MORPHODYNAMICS IN TROPICAL BEACHES OF VARYING ENERGY REGIMES

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UNDER THE FACULTY OF MARINE SCIENCES

by

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September 2015

To

My Beloved Family

DECLARATION

I hereby declare that the thesis entitled "Morphodynamics in Tropical Beaches of Varying Energy Regimes" is an authentic record of research work carried out by me under the supervision and guidance of Dr. Reji Srinivas, Scientist, Coastal Processes Group, National Centre for Earth Science Studies (NCESS), ESSO, Ministry of Earth Sciences, Govt. of India, Thiruvanathapuram in partial fulfillment of the requirements for the Ph.D. degree of Cochin University of Science and Technology under the Faculty of Marine Sciences and no part has been presented for the award of any degree in any University.

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September 11, 2015

September 11, 2015

Certificate

This is to certify that the thesis entitled "Morphodynamics in Tropical Beaches of Varying Energy Regimes" is an authentic record of research work carried out by Mrs. Silpa.B.L under my supervision and guidance at National Centre for Earth Science Studies (NCESS), Thiruvanathapuram in partial fulfillment of the requirements for the Ph.D. degree of Cochin University of Science and Technology under the Faculty of Marine Sciences and no part has been presented for the award of any degree in any University/Institute. The relevant corrections and suggestions of the doctoral committee and those arouse during pre synopsis seminar were incorporated.

Dr. Reji Srinivas

Supervising Guide

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PREFACE

Earth's coastline defines the interface between land and water. Although the area they cover is insignificant, their linear extent is enormous and the variety of landforms they evolve over earth's surface is remarkable. Over one third of the world's population lives either at the coasts or in adjacent coastal low land areas. The coast is a zone of intense energy input. This energy transported by waves, arrives at the coast and is available for work. The result is that the processes of sediment transport are set in motion – processes that cause morphological change. Thus the coasts are the most rapidly changing places on earth's surface and they play an important role in global transportation of sediments and hence studies on the coastal zone where air, land and water interact is a focus of particular interest among the scientific community. The coastal areas across the world are also of extreme economic importance as they contain abundant natural resources and favorite tourist destinations because of their highly scenic landscape.

The present study proposes to investigate the beach morphological changes and the driving forces along the three different energy regimes of the Kerala coast. The three coastal stretches are Poovar – Varkala (Southern Sector), Munambam- Chettuva (Central Sector) and Beypore

- Puthiyappa (Northern Sector). Being an extensive morphologic system, the Poovar - Varkala coastal stretch is taken up for detailed study. The study defines the beach stability by explaining the influence of natural and artificial structures on the coast of different energy regimes. It also delineates the impact of artificial structures installed to mitigate coastal erosion in the area and analyzes the practicality of different protective measures adopted along the beaches of the study area.

The whole work is addressed into 6 chapters

Chapter I deals with the general introduction, which provides the location, physiography, physical factors, coastal geomorphology, beach morphology and geologic setting of the study area. The objectives of the present work are given towards the end of this chapter.

Chapter II provide the details of the field work, methods of sample collection, processing, analytical procedures employed for textural, geochemical, remote sensing and GIS studies.

Chapter III enfolds the beach morphology and textural characteristics of the beach sediments of the study area.

Chapter IV describes shoreline change detection study for the period 1967-2000, 2000-2005 and 2005-2014.

Chapter V presents a pilot study in Vizhinjam port area by delineating the texture and geochemistry of nearshore sediments in the area. The contamination status of sediments is also worked out in this chapter.

Chapter VI presents the summary of the study and the salient conclusions drawn from the results thereof. The pertinent literatures cited are furnished towards the end of the thesis.

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CHAPTER I

INTRODUCTION

More than 70 percent of the earth is covered by worldwide, interconnected body of seawater. The abundance of water makes the earth unique among the planets of the solar system. The total area of the surface of the earth is about 197 million square miles, and about 140 million square miles of this are covered by the waters of the oceans and their marginal seas (Ordway, 1966). The continents are like gigantic islands above the surface of this single widespread ocean. Thus the oceans that were once barriers between continents are now much more appropriately regarded as connecting links between the continents. The water of the earth joined together in one continuous mass has been subdivided into: Atlantic, Pacific, Indian, Artic and Antartic oceans. These water mass meets the land in the shore at coast and thus coastline is defined as the interface between land and water. The coastline paradox states that a coastline does not have a well defined length. Measurements of the length of the coastline behave like a fractal, being different at different scale intervals. Treated as fractals, coastlines can yet be measured. The Central Intelligence Agency (CIA) World Factbook counts 356000 kilometers of world coastline, based upon measurement of about 250 countries and territories. Although the area they cover is insignificant, their linear extent is enormous and the variety of landforms they evolve over earth's surface is remarkable. Over one third of the world's population lives either at the coasts or in adjacent coastal low lands. The coast is a zone of intense energy input. This energy transported by waves arrives at the coast and is available for various activities operating there. The result is that the sediments are set in motion leading to transportation and other processes that cause morphological changes. Coasts are the most rapidly changing places on earth. The majority of seacoasts were sculptured by wave condition. Many are dominated by cliffs and other erosional features, in addition to submerged longshore bars and depositional platforms which are found not too far from the watermark. Many shorelines represent complex zones of sediment accumulation in the form of offshore or bay bars, spits, cuspate bars or tombolos and these are linked to the continent by mudflats or lagoons that are colonized by salt marsh or mangrove swamps particularly in tropical regions. They are often highly scenic and contain abundant natural resources. The mutual co-adjustment of coastal form and process is termed coastal morphodynamics (Woodroffe, 2002). The processes that operate on a section of the coast are a function of oceanographic and climatic factors, the nature of the hinterland and the pre-existing topography. Understanding the natural adjustments that occur between coastal landforms and the processes that influence them is essential for the better management of coastal resources. Under natural conditions the morphology of a coastline reflects responsive and dynamic equilibrium between the material from the coast and the hydrodynamic forcing factors such as waves and tidal currents. Coastal landforms act to attenuate wave and tidal energy and respond to changing energy conditions at a range of spatial and temporal state (Pethick, 1996, Pethick and Corrk, 2000). As water depths increase at the shore there is a resulting enhanced wave and tidal energy along the coast. In response, coastal landforms migrate both normal to (orthogonal with the coast) and parallel with the shore in order to maintain their position within the energy gradient. In this way as coastal energy level increase, mudflats migrate landwards to a lower energy level and could be replaced by sand beaches. The sandy tropical coasts undergo cyclic morphological changes in response to annual storm and swell conditions.

