2011)

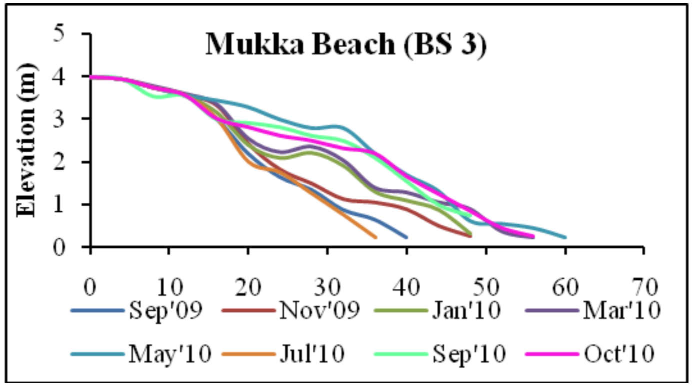
The superimposition of profiles of February 2010 on that of May 2010 and February 2011 on May 2011 revealed stable, wider and flatter beaches on either side of the rivermouth. All the profiles accreted at their maximum limit. However, there is difference in accretion pattern between southern and northern profiles. The profiles on southern side of the rivermouth the trend of deposition are gradually increased from BS 1 to BS 5 (102.5, 162.1, 104.2, 102.7, 181.8 in May 2010; 110.5, 165.2, 105.8, 137.9, 188.7 in May 2011). The similar trend is further observed on northern side from BS 9 to BS 6 (93.1, 94.5, 108.9, 122.3 in May 2010; 89.5, 92.2, 104.4, 125.5 in May 2011), suggests that pre-monsoon season is favourable for deposition. The dominant wave period during this period is 10 to 16 seconds, and wave height is less than 0.5 m. Further, due to less rainfall and discharge, stable profiles (BS 5 and BS 6) are observed in the vicinity of rivermouth (BS 5:181.8, 188.7 in May 2010 and May 2011 respectively; BS 6: 122.3 and 125.5 in May 2010 and May 2011 respectively). The above observations clearly suggest that rivermouth profiles accreted well during

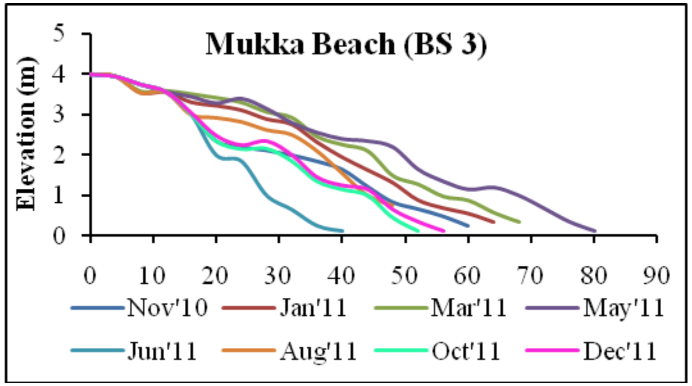

NITK Beach (BS 1)
Elevation (m)
Sep'09 Nov'09 Jan'09 Mar'10
May'10 Jul'10 Sep'10 Oct'10

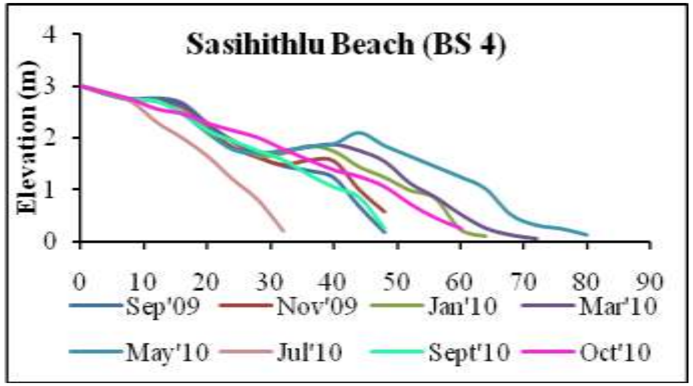

NITK Beach (BS 1)
Elevation (m)
Nov'10 Jan'11 Mar'11 May'11
Jun'11 Aug'11 Oct'11 Dec'11

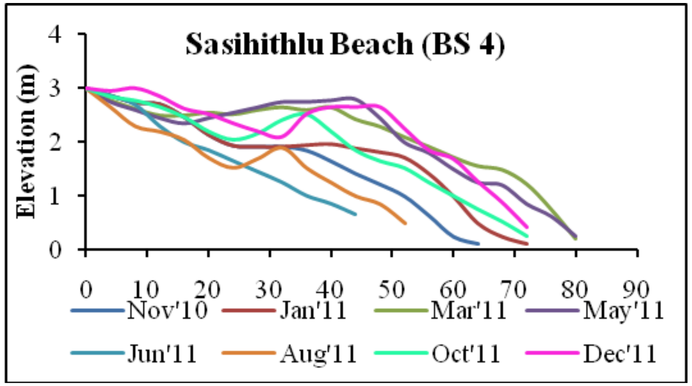

Mukka Beach (BS 2)
Elevation (m)
Sep'09 Nov'09 Jan'10 Mar'10
May'10 July'10 Sep'10 Oct'10

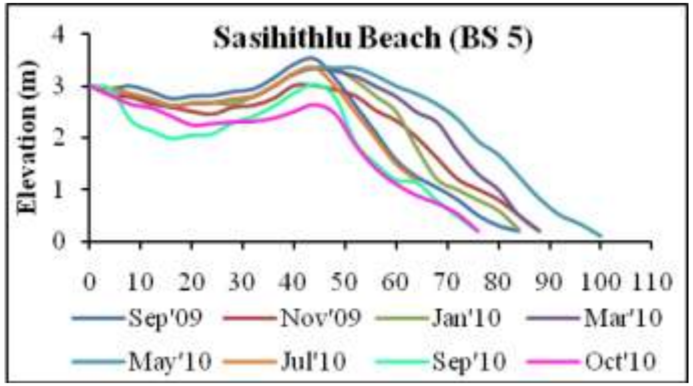

Mukka Beach (BS 2)
Elevation (m)
Nov'10 Jan'11 Mar'11 May'11
Jun'11 Aug'11 Oct'11 Dec'11

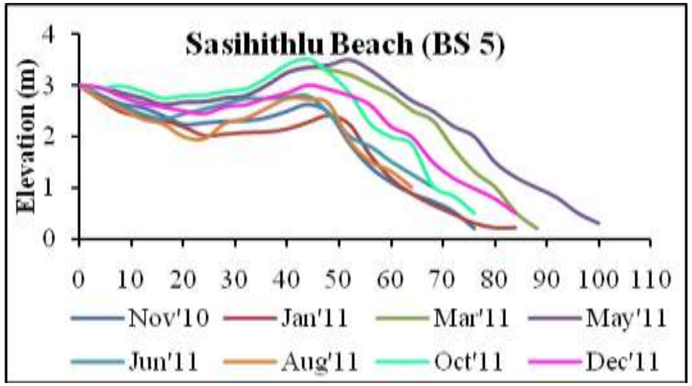

Mukka Beach (BS 3)
Elevation (m)
0 1 2 3 4 5
0 10 20 30 40 50 60 70
Sep'09
Nov'09
Jan'10
Mar'10
May'10
Jul'10
Sep'10
Oct'10

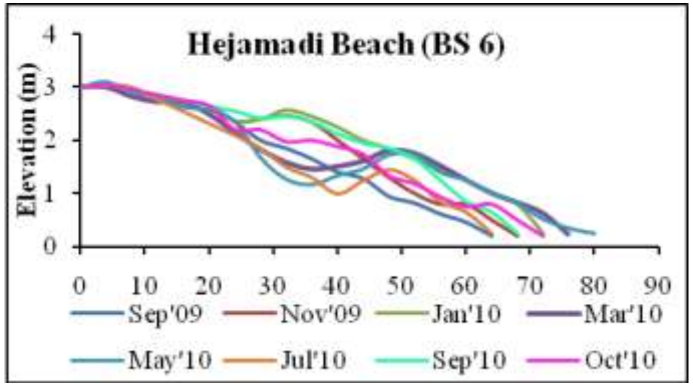

Mukka Beach (BS 3)
Elevation (m)
0 1 2 3 4 5
0 10 20 30 40 50 60 70 80 90
Nov'10
Jan'11
Mar'11
May'11
Jun'11
Aug'11
Oct'11
Dec'11

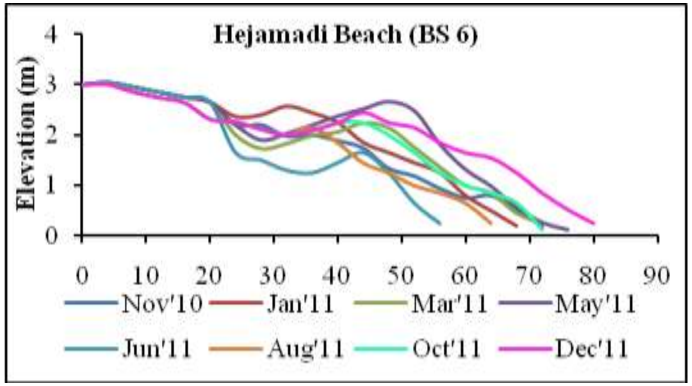

Sasihithlu Beach (BS 4)
Elevation (m)
0 1 2 3 4
0 10 20 30 40 50 60 70 80 90
Sep'09
Nov'09
Jan'10
Mar'10
May'10
Jul'10
Sept'10
Oct'10

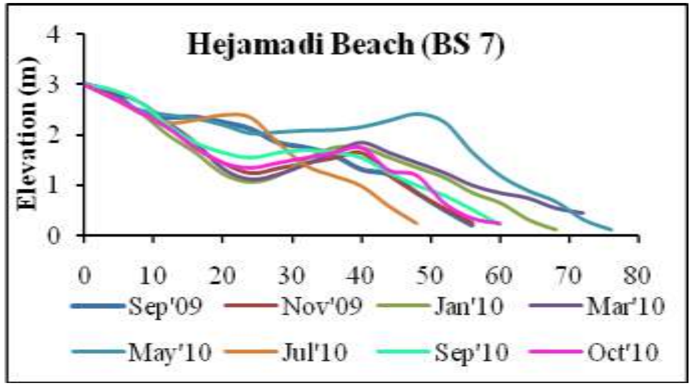

Sasihithlu Beach (BS 4)
Elevation (m)
0 1 2 3 4
0 10 20 30 40 50 60 70 80 90
Nov'10
Jan'11
Mar'11
May'11
Jun'11
Aug'11
Oct'11
Dec'11

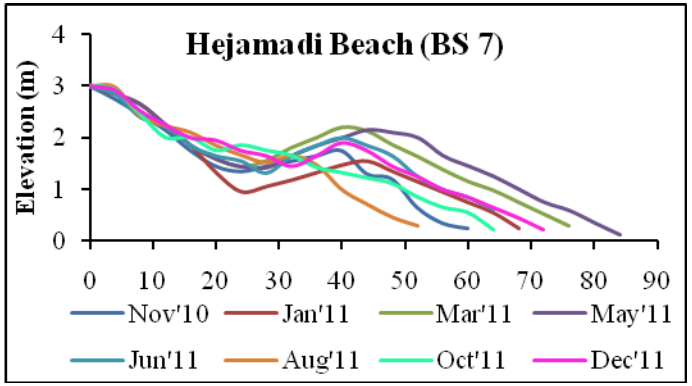

Sasihithlu Beach (BS 5)
Elevation (m)
0 1 2 3 4
0 10 20 30 40 50 60 70 80 90 100 110
Sep'09 Nov'09 Jan'10 Mar'10
May'10 Jul'10 Sep'10 Oct'10

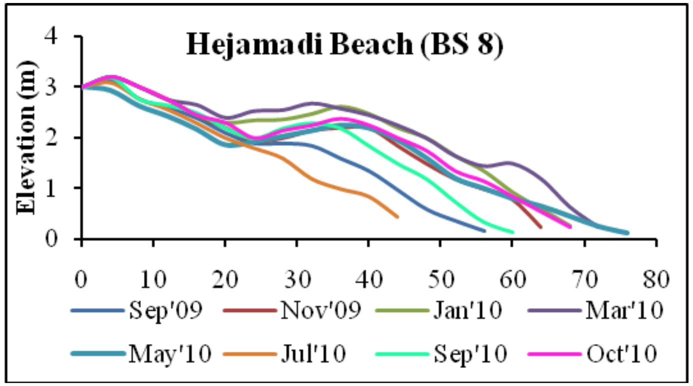

Sasihithlu Beach (BS 5)
Elevation (m)
0 1 2 3 4
0 10 20 30 40 50 60 70 80 90 100 110
Nov'10 Jan'11 Mar'11 May'11
Jun'11 Aug'11 Oct'11 Dec'11

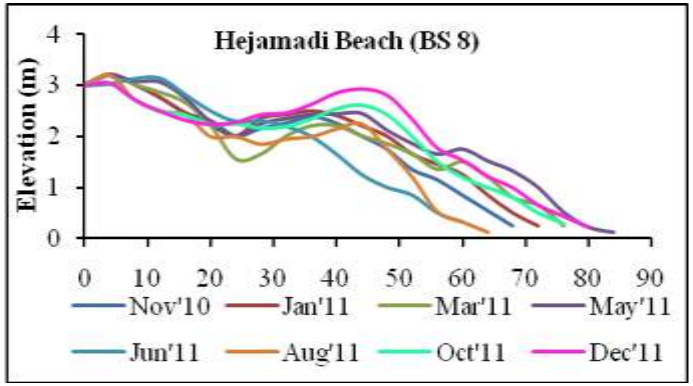

Hejamadi Beach (BS 6)
Elevation (m)
0 1 2 3 4
0 10 20 30 40 50 60 70 80 90
Sep'09 Nov'09 Jan'10 Mar'10
May'10 Jul'10 Sep'10 Oct'10

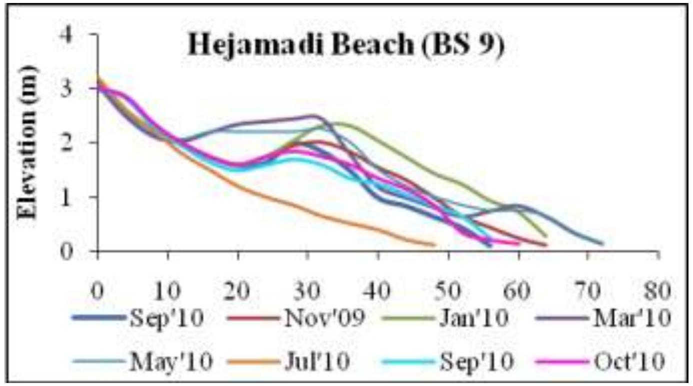

Hejamadi Beach (BS 6)
Elevation (m)
0 1 2 3 4
0 10 20 30 40 50 60 70 80 90
Nov'10 Jan'11 Mar'11 May'11
Jun'11 Aug'11 Oct'11 Dec'11


Hejamadi Beach (BS 7)
Elevation (m)
4
3
2
1
0
0
10
20
30
40
50
60
70
80
Sep'09
Nov'09
Jan'10
Mar'10
May'10
Jul'10
Sep'10
Oct'10


Hejamadi Beach (BS 7)
Elevation (m)
4
3
2
1
0
0
10
20
30
40
50
60
70
80
90
Nov'10
Jan'11
Mar'11
May'11
Jun'11
Aug'11
Oct'11
Dec'11


Hejamadi Beach (BS 8)
Elevation (m)
4
3
2
1
0
0
10
20
30
40
50
60
70
80
Sep'09
Nov'09
Jan'10
Mar'10
May'10
Jul'10
Sep'10
Oct'10


Hejamadi Beach (BS 8)
Elevation (m)
4
3
2
1
0
0
10
20
30
40
50
60
70
80
90
Nov'10
Jan'11
Mar'11
May'11
Jun'11
Aug'11
Oct'11
Dec'11



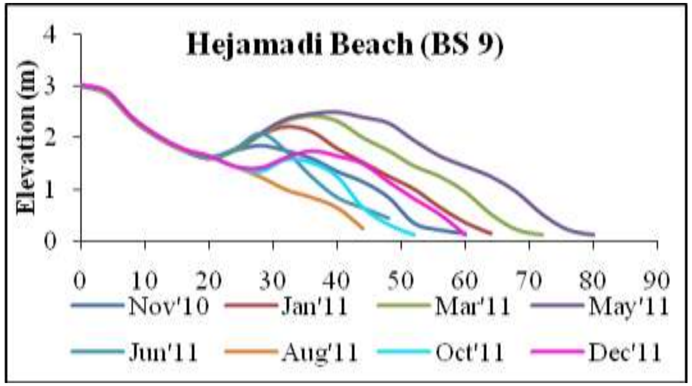


Figure. 4.1 Monthly variation in beach profiles from BS 1 to BS 9. Here X-axis indicates crossshore distance from the reference point (m); Y axis represents elevation (m) with respect to Bench Mark.

Table.4.1 Accretion and erosion of sediment during different months across the profiles

Months	Beach volume (m^3/m)									Seasons
	BS 1	**BS 2**	**BS 3**	**BS 4**	**BS 5**	**BS 6**	**BS 7**	**BS 8**	**BS 9**	
Sep'09	68.1	127.3	65.1	70.9	113.0	102.0	71.9	62.5	59.2	Post-monsoon
Oct'09	66.7	118.5	72.5	74.3	122.3	95.3	75.9	67.9	61.8	
Nov'09	70.8	126.5	75.9	73.2	117.6	104.9	76.4	71.5	65.6	
Dec'09	73.0	133.0	81.3	73.7	137.9	108.8	82.1	74.5	71.8	
Jan'10	81.6	142.6	83.6	85.9	142.2	110.3	84.3	76.5	75.0	
Feb'10	84.9	146.6	87.7	88.1	157.2	113.3	87.9	80.3	79.2	Pre-monsoon
Mar'10	89.9	154.0	90.3	90.7	164.2	116.3	91.4	82.5	83.3	
Apr'10	96.6	158.2	96.4	97.6	179.4	119.3	100.6	88.4	87.1	
May'10	102.5	162.1	104.2	102.7	181.8	122.3	108.9	94.5	93.1	
Jun'10	77.2	98.7	65.1	77.9	168.1	125.3	75.5	78.7	56.3	Monsoon
Jul'10	63.3	88.4	57.9	66.7	170.7	121.8	67.7	61.0	42.2	
Aug'10	71.0	93.1	65.1	71.3	131.0	100.4	76.7	63.5	50.9	
Sept'10	87.8	120.0	74.3	70.5	116.4	106.3	74.9	65.6	64.0	

Months	Beach volume (m^3/m)									Seasons
	BS 1	BS 2	BS 3	BS 4	BS 5	BS 6	BS 7	BS 8	BS 9	
Oct'10	85.8	125.9	86.7	82.0	125.9	85.8	67.3	74.4	67.2	Post-monsoon
Nov'10	88.7	119.7	93.1	86.0	114.8	98.0	71.4	80.1	69.2	
Dec'10	95.7	126.8	97.6	95.2	128.2	102.5	75.5	83.4	72.9	
Jan'11	83.5	129.7	99.8	99.6	141.4	104.5	76.0	85.5	78.5	
Feb'11	94.0	135.4	108.8	123.6	152.2	111.9	83.5	87.9	80.8	Pre-monsoon
Mar'11	97.2	143.0	103.0	130.3	166.2	114.2	90.3	90.4	82.6	
Apr'11	96.4	153.1	106.1	134.6	172.2	119.0	98.1	91.5	87.9	
May'11	110.5	165.2	105.8	137.9	188.7	125.5	104.4	92.2	89.5	
Jun'11	75.1	113.7	75.1	97.1	142.5	127.6	84.9	89.2	61.2	Monsoon
Jul'11	62.1	128.7	67.9	84.8	151.6	118.8	75.9	74.9	46.2	
Aug'11	57.3	125.1	65.1	68.9	139.7	125.9	66.8	89.2	51.1	
Sept'11	68.1	126.3	72.5	82.0	129.5	97.7	68.9	102.9	54.3	
Oct'11	66.7	119.0	81.3	104.7	118.7	104.7	76.3	112.7	59.6	Post-monsoon
Nov'11	70.8	126.7	94.3	111.2	120.5	111.9	81.3	126.4	64.0	
Dec'11	79.4	135.5	97.3	123.8	147.5	119.3	88.8	123.6	70.7	

pre-monsoon season. The noteworthy point during the pre-monsoon is formation of sand bar at the nearshore region, especially at BS 5 (Appendix II).

During the pre-monsoon, wind speed decreases and wave period increases, waves will start approaching from West and Northwest leading to northerly drift. This northerly drift removes the sand material from North (BS 9 to BS 5) and transports towards South (BS 5 to BS 1). Hence, most of the profiles on southern side (Feb'10 to May'10: BS 1 – 84.9 to 102.5 m^3/m; BS 2 – 146.6 to 162.1 m^3/m; BS 3 – 87.7 to 104.2 m^3/m; BS 4 – 88.1 to 102.7 m^3/m; BS 5 – 157.2 to 181.8 m^3/m) accreted more as compared with northern side (BS 6 – 113.3 to 122.3 m^3/m; BS 7 – 87.9 to 108.9 m^3/m; BS 8 –80.3 to 94.5 m^3/m; BS 9 –79.2 to 93.1 m^3/m) profiles.

4.2.1.2 Monsoon Period (June-2010-Sept 2010 and June 2011-Sept-2011)

The superimposition of profiles of May 2010 on that of July 2010 and May 2011 on July 2011 indicates net erosion from BS 1 to BS 9. This feature suggests that significant shoreward transport of materials from the profiles during monsoon months. The beach near the rivermouth on southern side accreted more sediment due to onset of monsoon (BS 5: 170.4 m^3/m and 151.6 m^3/m in July 2010 and July 2011) compare to the other profiles, whereas on northern side the profile (BS 6: 121.8 m^3/m and 118.8 m^3/m in July 2010 and July 2011) is eroded. At the same time the profiles away from the rivermouth on southern side (BS 1, BS 2, BS 3 and BS 4) and northern side (BS 7, BS 8 and BS 9) experienced relatively more erosion (Refer Table.4.1, June to Sept profiles for the years 2010 and 2011). This feature indicates that the effect of river discharge during the monsoon on beaches away from the rivermouth is very less. But near the rivermouth, it is more, particularly at BS 5. The trend of accretion at BS 5 is the clear indication of high monsoonal river discharge and longshore sediment transport towards south during this period. However, the common trend of erosion in this season has resulted in a steeper foreshore slope and reflective behaviour of beaches. At some places severe erosion in the lower foreshore resulted in the collapse of the seawall and temporary berm in the lower foreshore–like beach cliff (Appendix II).

4.2.1.3 Post-monsoon Period (Oct 2009—Jan 2010, Oct 2010-Jan 2011 and Oct 2011-Dec 2011)

The comparison of profiles from October 2009 to January 2010, October 2010 to January 2011, October 2011 to December 2011 indicated that all the nine profiles (BS 1 to BS 9) accreted followed by monsoonal erosional phase. The beaches near the rivermouth have shown alternative accretion and erosion processes (Oct’09-Jan’10, BS 5: 122.3, 117.6, 137.9, 142.2, and BS 6: 95.3, 104.9, 108.8, 110.3; Oct’10-Jan’11, BS 5:125.9, 114.8, 128.8, 141.4, and BS 6: 85.8, 98.0, 102.5, 104.5). This is due to gradual reduction in freshwater flow in the rivermouth and subsequent adjustment of sediment deposition pattern. However, the beaches away from the rivermouth (BS 1, BS 2, BS 3, BS 4, BS 7, BS 8 and BS 9), the trend of accretion pattern are drastically increased. This feature may be due to drastic change in wave energy from higher to lower level concentration. Though southern profiles (BS 1 to BS 5) accreted more as compared to northern profiles (BS 6 to BS 9) suggests significant onshore transport of materials and as well as longshore sediment transport towards south during this period.

The observation of beach morphology for a period of about 28 months (Sept 2009-Dec 2011) indicated that all the nine profiles (BS 1 to BS 9) achieved dynamic equilibrium by nature. The profiles at south and north are accreted during pre-monsoon season and eroded during monsoon. But the quantum of erosion on northern side is very significant, though beaches are located at small spatial interval but highly influenced by river discharge and monsoonal drift (Figures.4.2A and 4.2B). Based on the overall observation from the nine beaches and their variations in morphological setup, beaches are classified as stable, minor accreted, minor eroded and major accreted beaches (Table 4.2, Refer May 2010 and May 2011). Further the seawall on southern side (BS 2 and BS 3, Table 4.2, Refer May 2010 and May 2011) performed very well as compared to northern side and the result of this poor performance can be seen in BS 8 and BS 9 (Table 4.2, Refer May 2010 and May 2011).

Table. 4.2 Accretion and erosion of sediment during different seasons across the profiles

Profile No	Beach volume (m^3/m)						Remarks
	Pre monsoon		Monsoon		Post monsoon		
	May 2010	May 2011	July 2010	July 2011	Oct 2010	Oct 2011	
BS 1	102.5	110.5	63.3	62.1	85.8	66.7	Minor Accretion
BS 2	162.1	165.2	88.4	128.7	125.9	119.0	Stable
BS 3	104.2	105.8	57.9	67.9	86.7	81.3	Stable
BS 4	102.7	137.9	66.7	84.8	82.0	104.7	Major Accretion
BS 5	181.8	188.7	150.7	151.6	125.9	118.7	Minor accretion
BS 6	122.3	125.5	131.8	118.8	85.8	104.7	Minor accretion
BS 7	108.9	104.4	67.7	75.9	67.3	76.3	Stable
BS 8	94.5	92.2	61.0	74.9	74.4	112.7	Stable
BS 9	93.1	89.5	42.2	46.2	67.2	59.6	Minor erosion

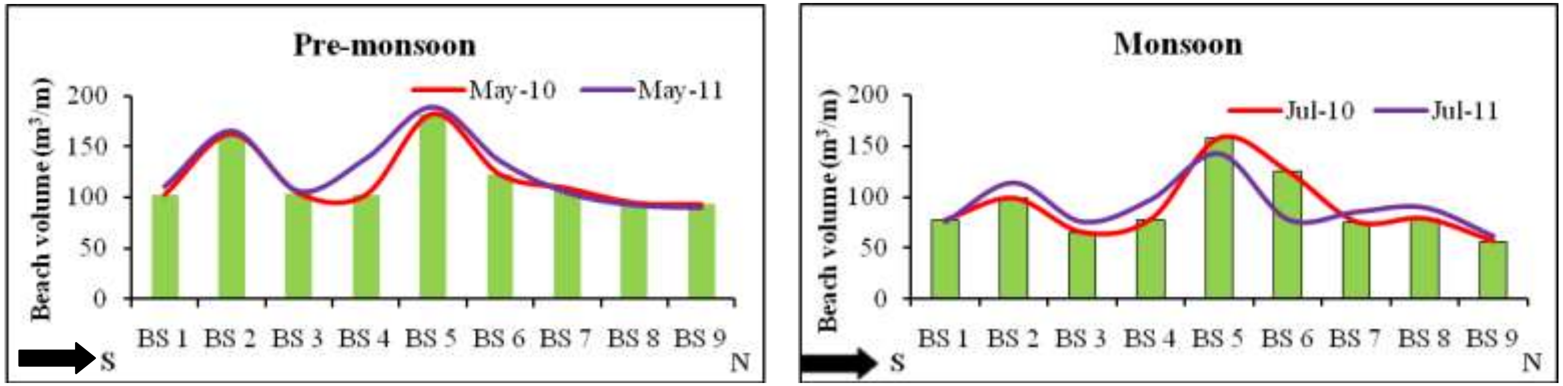


Figure.4.2A Spatial and temporal variation of beach volume from BS 1to BS 9 during pre-monsoon and monsoon

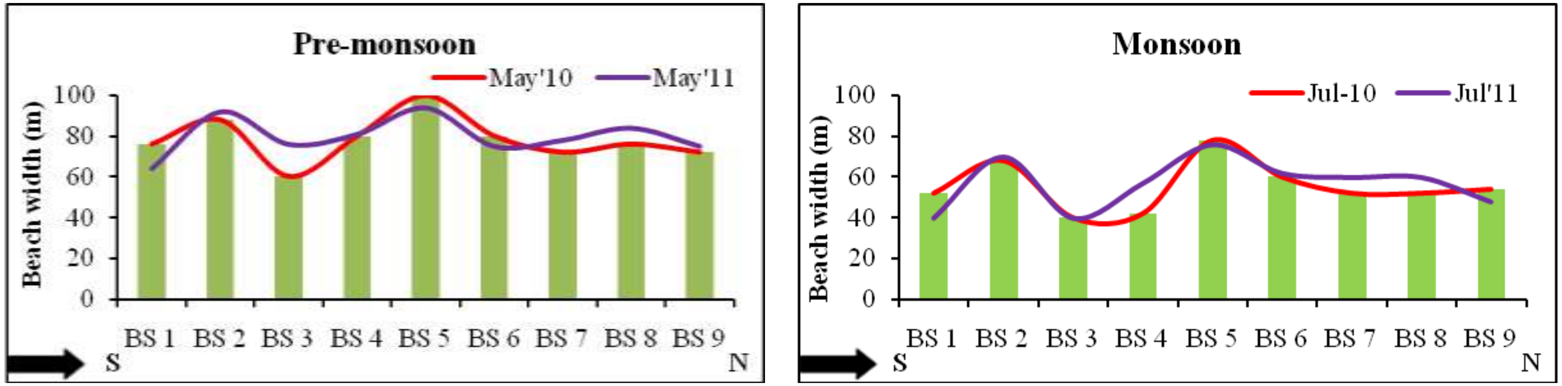


Figure.4.2B Spatial and temporal variation of beach width from BS 1to BS 9 during pre-monsoon and monsoon

Regarding the short-term changes during the monitored period, the vast majority of profiles recorded an accentuated accretion in May 2010 and May 2011 due to fair weather conditions prevail from the months between February to May, and also around 50% erosion is observed during the monsoonal storm events between June and September. In July, almost all the profiles underwent erosion at the foreshore due to drastic rise in wave characteristics (2-4.5m, 6-12 sec) and thereafter in October to January, the profiles initiated accretion stage from erosion stratum to depositional pattern due to gradual decrease in storm activity and corresponding mixed wave energy climate. Overall in annual cycle all the profiles return back to their original shape and quantum and hence it indicates that the beaches on either side of the rivermouth under equilibrium state with minor fluctuations.