Beach is one of the most dynamic and complex system of the coastal environment. It is defined as a zone of unconsolidated sediments extending landward from the mean low tide line to a place where there is some physiographic change such as a cliff or dune field or to the point where permanent vegetation is established (Komar, 1976). Beaches change constantly and their dynamics can teach us much about the processes that operate at shorelines. Although they appear stable under conditions of small waves, beaches erode so rapidly when attacked by heavy surf and storm waves and may completely change their character or even disappear in few hours. Most significant are the slow changes mostly in the form of growth that accompany small waves. In addition to these cyclic changes, beaches undergo large permanent modifications as the result of anthropogenic interventions. Hence an understanding of the causes of beach development and destruction has considerable economic importance as well. Almost all the sand that builds up beaches has come from the seafloor. A large amount of sand is brought into the ocean by runoff from the lands. In some areas a better source comes from the products of cliff erosion and in many tropical areas with coral reefs, the largest portion of the sand is derived from the erosion of coral and algal reefs that exist along or near the shore. Another important source of sand is from the Pliestocene deposits of the inner continental shelf. Finally a small source of sand is introduced more or less directly from the lands by offshore winds carrying dune sand into the sea where it is picked up by the waves and may be transported back onto the shore to form the beaches. The factors controlling the dynamics of the beaches are many. However, wind generated surface waves are the principal source of energy input in the littoral zone. They are responsible for the erosion of the coast and for the formation of depositional beach features. The variation in the coastal morphology mainly depends upon the sediment type, wave conditions, nature of beaches and coastal configuration (Shepard,1964). Beach balancing involves both cross shore and alongshore transport of sand and the development of rhythmic topography along the beach is an indication of the significance of movements of sands.

1.1 COASTAL GEOMORPHOLOGY OF INDIA

The Indian coastline, including the coastlines of Andaman and Nicobar islands in the Bay of Bengal and Lakshadweep islands in the Arabian Sea is about 7517km, of which the length of the coastline of mainland is 6100km. About 55%

of the Indian coastline is beach fringed (spits, barriers or sandy beaches on the shore) and the beaches have been generally either stable or receding in the past few decades. About a quarter of the coastline is still receiving sediment supplied from rivers. On the west coast there have been episodes of submergence due to earthquake subsidence, followed by alleviation and progradation, particularly found in Gulf of Kutch (Bird, 1985). Besides, the west coast is marked by the presence of steep rocky sectors, some with active cliffs others with slopes plunging directly into the sea. Along the west coast, the width of the shelf varies from about 340km in the north to less than about 60km in the south. The coast comprises various features like headlands, promontories, rocky shores, sandy spits, barrier beaches, embayment, estuaries, inlets, bays, marshy land and offshore islands. The coastal plains of the west coast are confined to a width of about 10 to 25km lying between the Arabian Sea and the Western Ghats extending from Gujarat to Kanyakumari. The shoreline of the west coast is one of the submergence attributed to rise in sea level against a stable coast (Ahmad, 1972). The most remarkable feature of the west coast is the widespread presence of estuaries and lagoons (Nair, 1987). The entire stretch of the west coast possesses relatively similar geological and climatological characteristics (Sajeev, 1993). The west coast of India experiences its major erosional phase during the south west monsoon (June – September), than the north east monsoon (December – January) and accretion during the other months (Hedge *etal*, 2009). The continental shelf along the east coast is narrow and the eastern coastline is essentially alluvial, gently indented, and extensively developed. Beaches on the Coromandel Coast are typically front cliffed dune margins. The chief prograding sectors on the east coast are the deltas of Krishna, Godavari, Mahanadi and the Ganges. Deltaic shorelines are generally muddy, but where sand is present beaches and spits have been formed. Spit growth on a smaller scale has accompanied the evolution of the Krishna delta between 1928 and 1978, general progradation having been interrupted by erosion of the coastline during the 1977 cyclone (Nageswara Rao and Vaidyanathan, 1979). On the Godavari delta, northward drifting of sand has extended sand spit at Kakkinada Bay by several kilometers during the past century (Sambasiva Rao and Vaidyanadhan, 1979). Northward sand drift on this coast is also indicated by the accumulations on the southern sides of the breakwaters at Madras and Visakhapatnam. On the Mahanadi delta there has been slight overall progradation by fluvial deposition, although in detail the shoreline has shown alternating advance and retreat. The Balasore coast, north of Palmyras point, is also thought to have prograded by deposition during the past century (Nagaraja, 1966). The total length of prograding shore, including delta, is about one fourth of the Indian coastline. The rest includes rocky overhanging cliffs or combinations of rocky and beachy shore.

1.2 COASTAL GEOMORPHOLOGY OF KERALA

Kerala coast is a 570km long narrow strip of land bordering the Arabian Sea at the south western part of the Peninsular India extending from latitudes $8^{0}15'$N to $12^{0}85'$N and longitudes $74^{0}55'$E to $77^{0}05'$E and has a remarkable straight coastline oriented in NNW-SSE direction (Sajeev, 1993). It is believed to have originated as a result of faulting during the late Pliocene (Krishnan, 1968).The Kerala coast is marked by marine erosion. Large areas of the Kerala coast undergo erosion during monsoon months. The coast of Kerala is of recent geological origin, made up of recent sediments. The coastal area is characterised by the occurrence of tertiary and recent sediments although crystalline promontories are exposed in isolated patches both in the south and northern part of the coast (Soman, 1997). The coastal stretch has distinct geologic-geomorphic characteristics. The Malabar Coast (north of Kadalundi) and Kollam -Trivandrum coast down south are rocky and lateritic. The central Kerala coast (Ponnani-Alappuzha stretch) is composed of purely alluvium of recent deposits with prominent paleo strandlines and barrier beaches. In the rocky parts, coastal cliffs are composed of crystalline rock and tertiary sediments. Both erosional and depositional features are evident. One of the most significant morphological features in the coastal region is the backwater system generally running parallel or perpendicular to the shoreline, locally known as *kayals* (backwaters). Their formation is linked with subsidence/lowering of sea level and emergence of sand bars/spits. However, Ashtamudi estuary, Beypore estuary and a few other backwaters, which trend perpendicular to the coast, are mainly incised river mouths uplifted in the Quaternary period. Numerous perennial rivers flow into the *kayals* and when the rivers are in spate, the backwaters overflow and discharge sizeable quantities of sediments into the sea.

1.3 PHYSICAL SETTINGS OF KERALA

1.3.1 Physiography

On the basis of physiographic and slope maps of Kerala (CESS, 1984), Kerala can be grouped into five distinct zones. They are mountain peaks of the Western Ghats rising above 1800 m from the mean sea level (MSL), the highlands at an altitude range of 600 - 1800 m, the midlands at an altitude of 300 - 600 m, the lowlands of 10 - 300 m and coastal plains of <10 m elevation (Soman, 1997)

Highland

Highlands occupying 20.35% of the area of the State form an important physiographic province. From the extreme north, the ranges run parallel to the coast as far as Vavamalai to the east of Kozhikode. The hilly tract lies mainly on the eastern edge close to Western Ghats, the peaks ranging in height from 915 to 2695m. Almost all rivers originate from this region. The Western Ghats form almost continuous mountain chain on the eastern boarder of the State, broken by Palghat gap and a few other small places.

Midland

The undulating western fringe of the highlands and the lateritised rocky spurs projecting westward and parts of the crustal breaks form the midland region. It covers nearly 8.44% of the total area of the State. While the midland constitutes most of the eastern parts of Kannur district, their area shrinks towards the west of Wayanad plateau where they occupy a narrow strip, coinciding with the steep slopes. From the west of Nelliampathi plateau to the north of the Cardomom hills, the elongated spurs separated by extensive ravines are seen to merge with the relatively gentler slopes of the low lands.

Low land

The area falling under the altitudinal range of 10-300m and consisting of dissected peneplains constitute the lowlands. The altitudinal range is quite asymmetric with the maximum area of 54.17% falling within this unit. Numerous flood plains, alluvial terraces, valley fills, colluviums and sedimentary formations are parts of the lowlands. In the northern and southernmost part of the State, this unit merges with the coastal plains with discernible steeper slopes than rest of the State. The higher altitudinal portions of the unit are seen more in the eastern parts of the southern and northern districts. In areas around Poovar-Vizhinjam, Kadakkavur – Varkala, north of Badagara, Bekal-Kasargod etc. this unit abuts the sea without the intervening coastal plains.

Coastal plains and Lagoons

The vast low-lying area fringing the coast is important in terms of economic activity and demographic distribution. It constitutes 16.40% of the area of the State. In central Kerala most of the area shows elevations of 4 to 6m above MSL, where it is 4 to 10m in north and south Kerala, except the coastal cliffs, promontories and sloping platforms. Beach dunes, ancient beach ridges, barrier flats, coastal alluvial plains, floodplains, river terraces, marshes and lagoons constitute this unit. It has the maximum width in the Alleppey and Aluva-Kaladi regions. A characteristic feature of this unit is the existence of numerous beach dune ridges, parallel and sub parallel to the coast, especially in the Alleppey – Cherthala regions. Their orientation indicates that the strandlines belong to atleast two stages and the maximum width between the oldest and the youngest, close to the present shoreline is 18km. Further, the coastal plain is seen to extend between numerous rocky ridges along the coast.

1.3.2 Physical Factors

1.3.2 a Climate

The territory of Kerala falls within the realm of tropical climate and the dominant feature is the monsoon. High variation in relief from the west coast to the hilly regions of the Western Ghats in the east, and proximity to the sea, influence the climatic parameters, resulting in subtropical type of climatic regime in certain areas in the eastern parts of the State. Further, the Western Ghats extending all along the eastern boarder of the State has a number of beaches across it, allowing heat waves to blow into Kerala from across the plains of TamilNadu. This in fact to a great extent influences the climatic conditions in the Palghat gap area and in Punalur in the Ariankavu pass region. On the basis of meteorological or climatic conditions, four seasons can be identified and are as, pre-monsoon or hot weather period (March to May), south-west (SW) monsoon (June to Sept), north-east (NE) monsoon (Oct-Dec) and winter (Jan-Feb). The SW monsoon constitutes the principal and primary season, which gives 75% of the annual rainfall, while NE monsoon provides a secondary rainfall which marks the retrieval of SW monsoon.

1.3.2 b Rainfall

Kerala experiences two monsoons, namely the south west (June to September) and the north east (October to December). Locally these are known as *Edavappathi* and *Thulavarsham*, respectively. The annual rainfall varies from 2250 to 2500mm during SW and while in NE monsoons it averages to 450 to 500mm. Occasional rainfall is also received between the two monsoons. The maximum amount of rainfall is recorded in areas where the Western Ghats have higher elevation and farther from the sea (Kozhikode, Peerimedu-Neriyamangalam). The southernmost districts of Trivandrum receive the minimum, where the Ghats are lower in elevation and are relatively closer to the coast (Machado, 1995).

1.3.2 c Temperature

The temperature in Kerala normally ranges from 28^0 to 32^0 C on the plains but drops to about 20^0C in the high lands. The atmospheric temperature is maximum (32^0C) during February to April and from June it gradually comes down due to heavy rainfall. An increasing trend is noticed again during the months of December to January. The variation in the maximum temperature is of 36° to 37°C along the coast but at places further inland this may go up. Land and sea breezes influence the coastal areas and here the seasonal and diurnal variations of temperature are almost of the same range (5-7^0). Temperature falls in the month of July, when the State receives plenty of rainfall and the sky is cloudy (Soman, 1997).

1.3.2 d Wind

Winds over the state are seasonal and notable change in the wind direction and speed is discernible between the coastal and inland regions of the state as well as between various localities (Soman, 1997). In the region of Palghat Gap, winds are predominantly from the east in the period from November to March and from west in the rest of the year. In other parts of the state, flow of wind is mainly governed by differential heating of land and watermass together with mountain wind (Pradeepkumar, 1994). The basic feature of wind distribution over Arabian Sea is the reversal of the wind systems during the monsoon. The reversals take place predominantly from south-west direction during May-September to north-east direction during December-March (Sajeev, 1993). Between these reversals are the transitions periods during which weak and variable winds prevail. The wind driven oscillation of surface water towards the shoreline, results a change in the existing equilibrium profile of the beach. The wind is also significant on a wide sandy beach as large quantities of sand can be blown from the beach.

1.3.2 e Waves

Waves are undulations on the surface of a liquid that move across the liquid, transferring energy but generally not resulting in the net transfer of mass (Woodroffe, 2002) and they are the most important cause of alteration and evolution of our coastlines. Wave information is important in the construction of various coastal structures, ports, harbours etc. and there statistics is very much essential in delineating the long term variability of beaches, and also for the different developmental activities of the coastal region. The west coast of India experiences high wave activity during the south west monsoon with relative calm conditions prevailing during rest of the year. Along the west coast, waves approach from W and WSW during south west monsoon, west and WNW during northeast monsoon and SW during fair weather period (Sanilkumar *etal*, 2006). The highest wave activity along the Kerala coast coincides with the occurrence of monsoonal winds during May to September, the roughest period being June to July. The wave climate along this coast is evidently controlled by the meteorological conditions in the neighbouring Arabian Sea and Indian Ocean (Felix, 2000).