The present investigation for the current study area also confirms the observations of earlier studies that wave and river discharge are the major driving force for the beach morphodynamic changes. During the monsoon high energy waves and higher discharge lead to erosion of the beaches. During the pre-monsoon months, low energy waves and low discharge cause onshore transport of sediment and leads to rebuilding of beaches after the erosional phase (Dattatri et al. 1997; Jayappa et al. 2003).

Beaches from BS 1 to BS 9 are exposed to higher rate of development in backshore and foreshore between the month of February and May. Seasonal variations in beach morphology during monsoon, post-monsoon and pre-monsoon are highly significant. However, the beaches from NITK Beach to Sasihithlu beach (BS 1 to BS 5) indicate that seasonal variations in the form of erosion/accretion pattern are highly dominated as compared with Hejamadi beaches (BS 6 to BS 9). Therefore, Hejamadi beaches (BS 6 to BS 9) are in the cycle of erosion trend while the NITK beach to Sasihithlu beach (BS 1 to BS 5) is in the processes of accretion trend during the data considered for the present study.

4.2.2 Alongshore Sediment Transport

Based on monthly beach profile volume changes between the profiles of southern and northern side, the alongshore sediment transport is calculated (Mm^3/year) in each season. For this, monthly beach sediment volume was calculated and then multiplied with alongshore distance (Table.4.3). By doing this, a distinct alongshore drift of material was identified; the two seasons pre-monsoon and monsoon showed significant changes. From the estimated alongshore transport, it is found that a net transport of about 0.0062 Mm^3/year and 0.0084 Mm^3/year towards south is observed for the period 2009-2010 and 2010-2011 respectively for the study area.

Table.4.3 Alongshore sediment Transport (Mm^3/year) in each season

Time Period	Alongshore sediment Transport (Mm^3/year)			Net transport (Mm^3/year)
	Post-monsoon season	Pre-monsoon season	Monsoon season	
Sept 2009-Sept 2010	0.0209	0.0260	0.0198	0.0062
Sept 2010-Sept 2011	0.0248	0.0292	0.0208	0.0084

To identify the eroded/accreted shoreline, alongshore beach volume is computed for 4 km length with respect to rivermouth towards south and north and the same quantification is presented in Table. 4.3A. The computed alongshore beach volume clearly suggests that southern side shoreline is accreted, while the northern side shoreline is eroded, since from Sept'09 to Dec'11. The variation of accumulation of sediment on southern side and northern side is varying from season to season. During the monsoon (June'10-Sept'10), particularly in July'10, the southern and northern shorelines accreted volume of about 305600 m^3/m and 146457 m^3/m, even it is erosional season. In the same way, July'11 presented accretion about 347250 m^3/m and 158022 m^3/m for southern side and northern side shorelines respectively. This change in sediment accumulation clearly indicates that southern side shoreline is accreting and at the same time the year 2011 represents as accretional year compared to the year 2010. The accretional trend on southern side can be seen in post-monsoon season and pre-monsoon also.

Table.4.3A comparison between southern side and northern side shorelines

Months	**Alongshore volume (m^3/m) by considering 4 km distance on either side of the rivermouth**	
	South	North
Sep'09	295950	147926
Oct'09	318500	150584
Nov'09	319050	159340
Dec'09	338300	168750
Jan'10	368300	173205
Feb'10	386350	180513
Mar'10	398950	186920
Apr'10	429500	197882
May'10	452600	209595
Jun'10	337500	168033
Jul'10	305600	146457
Aug'10	306000	145871
Sept'10	310650	155534
Oct'10	357000	147488
Nov'10	369050	159645
Dec'10	400900	167302
Jan'11	419600	172409
Feb'11	486500	182217
Mar'11	498200	188923
Apr'11	514450	198433
May'11	528850	205988
Jun'11	378100	181598
Jul'11	347250	158022
Aug'11	305300	166629
Sept'11	337500	162040
Oct'11	390700	176804

Nov'11	424100	191968
Dec'11	467300	201377

4.2.3 Beach width Analysis

The measured beach widths are varied from weeks to weeks, months to months and season to season in accordance with space, i.e from BS 1 to BS 9. The profiles located infront of seawall are performing very well as indicated in Table 4.4 for BS 2, BS 3, BS 8 and BS 9 maintained an average of beach width about 77 m, 60 m, 69 m and 62 m though they exposed to all kind of oceanographic characteristics (wave, wind and tide) and their impacts. However, open beaches such as BS 1, BS 4 and BS 7 were suffered mainly due to wave climate and managed average beachwidths of about 61 m, 65 m, 64 m, which varied significantly from season to season. But, the beach width in the vicinity of rivermouth, particularly at BS 5 and BS 6, the average beach widths are 84 m and 70 m. The maximum beach width observed at these locations is about 100 m and 80 m (May 2010). Even during the monsoon season, the beachwidths at these locations (BS 5 and BS 6) found to be more, but during the post-monsoon season, the beach widths are gradually reduced.

The mixed energy wave climate and low discharge resulted in subsequent distribution of sediment on adjacent beaches (BS 4 and BS 7; BS 4: 56 -62 m, 60-74 m, 72-76 m and BS 7: 60-65 m, 62-68 m, 62-68m) during the post-monsoon, therefore the beachwidths at BS 5 and BS 6 are reduced (BS5: 85-88 m, 76-84 m, 82-84 m and BS 6: 68-74 m, 64-70 m, 72-78 m). Further BS 5 profile started accreting in pre-monsoon (from February to May) and resulted in maximum beach width (May 2010- 100 m, May 2011- 94 m). This increment and reduction in beachwidth repeated over a period of observation (at short-term scale, 28 months) and hence it is in conformity with the results of earlier studies carried out by Jayappa et al. 2003, that the beach widths are maximum during pre-monsoon and minimum during monsoon seasons.

Table 4.4 Spatial and temporal variation in beach width

Months	Beach width (m)									Seasons
	BS 1	BS 2	BS 3	BS 4	BS 5	BS 6	BS 7	BS 8	BS 9	
Sep'09	50	72	40	52	83	65	59	64	58	Post-monsoon
Oct'09	52	73	44	56	85	68	60	65	60	
Nov'09	56	74	48	55	86	70	61	67	64	
Dec'09	60	76	48	57	86	72	63	67	66	
Jan'10	64	80	48	62	88	74	65	69	68	
Feb'10	68	84	52	64	88	75	66	70	68	Pre-monsoon
Mar'10	72	84	56	70	92	76	68	72	70	
Apr'10	76	84	56	76	92	76	68	72	72	
May'10	76	88	60	80	100	80	72	76	72	
Jun'10	48	72	44	65	86	65	60	58	60	Monsoon
Jul'10	52	68	40	42	78	60	52	52	54	
Aug'10	60	68	42	48	72	64	56	56	52	
Sept'10	64	68	48	50	76	68	60	60	56	

Months	Beach width (m)									Seasons
	BS 1	**BS 2**	**BS 3**	**BS 4**	**BS 5**	**BS 6**	**BS 7**	**BS 8**	**BS 9**	
Oct'10	68	70	56	60	84	64	62	64	56	Post-monsoon
Nov'10	72	76	60	64	76	70	63	68	60	
Dec'10	64	76	64	72	88	69	68	68	64	
Jan'11	72	76	64	74	84	70	68	72	64	
Feb'11	72	80	68	76	86	72	70	74	65	Pre-monsoon
Mar'11	72	84	70	80	88	73	74	76	68	
Apr'11	72	88	74	80	88	76	75	80	72	
May'11	64	92	76	81	94	75	78	84	75	
Jun'11	44	76	45	65	82	60	67	68	60	Monsoon
Jul'11	40	70	40	57	76	62	60	60	48	
Aug'11	48	72	44	60	66	64	55	64	52	
Sept'11	48	72	48	60	80	72	57	68	50	
Oct'11	52	72	50	72	82	72	62	74	52	Post-monsoon
Nov'11	60	74	52	74	84	76	64	78	57	
Dec'11	62	76	56	76	84	80	68	80	60	
Average beach width	61	77	60	65	84	70	64	69	62	-

4.2.4 Sedimentological investigations

Sediment samples were collected at monthly intervals along the length of shoreline associated with Mulky-Pavanje rivermouth. Totally about two hundred and fifty two sediment samples were collected from the lower low water mark of the profiles BS 1 to BS 9 for statistical analysis. The statistics derived from the sand samples were used to investigate the spatial variability and influence of sediment transport through grain size characteristics.

Single statistical parameter is not sufficient in identifying a given environment and therefore, it is necessary to relate various grain size parameters such as mean size, sorting, skewness and kurtosis to establish the nature of the sedimentary environment. Therefore, the statistical parameters analyzed in this study include mean size, standard deviation, skewness and kurtosis.

It is well known fact that the grain size character of sediments is controlled by wave energy input and it changes seasonally. The beaches on northern side and southern side experiencing similar oceanographic conditions, but there is difference in their textural parameters. It is probably due to the difference in sediment dispersion brought by rivers Mulky and Pavanje. Temporal and spatial variation in the grain size characteristics is evident from Table 4.5.

4.2.4.1 Pre-monsoon Period (Feb 2010-May 2010, Feb 2011-May 2011)

During the early pre-monsoon (February 2010 and February 2011), the foreshore sediments away from the rivermouth beaches (BS 1 to BS 4 and BS7 to BS 8) were dominated by fine to medium grained (mean values between 1 and 3), poorly sorted (Stand. Deviation values between 1 and 2) and positively skewed sediments (skewness values between -0.1 and +0.3), but near the vicinity of rivermouth sediments were (BS 5 and BS 6) found to be fine grained to medium sand, very well sorted (Stand. Deviation value < 0.35), negatively coarse skewed nature (skewness

Table.4.5 Textural variations on southern side and northern side of the rivermouth

Statistical Parameters	Seasons	BS 1	BS 2	BS 3	BS 4	BS 5	BS 6	BS 7	BS 8	BS 9
Mean	Post monsoon	1.45	1.65	2.02	2.10	2.04	1.37	0.96	1.57	1.24
	Early Pre-monsoon	1.54	1.53	1.51	1.83	2.03	1.34	0.90	1.77	2.03
	Late Pre-monsoon	1.69	1.67	1.37	1.54	1.76	1.37	1.54	1.44	1.75
	Monsoon	1.28	1.87	1.72	1.30	1.82	1.64	1.49	1.78	1.42
Standard Deviation	Post monsoon	0.54	0.48	0.50	0.51	0.60	0.79	0.71	0.68	0.89
	Early Pre-monsoon	0.24	0.68	0.28	0.62	0.57	0.59	0.86	0.46	0.39
	Late Pre-monsoon	0.49	0.55	0.38	0.55	0.50	0.65	0.61	0.60	0.48
	Monsoon	0.63	0.40	0.68	0.45	0.56	0.64	0.62	0.66	0.74
Skewness	Post monsoon	-0.24	-0.23	-0.15	-0.33	-0.44	-0.34	-0.39	-0.20	-0.40
	Early Pre-monsoon	-0.45	0.01	0.04	0.18	-0.22	-0.27	0.26	0.33	-0.61
	Late Pre-monsoon	-0.03	0.12	-0.02	0.28	-0.36	-0.14	0.24	-0.16	0.05
	Monsoon	-0.36	-0.54	-0.31	-0.48	-0.21	-0.20	-0.26	-0.06	-0.17
Kurtosis	Post monsoon	1.26	1.23	1.13	0.90	0.84	1.19	0.73	1.26	0.49
	Early Pre-monsoon	0.78	1.54	1.96	0.94	0.88	1.79	0.68	1.78	0.68
	Late Pre-monsoon	1.22	1.65	1.68	1.25	1.40	1.43	1.24	1.61	1.44
	Monsoon	0.78	0.99	1.20	1.03	0.87	1.01	1.48	1.19	0.85

values between -0.3 and -0.1). This may be due gradual decrease in wave energy and its effect on beaches away from the rivermouth and in the vicinity of rivermouth.

During the late phase of pre-monsoon (May 2010 and May 2011), the beaches away from the rivermouth (BS 1 to BS 4 and BS7 to BS 8) were dominated by medium grained positively skewed sediments. But near the rivermouth region (BS 5 and BS 6) sediments are dominated by medium grained (Mean value at BS 5:1.76 and BS 6:1.37), negatively skewed (Skewness value at BS 5:-0.36 and BS 6:-0.14) sediments. The variation in the sediment accumulation pattern between beaches away from the rivermouth and in the vicinity of rivermouth suggesting that there is onshore migration of sands, since wave energy has completely reduced as compared with monsoon (wave height<1m and wave period >10 sec).

4.2.4.2 Monsoon Period (Jun-2010-Sep 2010, Jun 2011-Sep-2011)

During the monsoon, the rivermouth region remained highly energetic and rich in suspended sediments. This was reflected in the sediment texture towards coarser sediments accumulation. The foreshore sediments were dominated by very coarse to coarse (Skewness > -0.3 and Skewness range between -0.3 and -0.1) as compared with those of pre-monsoon foreshore sediments. These coarser sediments were observed on beaches away from the rivermouth (Skewness at BS1:-0.36, BS 2:-0.54, BS 3:-0.31, BS 4: -0.48, BS 7: -0.26, BS 8:-0.06 and BS 9: -0.17) and also on beaches nearer to rivermouth (Skewness at BS 5:-0.21 and BS 6: 0.20). However from BS 9 to BS 1, the coarser nature of the sediments is gradually increasing (Skewness: -0.17; -0.06; -0.26; -0.20; -0.21; -0.48; -0.31; -0.54; -0.36), indicating that high longshore sediment flux towards south during the monsoon. The similar observations were also made by other researchers (Hegde et al. 2009; Nayak et al. 2010; Gumageri and Dwarakish 2011) for the southwest coast of India, and underline the concept that coarser sands are associated with erosional phase i.e monsoon season. Removal of finer sediments from foreshore region, leading to foreshore erosion and leaving behind coarse grained and dominantly negatively skewed sediments at the beaches on either side of the rivermouth, suggests high energy and strong winnowing action of waves during the monsoon season.

4.2.4.3 Post-monsoon Period (Oct 2009-Jan 2010, Oct 2010-Jan 2011, Oct 2011-Dec 2011)

During the post-monsoon, medium to fine grained, poorly sorted and negatively skewed sediments were found on the foreshore on either side of the rivermouth (BS 1 to BS 9). A large variation in the textural parameters in both space and time suggests prevalence of temporal and spatial variation in the energy conditions. Coarser sediments were observed during monsoon and slightly fine grained sediments during post-monsoon period, indicating progressive decrease in wave energy from the monsoon to post monsoon season.

Over a period of observation (short-term, 28 months), the pattern of sediment accumulation at all profiles did not change much. But there is change in sediment pattern with respect to season, mainly due to change in wave climate at away from beaches (BS 1- BS 4, BS 8-BS 9) and river discharge in the vicinity of rivermouth beaches (BS 5 and BS 6). Additionally the gradual increase in grain size from BS 9 to BS 1 indicates that strong longshore sediment towards south during the monsoon.

The observed variations in sediment texture in response to pre-monsoon, monsoon and post-monsoon further compared with previous studies carried out for south west coast of India indicated that coarser sediments are due to monsoon, fine to medium sands are associated with pre-monsoon and post-monsoon coastal conditions (Uday Verma et al. 1985; Chavadi and Nayak 1987; Mislankar and Antao 1992; Bhat et al. 2003; Lalu raj et al. 2008; Hegde et al. 2009, Reji Srinivas and Kurian Sajan 2010; Nayak et al. 2010).

4.2.5 Wave and Wind Analysis

The morphological changes of the beaches associated with rivermouth are much more complex owing to site specific control of wind and wave processes. Waves are found to provide necessary energy for the movement of water and sediments within the nearshore zone. In the study area, wave parameters (wave period, wave height and wave directions) are significantly controlled by monsoonal climate.

The wave parameter data was collected from data sources such as INCOIS and IMD were initially employed to find the percentage distribution of wave height and wave period for each month, i.e from January to December (Table. 4.6 to Table. 4.17). At the later stage in order to document the actual influence of wave parameters (percentage distribution wave height and wave period) on seasonal variations on morphology were analysed. The percentage distribution of wave height and wave period of the waves for the three seasons viz., pre-monsoon, monsoon and post-monsoon are presented in Tables 4.18, 4.19 and 4.20 respectively.

The monthly variation in waves and their associated parameters are significantly changed in response to seasonal climate. During the monsoon, the wave heights are ranging from 0.5 m to 4.5 m. But, the percentage of occurrence of wave height more than 2 m with wave period less than 12 seconds in southwest directions are observed along the length of the shoreline (Table 4.19 and Figure. 4.3).

The waves during monsoon are characterized by higher heights (2-4m), shorter periods (5-10 sec), and are confined to south-westerly and westerly directions (Table.4.19 and Figure.4.3). But, during the pre-monsoon and post-monsoon waves are characterized by lower heights (<1m) and higher periods (5-18sec) with the direction being more commonly south-westerly (Table. 4.18 and Table 4.20 and Figure. 4.3). Based on three years of dataset (2007-2010) and analysis, it can be concluded that the wave heights exhibit seasonal variations, but the periods and directions remain relatively constant. Due to cyclic trend in wave climate, the beaches eroded during monsoon, regain the same during post-monsoon and pre-monsoon seasons, showing cyclic nature of the beach process.

Breaker wave conditions (wave height and wave period) were visually observed from BS 1 to BS 9 during the field visit, which indicate that wave climate along the study area vary significantly (Table.4.21 and 4.22). The most energetic wave conditions are from southwest direction during monsoon, where 50% of breaker wave heights are larger than 1 m (wave period<8 seconds) and the wave climate is a mixture of swell and locally generated wind waves. Because of high wave energy, that approach shoreline in normal direction and hence net offshore transport of sediment takes place from the beaches. The lowest wave conditions prevail the study area are west and northwest during post-monsoon and pre-monsoon, where waves are predominantly wind waves and 50% of breaker wave heights are generally less than 0.5 m. During pre-monsoon and post-monsoon, net onshore sediment transport takes place on the beaches and represent deposition period. However, the predominant direction of waves at open sea during monsoon season is southwest and hence net erosion occurs in the beaches and further cause major morphological damages on the shoreline.

Based on observed wave climate, seasons are further classified as southwest monsoon (June – September), northeast monsoon (October – January) and fair weather period (February – May). The winds are stronger during southwest monsoon season and generally weak during northeast monsoon and fair weather period (Table. 4.23). During northeast monsoon and fair weather period, the predominant winds are easterly and south easterlies with the wind speed ranging from 1 to 19 km/hr. The waves generated due to easterly and south easterlies winds are relatively weak and that propagate away from the coast causes low energy wave condition. But, during the southwest monsoon, the predominant winds are from west and southwest, sometimes southeast. These winds generate high energy wave condition and responsible for coastal erosion in the form of onshore-offshore sediment transport.

Table 4.6 Percentage distribution of wave height and wave period in the month of January

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	3.79	10.61	6.82	0.76	0.00	0.76	6.06	3.03	0.00	1.52	4.55	3.03	2.27	0.76	0.00	43.94
1.0	2.27	10.61	11.36	0.00	0.00	0.00	5.30	0.76	0.00	4.55	1.52	2.27	0.76	0.76	0.00	40.15
1.5	5.30	0.76	3.03	2.27	3.03	1.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.91
2.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	11.36	21.97	21.21	3.03	3.03	2.27	11.36	3.79	0.00	6.06	6.06	5.30	3.03	1.52	0.00	100.00

Table 4.7 Percentage distribution of wave height and wave period in the month of February

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	28.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.57	3.57	0.00	0.00	0.00	0.00	35.71
1.0	0.00	3.57	3.57	0.00	0.00	0.00	0.00	0.00	0.00	7.14	0.00	0.00	0.00	0.00	0.00	14.29
1.5	0.00	0.00	7.14	3.57	10.71	0.00	0.00	0.00	3.57	0.00	0.00	0.00	0.00	0.00	3.57	28.57
2.0	0.00	0.00	0.00	7.14	7.14	3.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.86
2.5	0.00	0.00	0.00	0.00	3.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.57
3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	28.57	3.57	10.71	10.71	21.43	3.57	0.00	0.00	3.57	10.71	3.57	0.00	0.00	0.00	3.57	100.00

Table 4.8 Percentage distribution of wave height and wave period in the month of March

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	23.53	0.00	0.00	2.94	0.00	0.00	0.00	0.00	5.88	5.88	0.00	0.00	0.00	0.00	0.00	38.24
1.0	0.00	0.00	0.00	8.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.82
1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.0	0.00	0.00	0.00	2.94	20.59	20.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.94	0.00	47.06
2.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.94
3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.94
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	23.53	0.00	0.00	14.71	20.59	20.59	0.00	5.88	5.88	5.88	0.00	0.00	0.00	2.94	0.00	100.00

Table 4.9: Percentage distribution of wave height and wave period in the month of April

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	21.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.62
1.0	0.00	0.00	10.81	10.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.62
1.5	0.00	0.00	0.00	0.00	8.11	5.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.51
2.0	0.00	0.00	0.00	0.00	2.70	10.81	2.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.22
2.5	0.00	0.00	0.00	0.00	2.70	10.81	2.70	2.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.92
3.0	0.00	0.00	0.00	0.00	0.00	2.70	2.70	2.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.11
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	21.62	0.00	10.81	10.81	13.51	29.73	8.11	5.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00

Table 4.10 Percentage distribution of wave height and wave period in the month of May

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	9.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.64
1.0	2.41	2.41	9.64	8.43	10.84	3.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.35
1.5	4.82	6.02	8.43	6.02	2.41	4.82	1.20	0.00	0.00	0.00	0.00	2.41	0.00	0.00	0.00	36.14
2.0	0.00	0.00	0.00	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20
2.5	0.00	0.00	0.00	0.00	0.00	1.20	3.61	2.41	1.20	0.00	0.00	0.00	0.00	0.00	0.00	8.43
3.0	0.00	0.00	0.00	0.00	0.00	1.20	2.41	3.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.23
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	16.87	8.43	18.07	14.46	13.25	12.05	7.23	6.02	1.20	0.00	0.00	2.41	0.00	0.00	0.00	100.00

Table 4.11 Percentage distribution of wave height and wave period in the month of June

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	4.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.71
1.0	0.00	0.00	0.59	2.94	1.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.71
1.5	0.00	0.00	0.00	0.59	0.00	2.94	1.18	0.00	0.00	0.00	0.59	0.00	0.00	0.00	0.00	5.29
2.0	0.00	0.00	0.00	0.59	1.76	4.71	2.35	1.18	1.18	0.00	0.00	0.00	0.00	0.00	0.00	11.76
2.5	0.00	0.00	0.00	0.00	0.00	1.76	4.12	5.88	5.29	2.94	0.00	0.00	0.00	0.00	0.00	20.00
3.0	0.00	0.00	0.00	0.00	1.76	4.12	4.71	7.06	5.88	5.29	1.18	0.00	0.00	0.00	0.00	30.00
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.71	1.18	3.53	1.76	0.00	0.00	0.00	0.00	11.18
4.0	0.00	0.00	0.00	0.00	0.59	0.00	0.00	0.59	0.59	3.53	1.18	0.00	0.00	0.00	0.00	6.47
4.5	0.00	0.00	0.00	0.00	0.00	1.18	0.59	0.59	1.18	0.00	0.00	0.00	0.00	0.00	0.00	3.53
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.76	0.59	0.00	0.00	0.00	0.00	0.00	0.00	2.35
Sum Hs	4.71	0.00	0.59	4.12	5.29	14.71	12.94	21.76	15.88	15.29	4.71	0.00	0.00	0.00	0.00	100.00

Table 4.12 Percentage distribution of wave height and wave period in the month of July

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00
1.0	0.00	0.00	1.25	1.88	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00
1.5	0.00	0.00	0.00	1.25	2.50	3.75	5.00	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.00	13.13
2.0	0.00	0.00	0.00	0.00	0.63	0.63	13.75	13.75	0.63	0.00	0.00	0.00	0.00	0.00	0.00	29.38
2.5	0.00	0.00	0.00	0.00	2.50	0.00	8.75	12.50	3.13	0.00	0.00	0.00	0.00	0.00	0.00	26.88
3.0	0.00	0.00	0.00	0.63	0.63	0.00	5.63	6.25	2.50	0.00	0.00	0.00	0.00	0.00	0.00	15.63
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.88	3.13	0.00	0.00	0.00	0.00	0.00	0.00	5.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	5.00	0.00	1.25	3.75	8.13	4.38	33.13	34.38	9.38	0.00	0.00	0.63	0.00	0.00	0.00	100.00

Table 4.13 Percentage distribution of wave height and wave period in the month of August

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	52.54	0.00	1.13	2.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56.50
1.0	0.00	0.00	0.00	0.56	0.56	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.69
1.5	0.56	0.00	0.00	1.69	5.08	7.91	3.95	1.69	0.56	0.56	0.00	0.56	0.00	0.00	0.00	22.60
2.0	0.00	0.00	0.00	0.00	0.00	5.08	5.08	0.56	0.00	0.00	0.00	0.00	0.00	0.56	0.00	11.30
2.5	0.00	0.00	0.00	0.00	0.00	0.00	1.69	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.26
3.0	0.00	0.00	0.00	0.00	0.56	1.13	3.39	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.65
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	53.11	0.00	1.13	5.08	6.21	14.69	14.12	3.39	0.56	0.56	0.00	0.56	0.00	0.56	0.00	100.00

Table 4.14 Percentage distribution of wave height and wave period in the month of September

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	73.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.51	2.63	0.00	0.00	0.00	0.00	79.82
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5	0.00	0.00	0.00	0.00	0.00	0.88	1.75	4.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.02
2.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.0	0.00	0.00	0.00	0.00	0.00	0.88	3.51	8.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.16
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	73.68	0.00	0.00	0.00	0.00	1.75	5.26	13.16	0.00	3.51	2.63	0.00	0.00	0.00	0.00	100.00

Table 4.15 Percentage distribution of wave height and wave period in the month of October

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	0.00	24.32	2.70	0.00	0.00	0.00	0.00	0.00	0.00	2.70	5.41	2.70	0.00	0.00	0.00	37.84
1.0	0.00	0.00	2.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.70
1.5	0.00	0.00	0.00	0.00	0.00	5.41	8.11	5.41	2.70	0.00	0.00	0.00	0.00	0.00	0.00	21.62
2.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.70	0.00	0.00	0.00	0.00	0.00	0.00	2.70
3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.70	16.22	16.22	0.00	0.00	0.00	0.00	0.00	35.14
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	0.00	24.32	5.41	0.00	0.00	5.41	8.11	8.11	21.62	18.92	5.41	2.70	0.00	0.00	0.00	100.00

Table. 4.16 Percentage distribution of wave height and wave period in the month of November

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	0.00	21.62	2.70	2.70	0.00	0.00	0.00	0.00	0.00	10.81	0.00	0.00	0.00	0.00	0.00	37.84
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5	0.00	0.00	0.00	5.41	8.11	0.00	5.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.92
2.0	0.00	0.00	0.00	0.00	0.00	2.70	0.00	0.00	2.70	0.00	0.00	0.00	0.00	0.00	0.00	5.41
2.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.22	16.22	0.00	0.00	0.00	0.00	0.00	0.00	32.43
3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.41	0.00	0.00	0.00	0.00	0.00	0.00	5.41
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	0.00	21.62	2.70	8.11	8.11	2.70	5.41	16.22	24.32	10.81	0.00	0.00	0.00	0.00	0.00	100.00

Table 4.17 Percentage distribution of wave height and wave period in the month of December

T/H	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum T
0.5	0.00	21.05	5.26	10.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.84
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.0	0.00	0.00	0.00	0.00	2.63	0.00	2.63	5.26	15.79	2.63	0.00	0.00	0.00	0.00	0.00	28.95
2.5	0.00	0.00	0.00	0.00	2.63	0.00	5.26	2.63	18.42	2.63	0.00	0.00	0.00	0.00	0.00	31.58
3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.63
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	0.00	21.05	5.26	10.53	5.26	0.00	7.89	10.53	34.21	5.26	0.00	0.00	0.00	0.00	0.00	100.00

Table 4.18 Percentage distribution of wave height and wave period during pre-monsoon Season

Pre-monsoon season (February –May)																
T/H	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**Sum T**
0.5	17.58	1.10	2.75	0.55	2.20	2.20	2.20	0.80	1.10	1.65	0.55	1.10	1.55	0.00	0.00	35.33
1.0	1.10	1.65	7.14	7.69	4.95	1.65	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	25.18
1.5	2.20	2.75	4.95	3.30	4.40	3.30	0.55	0.00	0.55	0.00	0.00	1.10	0.00	0.00	0.55	23.63
2.0	0.00	0.00	0.00	1.65	5.49	6.20	0.55	0.77	0.00	0.00	0.00	0.00	0.00	0.55	0.00	15.21
2.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.66
3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	20.88	5.50	14.84	13.19	17.04	13.35	3.30	1.57	2.31	2.65	0.55	2.20	1.55	0.55	0.55	100.00

Table 4.19 Percentage distribution of wave height and wave period during monsoon season

Monsoon season (June -September)																
T/H	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**Sum T**
0.5	21.30	10.00	0.32	0.60	0.00	0.00	0.00	0.00	0.00	0.64	0.48	0.00	0.00	0.00	0.00	33.35
1.0	0.00	0.00	0.48	1.45	0.97	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.06
1.5	0.16	0.00	0.00	0.97	2.09	4.19	3.06	1.29	0.16	0.16	0.16	0.32	0.00	0.00	0.00	12.56
2.0	0.00	0.00	0.00	0.16	0.64	2.90	5.64	4.03	0.48	0.00	0.00	0.00	0.00	0.16	0.00	14.01
2.5	0.00	0.00	0.00	0.00	0.64	0.48	3.86	4.99	2.25	0.81	0.00	0.00	0.00	0.00	0.00	13.04
3.0	0.00	0.00	0.00	0.16	0.81	1.61	4.35	5.31	2.25	1.45	0.32	0.00	0.00	0.00	0.00	16.26
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.77	1.13	0.97	0.48	0.00	0.00	0.00	0.00	4.35
4.0	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.16	0.16	0.97	0.32	0.00	0.00	0.00	0.00	1.77
4.5	0.00	0.00	0.00	0.00	0.00	0.32	0.16	0.16	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.97
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.64
Sum Hs	21.46	10.00	0.81	3.34	5.31	9.66	17.07	18.20	6.92	4.97	1.77	0.32	0.00	0.16	0.00	100.00

Table 4.20 Percentage distribution of wave height and wave period during post-monsoon season

Post-monsoon season (October-January)																
T/H	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**Sum T**
0.5	2.05	15.98	5.33	2.46	0.00	0.41	3.28	1.64	0.00	2.87	3.28	2.05	1.23	0.41	0.00	40.98
1.0	1.23	5.74	6.56	0.00	0.00	0.00	2.87	0.41	0.00	2.46	0.82	1.23	0.41	0.41	0.00	22.13
1.5	2.87	0.41	1.64	2.05	2.87	1.64	2.05	0.82	0.41	0.00	0.00	0.00	0.00	0.00	0.00	14.75
2.0	0.00	0.00	0.00	0.00	0.41	0.41	0.41	0.82	2.87	0.41	0.00	0.00	0.00	0.00	0.00	5.33
2.5	0.00	0.00	0.00	0.00	0.41	0.00	0.82	2.87	5.74	0.41	0.00	0.00	0.00	0.00	0.00	10.25
3.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	3.28	2.46	0.00	0.00	0.00	0.00	0.00	6.56
3.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum Hs	6.15	22.13	13.52	4.51	3.69	2.46	9.43	7.38	12.30	8.61	4.10	3.28	1.64	0.82	0.00	100.00

Table. 4.21 Observed wave heights during the study period at each profiling location

Months	BS 1	BS 2	BS 3	BS 4	BS 5	BS 6	BS 7	BS 8	BS 9
May'10	0.5-0.75	0.5-0.75	0.5-0.75	0.5-0.75	1.0-1.5	0.5-1.0	0.5-0.75	0.5-0.75	0.5-0.75
June'10	1.0	1.0	1.0-1.5	1.0-1.5	1.0-1.5	1.0-1.5	1.0-1.5	1.0	1.0
July'10	1.5	1.5	1.5	1.5-1.75	1.5	1.0-1.75	1.5	1.5	1.5
Aug'10	1.0-1.5	1.0-1.5	1.0-1.5	1.5-2.0	1.5-2.0	1.5-2.0	1.0-1.5	1.0-1.5	1.0-1.5
Sept'10	0.5	0.5	0.5-0.75	0.5	0.5-0.75	0.5-0.75	0.5	0.5	0.5
Oct'10	0.5	0.5	0.5-0.75	0.5-0.75	0.5-1.0	1.0	0.75	0.5	0.5
Nov'10	0.5	0.5	0.5	0.75	0.5	0.75	0.5	0.25-0.5	0.25
Dec'10	0.25-0.5	0.25-0.5	0.25-0.5	0.25-0.5	0.25-0.5	0.25-0.5	0.25-0.5	0.25	0.25
Jan'11	0.5	0.5	0.5-0.75	1	1.0-1.5	1.25	1.0-1.25	0.5	0.25
Feb'11	0.5	0.5	0.5-0.75	1	1.25	1	0.5	0.5	0.25
Mar'11	0.5	0.5	0.5	0.5	0.5-1.0	0.5	0.5	0.5	0.5
Apr'11	0.5	0.5	0.75	1	1	1	0.75	0.5	0.5
May'11	0.5-0.75	0.5-0.75	0.5-0.75	0.5-0.75	1.0-1.5	0.5-1.0	0.5-0.75	0.5-0.75	0.5-0.75

Table. 4.22 Observed wave periods during the study period at each profiling location

Months	BS 1	BS 2	BS 3	BS 4	BS 5	BS 6	BS 7	BS 8	BS 9
May'10	15	13-14	14	12-14	12-14	12-14	13-14	13-14	15
June'10	10-11	8-10	8-10	8	8	8	8	10-11	10-11
July'10	8	7	7	7-8	7-8	7-8	7-8	7	7
Aug'10	6	6	6	6	5-6	5-6	5-6	6	6
Sept'10	11-12	11-12	11-12	10-11	10-11	10-11	10-11	10-11	12
Oct'10	13	13	13	12-13	12-13	12-13	12-13	12	13
Nov'10	12-13	12-13	12-13	13	13	13	13	12-13	12-13
Dec'10	11	10-11	10	10-11	10-11	10-11	10-11	10	11
Jan'11	10-11	10-11	10	10	11	11	11	11	10-11
Feb'11	11-12	12	12	12	12	12	12	11-12	11-12
Mar'11	13-14	13-14	13-14	11-12	11-12	11-12	11-12	13-14	14
Apr'11	13	12-13	12-13	10-11	10-11	10-11	11-12	12-13	13
May'11	15	13-14	15	12-14	12-14	12-14	13-14	13-15	15

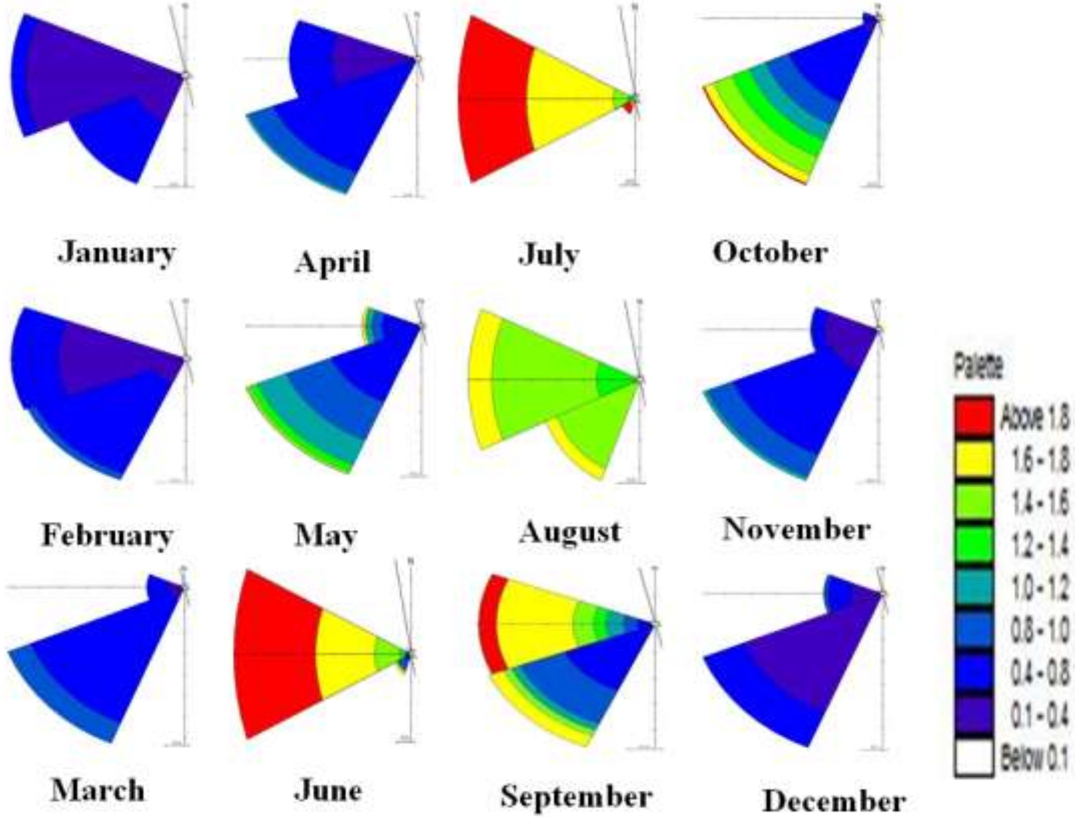


Figure. 4.3 Breaker wave heights (m) and their approaching direction

Table. 4.23 Observation of wind data recorded during 2007 to 2010

Months	No of days with wind speed (km/hr)				Percentage number days with wind from								
	62 or more	**20-61**	**1-19**	**0**	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**	**CALM**
January	0	0	29	2	2	10	68	18	0	1	0	1	0
February	0	0	27	1	2	18	60	14	0	1	0	2	3
March	0	0	30	1	5	19	54	13	0	2	1	2	4
April	0	0	26	4	10	21	38	11	1	3	3	6	7
May	0	0	28	3	12	14	28	13	2	4	5	14	8
June	0	0	26	4	3	6	27	21	4	14	13	6	6
July	0	0	29	2	4	5	18	13	2	17	23	10	8
August	0	0	27	4	8	5	13	10	2	17	21	14	10
September	0	0	28	2	8	10	31	19	3	8	6	9	6
October	0	0	30	1	8	13	46	20	2	3	2	4	2
November	0	0	29	1	2	12	62	19	1	2	0	1	1
December	0	0	29	2	1	6	70	16	0	1	3	1	2
Annual Total or mean	0	0	338	27	5	12	43	16	1	6	6	6	5

N-North, NE-Northeast, E- East, SE-Southeast,
S- South, SW-Southwest, W-West, NW-Northwest

4.3 Medium-term shoreline changes

Medium-term shoreline changes can be associated with several factors. Among which the most important factors are (1) changes in the amount of the river sand supply and (2) variations in the wave energy due to storm activity that reach the beach. Changes in the sand supplied to the coast are directly linked to major sediment sources i.e the rivers, which supply homogeneous sand. At the same time the seasonal fluctuations in storms leads to vary coastal geomorphology at regional scale. Therefore, medium term (10 to 60 years) shoreline changes are directly related to freshwater discharge variations and storm events. Sand transport is more, when the freshwater discharge is higher in the rivers and corresponding high level of precipitation that leads to higher rate of discharge.

A storm can be defined in a simple term as a violent atmospheric perturbation accompanied by strong winds with other elements. When this happens in the sea, the most immediate effects are the increase in wave height and sea level. Storms have important consequences upon the coastal geomorphology, particularly large storms, due to the fact that, the wave power is a quadratic function of wave height. Therefore, storm events have the ability to rapidly redistribute large volume of sediments, accelerates rate of erosion or accretion, and controls short-term and medium term shoreline movement (Morton et al. 1995). It is also obvious that storms cause an abnormal elevated water level (storm surge), which raise the level of wave attack on the shore; higher water levels enable waves of a higher size to shoal and penetrate farther landward; setup runup, overtopping, and over washing are enhanced during storms.

4.3.1 Rainfall Analysis

The rainfall data obtained from IMD observatory stations (IMD Panambur and IMD Kateel) for Mulky and Pavanje river catchments were analysed to see the rainfall variations from season to season and years to years. Table.4.24 presents the analysis

Table.4.24 Variations of rainfall in Mulky and Pavanje Catchments

Year	Annual Variations		Monsoon		Post-Monsoon	
	Rainfall (mm)		Rainfall (mm)		Rainfall (mm)	
	Mulky	Pavanje	Mulky	Pavanje	Mulky	Pavanje
1985	3141.2	2731.5	2625.5	2283.0	263.7	229.3
1986	3279.6	2851.8	2945.2	2561.0	281.6	244.9
1987	3084.8	2682.4	2659.4	2312.5	339.6	295.3
1988	3844.2	2442.8	2554.2	2221.0	13.8	125.6
1989	4779.5	4156.1	3921.8	3410.3	613.4	533.4
1990	4373.2	3802.8	3324.7	2891.0	296.5	257.8
1991	4802.9	4176.4	4543.0	3950.4	67.2	58.4
1992	5715.0	4331.6	5089.7	3925.8	515.0	447.8
1993	5442.4	4732.5	4528.2	3937.6	713.8	620.7
1994	5854.2	5102.3	5309.3	4305.8	339.0	549.8
1995	5552.2	4828.0	4914.6	4273.6	637.6	554.4
1996	4395.9	3822.5	4182.2	3636.7	176.6	153.6
1997	4607.0	4006.1	4350.1	3782.7	227.5	197.8
1998	4934.5	4290.9	4458.2	3876.7	467.8	406.8
1999	4386.2	3814.1	3330.3	2895.9	440.9	383.4
2000	3954.6	3175.8	2295.9	2733.4	485.2	342.4
2001	4991.2	4340.2	3782.8	3289.4	454.7	395.4
2002	3559.6	2583.8	2982.2	1828.7	304.8	518.0
2003	3924.7	3412.8	3718.4	3233.4	202.2	175.8
2004	3813.2	3235.3	3022.0	2547.3	102.4	89.0
2005	4358.2	3636.9	4008.8	3333.1	252.4	219.5
2006	3741.3	2687.3	3164.7	2185.9	221.8	192.9
2007	4875.9	4239.9	4134.7	3595.4	441.2	383.6
2008	5301.0	4609.6	4801.4	4175.1	428.4	372.5
2009	3986.2	3466.3	2985.6	2596.2	339.8	295.4
2010	4234.0	3681.8	3642.5	3167.4	289.2	251.5
2011	4268.1	3711.4	3630.7	3157.2	328.2	285.4

of annual precipitation data from 1985 to 2011, which depicts that maximum rainfall of about 5854.2 mm in 1994, minimum is about 3844.2mm in 1988 and average about 4414.8 mm on Mulky catchment area and in the similar way the maximum of about 5102.3 mm, minimum is about 2442.8 mm and average is about 3761.4 mm of rainfall occurred in the Pavanje catchment area during the same aforementioned time periods.

The precipitation level is gradually reduced from the year 1994 (5854.2 mm in Mulky catchment and 5102.3 mm in Pavanje) to 1997 (4607.0 mm in Mulky catchment and 4006.1 mm at Pavanje) and suddenly increased in 1998 (4934.5 mm in Mulky catchment and 4290.9 mm in Pavanje) and in the subsequent years (1999 and 2000) rainfall is further reduced (4386.2 mm to 3954.6 mm in Mulky catchment and 3914.1 mm to 3175.8 mm at Pavanje). The annual rainfall from 2001 to 2011 showed abrupt behaviour (4991.2 mm – 35559 mm – 3924.7 mm – 3813.2 mm – 4358.2 mm – 3741.3 mm – 4875.9 mm – 5301.0 mm – 3986.2 mm – 4234.0 mm – 4268.1 mm; 4340.2 mm – 2583.8 mm – 3412.8 mm – 3235.3 mm – 3636.9 mm – 2687.3 mm – 4239.9 mm – 4609.6 mm – 3466.3 mm – 3681.8 mm – 3711.4 mm on Pavanje catchment), but very drastic change in precipitation level is observed in 2009 on both catchments (Table. 4.24).

Seasonal analyses were also carried out using precipitation data (1985-2011). It is observed that the maximum rainfall is in the month of July followed by June and August. About 65-70 % of the total annual rainfall occurs during June to August, about 12-20 % in September to November and remaining downpour in the months between December and May (Figures. 4.4 and 4.5). During the study period (1985-2011), due to heavy rainfall, the Mulky and Pavanje rivers bring significant amount of sand in July, and followed by June to September. These months with high freshwater discharge correspond to higher precipitation range from 600 mm to 1500 mm on both catchments. Thus the level of precipitation has direct influence on coastal processes and shoreline alteration. The seasonal variation in oceanographic features of the study area is primarily influenced by the prevailing monsoon regime.

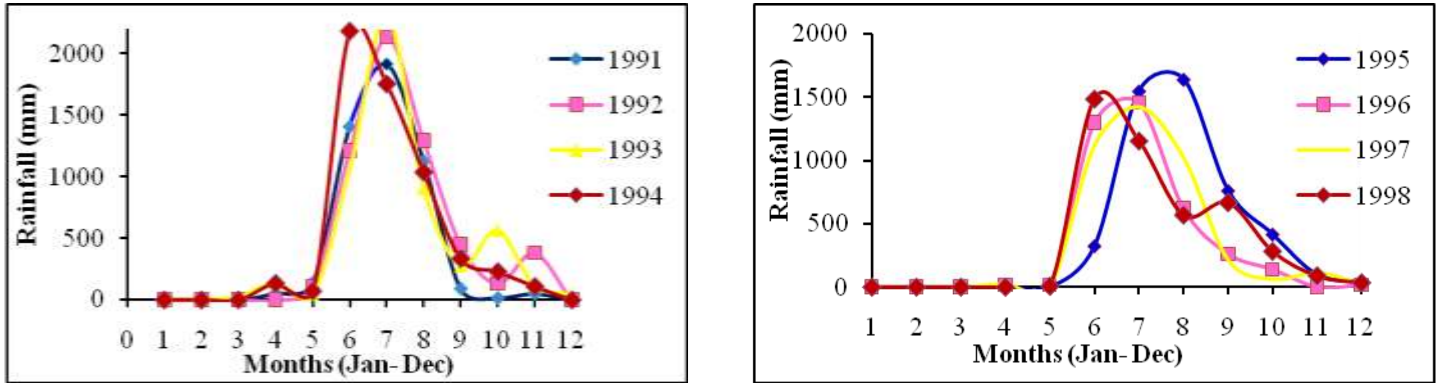


Figure 4.4 Time series of monthly rainfall of the Mulky River Basin

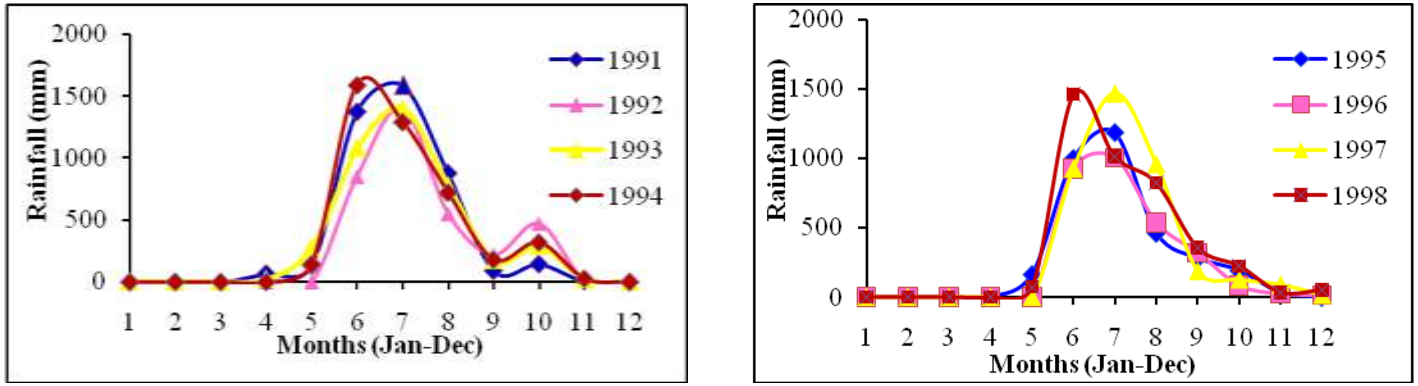


Figure 4.5 Time series of monthly rainfall of the Pavanje River Basin

Southwest monsoon commenced by the last week of May and monthly rainfall ranging from 6 mm in May to 1600 mm in July on the Mulky catchment and almost similar trend is observed in Pavanje basin also (5mm in May and less than 1500 mm in July) (Figures. 4.4 and 4.5). The annual precipitation in the Mulky area found to be slightly more than that of Pavanje catchment. The monthly rainfall in the two catchments clearly indicates the same behaviour over a scale of observations (1985 – 2011). On the Mulky and Pavanje catchments, the effect of storm activity gradually increased during the recent years (2005 to 2011). This trend clearly suggests that rivermouth area and associated beaches on either side are highly influenced by storm activity.

Due to high rainfall in the months between June and September beaches on either side of the rivermouth erode in the form onshore-offshore transport or alongshore transport. From October to January the rainfall reduces from higher level to lower level and hence beaches on either side of the rivermouth start accreting or rebuilding takes place. Due to very less rainfall from February to May beaches regain their profiles at their maximum extent. This observation further supports and confirms the beach profile survey and analysis, carried out along the length of the study area during recent years, i.e Sept 2009 – Dec 2011 (Refer section, 4.2.1). Therefore, it can be concluded that variation in rainfall events are directly related coastal morphology.

4.3.2 River Discharge Analysis

It is well known factor that the river's freshwater discharge and sediment flow into the sea are directly linked to each other and further leads to change in coastal morphology drastically in a short period of time. In this direction, the coastal morphology associated with the Mulky-Pavanje rivermouth has been investigated with the help of freshwater discharge data for the period between 1985 and 1998.

In order to archive the connection between coastal morphology and discharge, the change in the freshwater flow/discharge of two rivers Mulky and Pavanje are examined at annual and seasonal scales and presented in Table. 4.25. The records, which cover the period between 1985 and 1998, did not show a decreasing trend for freshwater discharge, but reveal a trend of increase in discharge and corresponding sediment flow into the rivermouth area, especially during 1988 and 1998. Over the last 10 years, i.e., 1988–1998, the average discharge for the two rivers are drastically increased, i.e Mulky river discharge about 1211 Mm^3 and Pavanje river discharge is 604 Mm^3. This observation is further confirmed with previous study conducted for Mulky and Pavanje catchments by Geetha and Krishnamoorthy 2010.

Table.4.25 Variations of discharge in Mulky and Pavanje Catchments

Year	Annual Variations Discharge (Mm^3)		Monsoon Discharge (Mm^3)		Post-Monsoon Discharge (Mm^3)	
	Mulky	Pavanje	Mulky	Pavanje	Mulky	Pavanje
1985	828.5	340.3	594.2	270.1	230.2	68.3
1986	1388.8	391.3	1055.6	479.8	327.1	148.7
1987	1219.7	439.2	971.9	441.8	244.0	110.9
1988	1240.7	548.9	945.7	429.9	295.0	134.1
1989	1177.2	482.1	942.8	428.5	225.6	102.6
1990	860.9	490.4	683.3	310.6	172.8	78.5
1991	966.3	465.3	868.4	394.7	91.9	41.8
1992	1070.5	486.6	866.6	393.9	203.9	92.7
1993	1200.2	545.5	892.0	405.5	308.2	140.1
1994	1423.2	646.9	1232.2	560.1	191.0	86.8
1995	1281.3	582.4	1126.6	512.1	144.5	65.7
1996	960.3	436.5	798.4	362.9	161.9	73.6
1997	1177.1	535.1	1018.8	463.1	158.3	72.0
1998	1614.8	734.0	1358.9	617.7	255.9	116.3

Due to less rainfall in 1988 (3844.2 mm at Mulky catchment and 2442.8 mm at Pavanje catchment; Refer section, 4.3.1), the rivers Mulky and Pavanje discharged only 1240.7 Mm^3 and 548.7 Mm^3 of freshwater into the Arabian sea respectively. Due to asymmetric variations in rainfall from 1989 to 1997 correspond to asymmetric discharges from both the rivers (1177.2 Mm^3 – 860.9 Mm^3 – 966.3 Mm^3 – 1070.5

Mm^3–1200.2 Mm^3 – 1423.2 Mm^3 – 1281.3 Mm^3 – 960.3 Mm^3 –1177.1 Mm^3 from Mulky river; 482.1 Mm^3 – 490.4 Mm^3– 465.3 Mm^3– 486.6 Mm^3–545.5 Mm^3– 646.9 Mm^3 – 582.4 Mm^3 – 436.5 Mm^3– 535.1 Mm^3 from Pavanje river). Further due to heavy rainfall in 1998 high freshwater discharge of about 1614.8 Mm^3 and 734.0 Mm^3 is observed from Mulky and Pavanje catchments respectively.

From seasonal point of view, both the rivers discharge about 65 % to 70 % (840 Mm^3 to 930 Mm^3 from Mulky river and 320 Mm^3 to 418 Mm^3 from Pavanje river) of the total annual discharge during monsoon season (June to Sept) and 15% to 20% of discharge (200 Mm^3 to 250 Mm^3 from Mulky river and 120 Mm^3 to 180 Mm^3 from Pavanje river) during post-monsoon season (Oct to Jan) and remaining discharge takes place during pre-monsoon season (Feb to May) into the Arabian sea (Figures 4.6 and 4.7).

During monsoon and post-monsoon period, the rivers Mulky and Pavanje overflow, discharge sizeable quantities of sediments into the sea, whereas during pre-monsoon periods, seawater enters into the rivermouth area leads sediment deposition and distribution on either side of the rivermouth. However, the discharge of the Mulky river is approximately two times more than that of Pavanje river (Table. 425). Because of the more flow in the Mulky river, which runs across the northern part of the rivermouth, the shoreline in the vicinity of rivermouth is predominantly shifting towards south. This southern shifting trend is further confirmed with previous studies carried out for the same study area (Kunte and Wagle 1991; Gangadhara 1995; Gumageri et al. 2012).