1.3.2 f Tides

Tides are movements of the oceans set up by the gravitational effects of the moon and the sun in relation to the earth. They are very long waves that travel across the oceans and are transmitted into bays, inlets, estuaries or lagoons around the world's coastline. The ebb and flow of tides produces regular changes in the level of the sea along the coast and generate tidal currents. Tidal oscillations impinging on a coastline may set up longshore currents. Tidal currents have little direct effect on the morphology of coast facing the open sea, but where they pass in and out of estuaries or through narrow straits they can scour the bordering shores (Bird, 2008). In general, tidal currents do not cause beach erosion or deposition, but they carry sediment along the coast in the nearshore zone, and this may eventually be delivered to beaches alongshore. The tides of Kerala are mixed, semidiurnal in nature and occur within the microtidal range < 2 (Baba and Kurian, 1988).

1.3.2 g Currents

Currents in the nearshore zone are important in several aspects. When of considerable strength they can be a distinct hazard to swimmers. At the same time, the nearshore currents have their beneficial aspects as well, causing a flushing of the nearshore waters, replacing them with generally cleaner offshore water. There are 2 wave-generated current systems in the nearshore zone which dominate the water movements in addition to the to and fro motions produced by the waves directly (Komar, 1976). These are (1) a cell circulation system of rip currents and (2) longshore currents produced by an oblique wave approach to the shoreline. The longshore current pattern along the south west coast is controlled by monsoons and the currents are of southward and comparatively strong during southwest monsoon period. At the same time for other seasons the currents are of bi directional depending on the geomorphic setup (Felix, 2000). The direction of littoral current along Kerala coast is towards north for waves approaching from 220^0 to 240^0 whereas it is southerly for waves approaching 280^0 to 300^0 (Kunte and Wagle, 2001).

1.4 GEOLOGICAL SETTING OF KERALA

Geologically, Kerala state shows four major rock units, viz: i) Precambrian crystallines, ii) Tertiary sedimentaries, iii) Laterites developed over Pre-Cambrian crystallines and Tertiary sedimentary rocks, and iv) Recent to Sub-Recent sediments. The Cenozoic sedimentary formations of Kerala unconformably overlie the Precambrian crystalline rocks. The crystalline rocks are represented by the gneiss-granulite suite of rocks and-the younger igneous complexes (Soman, 1980). These rocks are polydeformed and metamorphosed through several phases of tectonism and metamorphism which led to the formation of complex tectonites, including several faults, fractures and shear zones (Rao, 1976). The Precambrian crystalline rocks comprise chiefly of charnockite and khondalite group of rocks which are intruded by granites, pegmatites and basic dykes. Charnockite is the most common rock type. The Precambrian rocks cover more than 80% of the total area of Kerala (GSI, 1995). The khondalite group comprising garnet-sillimanite gneiss with or without graphite, garnet - biotite gneiss, garnet-quartz-feldspathic gneiss or granulite gneiss and quartzite are the predominant rock types in southern Kerala. These structures have played a significant role in graben subsidence and in the formation of sedimentary basins in the west coast (Rajendran, 1987). Tertiary sedimentary formation of Kerala overlies the Precambrian rocks and extends from Cape Comorin in the south to Manjeshwar in the north and comprises two facies of sediments.

(i) The continental facies, the Warkalli Formation, comprises carbonaceous clays with lignified tissues, china clays and friable sandstone.

(ii) The marine facies, the Quilon Formation, composes of sandstone and carbonaceous clays with thin bands of fossiliferous limestone depicting the transgressive events that occurred during Burdigalian (Upper part of Lower Miocene) time.

The third lithological unit is the laterites. It is iron-aluminium rich rock derived from the chemical weathering of either Precambrian crystallines or Tertiary sedimentaries. They are found as cap rocks or 'iron hats' over both the Precambrian crystallines as well as the Tertiary sedimentaries. The Recent to sub-Recent sediments include fringes of parallel sand bars, several flats, alluvial sands and lacustrine deposits. Polymict pebble bed separates this group from the Tertiary sedimentaries. This formation, particularly the beach sands, is the most economically important owing to the attractive concentration of valuable placer minerals like ilmenite, rutile, zircon, monazite etc.

1.5 BEACH MORPHOLOGY

Beaches are systems of continual change and are the most sensitive and delicately balanced system of the coast and adjust quickly to changes in wave energy and react rapidly with changes in sediment size. Beaches and their adjacent nearshore zones act as buffers to wave energy. Consequently they are sensitive to change over timescales ranging from a few seconds to several years. Response to energy variations may be traced through changes in morphology and sediments. But such information may not present the full spectrum of variations as many records are severely truncated. Wave action is the most striking geomorphic force on the shores of lakes, inland seas, bays and particularly along the margins of great oceans. Waves reshape the beach and sort the sediment according to grain size thus accelerating the beach morphological changes (Mwakumanya and Bdo, 2007). The prominent beach morphological features are berm, beach face, longshore bar and runnels, beach cusps, scarps and ridges (Fig 1.1). Waves play a major role in their formation and the wave climate is very much influenced by these morphological features. The interaction of incoming waves and the resultant nearshore processes with the nearshore morphology, i.e. beach morphodynamics, is the basis of many nearshore processes (Thomas, 1990).