In order to establish the relationship between precipitation and freshwater discharge, the monthly time series rainfall and river discharge are plotted (Figures. 4.8 and 4.9). The time series plot between rainfall and freshwater discharge for the period 1991 to 1994 and 1995 to 1998 indicate that as the precipitation level increases corresponding to the rate of freshwater discharge also increases from two river catchments. From this behaviour, a unique relationship is observed between precipitation and river discharge

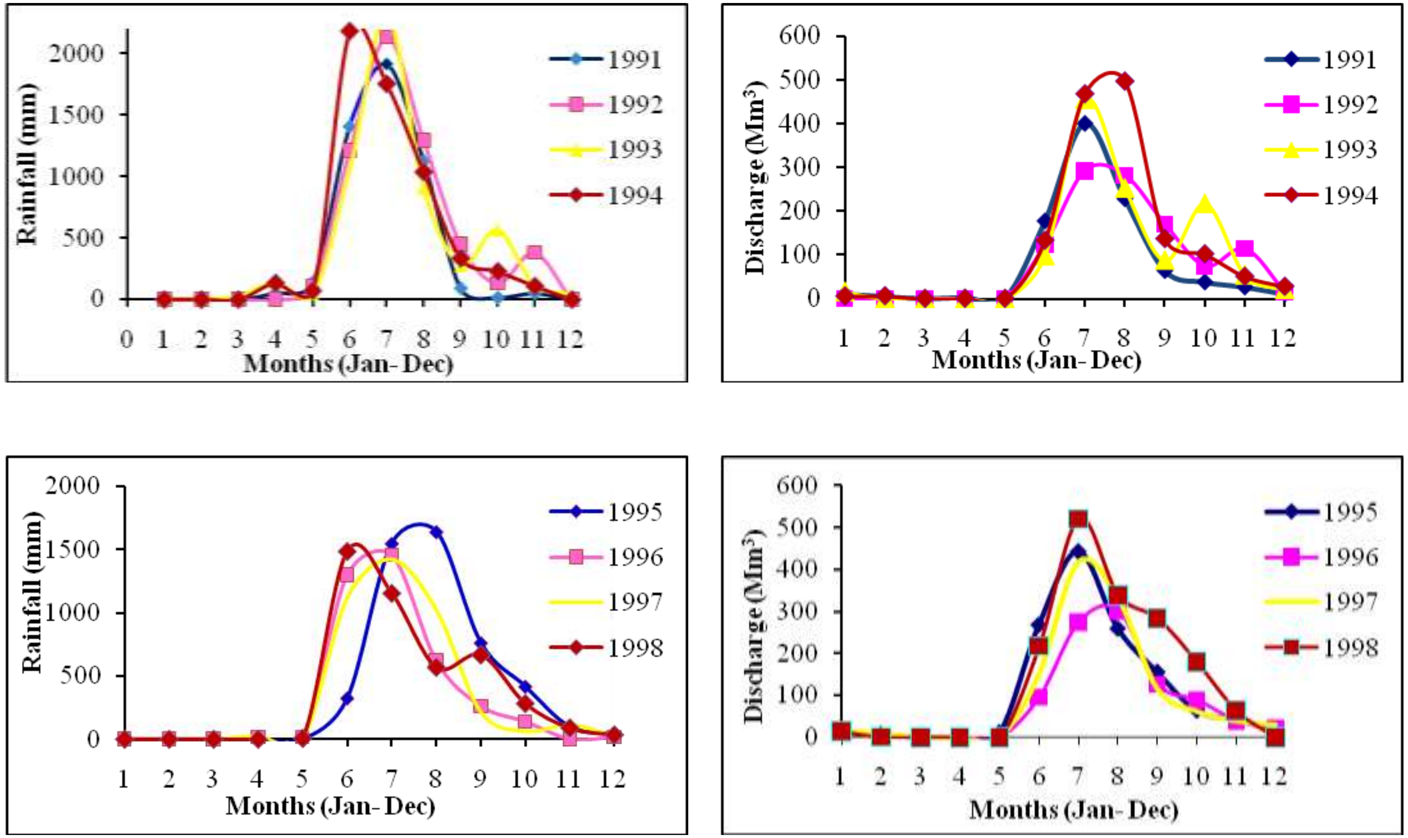


Figure 4.6 Time series of monthly rainfall and river discharge of the Mulky River Basin

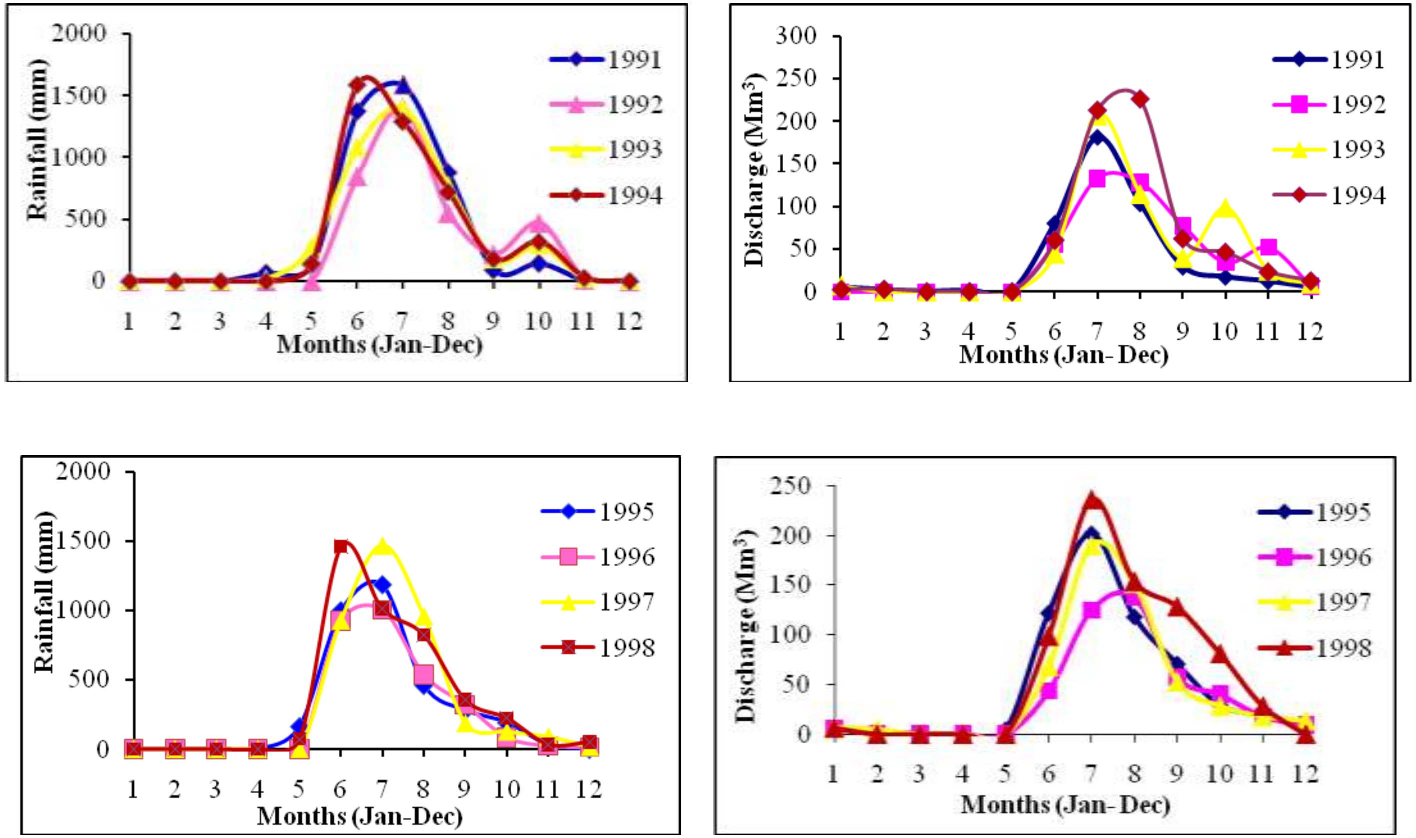


Figure 4.7 Time series of monthly rainfall and river discharge of the Pavanje River Basin

is that the rainfall in the catchment area of two rivers is directly proportional to that of freshwater discharges.

As a summary, during the year 1988 there is a low rainfall corresponding to low discharge and the year 1998 indicates higher rainfall corresponding to more discharge. Therefore, in order to establish the relationship between rainfall, freshwater discharge and shoreline change associated with Mulky-Pavanje rivermouth, the comprehensive study through remote sensing techniques for the period 1988 and 1998 was carried out and described in the following section.

4.4 Long-term Change Analysis

4.4.1 Rivermouth and spit morphology

Long-term (> 60 years) and short-term (< 10 years) change analyses were carried out using multidated remote sensing satellite imageries and topographical maps. The change detection analyses were initially started with Mulky-Pavanje rivermouth configuration and further extended on either side of the rivermouth to see the changes in the dynamics of spits.

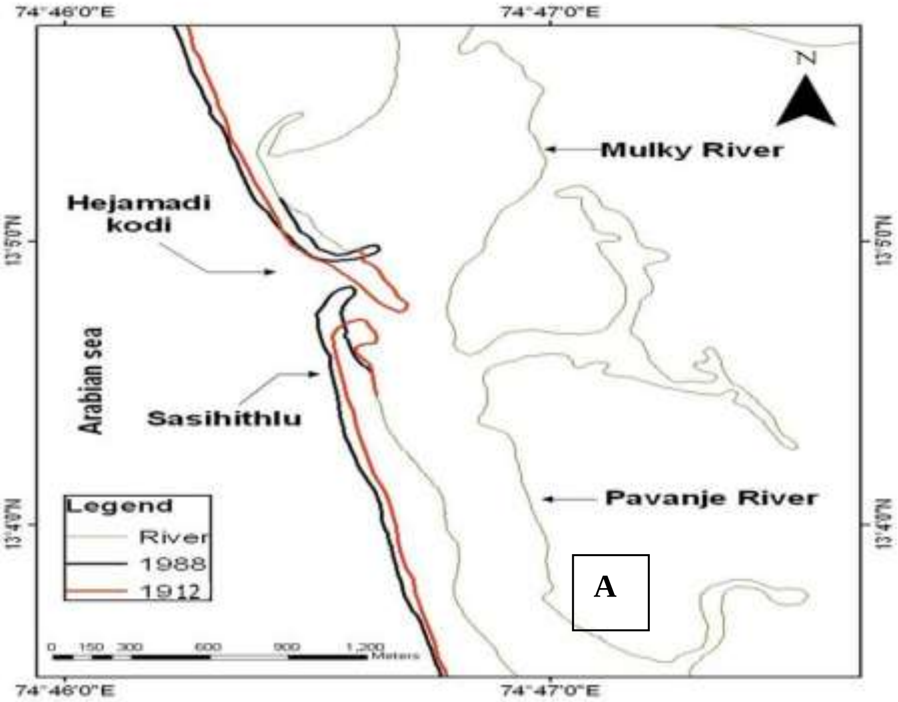
Long-term and short-term shoreline change detection analyses have been made by comparing the topographic map of 1912 with multidated satellite imageries, IRS –1D LISS – III images of January 1998 and December 2003, IRS – LISS III of May 2006 and IRS – P6 LISS IV (MX) of April 2009 and Toposheet of 1988. Multidated spatial data analyses around the Mulky Pavanje rivermouth and rivermouth configuration were mapped using ERADAS 9.2, a digital image processing software and ArcGIS 8.2, a GIS software. The detailed shoreline analysis shows the erosion and dynamic changes in the rivermouth configuration.

The rivers Mulky and Pavanje, flow about 1850 m and 5400 m respectively parallel to the coast, which result in the formation of two spits namely Hejamadi Kodi (Northern spit) and Sasihithlu (Southern spit). The Hejamadi spit is shorter in length as compared to that of Sasihithlu spit. The length of Sasihithlu spit is approximately 1.5 km and Hejamadi spit is about 1.0 km, both are formed by the deposition of sand near the rivermouth. Along the length of these spits, there is no noticeable vegetation. The towns Sasihithlu and Hejamadi are situated on the mainlands and extended their growth onto the spits too. On these sand spits fishing activities are carried out since from historical period. These spits are also sometimes used for berthing of boats. In addition, the percentage of fishermen is more on both the spits during summer for fishing. The rivermouth of Mulky and Pavanje have been migrating towards the South since long-time, forcing the two spits to change their shape, size and orientation (Kunte and Wagle 1991; Gangadhar 1995; Bhat and Subrahmanya 2000). Therefore, Sasihithlu and Hejamadi Kodi spits are subjected to severe erosion and accretion.

This section presents the study of the geomorphologic history of the two spits and their present status. The Mulky and Pavanje rivermouth is found to be dynamic and did undergo morphological changes over the period due to several factors such as change in wave climate, river discharge, longshore currents, longshore sediment transport and other natural processes. Therefore, the geomorphologic changes during the following periods were studied:

1. 1912-1988
2. 1988-1998
3. 1998-2003
4. 2003-2006
5. 2006-2009

The geomorphology of the rivermouth and dynamics of two spits were measured as in the aforementioned temporal scales. Finally the change in length of the spits and confluence width were measured and erosion and accretion of spit areas were computed with respect to 1912 and presented in Table. 4.26 and Table. 4.27.


74°46'0"E
74°47'0"E
N
Mulky River
Hejamadi
kodi
Arabian sea
Sasihithlu
Pavanje River
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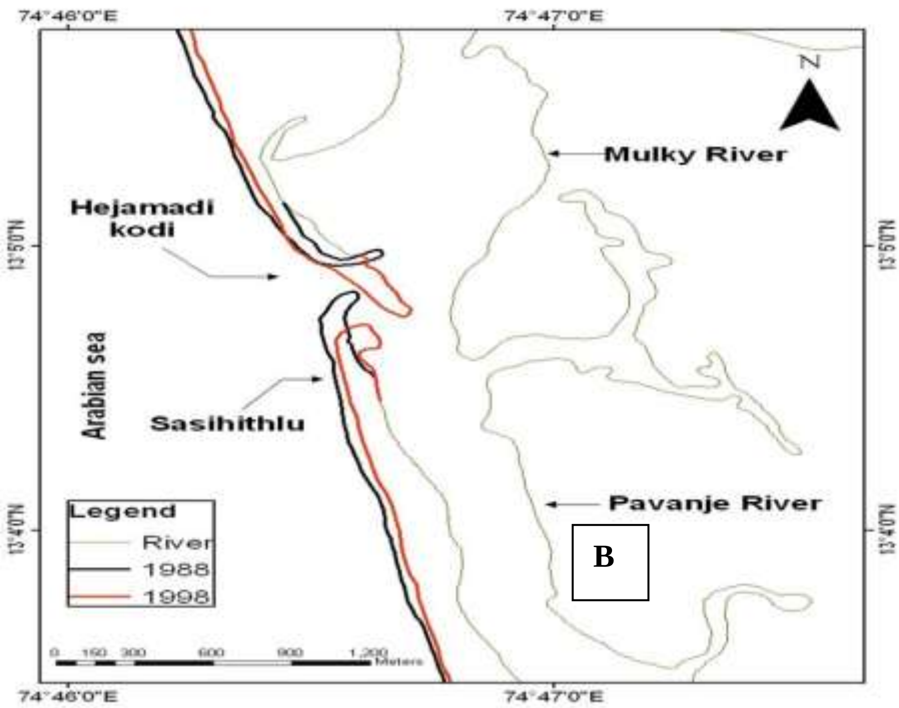
1988
1912
A
13°5'0"N
13°4'0"N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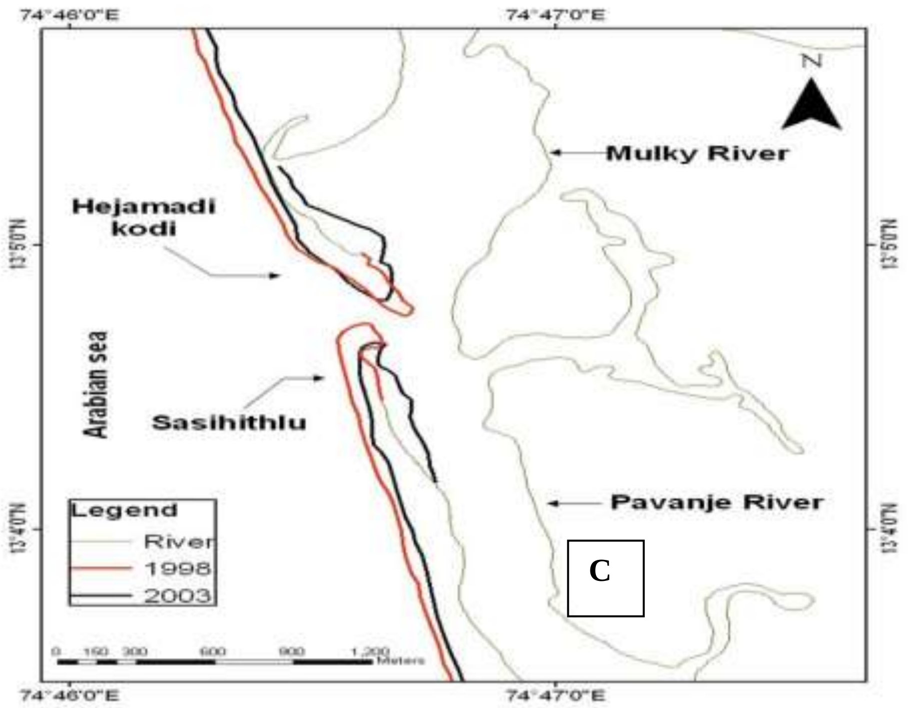
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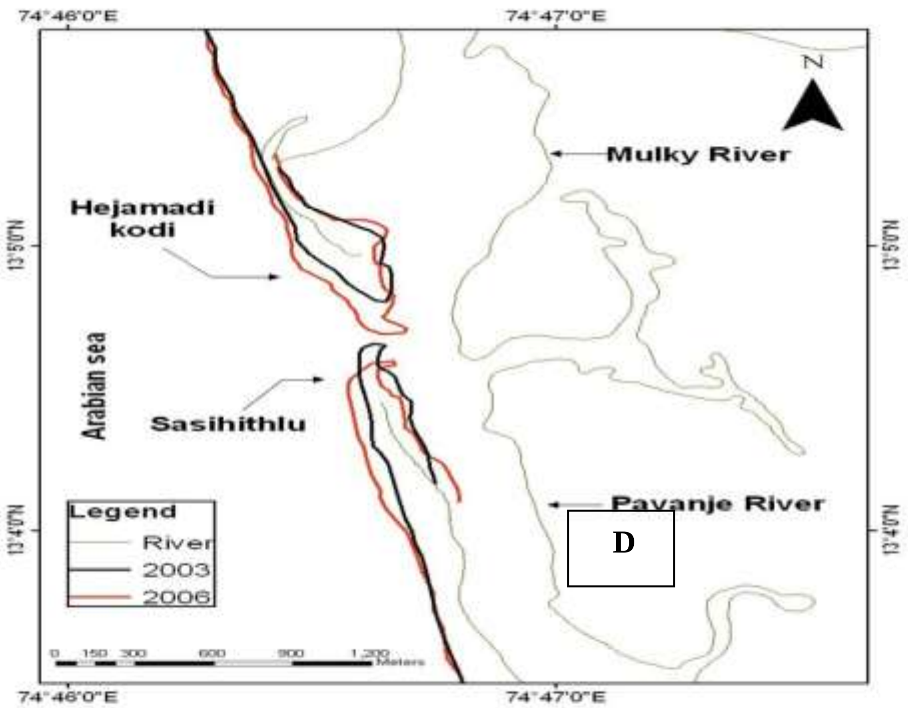
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0 150 300 600 900 1,200 Meters

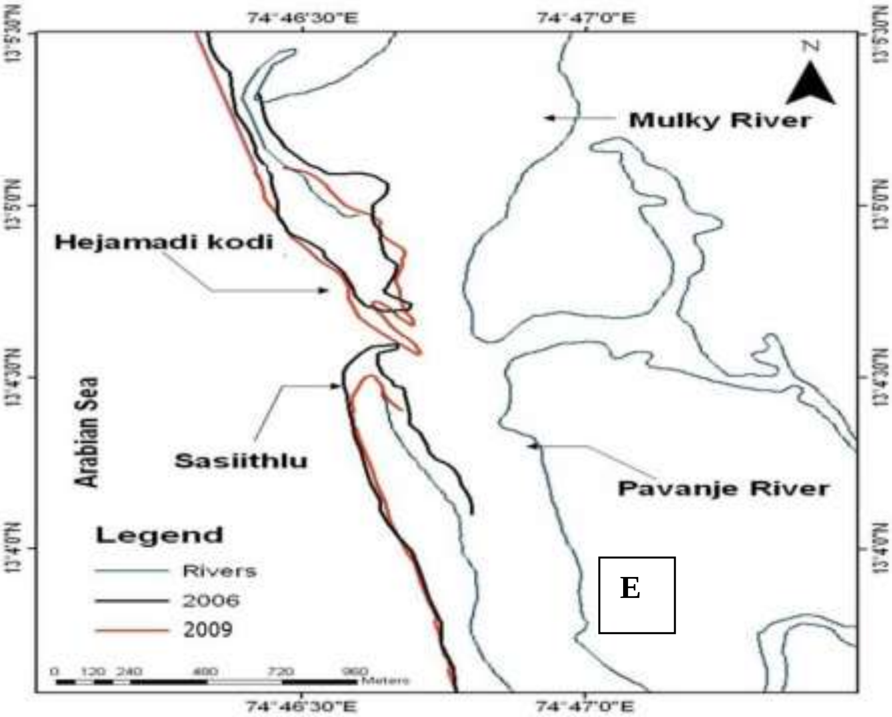


Figure. 4.8 Changes in shoreline on either side of the Mulky-Pavanje rivermouth. (A) 1912-1988, (B) 1988–1998, (C) 1998–2003, (D) 2003–2006 and (E) 2006–2009.

4.4.1.1 Period between 1912 and 1988

Figure 4.8A shows the shorelines of Sasihithlu and Hejamadi spits respectively for the years 1912 and 1988 (76 years), one can observe the migration of the rivermouth and erosion near the tip of Hejamadi spit and accretion near the tip of Sasihithlu sand spit. Discharge in the Mulky river (1614 Mm^3) is very large compared to that of the Pavanje river (734 Mm^3) and this might have induced the changes near the rivermouth.

Large quantity of sediments brought by the two rivers might have been the reason for the net gain of land near the rivermouth. The erosion of about 0.188 km^2 and accretion of about 0.015 km^2 took place at the spits of Hejamadi Kodi and Sasihithlu respectively with respect to 1912 shoreline. The erosion at Hejamadi spit and accretion at Sasihithlu spit are probably due to high river discharge from the two rivers near the rivermouth. The confluence width of the rivermouth is increased from 159 m to 182 m and showed tendency of moving towards south. At the same time Hejamadi spit length is shortened by 307 m and Sasihithlu spit increased by 202 m during 1912-1988.

4.4.1.2 Period between 1988 and 1998

During the period between 1988 and 1998 (Figure. 4.8 B), the Hejamadi spit has an accretion of 0.190 km^2 and it has elongated 364 m towards south whereas the Sasihithlu spit experienced erosion of about 0.123 km^2 and its length shortened by 210 m towards south. This change implies that the rivermouth is migrating towards south. This migration is probably due to sudden rise in the discharge of Mulky and Pavanje rivers in 1998 (1177.1 Mm^3 – 1614.8 Mm^3 from Mulky and 535.1 M m^3 – 734.0 Mm^3 from Pavanje) and also may be due to wave activities and other natural coastal processes. The confluence width of the rivermouth was 182 m during 1988 which is narrowed down to 95 m during 1998.

4.4.1.3 Period between 1998 and 2003

Figure 4.8 C shows the shorelines of 1998 and 2003 (5 years). No major migration of the rivermouth is observed, but there is minor erosion on both spits (0.117 Km^2 at Sasihithlu spit and 0.102 Km^2 at Hejamadi spit) and reduction in spit lengths (Sasihithlu spit by 0.190 km and Hejamadi spit by 0.233 km). However, due to erosion of the sharp edges near the tip of the Hejamadi and Sasihithlu spit, the confluence width has increased upto 285 m. The erosion of the spits might have been caused by the heavy river flow from the two rivers during the monsoon.

The period 1998–2003 revealed significant erosion on either side of the rivermouth, particularly at Sasihithlu and Hejamadi spits. The eroded sand moved by waves approaching from the northwest direction, generating north flowing longshore currents, due to this, northern part of the rivermouth, namely Hejamadi spit showed deposition. This accretion processes was probably due to wind, longshore currents

Table.4.26 Changes in spit area, spit length and confluence width around Mulky - Pavanje Rivermouth

Year	Area (km^2)		Length of spit (km)		Confluence width (m)	Change in length of spit (km) with respect to 1912	
	Sasihithlu	Hejamadi	Sasihithlu	Hejamadi		Sasihithlu	Hejamadi
1912	0.358	0.425	1.542	0.654	159	-	-
1988	0.373	0.237	1.744	0.347	182	Elongated by 0.202	Shortern by 0.307
1998	0.235	0.615	1.332	1.018	95	Shortern by 0.210	Elongated by 0.364
2003	0.241	0.323	1.352	0.421	285	Shortern by 0.190	Shortern by 0.233
2006	0.244	0.538	1.347	0.974	182	Shortern by 0.195	Elongated by 0.320
2009	0.255	0.581	1.392	1.009	195	Shortern by 0.150	Elongated by 0.355

Table.4.27 Changes in spit net area and spit net length around Mulky - Pavanje Rivermouth with respect to 1912

Year	Net Erosion (-) / Net accretion (+) (Km^2)		Chane in Length of spit (km)	
	Sasihithlu	Hejamadi	Sasihithlu	Hejamadi
1988	+0.015	-0.188	+0.202	-0.307
1998	-0.123	+0.19	-0.210	+0.364
2003	-0.117	-0.102	-0.190	-0.233
2006	-0.114	+0.113	-0.195	+0.320
2009	-0.103	+0.156	-0.150	+0.355

and wave climate which leads to accumulation of large volumes of sand on northern side (Fig. 4.8 C).

4.4.1.4 Period between 2003 and 2006

Figure 4.8 D depicts the shorelines of the spits for the years 2003 and 2006 (3 years). During this period the Hejamadi sand spit is accreted (0.113 km^2) and at the same time the tip of Sasihithlu spit eroded with quantum of about 0.114 km^2. Due to increase in spit length on Hejamadi (0.320 km) and reduction in spit length at Sasihithlu (0.195 km), the rivermouth has shifted towards south. Because of this, the confluence width of the rivermouth becomes still narrower with width about 182 m.

4.4.1.5 Period between 2006 and 2009

During the time frame 2006 and 2009 (3 years), due to the effect of high freshwater discharge, the Sasihithlu spit is further eroded, but Hejamadi spit is accreted. However, the shoreline associated with Sasihithlu spit maintained stable state but Hejamadi spit shoreline is under the processes of accretion and erosion (Figure 4.8 E). This accretion/erosion and stability are due to the sediments brought by the two rivers and distributed on either side of the rivermouth. But, the major contribution is from Mulky River (1614 Mm^3) and hence the Hejamadi spit is accreted by 0.156 km^2 but Sasihithlu spit is eroded by 0.103 km^2 towards south. In addition to this, Sasihithlu spit length is reduced to 0.150 km and Hejamadi spit increased by 0.355 km respectively between the confluence width 195 m.

During the period between 2006 and 2009, the shoreline associated with rivermouth at the south and north is almost maintained equilibrium. This indicates that during 2006-2009, there are not much significant changes either in terms of shoreline configuration or in terms of rivermouth dynamics. Hence, the period 2006-2009 may be considered as the stable period (Fig. 4.8 E).

Figures 4.8 A to 4.8 E show the consolidated data from 1912 to 2009 regarding change in confluence width, change in length of Sasihithlu spit, change in length of

Hejamadi sand spit and migration of the rivermouth in a graphical form. From the Figures 4.8 A to 4.8 E, it can be clearly seen that the confluence width has changed significantly during the period of observation and it also demonstrate that lengths of the Sasihithlu and Hejamadi spits keep changing from time to time. All the Figures further prove that rivermouth had not stabilized during the study period. Thus, it may be concluded that the spits have not been remained stable during the period of observation.

The long-term change analyses indicate asymmetrical change in confluence width of rivermouth from 285 m to 95 m (Table. 4.26) in the last 97 years and the rivermouth shifted towards south. In addition, the spit length variations on either side changed abruptly from 0.654 km to 1.018 km on Hejamadi and 1.744 km to 1.392 km on Sasihithlu spits respectively. From the observation of 97 years data, it is found that the spit growth is in the direction of net longshore transport irrespective of seasonal drift. The southward growth of Hejamadi spit clearly indicates the effective longshore drift in the study area during the years 1912-2009 is towards south. Supply of sediments for the growth of these spits is mainly from longshore drift and distribution of riverine sediments.

Infact the development of spits and shifting of rivermouths are common problems along the Karnataka coast. Several earlier researchers also observed tendency of shifting of rivermouth towards south for the Karnataka coastline (Kunte and Wagle 1991; Dwarakish et al 1998; Raghavan et al. 2001; Hegde et al. 2009; Nayak et al. 2010; Gumageri and Dwarakish 2011).

4.4.2 Shoreline Changes

Long-term and short-term shoreline changes as well as erosion/accretion patterns have been estimated for the periods 1912-1988, 1988-1998, 1998-2003, 2003-2006 and 2006-2009. The accretion and erosion patterns along the length of the study area were analysed for every 250 m interval by considering aforementioned periods and plotted as shown in Figure.4.9 and the estimated values of beach width and beach area of erosion or accretion are presented in Table.4.28.

4.4.2.1 Period between 1912 and 1988

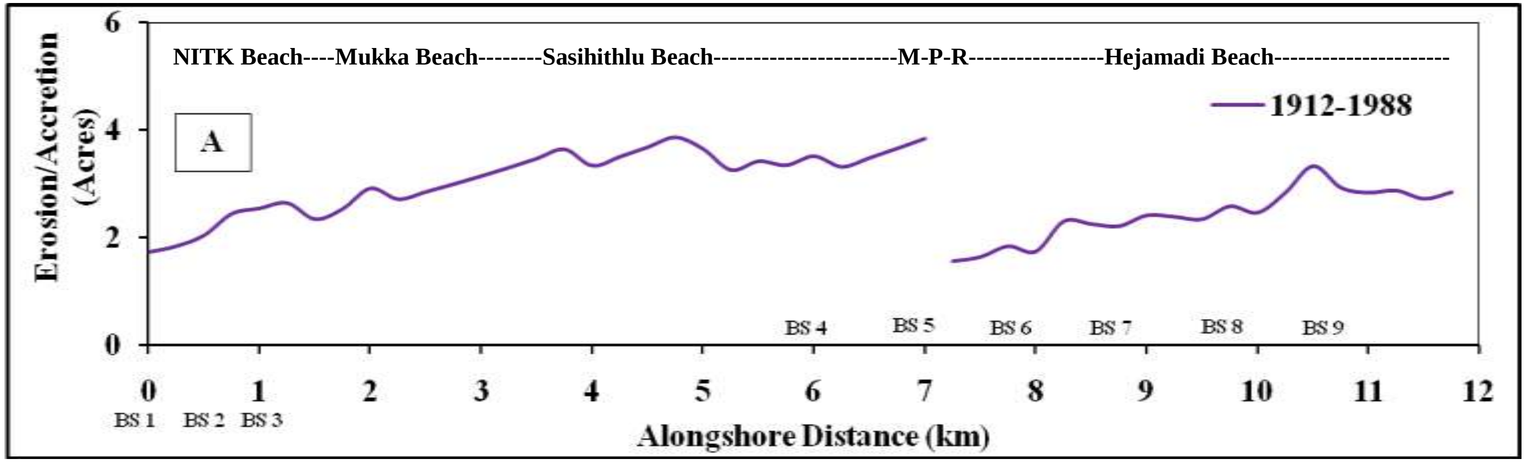
The period between 1912 and 1988 (Figure. 4.9 A and Table. 4.28), it can be observed that there is an increase in the sand area about 89.15 acres and 49.11 acres on the southern side and northern side of the rivermouth respectively. The maximum accreted area (3.87 acres) found at 4750 m and minimum area (1.74 acres) is observed at 0 m. In the similar way maximum and minimum beach widths i.e 63 m and 28 m are also found at the same above mentioned sectors on southern side of the rivermouth.

On the other hand, sectors 10500 m and 7250 m represent maximum and minimum areas on the shoreline of northern side of the rivermouth, i.e 3.33 acres and 1.57 acres. Due to maximum and minimum areas in the aforementioned sectors, the beachwidths are also presented maximum and minimum widths, which are about 54 m and 25 m on the northern side of the rivermouth. However, most of the beach widths are more than 50 m on southern side and 40 m on the northern side of shorelines.

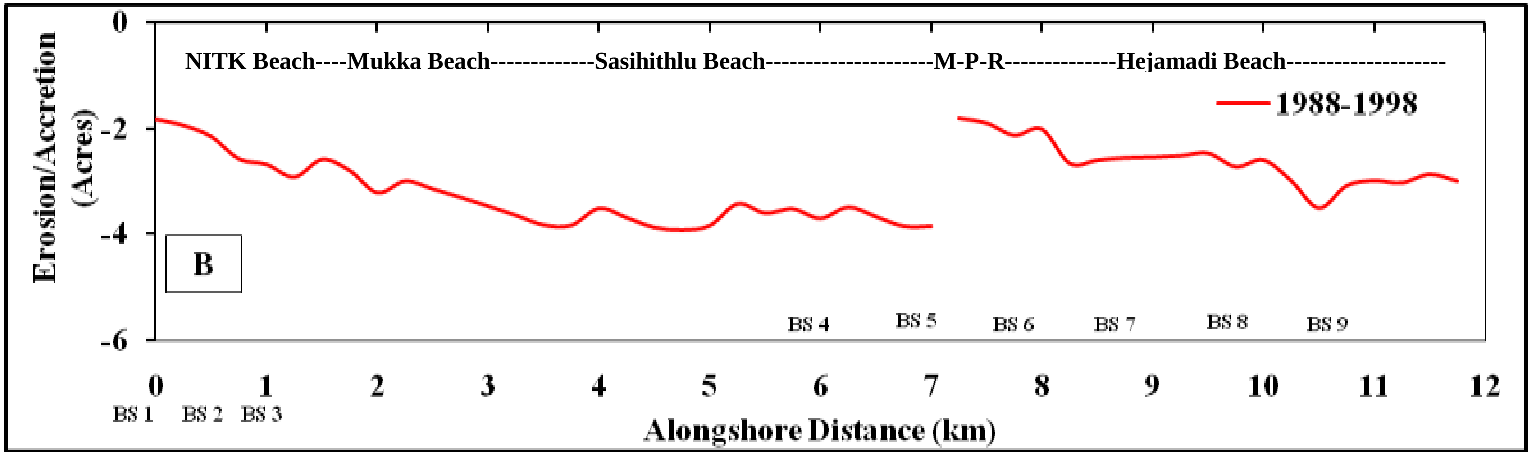
This long-term (1912-1988) shoreline change analysis reveals that the northern side shoreline is highly accreted (49.11 acres) though it is less coverage (7250 m to 12000 m) as compared with southern side of the shoreline (89.15 acres). Therefore, it can be concluded that the period 1912-1988 shows accretion on northern side.

4.4.2.2 Period between 1988 and 1998

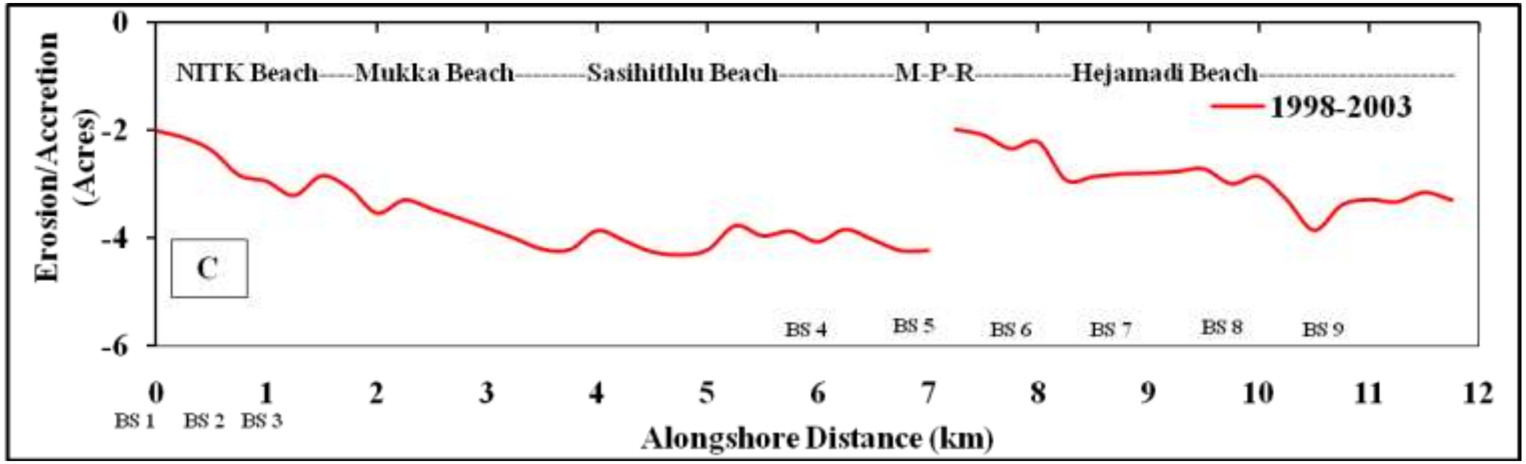
During the period between 1988 and 1998, the shorelines associated with Mulky – Pavanje rivermouth have been reduced to 94.72 acres (on southern side) and 52.93 acres (on northern side) (Figure.4.9 B and Table. 4.28). In this period, both the shorelines i.e south and north are drastically eroded. This erosion of shoreline area is due to the natural and human activities in the region. The most natural phenomena may be the damming of freshwater discharge and rainfall events on both catchments



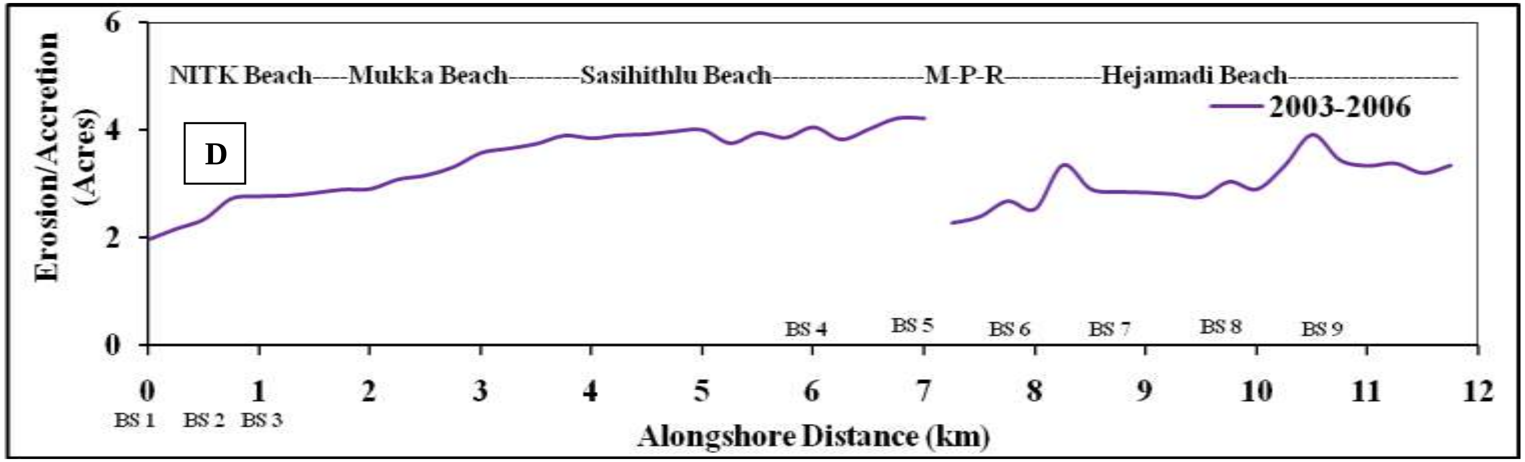
Erosion/Accretion (Acres)
6
4
2
0
NITK Beach----Mukka Beach--------Sasihithlu Beach----------------------M-P-R----------------Hejamadi Beach---------------------
A
1912-1988
BS 4
BS 5
BS 6
BS 7
BS 8
BS 9
0 1 2 3 4 5 6 7 8 9 10 11 12
BS 1 BS 2 BS 3
Alongshore Distance (km)



Erosion/Accretion (Acres)
0
-2
-4
-6
NITK Beach----Mukka Beach------------Sasihithlu Beach--------------------M-P-R-------------Hejamadi Beach-------------------
1988-1998
B
BS 4
BS 5
BS 6
BS 7
BS 8
BS 9
0 1 2 3 4 5 6 7 8 9 10 11 12
BS 1 BS 2 BS 3
Alongshore Distance (km)



C
NITK Beach----Mukka Beach--------Sasihithlu Beach-------------M-P-R-----------Hejamadi Beach
1998-2003
Erosion/Accretion (Acres)
0
-2
-4
-6
0 1 2 3 4 5 6 7 8 9 10 11 12
BS 1 BS 2 BS 3 BS 4 BS 5 BS 6 BS 7 BS 8 BS 9
Alongshore Distance (km)



D
NITK Beach----Mukka Beach--------Sasihithlu Beach----------------M-P-R----------Hejamadi Beach
2003-2006
Erosion/Accretion (Acres)
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12
BS 1 BS 2 BS 3 BS 4 BS 5 BS 6 BS 7 BS 8 BS 9
Alongshore Distance (km)

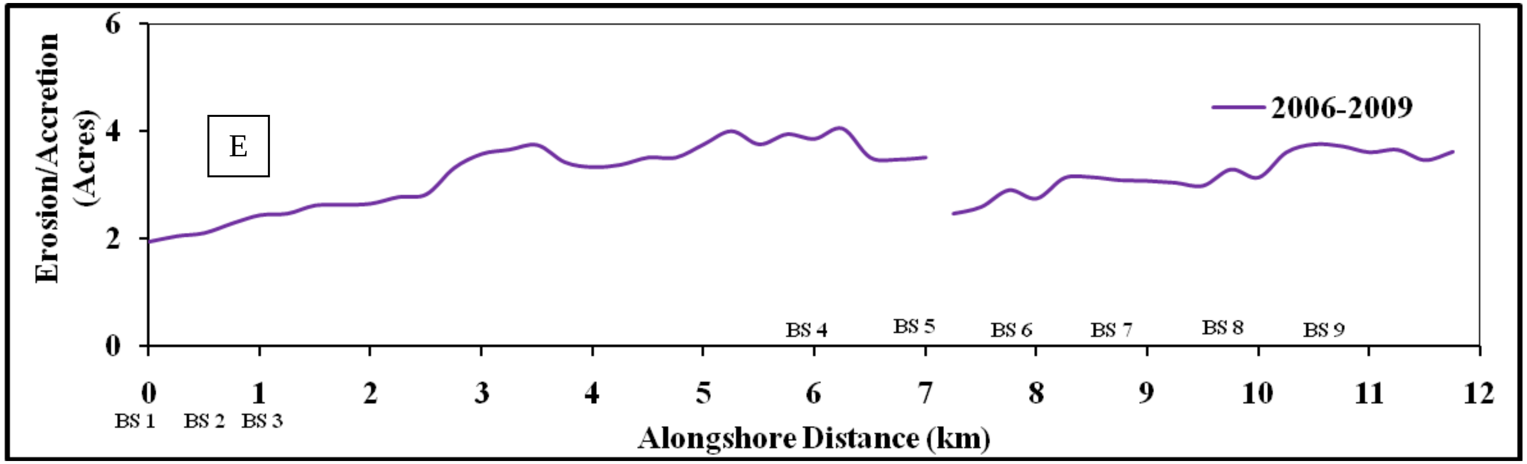


Figure. 4.9 The changes in accretion and erosion patterns along the length of the study area during the periods, A) 1912-1988, B) 1988-1998, C) 1998-2003, D) 2003-2006 and E) 2006-2009

Table. 4.28 Variation in accumulation of sediment and beach width (BW) for every 250m interval

Distance (m) from South to North	1912-1988		1988-1998		1998-2003		2003-2006		2006-2009		Remarks
	Area (Acres)	Beach width (m)	Area (Acres)	Beach width (m)	Area (Acres)	Beach width (m)	Area (Acres)	Beach width (m)	Area (Acres)	Beach width (m)	
0 (BS 1)	1.74	28	-1.83	-30	-2.01	-33	1.98	32	1.94	31	A
250	1.85	30	-1.94	-31	-2.14	-35	2.18	35	2.05	33	A
500 (BS 2)	2.05	33	-2.15	-35	-2.37	-38	2.35	38	2.11	34	A
750	2.45	40	-2.57	-42	-2.83	-46	2.74	44	2.29	37	E
1000 (BS 3)	2.55	41	-2.68	-43	-2.95	-48	2.78	45	2.44	40	E
1250	2.65	43	-2.92	-47	-3.21	-52	2.79	45	2.47	40	E
1500	2.35	38	-2.59	-42	-2.84	-46	2.84	46	2.62	42	A
1750	2.54	41	-2.79	-45	-3.07	-50	2.91	47	2.63	43	A
2000	2.92	47	-3.21	-52	-3.53	-57	2.92	47	2.66	43	ME
2250	2.72	44	-2.99	-48	-3.29	-53	3.10	50	2.78	45	A
2500	2.86	46	-3.14	-51	-3.46	-56	3.17	51	2.83	46	E

A-Accreting; MA-Majorly accreting; E-Eroding; ME- Majorly Eroding

Distance (m) from South to North	**1912-1988**		**1988-1998**		**1998-2003**		**2003-2006**		**2006-2009**		**Remarks**
	Area (Acres)	**Beach width (m)**	**Area (Acres)**	**Beach width (m)**	**Area (Acres)**	**Beach width (m)**	**Area (Acres)**	**Beach width (m)**	**Area (Acres)**	**Beach width (m)**	
2750	3.00	51	-3.30	-53	-3.63	-59	3.33	54	3.33	54	A
3000	3.15	54	-3.46	-56	-3.81	-62	3.59	58	3.59	58	A
3250	3.31	56	-3.64	-59	-4.00	-65	3.67	59	3.67	59	A
3500	3.47	59	-3.82	-62	-4.20	-68	3.76	61	3.06	61	ME
3750	3.65	54	-3.83	-62	-4.21	-68	3.91	63	3.33	56	ME
4000	3.34	57	-3.51	-57	-3.86	-62	3.86	63	3.38	54	A
4250	3.51	60	-3.68	-60	-4.05	-66	3.92	63	3.39	55	E
4500	3.68	63	-3.87	-63	-4.25	-69	3.94	64	3.52	57	E
4750	3.87	59	-3.92	-63	-4.31	-70	3.99	65	3.52	57	ME
5000	3.65	53	-3.83	-62	-4.22	-68	4.02	65	3.77	61	E
5250	3.26	55	-3.42	-55	-3.77	-61	3.77	61	4.02	65	A
5500	3.42	54	-3.59	-58	-3.95	-64	3.96	64	3.77	61	A
5750	3.35	57	-3.52	-57	-3.87	-63	3.87	63	3.96	64	A
6000 (BS 4)	3.52	51	-3.69	-60	-4.06	-66	4.07	66	3.87	63	A

Distance (m) from South to North	1912-1988		1988-1998		1998-2003		2003-2006		2006-2009		Remarks
	Area (Acres)	Beach width (m)	Area (Acres)	Beach width (m)	Area (Acres)	Beach width (m)	Area (Acres)	Beach width (m)	Area (Acres)	Beach width (m)	
6250	3.32	54	-3.49	-56	-3.83	-62	3.84	62	3.22	66	E
6500	3.49	56	-3.66	-59	-4.03	-65	4.03	65	3.12	57	ME
6750	3.66	59	-3.84	-62	-4.23	-68	4.23	69	3.04	56	ME
7000 (BS 5)	3.84	62	-3.84	-62	-4.23	-68	4.23	69	3.52	57	ME
Total Area / Avg BW	**89.15**	**50**	**-94.72**	**-53**	**-104.19**	**-58**	**99.72**	**56**	**92.34**	**52**	**E**
7250	1.57	25	-1.81	-29	-1.99	-32	2.28	37	2.47	40	**A**
7500 (BS 6)	1.65	27	-1.90	-31	-2.09	-34	2.40	39	2.59	42	**MA**
7750	1.85	30	-2.13	-34	-2.34	-38	2.69	44	2.91	47	**MA**
8000	1.75	28	-2.01	-33	-2.21	-36	2.55	41	2.75	45	**MA**
8250	2.31	37	-2.66	-43	-2.92	-47	3.36	54	3.14	51	**MA**
8500 (BS 7)	2.26	37	-2.60	-42	-2.86	-46	2.92	47	3.15	51	**MA**
8750	2.22	36	-2.55	-41	-2.81	-45	2.86	46	3.10	50	**MA**

Distance (m) from South to North	1912-1988		1988-1998		1998-2003		2003-2006		2006-2009		Remarks
	Area (Acres)	**Beach width (m)**	**Area (Acres)**	**Beach width (m)**	**Area (Acres)**	**Beach width (m)**	**Area (Acres)**	**Beach width (m)**	**Area (Acres)**	**Beach width (m)**	
9000	2.42	39	-2.54	-41	-2.80	-45	2.85	46	3.08	50	**MA**
9250	2.39	39	-2.51	-41	-2.77	-45	2.82	46	3.05	49	**A**
9500	2.35	38	-2.47	-40	-2.71	-44	2.77	45	2.99	48	**A**
9750 (BS 8)	2.59	42	-2.72	-44	-2.99	-48	3.05	49	3.30	53	**A**
10000	2.47	40	-2.59	-42	-2.85	-46	2.91	47	3.15	51	**A**
10250	2.84	46	-2.98	-48	-3.28	-53	3.35	54	3.62	59	**A**
10500	3.33	54	-3.50	-57	-3.85	-62	3.93	64	3.77	61	**A**
10750 (BS 9)	2.93	47	-3.08	-50	-3.39	-55	3.45	56	3.73	60	**A**
11000	2.84	46	-2.98	-48	-3.28	-53	3.35	54	3.62	59	**A**
11250	2.88	47	-3.02	-49	-3.33	-54	3.39	55	3.67	59	**A**
11500	2.73	44	-2.86	-46	-3.15	-51	3.21	52	3.47	56	**A**
11750	2.85	46	-2.99	-48	-3.29	-53	3.36	54	3.63	59	**A**
12000	2.87	46	-3.01	-49	-3.31	-54	3.38	55	3.66	59	**A**
Total Area / Avg BW	**49.11**	**40**	**-52.93**	**-43**	**-58.22**	**-47**	**60.88**	**49**	**64.84**	**52**	**A**

(Rainfall and discharge were low in 1988 and drastically increased in 1998; Refer section, 4.3). Therefore, this period can be considered as erosion period.

Because of erosion on southern side and northern side shorelines, the beach widths are also reduced. The maximum beach width of about -30 m and -29 m are observed at 0 m and 7250 m and minimum beach widths (-63 m at south and -57 m on north) found at 4750 m and 10500 m.

4.4.2.3 Period between 1998 and 2003

During this period, the shorelines at south and north are further eroded as compared with 1988-1998. The erosion from 94.72 acres to -104.19 acres and from 52.93 acres to -58.22 acres is observed on southern side and northern side shorelines respectively (Figure.4.9 C and Table. 4.28). This period (1998-2003) can be considered as highly eroded period. This erosion is probably due to gradual increase in rainfall from 1998 to 2003 on Mulky and Pavanje catchments (Refer section, 4.3) and corresponding increase in oceanographic characteristics (wave, tide and current, storm surge and so on).

During this period, the maximum beach widths of about -33 m (0 m) and -32 m (7250 m), and minimum beach widths of about -70 m (4750 m) and -62 m (10500 m) are observed on southern side and northern side shorelines. At the same locations (i.e 0 m, 7250 m, 4750 m and 10500 m), about -2.01 acres and 2.60 acres observed as more sand accumulated areas, and about -4.31 acres and -3.85 acres as eroded areas during the period 1998-2003. From this beach area and beach width analyses, the period 1998-2003 can be considered as highly and significantly eroded period.

4.4.2.4 Period between 2003 and 2006

The most opposite phenomenon is observed on the shorelines (south and north) located on either side of the rivermouth with respect to period 1998-2003. That is both the shorelines have showed accretion with quantum of about 99.72 acres (on south) and 60.88 acres (on north) (Figure.4.9 D and Table. 4.28). This accretion phenomenon may be due to gradual decrees in the occurrence of annual rainfall from 2003-2006 (Table. 4.24; Refer section, 4.3). Because of this trend of accretion, most of the sectors showed accretion more than 3.0 acres on southern side while on the northern side it is about more than 2.0 acres. Based on this observation, the period 2003-2006 can be considered as accretion period.

Due to accretion on shorelines (south and north) located on either side of the rivermouth, the maximum accretion of about 4.23 acres and 3.93 acres found at 7000 m 10500 m and minimum accretion observed at 0 m and 12000 m with quantum of about 1.98 acres (south) and 1.99 acres (north). Further at the same locations, the maximum beach widths 69 m and 64 m and minimum beach widths 32 m and 37 m were observed. However on an average 3.44 acres and 2.96 acres as accretion and 56 m and 49 m as beach widths were observed on southern side and northern side shorelines respectively.

4.4.2.3 Period between 2006 and 2009

During this period southern shoreline is eroded while northern shoreline accreted as compared with the period 2003-2006. About 92.34 acres was observed as erosion on the southern side shoreline while on the northern shoreline accreted about 64.84 acres (Figure 4.9 E and Table 4.28). This observation clearly indicates that southern side shoreline is under the processes of erosion but northern side shoreline is under processes of accretion.

Though there is erosion trend at southern side of the shoreline during the period, 2006 to 2009, the maximum area of about 4.04 acres found at 6750 m and minimum area of about 1.94 acres found at 0m. But on the northern side the sectors are not accreted much but they maintain accretion trend, due to this the maximum area of about 3.77 acres and minimum area of about 1.04 acres observed at 10500 m and 11750 m respectively. The maximum beach width of about 66 m (6250 m) and 61 m (10500m) and minimum beach width of about 31 m (0 m) and 40 m (7250 m) were observed on southern side and northern side shorelines.

The shoreline change analysis was carried out using data 1912 to 2009, and identified accretion and erosion sectors. This shoreline analysis reveals that most of the sectors on the southern side shoreline are under severe erosion condition, particularly the sectors near the rivermouth (6250 m to 7000 m), and the sectors which are not protected by seawall i.e 4500 m to 4750 m and the sector backed by seawall, but seawall is located on the active zone of the beach i.e 2000m. On the other hand northern side shoreline shows accretion trend, and most of the sectors are accreted and some are accreted heavily. Thus the northern side shoreline can be considered as accretion shoreline; while the southern shoreline can be called as an eroded shoreline.

Based on the overall shoreline change analysis and observation during the periods 1912-1988, 1988-1998, 1998-2003, 2003-2006 and 2006-2009, the accretion and erosion sectors are identified by considering northern and southern shoreline. The sectors are classified as eroded (E), majorly eroded (ME), accreted (A), and majorly accreted (MA) during the period from 1912-2009 and presented in Table. 4.28. Based on this observation, it is further confirmed that that southern shoreline is in the process of erosion while the northern shoreline is in the process of accretion over the observation period from 1912 to 2009.

4.5 Land use and land cover changes

The modern scientific technologies of remote sensing and digital image processing are extremely useful in periodic assessment of the coastal land-use and land cover (LU/LC) changes and analyze them to formulate better coastal management. There are many studies which used satellite imagery and digital image processing techniques to map coastal zones, coastal dynamics and shoreline conditions.

Remote Sensing data provides a synoptic view of the coastal zones with large area coverage. Comprehensive information on the spatial distribution of land use/land cover categories and the pattern of their change is a prerequisite for planning, utilization and management of the land resources of the country. Land use is obviously constrained by environmental factors such as soil characteristics, climate, topography and vegetation. But it also reflects the importance of land as a key and finite resource for most human activities. To improve the economic condition of any area every bit of available land has to be used in most rational way. This requires the present and the past land use/ land cover information of the area. Temporal changes in land cover have become possible in less time, at lower cost and with better accuracy through remote sensing technology.