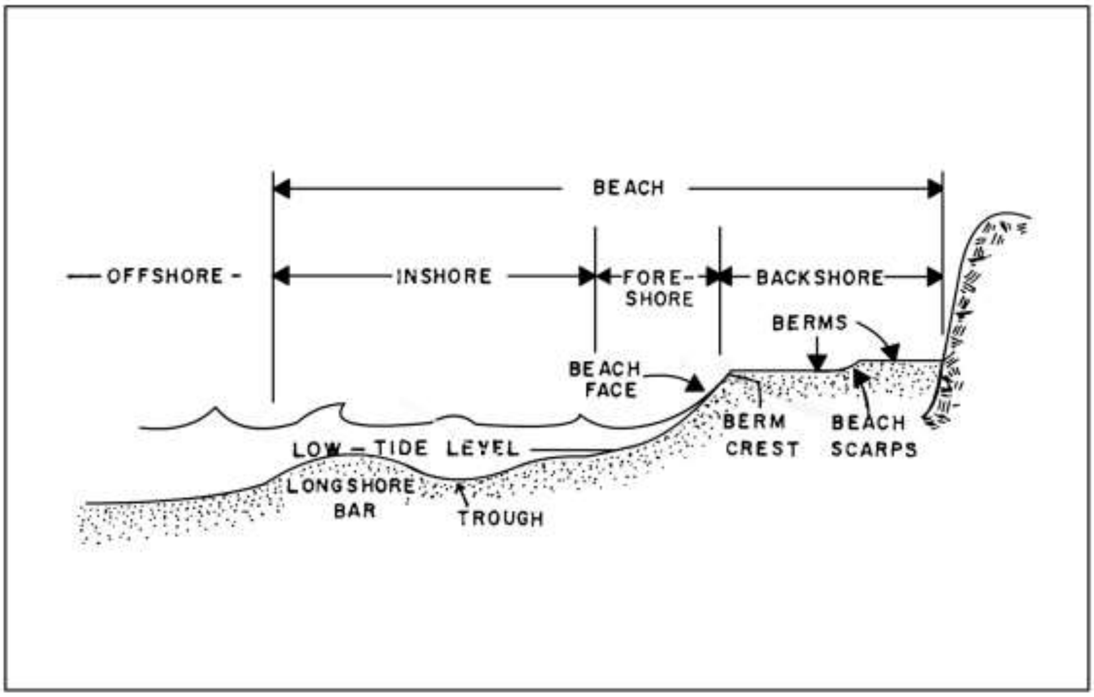


Fig 1.1 Beach profile and other related features

1.6 OBJECTIVES OF THE STUDY

The coastal zone is subjected to various pressures such as high density of population, intensive developmental activities and severe coastal erosion. Several studies are being carried out and coastal management plans are being proposed for different sectors of the coast for its development. The management plans are highly dependent on the nearshore hydrodynamics and coastal morphodynamics in addition to other socio-economic factors. The sandy portion of the coastal zone is a complex and dynamic environment which is studied in detail in this thesis. Beach morphology varies with time with changing hydrodynamic forcing such as waves, currents and tides. Major changes to the morphology occur over a longer time scales while various changes like profile modification, berm development, rhythmic formations like beach cusps, longshore bar and troughs, shoreline changes etc. takes place over shorter time periods of days, months and years. These short term modifications to morphology are dependent on the beach and profile type, sediment characteristics, type of morphology, shoreline orientation, and presence of mudbanks, nearshore characteristics and human intervention. The nature and quantum of such coastal morphodynamics define the type of coastal management and intervention plans.

The main objectives are to

- Study the beach morphodynamics of varying energy regimes.
- Elucidate the morphological changes of high energy coast and the influence of artificial structures thereof.
- Delineate spatio-temporal sediment distribution in beach and nearshore of varying energy conditions.
- Study the erosion/accretion rate using remote sensing data for the years 1967, 2000, 2005 and 2014 and
- Preparation of baseline data on the forthcoming Vizhinjam port.

1.7 SCOPE OF THE STUDY

- To assess and ascertain the beach stability by explaining the influence of natural and artificial structures on the coast of different energy regimes

1.8 RELEVANCE AND PURPOSE OF THE STUDY

- The study could address issues related to severity of erosion of coasts in the study area and could be extend to similar areas.
- Bring out the Impact of artificial structures installed to mitigate coastal erosion in the area and

- An appraisal of the practicality of different protective measures adopted along the beaches of the study area.

1.9 LOCATION OF THE STUDY

The present study proposes to investigate the short and long term beach morphological changes and the driving forces which brought out the energy along the 3 different energy regimes of the Kerala coast. Baba and Kurian, 1988 classified the Kerala coast into different zones of wave energy regime and as reflected from the literature, the sectors selected for the present study are Poovar-Varkala (Southern sector), Munambam–Chettuva (Central Sector) and Beypore- Puthiyappa (Northern Sector) (Fig 1.2, Table 1.1). Being a high energy zone, the variations in morphology is drastic in Poovar-Varkala sector and hence the entire stretch is taken up for detailed study (Fig 1.3). The study area extending from Poovar- Varkala (60km) is bordered by Poovar inlet in the south and Varkala cliff (lateritic) in the north. The Central sector constitutes a straight sandy coast that extends from Munambam inlet to Chettuwa inlet (40km) with breakwaters on either side of the inlets. In the Northern sector the study area lies between Beypore tidal inlet / breakwater in the south and Puthiyappa breakwater in the north (20km). All the 3 locations have seawalls and breakwaters which drastically modify the coastal morphology. The coastal sectors of Munambam-Chettuwa and Beypore-Puthiyappa have strong occurrence of mudbanks.