Based on remote sensing and GIS techniques, the present study attempted to identify the land use/ land cover changes in the vicinity of Mulky-Pavanje rivermouth. The study area is receiving increased attention in view of the natural resources like fisheries, agricultural plantations and existing industrial base etc. Therefore, a study of coastal landforms provides clues to the process operating in the Mulky-Pavanje rivermouth area. Thus, it is of paramount importance to understand the coastal landforms and their spatial and temporal changes.

In this direction, Mulky–Pavanje rivermouth around 3 km X 3 km is considered for land use/ land cover changes in the recent years, i.e 1998 and 2009. The results of land use / land cover change maps shown in Fig. 4.10. The identified features and the respective areas for 1998 and 2009 are given in Table 4.29.

The built-up area around the river mouth has been drastically increased from 88.76 hectares to 96.87 hectares due to developmental activities such as industrialization and urbanization. The beach vegetation which was 42.01 hectares during 1998 has been decreased to 39.86 hectares in 2009 due to irregular changes in the shoreline configuration. Beach sand has also increased from 89.01 hectares to 92.50 hectares due to abrupt change in erosion/accretion process on the spits. Further, mangroves were reduced from 52.12 hectares to 50.16 hectares. But river sand increased from 2597.3 hectares to 2607.08 hectares. This may due to gradual increase in river discharge and rainfall events in recent years on Mulky and Pavanje catchments. In addition water body is increased from 85.30 hectares to 86.41 hectares. This behavior probably due to enormous erosion associated with shoreline in recent years. However there are some minor changes observed in mixed plantation and scrub land around the Mulky – Pavanje river mouth during the study period (1998-2009).

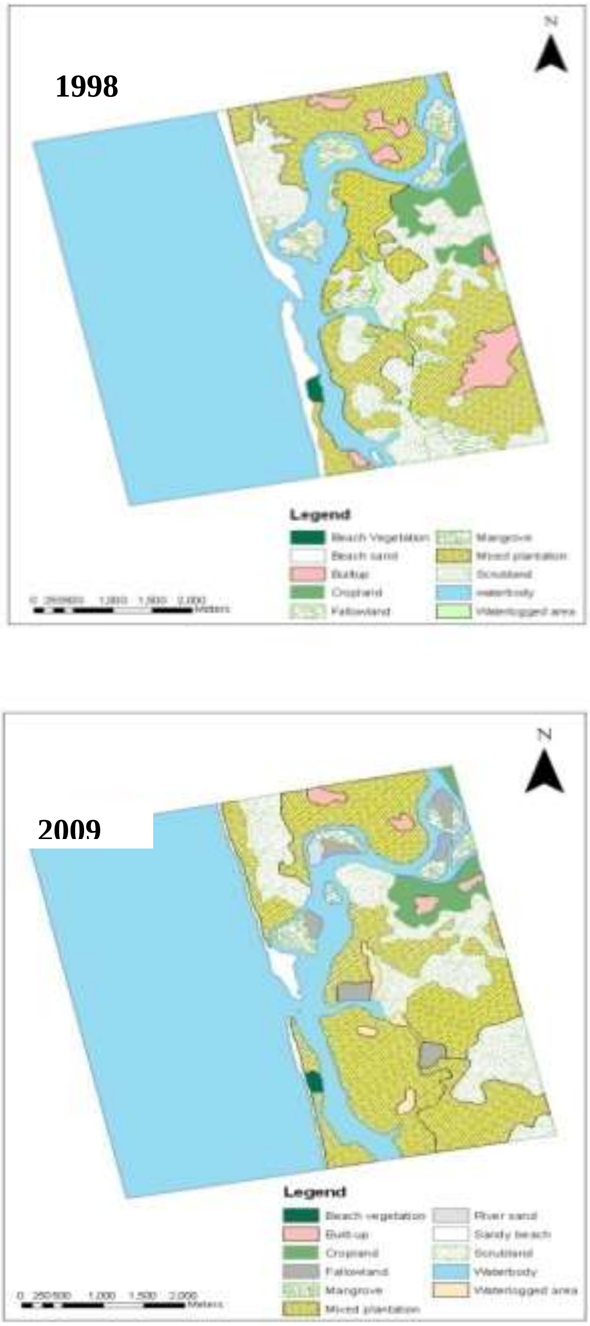


Figure. 4.10 Land use/Land cover changes around the Mulky – Pavanje rivermouth

Table.4.29 Land use/ Land cover changes around Mulky – Pavanje rivermouth

LU/LC Class	1998 (ha)	2009 (ha)
Beach vegetation	42.01	39.86
Beach sand	89.01	92.50
Mangroves	52.12	50.16
Mixed plantation	667.39	658.3
Waterlogged area	16.22	15.28
Built-up	88.76	96.87
Water body	85.3	86.41
Scrub land	90.68	82.33
River sand	2597.3	2607.08

4.6 Application of ANN in coastal processes modeling

4.6.1 Forecasting of Wave height for large lead time

The time series significant wave height over the period (2007-2010) was considered for analysis. The maximum, minimum and average wave heights during 2007, 2008, 2009 and 2010 are presented in Table. 4.30. Forecasting of wave height was attempted with application of ANN. Here, two popularly known neural network systems such as FFBP (Feed Forward Back Propagation) and NARX (Nonlinear Autoregressive model with Exogenous inputs) were used. Based on training and testing of FFBP and NARX the performance indices are calculated to check the accuracy of developed models.

Performance indices in training and testing stages of FFBP and NARX models are presented in Tables.4.31 and 4.32. The Tables.4.31 and 4.32 clearly indicate that the CE values are decreasing and RMSE values are increasing in models FFBB and NARX as the forecasting time is increased. The CE values for training and testing in FFBP model are ranged from 0.997 to 0.785 and 0.984 to 0.745 respectively, whereas in NARX model CE values are between 0.995 to 0.806 and 0.992 to 0.774 respectively for the prediction time from 3hr to 120hr. Thus the results suggest that Model NARX is performing better than FFBP in terms of prediction capability.

Table.4.30 Characteristics of Significant Wave Height

Statistics	Training			
	2007	**2008**	**2009**	**2010**
Maximum	4.84m	5.02m	4.10m	4.28m
Minimum	0.29m	0.48m	0.44m	0.43m
Mean	1.70m	2.44m	1.61m	1.73m
Std. Deviation	0.96m	1.08m	0.96m	0.88m
	Testing			
Maximum	2.98m	3.18m	2.54m	2.39m
Minimum	0.35m	0.48m	0.51m	0.74m
Mean	1.29m	1.69m	1.00m	1.29m
Std. Deviation	0.53m	0.64m	0.46m	0.37m

The time series plot for 3hr, 6hr, 12hr, 24hr, 48hr, 72hr, 96hr and 120hr forecasting for models FFBP and NARX are presented in Figures.4.11 and 4.12. Figures.4.11A and 4.12A indicate that for 3hr lead time the forecasted wave heights are in good agreement with those of the observed wave heights, and then the corresponding CE values are 0.982 and 0.992 with smaller RMSE values in FFBP and NARX respectively. This kind of response suggests an excellent smaller prediction can be achieved through the application of ANN.

Figures.4.11 B and 4.12 B show slightly larger lead time i.e 6hrs; the better predictions in terms of error statistics are noticed. But prediction accuracy found to be gradually decreasing as compared with 3hr prediction. Here for 6hr prediction, the RMSE valued varied from 0.356 to 0.345 and CE values varied from 0.972 to 0.987 for FFBP but in NARX models respectively.

Table.4.31 Performance of FFBP in terms of error statistics

Lead Period	FFBP			
	Training		Testing	
	RMSE	CE	RMSE	CE
3 hr	0.184	0.997	0.234	0.984
6 hr	0.258	0.993	0.356	0.972
9 hr	0.316	0.985	0.576	0.943
12 hr	0.367	0.958	0.454	0.925
24 hr	0.506	0.934	0.627	0.905
48 hr	0.642	0.893	0.825	0.855
72 hr	0.673	0.875	0.759	0.832
96 hr	0.712	0.856	0.856	0.805
120hr	0.477	0.785	0.524	0.745

Table.4.32 Performance of NARX in terms of error statistics

Lead Period	NARX			
	Training		Testing	
	RMSE	CE	RMSE	CE
3 hr	0.319	0.995	0.422	0.992
6 hr	0.251	0.994	0.345	0.987
9 hr	0.214	0.972	0.325	0.965
12 hr	0.365	0.963	0.472	0.954
24 hr	0.252	0.943	0.501	0.925
48 hr	0.641	0.938	0.732	0.914
72 hr	0.767	0.905	0.835	0.864
96 hr	0.718	0.862	0.954	0.823
120hr	0763	0.806	0.910	0.774

The Figures.4.11 C and 4.12 C show lead time of about 12hrs. Here the better predictions in terms of error statistics are noticed (RMSE-0.472, CE-0.954 in NARX; RMSE-0.454, CE-0.925 in FFBP). But prediction accuracy found to be gradually decreasing as compared with 6hr prediction.

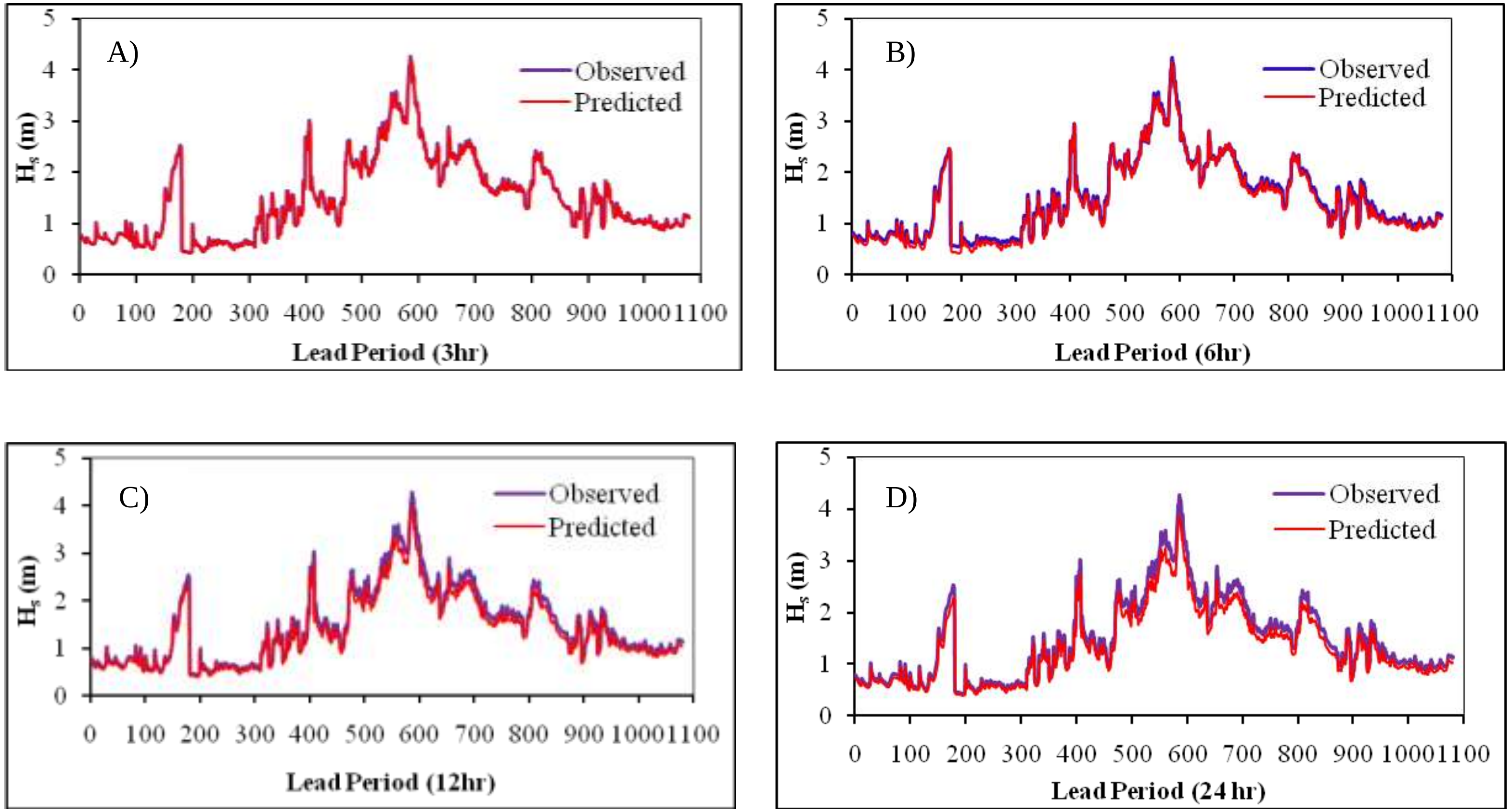
For one day prediction (Figures.4.11 D and 4.12 D) i.e. 24 hrs, the CE values are noticed to be slightly low compared with previous prediction. The CE values reduced to 0.905 in FFBP and as in the case of NARX slightly more 0.925 is noticed. From this prediction onwards NARX is performing better than FFBP.

In the case of two days (48hrs) prediction, the CE values are further reduced and RMSE values are increased (RMSE-0.732, CE-0.914 in NARX; RMSE-0.825, CE-0.855 in FFBP). It can be observed that the presence of minor lag between forecasted values and observed values in both FFBP and NARX (Figures.4.11 E and 4.12 E).

Figures.4.11 F and 4.12 F present quite more lag between observed and predicted values for the prediction of 72hr. The same behavior can also be seen in terms of error statistics, i.e RMSE-0.835, CE-0.0.864 in NARX; RMSE-0.759, CE-0.832in FFBP. Based on error statistics it can be concluded that NARX model performing better than FFBP.

For the prediction of 96hr (4days), the model NARX is performing better than FFBP shown in Figures.4.11 G and 4.12 G. Again in terms of accuracy CE values for both FFBP and NARX are further decreased and RMSE values are increased.

Finally for 120hrs (5days) predictions maximum lag is observed between predicted and observed values in both FFBP and NARX (Figures.4.13 H and 4.14 H). As a whole the prediction from 24hrs to 120hrs suggests that NARX is performing much better than FFBP. The same trend is observed in terms of CE and RMS. Further it may also be noticed from the Figures.4.11 and 4.12, that the smaller prediction intervals are associated with better prediction accuracies.


A)
Observed
Predicted
H_s (m)
0
1
2
3
4
5
0 100 200 300 400 500 600 700 800 900 1000 1100
Lead Period (3hr)
B)
Observed
Predicted
H_s (m)
0 100 200 300 400 500 600 700 800 900 1000 1100
Lead Period (6hr)
C)
Observed
Predicted
H_s (m)
0 100 200 300 400 500 600 700 800 900 1000 1100
Lead Period (12hr)
D)
Observed
Predicted
H_s (m)
0 100 200 300 400 500 600 700 800 900 1000 1100
Lead Period (24 hr)

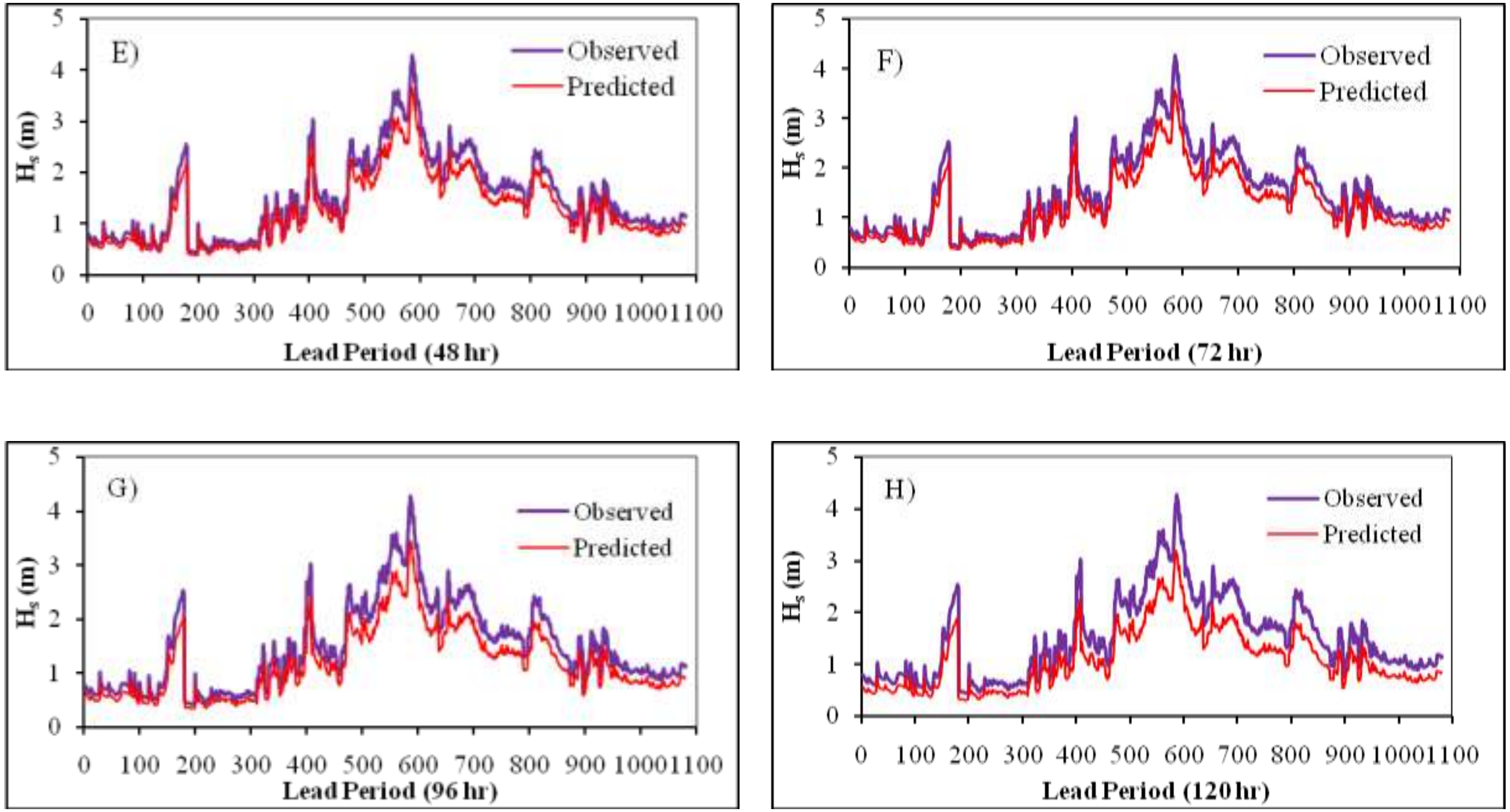
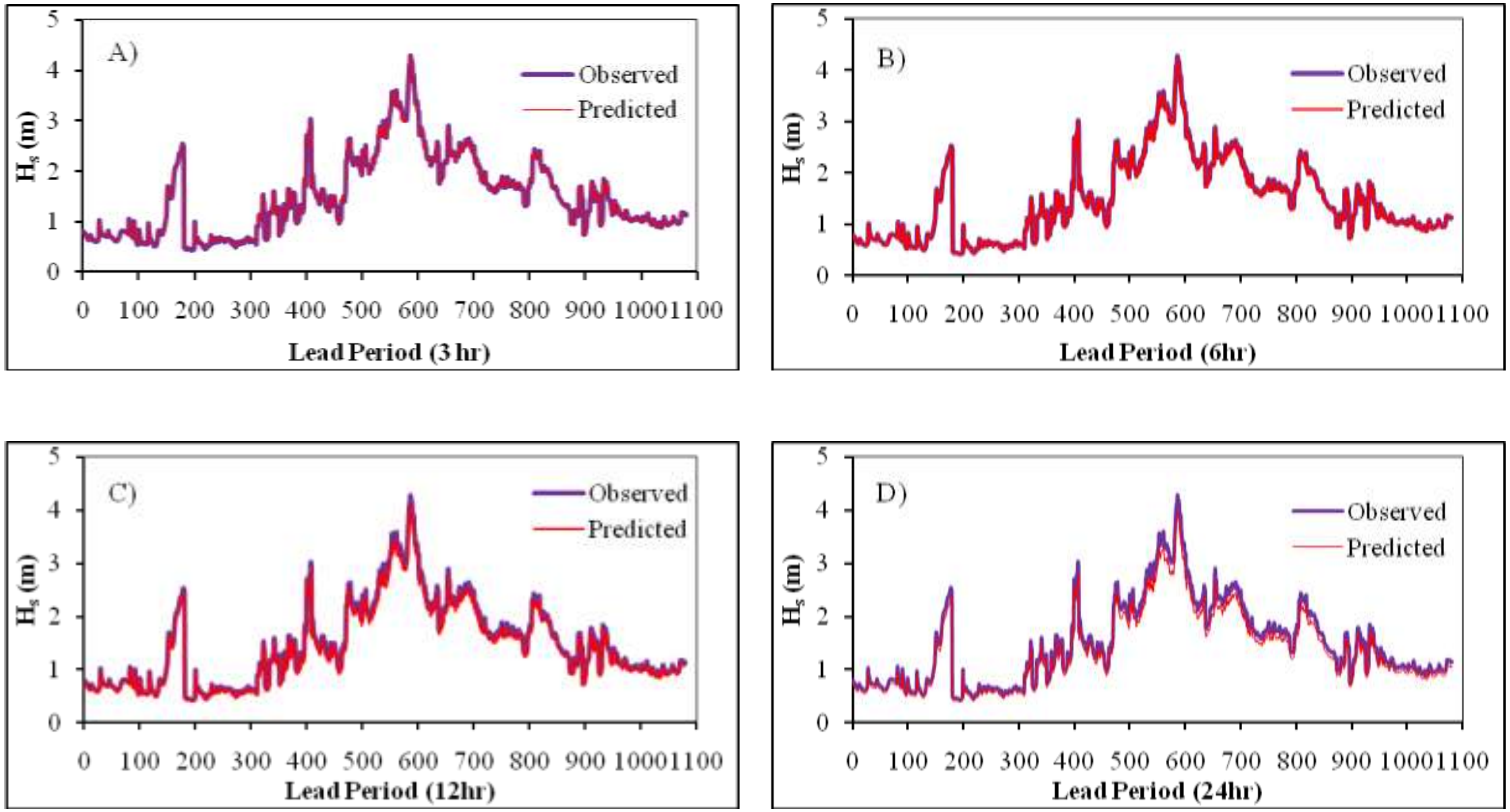


Figure. 4.11 Comparison of the observed and predicted time series of wave height using model FFBP from 3-120hr forecasting.


A)
B)
C)
D)
Observed
Predicted
H_s (m)
0
1
2
3
4
5
0 100 200 300 400 500 600 700 800 900 1000 1100
Lead Period (3 hr)
Lead Period (6hr)
Lead Period (12hr)
Lead Period (24hr)

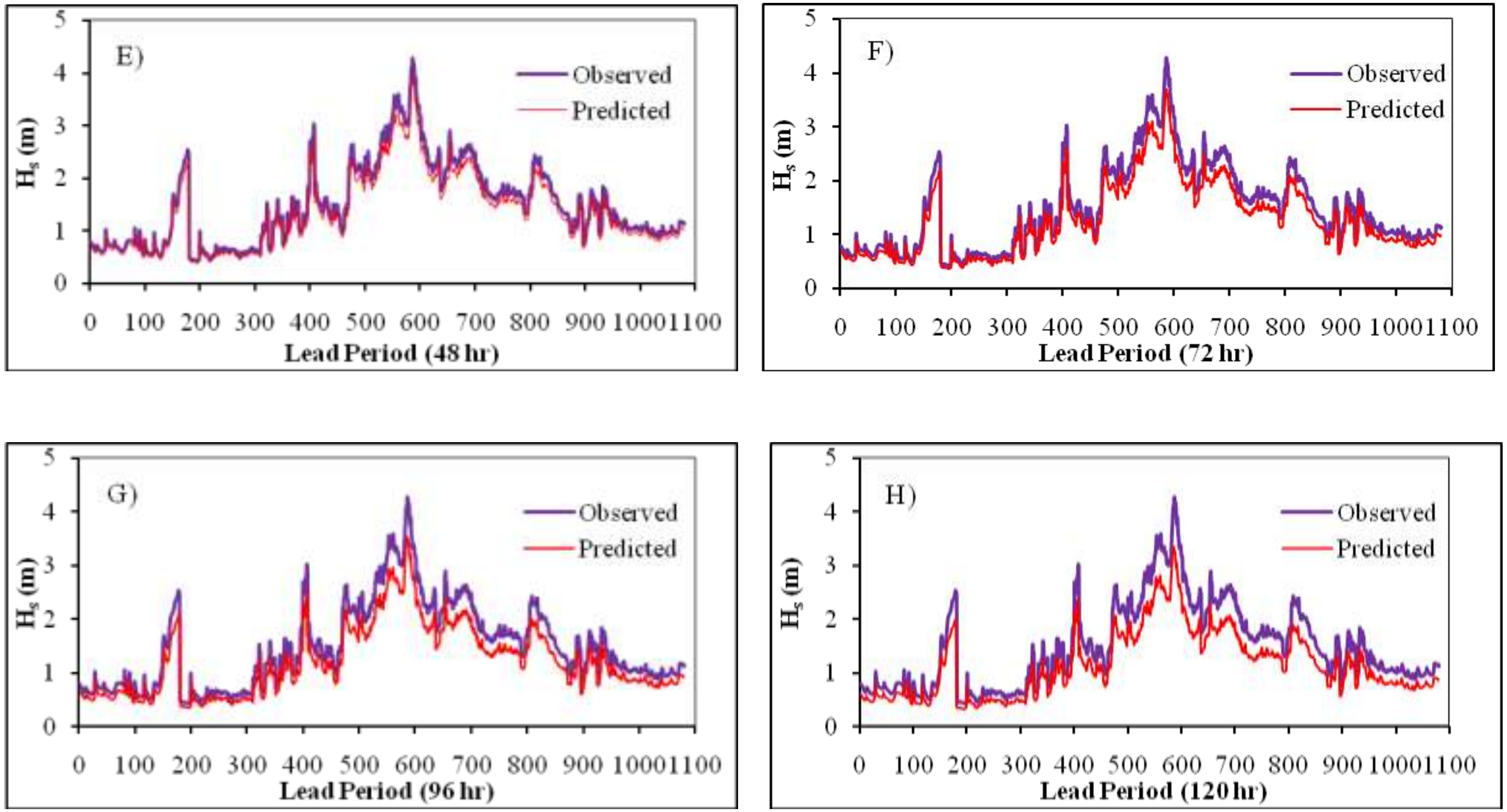


Figure. 4.12 Comparison of the observed and predicted time series of wave height using model NARX from 3-120hr forecasting

In all cases (3hr-120hr), the prediction accuracy is gradually decreased for FFBP and NARX. However from 3hr to 24 hr predictions are good in agreement with observed significant wave height values and these waves are observed in the study region. Thus model developed by ANN can be used for study region in order to provide protection measures, particularly at Mulky-Pavanje rivermouth to prevent shifting of rivermouth and to reduce Sasihithlu spit erosion.

4.5.2 Prediction of Littoral Drift

This section explains prediction of littoral drift with the application of ANN. For the prediction of littoral drift, the data obtained from INCOIS for the period 2007 was used. The influencing parameters such as significant wave height H_s, wave period (T_z), breaking wave height (H_b) and breaking angle (α_b) were derived from INCOIS database. Additionally instead of surf zone width (W) the measured beachwidth, which measured daily basin in the field in the year 2007 at BS 1 was used. These factors are the direct responsible factors to cause the littoral drift (Q) and hence they are used as inputs to the ANN models. Further the computed littoral drift (Q) obtained from SPM (1984), which was used as an output to the models.

The Table. 4.33 presents ranges of the H_s, T_z, H_b, α_b, W as well as rate of the Q along with their mean values and standard deviations involved during the training and testing exercises. The rate of littoral drift was found to be randomly varying with the independent causative variables (H_s, T_z, H_b, α_b, W).

Two neural network models were developed in order to forecast the littoral drift. The predicted drift may provide approximate variation over seasonal and annual changes. Two models such as FFBP and NARX of the ANN were used just to compare the performance with the two cases i.e forecasting of wave height and prediction of littoral drift, the current section deals with it.