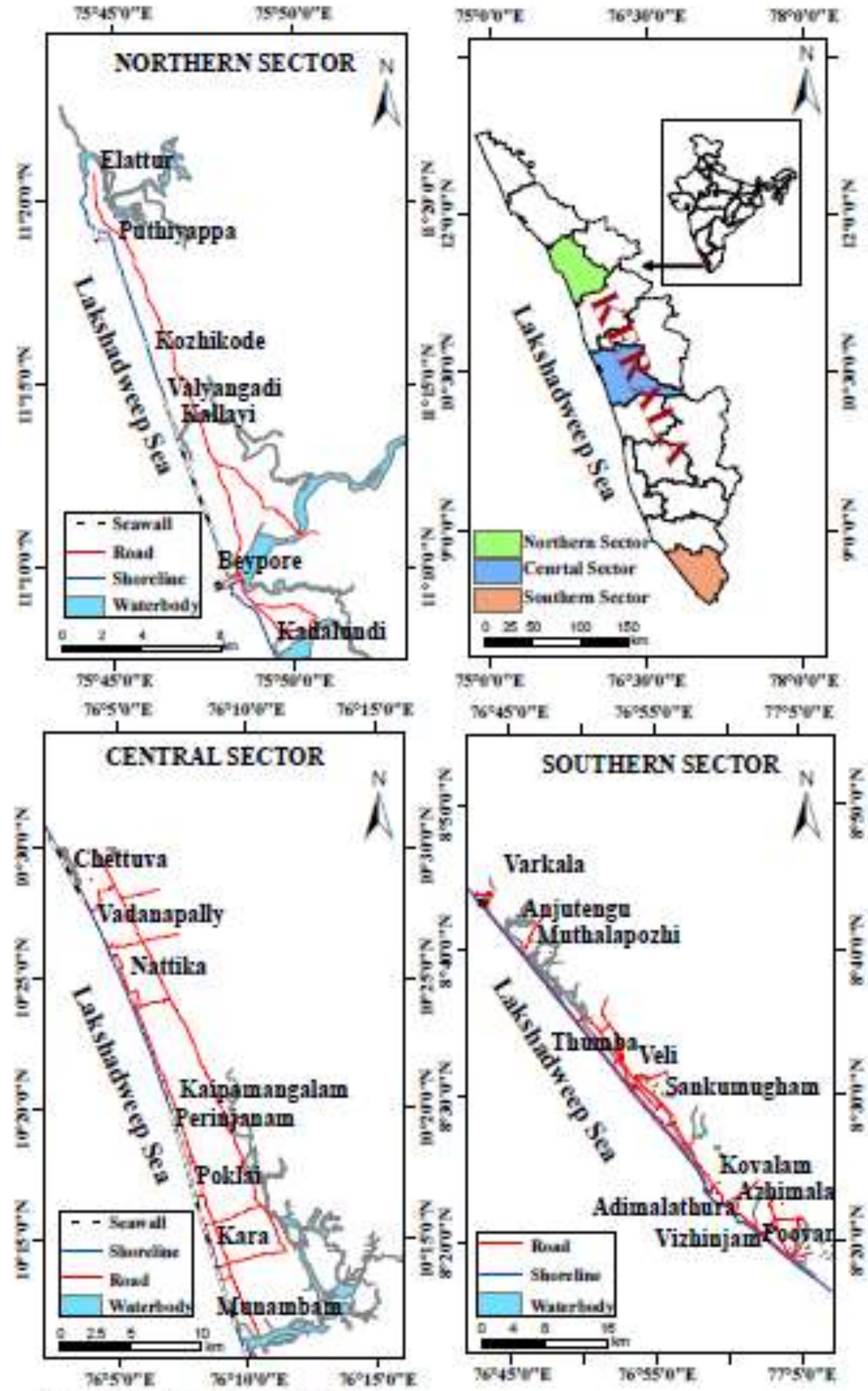


Fig 1.2 Location Map of the Study Area

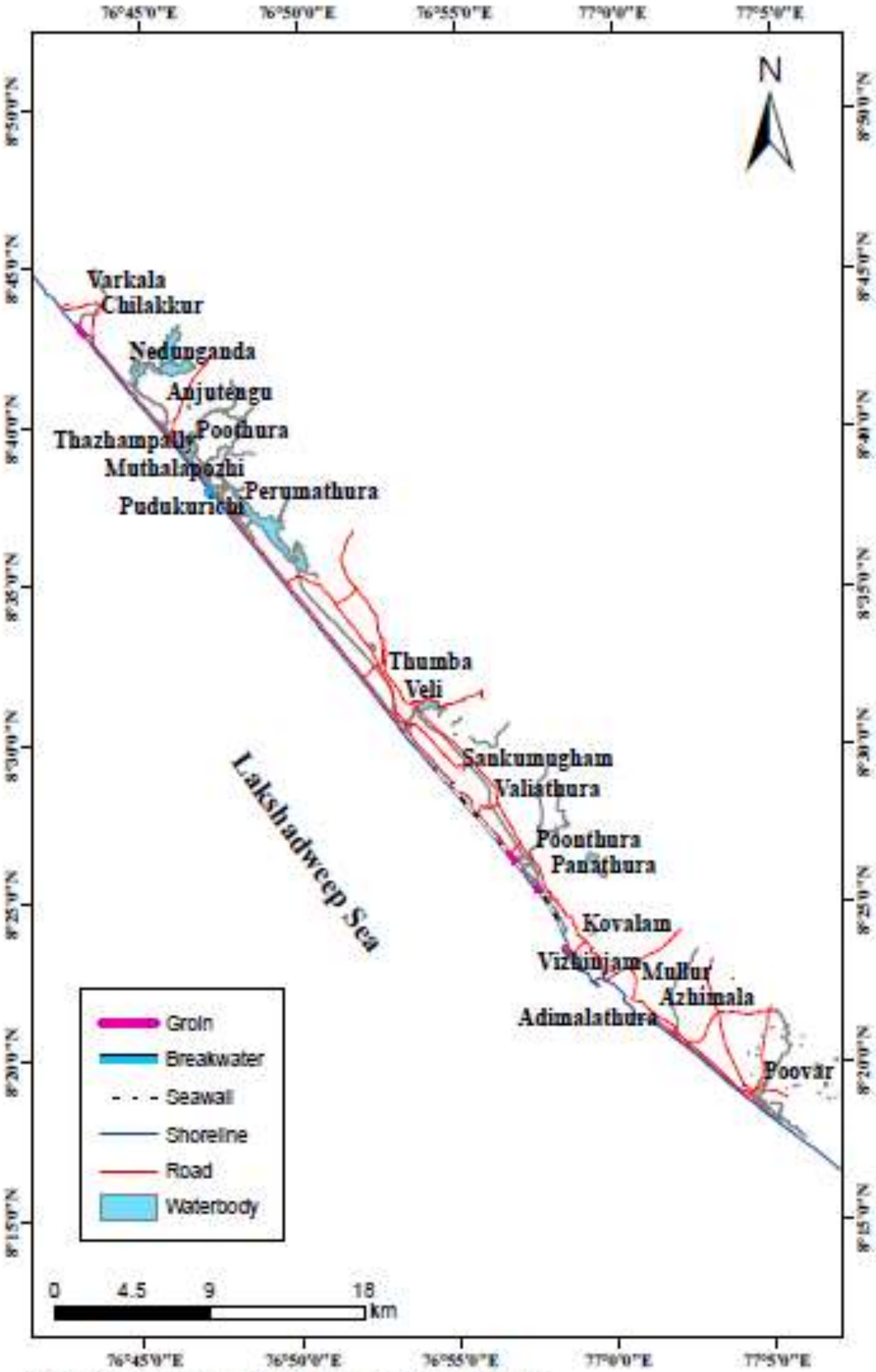


Fig 1.3 Location Map of Southern Sector (in detail)

The development of Vizhinjam port will be an important infrastructure to cater the container trades and these facilities may significantly impact the overall morphology and dynamics of that area. Hence a pilot study has been carried out to create a base line data for the upcoming Vizhinjam International Seaport which is dealt towards the end of the chapter.

Table 1.1 Study locations

LOCATION	COASTAL AREA COVERED
Southern Sector	Poovar – Varkala (08^0 20' 30"N & 76^0 53' 10"E - 8^0 44' 18"N & 76^0 41' 59"E)
Central sector	Munambam – Chettuwa (10^0 10' 49"N & 76^0 09' 46" E- 10^0 30' 25"N & 76^0 02' 24"E)
Northern Sector	Beypore – Puthiyappa (11^0 09' 46" N & 75^0 48' 08"E- 11^0 18' 59"N & 75^0 44' 44"E)

CHAPTER II

MATERIALS AND METHODS

This chapter deals with the various methods employed in sample collection, sample processing and their analysis.