Table.4.33 Statistics of the training and testing data set

Data	Variables	Max	Min	Mean	Std. Deviation
Training	H_s (m)	4.31	0.34	1.64	1.02
	T_z (sec)	8.00	3.30	5.45	1.24
	H_b (m)	2.42	0.03	1.52	1.11
	α_b (deg)	5.97	0.85	1.53	0.41
	W (m)	43.00	15.00	30.91	7.30
	Q (kg/s)	15.56	1.10	1.39	2.17
Testing	H_s (m)	3.76	0.36	1.43	0.86
	T_z (sec)	9.39	3.53	6.94	1.67
	H_b (m)	2.67	0.34	1.09	0.52
	α_b (deg)	2.29	0.85	1.00	0.23
	W (m)	43.00	15.00	34.75	4.48
	Q (kg/s)	8.05	1.00	1.63	1.49

The performances of developed models (FFBP and NARX) were verified with error statistics such as RMCE, CC and CE were computed for training and testing and presented in Tables. 4.34 and 4.35. Additionally, with the help of scatter plots the comparison between observed littoral drift and predicted littoral drift is made for the testing data and showed in Figures. 4.13 and 4.14.

Table.4.34 Performance of FFBP in terms of error statistics

FFBP	RMSE	CC	CE
Training	1.423	0.837	0.972
Testing	1.148	0.878	0.947

Table.4.35 Performance of NARX in terms of error statistics

NARX	RMSE	CC	CE
Training	1.313	0.865	0.907
Testing	1.079	0.890	0.979

The Tables. 4.34 and 4.35, clearly show the difference the between NARX and FFBP in terms CC, CE and RMSE. The CC for FFBP is 0.878 in testing while in NARX, more CC value is observed, i.e 0.890. The similar difference is further observed between CE and RMSE values. The CE values varied from 0.947 to 0.979 between FFBP and NARX. Further the RMSE value in the case of NARX is 1.079, but it is quite more in case of FFBP (i.e. 1.148). Thus it can be concluded that the models FFBP and NARX exhibit almost equal performance. But in terms of error analysis NARX showed better performance as compared to FFBP. This behaviour probably due to less error in the data sets, since NARX is feed forward network.

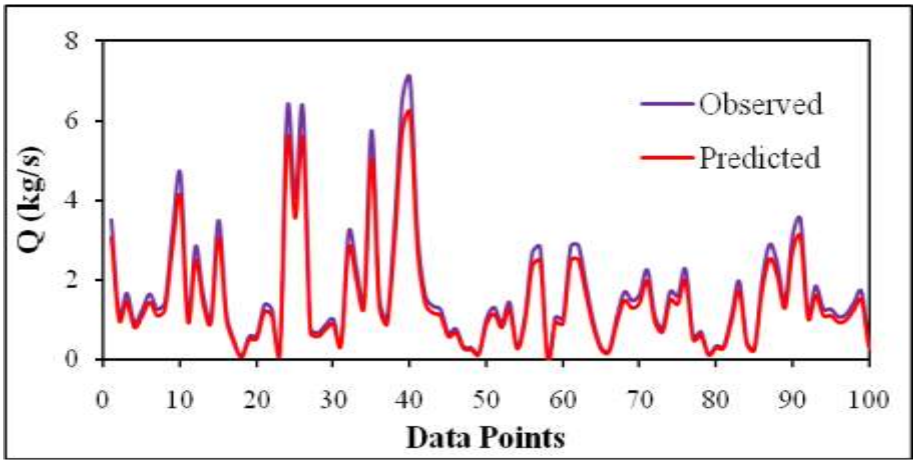


Figure.4.13 Comparison between observed and predicted drift in FFBP

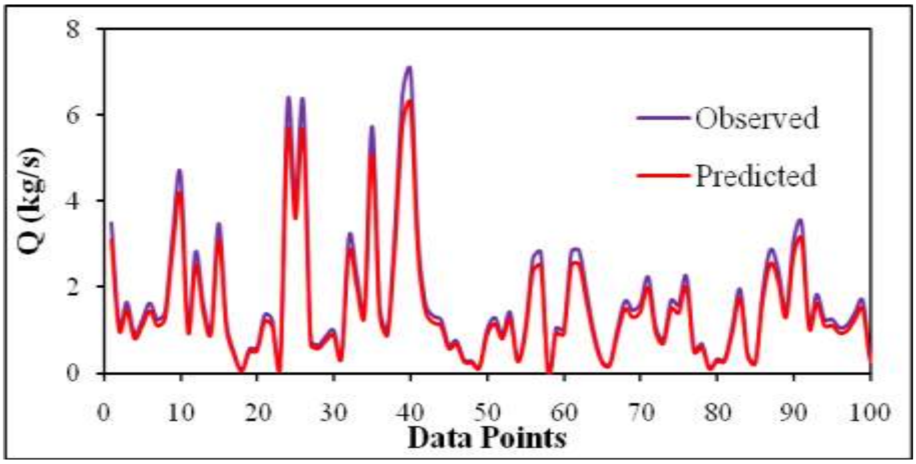


Figure.4.14 Comparison between observed and predicted drift in NARX

From the Figures. 4.13 and 4.14, it may be noted that there is very small lag between the predicted drift and the observed drift, indicating absence of any systematic error. Though NARX scatter plot showing quite better matching between observed and predicted drift as compared with FFBP.

The observed and predicted littoral drift is almost matching with observed drift in the region. The observed drift moving towards south is predominantly influencing the study area. The same drift causing erosion along the southern side shoreline and in the vicinity of rivermouth. This trend further confirmed with long-term shoreline change analysis (Refer 4.4).

As a summary, the Artificial Neural Network (ANN) technique is used to predict the very important parameters of coastal engineering such as wave height and littoral drift, which cause erosion in the study area. With the help of advance prediction of wave height for any particular coastal region, it is possible to provide proper design and plan for all coastal and ocean related activities like construction, maintenance, transportation, fishing etc.

Littoral drift poses severe problems in coastal and harbor operations since it results in siltation of deeper navigation channels due to which bigger ships can not enter or leave the harbor area. Therefore, an accurate estimation of the drift is needed in order to know the amount of excavation required so that corresponding budgetary provisions could be made in advance.

In this direction, two commonly used training schemes ANN such as FFBP and NARX are used to forecast the weave height and to predict littoral drift for the Mulky-Pavanje associated coastline. In the forecasting of wave height for 120hr LEAD time, the performance of NARX and FFBP proved very good at smaller lead time. But for the larger lead time NARX revealed better performance over the FFBP.

In the similar way, littoral drift prediction was attempted by using FFBP and NARX of ANN providing several parameters as inputs. In this case also NARX performed better than FFBP. Thus, it can be concluded that the application of ANN in coastal engineering proved to be capable of wave height and littoral prediction in advance with more accurate with acceptable accuracy.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary and Conclusions

To understand the coastal geomorphological behaviour on either side of the Mulky-Pavanje rivermouth at short-term temporal scale, three different datasets, such as beach profile survey, sediment sampling and wave data are gathered

Beach profile survey has been carried out at selected nine locations based on reconnaissance survey from September 2009 to December 2011, which forms short-term shoreline monitoring. The beach profile analyses indicated that northern side beaches are highly vulnerable to erosion than the southern side beachs. All the nine profiles have regained their original profiles by the end of pre-monsoon season after severe erosion in monsoon season through gradual development of profiles in post-monsoon season. This observation clearly indicates that the accretion and erosion pattern along the shoreline associated with Mulky-Pavanje rivermouth (south and north) are cyclic in nature and beaches are maintaining dynamic equilibrium.

Sediment samples collected from foreshore region by handgrab method at short-term temporal scale (September 2009 to December 2011). Texture of sediments is associated with seasonal wave conditions and river discharge. Coarser sediments are associated monsoon condition and finer are associated non-monsoon condition. However, freshwater discharge also induces sediment texture in the vicinity of rivermouth to vary significantly based upon high and low level of flow.

As for the wave characteristics, wave data has been obtained from the offshore, by deploying wave rider buoy at New Mangalore Port Trust (NMPT) area in the year 2007 at a depth of 15 m (Data source: INCOIS). Additionally ship observed wave records were obtained from Indian Metrological Department (IMD) Pune for the period between 2007 and 2010. Further visual observations of breaking wave type were made during the field visits. All these three datasets have been used to see the influence on shoreline morphology at short term scale. The wave heights exhibit yearly variations, but the periods and directions remain relatively constant. Due to cyclic trend in wave climate, the beaches erode during monsoon; subsequently deposition takes place during post-monsoon and pre-monsoon seasons.

In order to observe the medium-term shoreline changes associated with Mulky-Pavanje rivermouth, two important datasets such as precipitation and river discharge are obtained from National Data Centers.
In this direction, the current study made an attempt to correlate the storm activity, freshwater discharge and coastal morphology in response to Mulky-Pavanje estuarine shoreline. For this, the rainfall data and freshwater discharge data are obtained from IMD observatory stations for the periods 1985-2011 and 1985-1998. From the rainfall and freshwater discharge analysis it is observed that during the monsoon and post-monsoon period, because of heavy rainfall, the rivers Mulky and Pavanje overflow, discharge sizeable quantities of sediments into the sea, whereas during pre-monsoon periods (less rainfall), the river discharge gradually reduces and hence seawater enters into the rivermouth area leads sediment deposition and distribution on either side of the rivermouth. Because of the variations in the rainfall and river discharge, the shoreline in the vicinity of rivermouth is predominantly affected and shifted towards south.

The long-term change analyses in the vicinity of rivermouth, particularly for the rivermouth configuration and spit dynamics are attempted by using multidated satellite imageries and toposheets for the period 1912-2009 (97 years). The long-term change analyses showed that during the last 97 year period, the rivermouth configuration and spit morphology have undergone considerable changes. The spit area and spit lengths associated with rivermouth (south- Sasihithlu spit and north-Hejamadi spit) indicated cyclic behavior in terms of accretion and erosion. As the change in the observation scale (1912-1988, 1988-1998, 1998-2003, 2003-2006 and

2006-2009) Sasihithlu spit is eroded and Hejamadi spit is accreted. However, accretion trend is oriented with Hejamadi spit and gradual erosion trend at Sasihithlu spit during the observed period. The development (accretion) of Hejamadi spit is mainly due to strong longshore sediment transport towards south since from historical period. Because of gradual accretion at Hejamadi spit (north) and gradual reduction in Sasihithlu spit, the rivermouth is shifting towards south over the period of observation (1912-2009).

Further research work is extended for long-term shoreline change analyses. The long-term shoreline change analyses are made for the same period, i.e 1912-2009 with the help of same satellite imageries and toposheets. The analyses of long-term shoreline on either side of the rivermouth (south-7km and north-5km) reveals that the variations in shorelines (south and north) and accretion and erosion or cyclic in nature over a period of time. As a whole the quantum erosion on southern side found to be more as compared to northern side shoreline.

Additionally land use/ land cover change analysis is employed for recent years (1998-2009) by considering 3 km X 3 km area around the Mulky-Pavanje rivermouth. Because of development of urbanization and industrialization around the rivermouth, the built-up area has been drastically increased, while the other coastal related geological features such as beach vegetation, mangroves, river sand are drastically reduced during the period 1998-2009.

Further the Artificial Neural Network (ANN) technique is used to model the very important parameters of the coastal engineering such as wave height and littoral drift. The data obtained from INCOIS and IMD for the period 2007 to 2010 were used to model the coastal parameters (wave height and littoral drift). In order to provide accurate and acceptable prediction for these parameters two different networks such as FFBP and NARX were used. The developed models were evaluated using error statistics (RMSE, CC and CE). In both cases the NARX model performed better than FFBP. And further proved that the parameters, wave height and littoral drift are the direct responsible factors to cause erosion in the Mulky-Pavanje rivermouth and associated shoreline.

5.2 Scope for Future Works

1. Temporal shoreline monitoring techniques can be extended for other shorelines and as well as rivermouth regions along the East and west coast of India.
2. Land use land cover change analyses can be extended for larger coastal zones using high resolution remote sensing data.
3. Forecasting of wave height with help of ANN can be extended to still larger lead time and obtained forecasts can be compared with other modelling techniques.
4. By using several influencing factors, the prediction of littoral drift can be made with the help of ANN and obtained predictions can be compared with other modelling techniques.

REFERENCES

Agrawal J D and M C Deo. (2002). “On-line wave prediction”. *Marine Struct.* 15. 57–74.

Agrawal J D and M C Deo. (2004). “Wave parameter estimation using neural networks”. *Marine Struct*. 17. 536–550.

Ahmadreza Zamani, Dimitri Solomatine, Ahmadreza Azimian, Arnold Heemink. (2008). “Learning from data for wind–wave forecasting”. *Ocean Engg*. 35. 953– 962.

Albert E Browder, Robert G Dean. (2000). “Monitoring and comparison to predictive models of the Perdido Key beach nourishment project, Florida, USA”. *Coast. Engg*, 39, 173–191.

Alesheikh A A, Ghorbanali A, Nouri N. (2007). “Coastline change detection using remote sensing”. *Int. J. Environ. Sci. Tech*, 4 (1), 61-66.

Alsharhan A S, El-Sammak A A, (2004). “Grainsize analysis and characterization of sedimentary enevironments of the United Arab Emirates coastal area”. *J. coast. Res*, 20(2). 464-477.

Ana Vila Concejo. Michael G Hughes, Andrew D Short, Roshanka Ranasinghe, (2010). “Estuarine shoreline processes in a dynamic low-energy system”. *Ocean Dynamics*, 60, 285–298.

Andrew G Cooper J. (1994). “Sedimentary processes in the river-dominated Mvoti estuary, South Africa”. *Geomorphology,* 9, 271-300.

Anfuso G, Martı´nez del Pozo J A, Nachite D, Benavente J, Macias A. (2007). “Morphological characteristics and medium-term evolution of the beaches between Ceuta and Cabo Negro (Morocco)”. *Environ Geol*, 52, 933-946.

Anfuso G, Pranzini E Vitale G. (2011). “An integrated approach to coastal erosion problems in northern Tuscany (Italy): Littoral morphological evolution and cell distribution”. *Geomorphology*, 129(3-4), 204-214.

Anil Ari H, Yalcin Yuksel, Esin Ozkan Cevika, Isikhan Guler, Ahmet Cevdet Yalciner, Bulent Bayram, (2007). “Determination and control of longshore sediment transport: A case study”. *Ocean Engg,* 34, 219–233.

Antonio Jabaloy Sanchez, Francisco Jose Lobo, Antonio Azor, Patricia Barcenas, Luis Miguel Fernandez Salas, Victor Diaz del Rio and Jose Vicente Perez Pena (2010). “Human driven Coastline changes in the Adra River deltaic system, southeast Spain”. *Geomorphology*. 119. 9-22.

Anurag More and M C Deo (2003).” Forecasting wind with neural networks”. *Marine Struct*, 16, 35–49

Appeaning Addo K, Walkden M, Mills J P. (2008). “Detection, measurements and prediction of shoreline recession in Accra, Ghana”. *IRPRS J. Photo. Remote sensing*, 63, 543-558.

Arkal Vittal Hegde, B Raveendra. (2000). “Short-Term and Long-Term Geomorphological Dynamics of Mangalore Spits Using IRS-1A/1C Data”. *J. Indian Society Remote Sensing*. 28(4), 233-247.

ASCE Task Committee (2000). “The ASCE task committee on application of artificial neural networks in hydrology”, *J. Hydrol. Eng,* ASCE, 5(2), 115–136, 2000.

Avinash Kumar, Narayana A C, K S Jayappa, (2010). “Shoreline changes and morphology of spits along southern Karnataka, west coast of India: A remote sensing and statistics-based approach”. *Geomorphology*, 120, 133–152.

Backstrom J T, Jackson D W T, Cooper J A G. (2009). “Shoreface morphodynamics of a high-energy, steep and geologically constrained shoreline segment in Northern Ireland”. *Marine Geo*, 257, 94–106.

Bang Fuh Chen, Han Der Wang, Chih Chun Chu. (2007). “Wavelet and artificial neural network analyses of tide forecasting and supplement of tides around Taiwan and South China Sea”. *Ocean Engg*, 34, 2161–2175.

Baptista P, L Bastos , C Bernardes, T Cunha, J Dias. (2008). “Monitoring Sandy Shores Morphologies by DGPS—A Practical Tool to Generate Digital Elevation Models”. *J. Coast. Res*, 24(6), 1516–1528.

Bernabeu A M, Medina R, Vidal C. (2003). “A morphological model of the beach profile integrating wave and tidal influences”. *Marine Geo*. 197, 95-116.

Bhat M S, Hegde V S. (2003). “Morphology and sediment movement in a monsoon influenced open beach at Gangavalli, near Gokarna (Central west coast of India)”, *Indian J. Mar. Sci*, 32(1), 31-36.

Bradley M. Romine, Charles H Fletcher, Neil Frazer L, Ayesha S Genz, Matthew M, Barbee, Siang-Chyn Lim. (2009). “Historical Shoreline Change, Southeast Oahu, Hawaii; Applying Polynomial Models to Calculate Shoreline Change Rates”. *J. Coast. Res*, 25(6), 1236–1253.

Brian Baily and David Nowell (1996). “Techniques for monitoring coastal change: a review and case study”. *Ocean & Coast Mgmt*, 32(2), 85-95.

Bruce C Douglas, Mark Crowell, Stephen P Leatherman. (1998). “Consideration for shoreline position prediction”. *J. Coast Res*, 14(3), 1025–1033.

Bu-Li Cui and Xiao-Yan Li (2011). “Coastline change of the Yellow River estuary and its response to the sediment and runoff (1976–2005)”. *Geomorphology*. 127, 32–40.

Can Elmar Balas and M Levent Koç. (2010). "Artificial neural networks based on principal component analysis, fuzzy systems and fuzzy neural networks for preliminary design of rubble mound breakwaters". *Applied Ocean Res*, 32, 425-433.

Chandramohan P, B U Nayak and V S Raju. (1988). "Application of Longshore Transport Equations to the Andhra Coast, East Coast of India". *Coast Engg*, 12, 285-297.

Chandramohan, P. and B. U. Nayak. (1991)." Longshore sediment transport along the Indian Coast". *Indian J. Marine Sci*, 20, 110–114.

Chandramohan P, Jena B. K, Kumar V S. (2005). "Littoral drift sources and sinks along the Indian coast". *Current Sci*, 81, 292–297.

Chauhan H B, Shailesh Nayak. (2005). "Land Use/Land Cover Changes Near Hazira Region, Gujarat Using Remote Sensing Satellite Data. *J. Indian. society Remote Sensing*, 33(3). 413-420.

Ching Piao Tsai, Chang Lin, Jia N Shen. (2002)."Neural network for wave forecasting among multi-stations". *Ocean Engg*. 29. 1683–1695.

Coastal Engineering Manual (2003), US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. Vicksburg,

Coastal Engineering Manual (2006), US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. Vicksburg,

Collen J D, Garton D W, Gardner. (2009). "Shoreline changes and sediment redistribution at Palmyra Atoll (Equatorial Pacific Ocean): 1874-Present". *J. Cost Res*, 25(3), 711-722.

Courtney A Schupp, Jesse E McNich, Jeffrey H List. (2006). "Nearshore shore-oblique bars, gravel outcrops, and their correlation to shoreline change". *Marine Geol*, 63-70.

Daphne van der wal, Kenneth Pye, Adrian Neal. (2002). "Long-term morphological changes in the Ribble Estuary, northwest England." *Marine Geo*, 189, 249-266.

Dattatri J, Kamath M. (1997). "Littoral drifts and maintenance dredging at New Mangalore port". Proc. Second Indian National Conference on Harbour and Ocean Engineering (INCHOE-97) (Thiruvananthapuram, India), 578–585.

Dattatri J, N B S Rao, Subba Rao, Dwarakish G.S and Nagendra Kumar B. (1997), "Beach profile studies along Dakshina Kannada Coast of Karnataka State". Proc. Second Indian Nat. Conf. on Harbor and Ocean Engg (INCHOE-97), Thiruvananthapuram, December 7-10, 1135-1143.

Deo M C and Chaudhari G. (1998). "Tide prediction using neural networks". *Comp Aided Civil Infrastructure Engg* 13, 113–120.

Deo M C and Naidu C S. (1999). "Real time wave forecasting using neural networks". *Ocean Engg*, 26, 191–203.

Deo M C and N Kiran Kumar. (2000). "Interpolation of wave heights". *Ocean Engg*. 27, 907–919

Deo M C, Jha A, Chaphekar A S and Ravicant K. (2001). "Neural networks for wave forecasting". *Ocean Engg.* 28. 889–898

Dipnarayan Ganguly, Anirban Mukhopadhyay, Rahul Krishna Pandey, Debasish Mitra. (2006). "Geomorphological Study of Sundarban Deltaic Estuary". *J. Indian Society of Remote Sensing*, 34(4), 431-435.

Dolan Eversole, Charles H Fletcher, (2003). "Longshore sediment transport rates on a reef-fronted beach: Field data and empirical models Kaanapali beach, Hawaii". *J. Cost Res*, 19(3), 649-663.

Donald K Stauble, Jeffery R Tabar. (2003). "The use of submerged narrow crested breakwaters for shoreline erosion control". *J. Cost Res*, 19(3), 684-722.

Dong Hyawn Kima, Woo Sun Park. (2005). "Neural network for design and reliability analysis of rubble mound breakwaters". *Ocean Engg*, 32.1332–1349.

Dookie Kim, Dong Hyawn Kimb, Seongkyu Chang. (2008). "Application of probabilistic neural network to design breakwater armor blocks". *Ocean Engg*, 35.294–300.

Dov Zviely, Micha Klein. (2003). "The environmental impact of the Gaza strip coastal constructions". *J. Cost Res*, 19(4), 1122-1127.

Dwarakish G S, Dattatri J, Anisha M. (1997). "Remote sensing application for study of river mouth changes of Dakshina Kannada district, Karnataka". Proc. Int. conf. on remote sensing and GIS, Hyderabad, India. 473–483.

Dwarakish G S, J Dattatri, N B S Rao and Subba Rao. (1998). "Application of remote sensing to study the dynamic changes of Nethravathi-Gurupur rivermouth, D.K. Coast, Karnataka. Proc. Int. symp on information Technology in Oceanography, NIO, Goa, India, 72.

Dwarakish G S and Usha Natesan (2002). "Coastal Structures Vs Shoreline Configuration". *NITK Res Bulletin*,11(3), 25–33.

Dwarakish G S, Vinay S A, Dinakar S M, Jagadeesha Pai, Mahaganesha, Usha Natesan. (2008). "Integrated coastal zone management plan for Udupi coast using remote sensing, geographical information system and global position system". *J. Applied Remote Sensing*, 2, 1-22.

Dwarakish G S, Vinay S A, Usha Natesan, Toshiyuki Asano, Taro Kakinuma, Katta Venkataramana, Jagadeesha Pai.B, M K. Babita. (2009). "Coastal vulnerability assessment of the future sea level rise in Udupi coastal zone of Karnataka state, west coast of India". *Ocean & Coastal Mgmt*, 52, 467–478.

El-Asmar H M, M E Hereher. (2010). “Change detection of the coastal zone east of the Nile Delta using remote sensing”. *Env Earth Sci*. 62. 769-777.

Elba L Rodriguez, Robert G Dean, (2009). “A sediment budget analysis and management strategy for Fort Pierce inlet, Florida”. *J. Cost Res*, 25(4), 870-883.

Elizabeth H Boak, Ian L Turner, (2005). “Shoreline Definition and Detection: A Review”. *J. Cost Res*, 21(4), 688-703.

Elizabeth M Lacey, John A Peck. (1998). “Longterm beach profile variations along the south shore of Rhode Island, U. S.A”. *J. Cost Res*, 14(4), 1255-1264.

Folk R L, Ward W C. (1957). “Brazos River bar: A study in the significance of grain size parameters”. *J. Sed. Pet*, 27, 3–27.

Franck Dolique, Edward J Anthony, (2005). “Short-term profile changes of sandy pocket beaches affected by Amazon-derived mud, Gayenne, French Guiana”. *J. Cost Res*, 21(6), 1195-1202.

Frihy O E, Komar P D (1998). “Long-term shoreline changes and the concentration of heavy minerals in beach sands of the Nile-delta, Egypt”. *J. Marine Geo*, 115 (3–4), 253–261.

Frihy O E, Kh Dewidar M, Nasr S M, El Raey M M. (1998). “Change detection of the northeastern Nile Delta of Egypt: Shoreline changes, spit evolution, margin changes of Manzala lagoon and its islands”. *Int. J. Remote Sensing*, 19, 1901-1912.

Gangadhara Bhat H. (1995). “Long-term shoreline changes of Mulki-Pavanje and Nethravathi-Gurupur estuaries, Karnataka”, *J. Indian Society of Remote Sensing*, 23(3), 147-153.

Gangadhara Bhat H, Subrahmanya K.R, (2000). “Shoreline Changes and evolution of the coastal zone in Southern Karnataka, India - An Analysis based on Multi-

Temporal Data". *ISPRS Int Arch Photogrammetry and Remote Sensing*, XXXIII, Part B7, Amsterdam, 191-197.

Geetha Sasikumar and M Krishnamoorthy. (2010). Faecal indicators and salinity water quality of shelfish-harvesting environment: influences of seasonal monsoon and river-runoff. I*ndian J. marine sci*, 39(3), 434-444.

George M Kiminsky, Petr Ruggiero, Marten C Bujisman, Diana McCandless and Guy Gelfenbaum (2010). "Historical Evolution of the Columbia River littoral cell". *Marine Geo*. 273. 96-126.

Gerd Masselink, Paul Russel, Ian Turner, Chris Blenkinsopp, (2009). "Net sediment transport and morphological change in the swash zone of a high-energy sandy beach from swash event to tidal cycle time scales". *Marine Geo*, 18-35.

Gesche Krause, (2004). "The 'Emery-Method' revisited- Performance of an inexpensive method of measuring beach profiles and modifications". *J. Cost Res*, 20(1), 340-346.

Giorgio Anfuso, Francisco Javier Gracia, (2005). "Morphodynamic characteristics and short-term evolution of a coastal sector in SW Spain: Implications for coastal erosion management". *J. Cost Res*, 21(6), 1139-1153.

Goda Y (2003). "Revisiting Wilson's formulas for simplified wind wave prediction". *J. Water way, Port, Coast Ocean Engg*, 129(2), 93-95.

Graham Evans and Ricardo Pergo (2003). "Rias, estuaries and incised valleys: is a ria an estuary?". *Marine Geo*, 196. 171-175.

Gujar A R, Ganesan P, Iyer S D, Gaonkar S S, Ambre N V, Loveson V J, Mislankar P G. (2011). "Influence of morphodynamic variability over seasonal beach sediments and its probable effect on coastal development". *Ocean & Coast Mgmt*, 54, 514-523.

Gumageri Nagaraj, Amruth Karjagi, Mohan Kumar, Dwarakish G S. (2011). "Geomorphological Behaviour of Sasihithlu, Mangalore Coast, West Coast of India". *Int. J. Earth Sci. Engg*, 4(3), 467-476.

Gumageri Nagaraj, Dwarakish. G S. (2011). "Shoreline Changes along the Mangalore Coast, West Coast of India". *Int. J. Earth Sci. Engg*, 4(3), 63-70.

Gumageri Nagaraj and Dwarakish G S (2011). "Investigation of Geomorphic processes on Mulky-Pavanje Rivermouth, West Coast of India". Proc. Nat. Conf. of *ocean Society of India (OSICON-11)*, National Institute of Ocean Technology Chennai, 126-127.

Gunawardena.Y S, Pinkerton H, Romanowicz R. (2009). "Nonlinear transfer function modelling of beach morphology at Duck, North Corolina". *Coast. Engg*, 56, 46-58.

Hanamgonda P T, Mitra D. (2007). "Dynamics of the Karwar coast, India, with spatial reference to study of tectonics and coastal evolution using remote sensing data". *J. Cost Res*, 50, 842-847.

Hanslow D J. (2007). "Beach Erosion Trend Measurement: A Comparison of Trend Indicators". *J. Cost Res*, 50, 588-593.

Hashemi M R, Z Ghadampour, S P Neil. (2010). "Using an artificial neural network to model seasonal changes in beach profiles". *Ocean Engg.* 37, 1345-1356.

Hegde V S, Kanchanagouri, Hanamgond P T, Huchchannavar G K, Shalini G, Bhat M S. (2004). "Depositional environment and silting in the Sharavati estuary, central west coast of India". *Indian J. Marine Sci*, 33(3), 296-302.

Hegde V S, Shalini G, Nayak S R, Rajawat A S, Surynarayana A, Jaykumar S, Koti B K, Girish G K. (2009). "Low-Scale Foreshore Morphodynamic Processes in the Vicinity of a Tropical Estuary at Honnavar, Central West Coast of India". *J. Cost Res*, 25(2), 305-314.