FIELD SURVEY AND SAMPLE COLLECTION

*2.*1 BEACH PROFILING

Beach profiles describe the cross section of the beach. Onshore – offshore sediment transport is better described by beach profile changes. Beach profile and sediment characteristics investigations including nearshore bathymetric survey were carried out during pre-monsoon, monsoon and post-monsoon within the sectors.In order to understand the seasonal beach erosion/accretion pattern, beach profile measurements were carried out for a period of minimum one year (2008, 2009, 2010) in all the three sectors. These measurements were taken at 5m intervals from backshore to waterline during low tide using dumpy level and metric staff (Leica/Nippon make). Though there are many surveying methods, the most widely used and reliable method is Leica/Nippon make and hence adopted for the present study. Permanent and stable locations were identified and fixed as bench marks for regular profile measurements. These were normally the reference stones laid by the Coastal Erosion Studies Wing of the Irrigation Department which are available throughout the coast. The profile locations were selected based on the geomorphologic setting. Total twenty stations were monitored along Southern sector which is of 60km in length. In Central (40km) and Northern sector (20km), profiles were taken from fifteen stations.

Littoral Environmental Observations (LEO) which includes the visual measurement of breaker wave height, period and direction were also made at all the three sectors. The average height of ten consecutive waves constitutes the significant wave height. The wave period was measured using a stop watch by observing the time required for ten consecutive wave crests to pass a fixed point and the average was recorded. The breaker wave direction was measured using Brunton compass. Longshore current velocity and direction were measured by releasing neutrally buoyant floats in the surf zone and the distance traveled by the floats in a minute was recorded and represented in meter per second (m/s). The measurement was repeated and the average value was recorded.

2.2 GRANULOMETRIC STUDIES

2.2.1 Texture

Surficial sediment samples were collected from the backshore, berm and foreshore by scooping along the profile stations in the three sectors. The collected sediments were subjected to textural analysis to understand its spatio-temporal variation in the beach and in the innershelf environment. Approximately 1 kg in weight was washed free of salt, silt and clay and finally oven dried. From this 100 gm was separated by the conning and quartering method. Shells and shell fragments, if any present in the samples were separated either by hand-picking method or by adding dilute HCL, as the presence of this would distort the trend of analysis. The samples were then sieved for 15 minutes in a semi automatic, motor driven mechanical Ro-Tap sieve shaker using a set of standard ASTM sieves at 1/2 Φ intervals (Ingram, 1971). The weight of each fraction representing a particular grain size was measured. The graphic mean, median, standard deviation, skewness and kurtosis were calculated based on the formula of Folk and Ward (1957).

2.2.1 a Statistical parameters

Four-grain size parameters are generally used to describe the grain size distribution. They are mean, standard deviation, skewness and kurtosis. In addition to these, the median and mode are also of great use in understanding the grain size variations in relation to environment of deposition and energy conditions of the depositing medium (Folk and Ward, 1957).

(i) Mean grain size (Mz)

Mean is the statistical average expressed in phi (φ) units. Different researchers have suggested different formulae, for calculating these statistical parameters, but the widely accepted one is put forward by Folk and Ward (1957).

$$\text{Mean (Mz)} = \frac{(\varphi 16 + \varphi 50 + \varphi 84)}{3}$$

(ii)Median

The median is a mid lying value and should be abandoned as a measure of average size. It is based on only one point of the cumulative curve

(iii)Mode

Most frequently occurring particle size.

(iv)Standard deviation (σ)

Standard deviation is a measure of sorting. Uniformity within a sample of sediment can be measured by these parameters. It is one of the most useful parameters in recognizing the efficiency of the depositional media.

$$\text{Standard deviation } (\sigma) = \frac{(\varphi 84 - \varphi 16)}{4} + \frac{(\varphi 95 - \varphi 5)}{6.6}$$

According to Folk and Ward (1957) the divisional points based onstandard deviation are as given below

Standard deviation	***Sorting***
<0.35(φ)	Very well sorted
0.35 - 0.50(φ)	Well sorted
0.50 - 0.71 (φ)	Moderately well sorted
0.71 - 1(φ)	Moderately sorted
1 - 2(φ)	Poorly sorted
2 - 4(φ)	Very poorly sorted
>4(φ)	Extremely poorly sorted

(v) Skewness (Sk)

The asymmetry of the grain size distribution in a sediment sample is measured by skewness. The skewness index by Folk and Ward (1957) is the best measure, as it covers the full curve.

$$\text{Skewness (Sk)} = \frac{\varphi 16 + \varphi 84 - 2\varphi 50}{2(\varphi 84 - \varphi 16)} + \frac{\varphi 5 + \varphi 95 - 2\varphi 50}{2(\varphi 95 - \varphi 5)}$$

The limits of skewness as given by Folk and Ward (1957) are as follows:

Skewness value	***Type of skewness***
>0.30	Very finely skewed
0.30 to 0.10	Finely skewed
0.1 0 to -0.1 0	Nearly symmetrical
-1.1 to -0.30	Coarse skewed
<-0.30	Very coarse skewed

Sign of skewness is related to the environmental energy (Duane, 1964). Negative skewness (coarse skewness) is correlated with high energy and winnowing action (removal of fines) and positive I fine skewness with low energy levels (accumulation of fines).

(vi) Kurtosis (K_G)

Kurtosis is considered as one of the important textural parameters to distinguish various environments as explained by Duane (1964), and Mason and Folk

(1958). It is a measure of the contrast between sorting observed in the central part of the particle size distribution with that of the tails.

$$\text{Kurtosis } (K_G) = \frac{\varphi 95 - \varphi 5}{2.44(\varphi 75 - \varphi 25)}$$

It represents the degree to which the particles are concentrated near the center of the curve (Platykurtic- broad curves, mesokurtic- middle and leptokurtic- peaked curves). Many curves designated as "normal" by the skewness measure turn out to be markedly non-normal when the Kurtosis is computed.The limits of kurtosis as given by Folk and Ward (1957) are as follows

Kurtosis value	**Type of Kurtosis**
<0.67	Very platykurtic
0.67 - 0.90	Platykurtic
0.90 - 1.11	Mesokurtic
1.11 - 1.50	Leptokurtic
1.50 -3	Very leptokurtic
>3	Extremely Leptokurtic

2.3 PIPETTE ANALYSIS

Offshore samples collected from selected locations were subjected to pipette analysis. It is the most popular and widely used method for finding granulometric proportions of mud dominant sediments. As the innershelf sediments contain particles ranging from sand size to clay size, both dry sieving and wet analysis were used. Mechanical analysis was carried out on samples containing >80% of sand after sieving through the 230 mesh (ASTM) (<62.5 micron).By wet sieving the coarser and the finer fractions can be differentiated. The raw samples are first treated with 1N dilute HCl, to remove shells and subsequently with hydrogen peroxide to remove organic matter. After the preliminary treatments, about 20-30g samples were dispersed in a 0.025N Sodium hexametaphosphate solution and kept overnight for deflocculation. It was then sieved through a 230 mesh. The sand size material retained on the sieve was dried and weighed. The collected sand was sieved to obtain data on particles coarser than 62.5 micron. The aliquot were subjected to pipette analysis following the method suggested by Carver (1971) to determine the silt and clay proportions.