Hegde V S, Shailesh R Nayak, Shalini G, Krishnaprasad P A, Rajawat A S, Girish K H, Tejaswini B. (2012). “Spit dynamics along the central west coast of India: Implications for coastal zone management”, *J. Cost Res*, (Article in press).

Hesham M, El-Asmar , Kevin White. (2002). “Changes in coastal sediment transport processes due to construction of New Damietta Harbour, Nile Delta, Egypt”. *Coastal Engg*, 46, 127–138.

Hilary F Stockdon, Asbury H Sellenger Jr, Jeffery H List, Rob A Holman. (2002). “Estimation of shoreline position and change using Airborne Topographic Lidar data”. *J. Cost Res*, 18(3), 502-513.

Hsien-Kuo Chang.and Li-Ching Lin. (2006). “Multi-point tidal prediction using artificial neural network with tide-generating forces”. *Coastal Engg*, 53, 857–864.

Hyawn Kima, Woo Sun Park. (2005). “Neural network for design and reliability analysis of rubble mound breakwaters”. *Ocean Engg*. 3, 1332–1349.

Ichirou Takeda, (2003). “Stability and height of the landward limit of the backshore at Japanese beaches”. *J. Cost Res*, 19(4), 1082-1093.

Intergovernmental Panel on Climate Change (IPCC)- (2001): The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by Houghton, J T, Y Ding, D J Griggs, M Noguer, P J, Linden X Dai, Cambridge University Press, Cambridge, United Kingdom and New York, USA.

Irene Delgado, Graham Lloyd. (2004). “A simple low cost method for one person beach profiling”. *J. Cost Res*, 20(4), 1246-1252.

Mahjoobi J, Ehsan Adeli Mosabbeb. (2009). “Prediction of significant wave height using regressive support vector machines”. *Ocean Engg*, 36, 339–347

Jain P and M C Deo. (2007). “Real-time wave forecasts off the western Indian coast”. *App Ocean Res*, 29. 72–79.

Jardine T P. (1979). “The reliability of visually observed wave heights”. *Coastal Engg*, 3, 33-38.

Javier Benavente, Francisco-Javier Gracia, Giorgio Anfuso, Francisco Lopez-Aguayo. (2005). “Temporal assessment of sediment transport from beach nourishments by using foraminifera as natural tracers”. *Coastal Engg*, 52, 205–219.

Jayappa K S, Vijaya Kumar G T, Subrahmanya. (2003). “Influence of coastal structures on the beaches of southern Karnataka, India”. *J. Cost Res*, 19(2), 389-408.

John J B Rooney, Charles H Fletcher III. (2005). “Shoreline change and Pacific climatic oscillations in Kihei, Maui, Hawaii”. *J. Cost Res*, 21(3), 535-547.

Jonathan A Warrick, Douglas A George, Guy Gelfenbaum, Peter Ruggiero, George M Kaminsky, Matt Beirene. (2009). “Beach morphology and change along the mixed grain size delta of the dammed Elva River Washington”. *Geomorphology*, 111,136-148.

Jorge Guillen and Albert Palanques. (1996). “Short- and medium-term grain size changes in deltaic beaches (Ebro Delta, NW Mediterranean)”. *Sed Geo*, 101. 55-67.

Jose A Jimenez, Agustin Sanchez, Josep Bou, Miquel A Oritiz. (1997). “Analysing short-term shoreline changes along the Ebro delta (Spain) using Aerial photographs”. *J. Cost Res*, 13(4), 1256-1266.

Jose M Horrillo- Caraballo and Dominic E Reeve (2010). “An investigation of the performance of a data driven model on sand and shingle beaches”. *Marine Geo*, 274, 120-134.

Jun-Young Park, John T Wells. (2005). "Longshore sediment transport at Cape Lookout, North Carolina: Shoal evolution and the regional sediment budget". *J. Cost Res*, 21(1), 1-17.

Singh K, M C Deo, V Sanil Kumar. (2008). "Prediction of littoral drift with artificial neural networks". *Hydro Earth Syst Sci*, 12, 267–275.

Kaiser M F M, Frihy O E. (2009). "Validity of the equilibrium beach profiles: Nile Delta Coastal Zone, Egypt". *Geomorphology*, 107, 25–31.

Kalra R, Deo M C, Kumar R, Aggarwal V K. (2005a). "Artificial neural network to translate offshore satellite wave data to coastal locations". *Ocean Engg*. 32, 1917–1932.

Kalra R, Deo M C, Kumar R, Aggarwal V K, (2005b). "RBF network for spatial mapping of wave heights". *Marine Struct*, 18, 289–300.

Kalra R, Deo M C. (2007). "Derivation of coastal wind and wave parameters from offshore measurements of TOPEX satellite using ANN". *Coastal Engg*, 54, 187–196.

Kasinatha Pandian P, Ramesh S, Ramana Murthy M V, Ramachandran S, Thayumanavan S. (2004). "Shoreline changes and nearshore processes along Ennore coast, East coast of India". *J. Cost Res*, 30(3), 828-845.

KREC Study Team (1994). "Study on coastal erosion (Dakshina Kannada district), input to environmental master plan study". Karnataka Regional Engineering College, Surathkal.

Kumar A, Jayappa K S. (2009). "Long and short term shoreline changes along Mangalore coast, India". *Int. J. Envi Res*, 3(2), 177-188.

Kunte P D and Wagle B G (1991). "Spit Evolution and shore drift direction along south Karnataka coast, India". *gionale di Geologia*, 53(2).71-80.

Kunte P D and Wagle B.G. (2001). “Littoral transport studies along west coast of India—a review”. *Indian J. Marine Sci*, 30, 57–64.

Laluraj C M, Girish Gopinath, P K Dinesh Kumar, K K Balachandran. (2008). “Hydrodynamic and Geomorphic Controls on the Morphology of an Island Ecosystem in the Vembanad Lake, West Coast of India”. *J. Cost Res*, 24(2B). 145-150.

Laura J Moore. (2000). “Shoreline mapping techniques”. *J. Cost Res*, 16(1), 111-124.

Laurel Gorman, Andrew Morang, Robert Larson. (1998). “Monitoring the coastal environment; Partt IV: Mapping, shoreline changes and bathymetric analysis”. *J. Cost Res*, 14(1), 61-92.

LaValle P D, Lakhan V C, Trenhaile A S. (2001). “Space–time series modelling of beach and shoreline data”. *Envi Model & Software*, 16, 299–307.

Lee L. (2006). “Neural network prediction of a storm surge”. *Ocean Engg*, 33, 483–494.

Lee T L, Jeng D S. (2002). “Application of artificial neural networks in tide forecasting. *Ocean Engg*, 29(9), 1003–1022.

Leea T L, C P Tsai, D.S. Jeng, R J Shieh. (2002). “Neural network for the prediction and supplement of tidal record in Taichung Harbour, Taiwan” *Adv. Engg Soft* 33,329–338.

Leo Papea, B G Ruessinka, Marco A Wieringb, Ian L Turner. (2007). “Recurrent neural network modelling of near shore sandbar behaviour”. *Neural Networks*. 20. 509–518.

Londhe S.N., M.C. Deo. (2003). “Wave tranquility studies using neural networks. *Marine Structures*, 16, 419–436.

Londhe S N (2008). “Soft computing approach for real-time estimation of missing wave heights”. *Ocean Engg*, 35, 1080– 1089.

Mahjoobi J, A Etemad-Shahidi, M H Kazeminezhad. (2008). “Hindcasting of wave parameters using different soft computing methods”. *App Ocean Res*, 30, 28–36.

Mahmoud M El Banna. (2007). “Erosion and accretion rates and their associated sediment characters along Ras El Bar coast, northeast Nile Delta, Egypt”. *Environ Geol*, 52, 41–49.

Makarynskyy O. (2004). “Improving wave predictions with artificial neural networks”. *Ocean Engg*. 31, 709–724.

Makarynskyy O. (2007). “Artificial Neural Networks in merging wind wave forecasts with field observations”. *Indian J. Marine Sci*, 36 (1),7-17.

Makarynskyy O, Pires-Silva A A, Makarynska, D, Ventura-Soares C. (2005). “Artificial neural networks in wave predictions at the west coast of Portugal”. *Computer Geosci*, 31, 415–424.

Mallik T K, Samsuddin M, Prakash T N, Vasudevan V, Terry Machado. (1987). “Beach Erosion and Accretion - An Example from Kerala, Southwest coast of India”. *Env Geo*, 10(2), 105-110.

Mandal S and Prabaharan N. (2006). “Ocean wave forecasting using recurrent neural networks”. *Ocean Engg*, 33, 1401-1410.

Mandal S. (2001). “Back propagation neural network in tidal level forecasting”. *J. Water, Port, Coast Ocean Engg*, 127 (1), 54–55.

Mandal S, Subba Rao, D H Raju. (2005). “Ocean wave parameters estimation using back propagation neural networks”. *Marine Structures*, 18, 301–318.

Mandal S and Prabaharan N. (2010). “Ocean wave forecasting using recurrent neural networks”. *The open Ocean Engg J.*, 3, 12-17.

Mani Murali, R.Shakuntala Ekka, P Vethamony, D Ilangovan. (2007). “Land use/Land cover Studies of Areas in and around Paradip Port, East Coast of India”. 4th Indian Nat. Conf. on Harbour and Ocean Engg, 12-14, Dec. 2007, at NITK, Surathkal, 441-445.

Mani Murali R, Deepak Shrivastava, Vethamony P. (2009). “Monitoring shoreline environment of Paradip, east coast of India using remote sensing”. *Current Sci*, 97(1), 79-83.

Marcel J F Stive, Stefan G J, Aarninkhof Luc Hammb, Hans Hansonc, Magnus Larson, Kathelijne M Wijnbergd, Robert J Nicholls, Michele Capobianco, (2002). “Variability of shore and shoreline evolution”. Coastal Engg, 47, 211–235.

Marcel R A van Gent, Henk F P van den Boogaard, Beatriz Pozueta, Josep R Medina. (2007). “Neural network modelling of wave overtopping at coastal structures”. *Coastal Engg*, 54, 586–593.

Martin J Austin, Gerhard Masselink. (2006). “Observations of morphological change and sediment transport on a steep gravel beach”. *Marine Geo*, 229, 59–77.

Mary Jean Pajak, Stephen Leatherman, (2002). “The waterline as shoreline indicator”. *J. Cost. Res*, 18(2), 329-337.

Mehmet Bilgili, Besir Sahin, Abdulkadir Yasar. (2007). “Application of artificial neural networks for the wind speed prediction of target station using reference stations data”. *Renewable Energy*, 32, 2350–2360.

Mehmet O¨zger (2010). “Significant wave height forecasting using wavelet fuzzy logic approach”. Ocean Engg, 37, 1443–1451.

Michal Lichter, Dov Zviely, Micha Klein. (2010). “Morphological patterns of southeastern Mediterranean river mouths: The topographic setting of the beach as a forcing factor”. *Geomorphology*, 123, 1–12.

Mislankar P G, Antao F B. (1992). “Textural studies of beach sediments from Sadashivgad and Karwar, central west coast of India”. *Indian J. Earth Sci*, 19(2-3), 70-78.

Mitchell D Harley, Ian L Turner, Andrew D Short, Roshanka Ranasinghe. (2011). “Assessment and integration of conventional, RTK-GPS and image-derived beach survey methods for daily to decadal coastal monitoring”. *Coastal Engg*, 58, 194–205.

Mohamed A K Elsayed, Nazeih A Younan, Alfy M Fano, Khalid H Baghdady, (2005). “Accretion and erosion patterns along Rosetta Promontory, Nile delta coast”. *J. Cost. Res*, 21(3), 412-420.

Mohd-Lokman H, Rosnan Y, Ejria S, Shazili N A M, Kassim K K Y. (1998). “Deducing sediment transport direction and the relative importance of rivers on a tropical microtidal beach using the “McLaren model”. *Env Geo*, 34 (2/3), 128-134.

Muñoz-Perez J J, Medina R. (2010). “Comparison of long, medium and short-term variations of beach profiles with and without submerged geological control”. *Coastal Engg*, 57, 241–251.

Murray Hicks D, Terry M Hume, Andrew Swales, Malcolm O Green. (1999). “Magnitudes, spatial extent, time scales and cause of shoreline change, adjacent to an ebb tidal delta, Katikati inlet, New Zealand”. *J. Cost. Res*, 15(1), 220-240.

Mwakumanya A M, T M Munyao, E K Ucakuwun. (2009). “Beach width analyses in beach erosion hazard assessment and management at Bamburi beach, Mombasa, Kenya”. *J. Geo and Reg Plan*, 2(12), 299-309.

Navrajan Tirkey, Biradar R S, Madhavi Pikle, Sunit Charatkar. (2005). “A study on shoreline changes of Mumbai coast using remote sensing and GIS”. *J. Indian Society of Remote Sensing*, 33(1), 86-91.

Nayak S R, Hegde V S, Shalini G, Rajawat A S, Girish K H, Jayakumar S, Suryanarayana A. (2010). “Geomorphic Processes in the Vicinity of the Venkatapur River Mouth, Central West Coast of India: Implications for Estuarine Sedimentation”. *J. Cost. Res*, 26(5), 925-934.

Nicholas J Cooper, John S Pethick. (2005). “Sediment budget approach to addressing coastal erosion Problems in ST. Oueen’s Bay, Jersey”. *J. Cost. Res*, 21(1), 112-122.

Omar Defeo, Anton McLachlan, David S Schoeman, Thomas A Schlacher, Jenifer Dugan, Alan Jones, Mariano Lastra, Felicita Scapini. (2009). “Threats to sandy beach ecosystems: A Review”. *Estuarine, Coast Shelf Sci*. 81, 1–12.

Onkar S Chauhan.(1995). “Monsoon induced temporal changes in beach morphology and associated sediment dynamics, central east coast of India”. *J. Cost. Res*, 11(3), 776-787.

Ozgur Kisi. (2008). “Constructing neural network sediment estimation models using a data driven algorithm”. *Maths Comp Sim*, 79, 94–103.

Padhy C P, Sen D, Bhaskaran P K. (2008). “Application of wave model for weather routing of ships in the North Indian Ocean”. *Natural Hazards*, 44, 373–385.

Pari Y, Ramana Murthya M V, Jaya kumar S, Subramaniana B R, Ramachandran S.(2008). “Morphological changes at Vellar estuary, India—Impact of the December 2004 tsunami”. *J. Env Mgmt*, 89, 45–57.

Patrick L Barnard and Jonathan A Warrick. (2010). “Dramatic beach and nearshore morphological changes due to extreme flooding at a wave-dominated river mouth”. *Marine Geo*, 271,131–148.

Peter Ruggiero, George M Kaminsky, Guy Gelfenbaum, Brian Voigt. (2005). "Seasonal to interannual morphodynamics along a high energy dissipative littoral cell". *J. Cost. Res*, 21(3), 553-578.

Ping Wang and Nicholas C Kraus. (1999). "Longshore sediment transport rate measured by short-term impoundment". *J. Waterway, Port, Coastal and Ocean Engg*, May/June, 118-126.

Plomaritis T A, Paphitis D, Collins M. (2008). "The use of grain size trend analysis in macrotidal areas with breakwaters: Implications of settling velocity and spatial sampling density". *Marine Geo*, 253, 132–148.

Pooja Jain and M C Deo. (2008). "Artificial Intelligence tools to forecast Ocean waves in real time". *The open Ocean Engg J*., 1, 13-20.

Prakash T N, Black K P, Mathew J, Kurian N P, Thomas K V, Shahul Hameed T S, Vinod M V, Rajith K. (2007). "Near shore and Beach Sedimentary Dynamics in a Placer-Dominated Coast, Southwest India". *J. Cost. Res*, 23(6), 1391-1398.

Prithviraj M, Sengupts S, Ghosh S K, Ramana I V, Chakraborty D. (1995). "Documentation of the long-term coastal geomorphic changes within the Hugli River Estuary, India". *J. Asian Pacific Remote Sensing*, 3(1), 1-9.

Raghavan B R, Vinod B T, Dimple K A, Venkatesh Prbhu H, Udayashankar H N, Sreedhara Murthy T. (2001). "Evaluation of the Nethravathi spit complex, west coast of India: Integrated change detection study using topographic and remotely sensed data". *Indian J. Marine Sci*, 30(4), 268-270.

Rajamanickam G V and Gujar A R. (1997). "Grain size studies on the nearshore sediments of Jaigad, Ambwah and Varvada Bays, Maharashtra". *J. Geo society of Indi*,. 49, 567-576.

Rajawat A S, Gupta Mukesh, Yashwant Pradhan, A V Thomos Kutty, S R Nayak. (2005). “Coastal processes along the Indian Coast—case studies based on synergistic use of IRS-P4OCM and IRS-1C/1D data”. *Indian J. Marine Sci,* 34 (4):459–472.

Rajith K, Kurian N P, Thomas K V, Prakash T N, Hameed T S. (2008). “Erosion and accretion of a placer mining beach of SW Indian coast”. *Marine Geodesy,* 31, 128-142.

Rajiv Nigam, Rajani Panchang, Priyanka Baerjee. (2005), “Forminifera in surface sediments of Mandovi river estuary: Indicators for mioning pollution and high sea stand in Goa, India”. *J. Cost. Res*, 21(4), 853-859.

Ranga Rao V, Ramana Murthy M V, Manjunath Bhat, Reddy N T.(2009). “Littoral sediment transport and shoreline changes along Ennore on the southeast coast of India: Field observations and numerical modelling”. *Geomorphology,* 112, 158–166.

Reeve D E, M Spivack. (2004). “Evolution of shoreline position moments”. *Coastal Engg*, 51 661– 673.

Reji Srinivas and Kurian Sajan. (2010). “Significance of Textural analysis in the sediments of Kayamkulum lake, southwest coast of India”. *Indian J. Marine Sci*, 39(1), 92-99.

Robert Larson, Andrew Morang, Laurel Gorman. (1997). “Monitoring coastal environment part II: Sediment sampling and geotechnical methods”. *J. Cost. Res*, 13(2), 308-330.

Roberto R Kokot, Alejandro A J Monti, Jorge O Codignotto.(2005). “Morphology and short term changes of the Caleta Valdes barrier spit, Argentina. *J. Cost. Res*, 21(5), 1021-1030.

Rongxing Li, Jung-Kuan Liu, Yaron Felus. (2001). “Spatial modelling and analysis for shoreline change detection and coastal erosion monitoring”. *Marine Geodesy*, 1-12.

Sajeev R, Sankaranarayanam V N. (1996). “Seasonal changes of the sediment size distribution and stability along the beaches of Kerala, south west coast of India, *Indian J. Marine Sci*, 25, 216-220.

Sam Smith A W , L A Angus Jackson. (1992). “The variability in width of the visible beach”. *J. Shore and Beach*, 58(3), 7-14.

Sandrine Aubie, Jean-Pierre Tastet. (2000). “Coastal erosion processes and rates: An historical study of the Gironde Coastline, southwestern France”. *J. Cost. Res*,16(3), 756-767.

Sanil Kumar V, K C Pathak., P Pednekar, N S N Raju, R Gowthaman (2006). “Coastal processes along the Indian coastline”. *Current Sci*, 91(4), 530–536.

Schoonees J S, Theron A K, Bevis D. (2006). “Shoreline accretion and sand transport at groynes inside the Port of Richards Bay”. *Coastal Engg*, 53, 1045–1058.

Sfetsos A. (2000). “A comparison of various forecasting techniques applied to mean hourly wind speed time series”. *Renewable Energy*, 21. 23-35.

Shore Protection Manual. (1984). Coastal Engineering Research Centre, US Army Corps of Engineers, Washington, DC.

Singh A K, M C Deo, V Sanil Kumar. (2008). “Prediction of littoral drift with artificial neural networks”. *Hydro Earth Sci system*. 12. 267–275.

Singh A K, Deo M C, Sanil Kumar V. (2007). “Neural network– Genetic Programming for sediment transport”, *J. Maritime Engg*, The Institution of Civil Engineers, London, 160, Issue MA3, 113-119.

Subba Rao. (2000). "Study on grain size parameters of KREC beach sand, west coast of India". *KREC Res bul*, Karnataka Regional Engineering College Surathkal, 9(1), 8-15.

Subba Rao. (2001). "Causes of Erosion along Karnataka coast. National workshop on Coastal erosion and protection Management". Dept of Applied Mechanics and Hydraulics. Karnataka Regional Engineering College Surathkal.

Subba Rao. (2002). "Breach erosion along Dakshina Kannada coast". *KREC Res Bul*, Karnataka Regional Engineering College Surathkal, 11(1), 1-9.

Subba Rao, Kiran G Srilal Praveen Suvarna S, Madhu Babu, B R Subramaniaan and R S Kankara. (2007). "Modelling of coastal Process around Gurupur-Nethravathi rivermouth using MIKE-21". Fourth Indian Nat. Conf. on Harbour and Ocean Engg (INCHOE-2007) held at NITK Surathkal during 12-14 December 2007, 392-401.

Subba Rao and Mandal.S. (2005). "Hindcasting of storm waves using neural networks". *Ocean Engg*, 32, 667–684.

Sushma Prasad, Pandarinath K, Gupta S K. (1998). "Geomorphology, tectonism and sedimentation in the Nal region, western India". *Geomorphology*, 25, 207–223.

Tara L Miller, Charles H Fletcher, (2003). "Waikiki: Historical analysis of an engineered shoreline". *J. Cost. Res*, 19(4), 1026-1043.

Thampanya U, Vermaat J E, Sinsakul S, Panapitukkul N. (2006). "Coastal erosion and mangrove progradation of Southern Thailand". *Estuarine, Coast Shelf Sci*, 68, 75-85.

Toru Tamura, Keisshi Horaguchi, Yoshiki Saito, Van lap Nguyen, Masaaki Tateishi, Thi Kim Oanh Ta, Futoshi Nanayama, Kazuaki Watanabe. (2010). "Monsoon-influenced variations in morphology and sediment of a mesotidal beach on the Mekong River delta coast". *Geomorphology*, 116, 11-23.

Tsong-Lin Lee. (2004). "Back-propagation neural network for long-term tidal predictions". *Ocean Engg*, 31, 225–238.

Udhaba Dora G, Sanil Kumar V, Sajiv Philip C, Glejin Johnson, Vinayaraj P, Gowthaman R. (2011). "Textural characteristics of foreshore sediments along Karnataka shoreline, west coast of India". *Intl. J. Sed Res*, 26, 364-377.

Veerayya M, Shenoi S S C, Murthy C S. (1985). "Morphology and grain-size characteristics of a log-spiral beach at Nagwa (Diu), west coast of India". *Indian J. Marine Sci*, 14, 127-132.

Veerayya M, Muralinath A S. (1994). "Sediment movement on the continental shelf off Bombay, India". *Continental Shelf Res*,14(15),1689-1700.

Vousdoukas M I, Velegrakis A F, Karambas T V. (2009). Morphology and sedimentology of a microtidal beach with beach rocks: Vatera, Lesbos, NE Mediterranean. *Continental Shelf Res*, 29, 1937–1947.

Yagoub M M, Giridhar Reddy Kolan.(2006). "Monitoring coastal zone land use and land cover changes of Abu Dhabi using Remote Sensing. *J. Indian Society Remote Sensing*, 34(1), 57-68.

Yvonne Baattiau-Queney, Jean Francois Billet, Sylvain Chaverot, Philippe Lanoy-Ratel. (2003). "Recent shoreline mobility and geomorphologic evolution of macrotidal sandy beaches in the north of France", *Marine Geo*, 194, 31-45.

Zuo Xue, Aiping Feng, Ping Yin, Dongxing Xia. (2009). "Coastal erosion induced by human activities: A northwest Bohai sea case study". *J. Cost. Res*, 25(3), 722-723.

List of Publications based on PhD Research Work

International Journals

1. Gumageri Nagaraj, Amruth Karjagi, Mohan Kumar, Dwarakish G S. (2011). "Geomorphological behaviour of Sasihithlu, Mangalore Coast, West Coast of India". *Int. J. Earth sci. Engg*, 4(3), 467-476.

2. Gumageri Nagaraj and Dwarakish G S (2011) "Shoreline Changes along the Mangalore Coast, West Coast of India". *Int. J. Earth sci. Engg*, 4(3), 63-70.

3. Gumageri Nagaraj, Mohan Kumar K N and Dwarakish G S (2011). "Land Use and Land Cover Changes around the Rivermouths of Mangalore, West Coast of India". *Int. J. Earth sci. Engg*, 4(6), 350-353.

4. Gumageri Nagaraj, Dwarakish G S, Sreenivasulu Dandagala and Usha Natesan (2012). "Neural Network for Ocean Wave Forecasting". *Int. J. Artificial Intel Sys and Machine Learn*, 4(3), 167-172.

5. Gumageri Nagaraj and Dwarakish G S "Monitoring the Longterm and Shortterm shoreline changes in the vicinity of Mulky-Pavanje rivermouth, southwest coast of India". *J. Coast conserv, Plan and Mgmt (Revised and Resubmitted).*

National Journals

1. Mohan Kumar K N, Amruth Karjagi, Gumageri Nagaraj, Arun Kamath, Varun V M, Dwarakish G S, Usha Natesan (2010). "Effect of coastal landforms on beach morphology along Sasihithlu Coast, West coast of India". *NITK Res Bul*, 19(2), 21-29.
2. Pavithra N R, Gumageri Nagaraj, Dwarakish G S and Usha Natesan. "Longshore Sediment Transport Rate for Mangalore Coast". (Accepted, *NITK Research Bul*).

International Conferences

1. Amruth Karjigi, Mohan Kumar, Gumageri Nagaraj, Varun, Arun Kamath, Dwarakish G S and Usha Nateshan (2010). “Beach Morphological characteristics and Coastal Processes along Dakshina Coast, West Coast of India”. Proc. Int. Conf. on *Hydro Sci and Engg (ICHE 2010)*. Indian Institute of Technology Madras. Chennai, 1532-1541.

2. Gumageri Nagaraj, Amruth Karjigi, Mohan Kumar, Dwarakish G S, Usha Nateshan (2010). “Sediment characteristics of Dakshina Kannda coast, West coast of India*”.* Proc. Int. Conf. on *Earth Sci and Engg (ICEE-2010).* Mallareddy Engg College, Hyderabad. 57-62.

3. Gumageri Nagaraj, Sabarimon S and Dwarakish G S (2012). “Study of Coastal Processes using Remote Sensing and GIS: A Case Study of Mulky-Pavanje Rivermouth Area, Mangalore”. *Proc. Int. Conf. of “GEOMATRIX-12”.* Indian Institute of Technology Bombay, 526-528. .

National Conferences

1. Amruth Karjigi, Mohan Kumar, Gumageri Nagaraj, Varun, Arun Kamath, Dwarakish G S and Usha Natesan (2010). “A Study on Variations in the Sediment Dynamics along Dakshina Kannada, West Coast of India”. Proc. Nat. Conf. on *Coastal processes, Resources and Management*. Center for Earth Science and Engineering Trivandrum. 11-15.

2. Gumageri Nagaraj and Dwarakish G S (2011). “Spit Evolution in the vicinity of Mulky-Pavanje rivermouth, west coast of India”. *Proc. Nat. sem on Coastal Hazards, Resources and Management*, Mangalore University, 57.

3. Gumageri Nagaraj and Dwarakish G S (2011). “Investigation of Geomorphic processes on Mulky-Pavanje Rivermouth, West Coast of India”. Proc. Nat. Conf. of *ocean Society of India (OSICON-11),* National Institute of Ocean Technology Chennai, 126-127.

4. Gumageri Nagaraj, Pavithra N R, Sreenivasulu D and Dwarakish G S (2011). "Neural Network for wave forecasting". Proc. Nat. Conf. on *Hydraulics & Water Resources (HYDRO-2011),* Sardar Vallabhbhai National Institute of Technology, Surat & Indian Society for Hydraulics, 1063-1069.

Appendix I

Field Data collection

Plate.1 Beach Profile Suvey

Plate.2 Sediment sample collection

Plate.3 Beach Width Measurmant

Plate.4 GPS Tracing along the length of the study area for HWL

Appendix II

Site Specific Features

Plate.1 Protection by Sewall at Mukka Beach

Plate.2 Mulky-Pavanje Rivermouth

Plate. 3 Formation of sandbar near rivermouth on southern side

Plate. 4 Direct wave action on Sewall

Bio-Data

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