2.4 HEAVY MINERAL SEPARATION

About 50g of the sediment sample was washed with distilled water to remove finer fractions (<63u) and afterwards it was treated with diluted HCl to remove the shell fragments and iron coatings on the grains. It was then washed with distilled water and dried in hot air oven. The dressed dried sample was subjected to dry sieving so as to get two size fractions viz. 0.25 -1.0 mm (medium) and 0.063 - 0.25 mm (fine). The heavy and light minerals were separated using a high density (2.89 gm/cc) liquid bromoform. The percentages of heavy and light minerals were calculated following the Milner (1962). Heavy minerals separated from each fraction were mounted using Canada balsam. About three hundred mineral grains were counted in each slide (Fatela and Taborda, 2002) and number percentages were calculated.

2.5 GEOCHEMISTRY

2.5.1 Organic carbon content

All the samples were washed free of salt with distilled water and dried at 35°C. This drying temperature is preferred so as to prevent the oxidation of organic matter. The dried samples were powdered and are used for the organic carbon estimation. The organic carbon for the bulk samples was determined by wet oxidation method following El Wakeel and Riley (1957). The principle is that the organic matter in the sample is oxidized by a known quantity of chromic acid and the amount of chromic acid consumed is determined by titration against ferrous ammonium sulphate to obtain percentage of organic carbon.

$$\% \text{ Organic carbon} == (1- T/S)\ 10$$

S - Titre value of the standard, T - Titre value of sample

2.5. 2 Major and Minor elements

The analysis of major and trace metals in the sediment was carried out by taking dried raw samples, where salinity was removed and finely powdered using agate mortar. From this, 0.5 gm of the powdered sediment was digested with $HClO_4$ -

HF-HNO3 acid mixture in clear Teflon crucible following the method of Shapiro and Brannock (1962).

The present study focus on the major and trace metal contamination and its relation with texture and OC in the surfacial sediment samples by using statistical parameters like contamination factor (CF), pollution load index (PLI) and geo accumulation index (I_{geo}).

CF is determined by using the metal content in sediment and continental shale as background value (Turekian and Wedepohl, 1961).

$$CF = C_{metal} / C_{background\ value}$$

Pollution load index is a quick tool for comparing the pollution status of sediments from different sampling locations (Tomilinson et al., 1980). The PLI represents the number of times the metal content in sediments exceeds the background value, which helps to understand the level of heavy toxicity.

$$PLI = \sqrt[n]{(CF1 \times CF2 \times CF3 \times \ldots \times CFn)}$$

This was calculated using heavy and trace metal data and concentration of world shale average as background value.

The geo accumulation index (I_{geo}) is to assess the quantification of metal contamination in sediments following Muller (1979).

$$I_{geo} = \log_2 [C_n / (1.5 \times B_n)]$$

Where, C_n= measured concentration of heavy metal in the sediments.

B_n = geochemical background value in average shale of element n.

1.5 = is the background matrix correlation in factor due to lithogenic effects.

2.6 HYDRODYNAMIC MEASUREMENTS

Collection of hydrodynamic data such as waves, tides and currents pertaining to the study area is essential for understanding the dynamic coastal processes and sediment transport pattern of the study area. The following equipments were used in hydrodynamic measurements and their operation is briefly described.

The Wave and Tide Recorder (Non directional) is a sophisticated pressure based wave recorder provides wave height and period, together with full spectral analysis. High accuracy sensors are used in the equipment for the measurement of wave heights, period, water level and water temperature. The Directional Wave Recorder is basically the same as wave & tide recorder, but with a direction measuring mechanism called a flux gate compass and Valeport 2-axis EM current sensor. Recording Current Meter (RCM) is a new generation current meter with a 'Seaguard' data logger platform and the Doppler Current Sensor (DCS) which gives the current parameters measured at the desired depth. The

Acoustic Doppler Current Profiler (ADCP) with Directional Wave measures multi-directional wave spectra, current velocity profiles and water level at the same time. ADCP records more accurate significant wave height, peak direction and wave statistics by correcting for bias effects due to wave/current interaction and directional averaging.

2.7 REMOTE SENSING

Remote sensing and GIS were used for finding out the shoreline changes and for the qualitative mapping of suspended sediment concentration. Landsat Enhanced Thematic Mapper Plus (ETM+) satellite image of 2000, IRS- P6 LISS IV satellite image of 2005-06, Landsat-8 Operational Land Imager (OLI) of 2014 and topographic map of 1967 are the sources of data for the study. Both spatial and non-spatial data were collected through field survey, and interpretation of satellite images of Landsat-7 ETM+, Landsat-8(OLI), IRS-P6 LISS IV and topographic map of Survey of India. Various procedures, adopted in the field and laboratory to collect and process each data set, are explained in detail in the following paragraphs.

2.7.1 a Satellite data collection and analysis: The satellite data of Landsat-7

ETM+ (2000) and Landsat-8 OLI (2014) downloaded from Earth Explorer and IRS-P6 LISS IV (2005-06) available with the National Center for Earth Sciences Studies, Thiruvananthapuram, Kerala, (both digital and geo-coded FCC) of the study area, were utilized. Geocoded data was helpful in the field to obtain ground control points and digital data was processed in the laboratory using digital techniques. LISS IV is one of the three sensors on IRS-P6, which provides multispectral data in three bands; two in visible (0.52-0.59 and 0.62-0.68 microns), one in infrared (NIR, 0.77-0.86 microns) regions of electromagnetic spectrum. It has a spatial resolution of 5.8m. A path-row based full scene product covers an area of 23.9 x 23.9 km.

Landsat-7 ETM+ has eight bands; three in visible (0.45-0.52, 0.52-0.60 and 0.63-0.69 microns), two in near infrared (0.77-0.90 and 1.55-1.75 microns), one in thermal (10.40-12.50 microns) and one in mid-infrared (2.08-2.35 microns) region of the electromagnetic spectrum. Eighth band is in panchromatic mode (0.52-0.90 microns). It has a spatial resolution of 15m for panchromatic band and 30m for remaining seven bands. A path-row based full scene product covers an area of 170 x 185 km.

Operational Land Imager is one of the two sensors of Landsat-8 which has nine spectral bands; four in visible (0.43-0.45, 0.45-0.51, 0.53-0.59 and 0.64-0.67 microns), one in near infrared (0.85-0.88 microns) and two in shortwave infrared (1.57-1.65 and 2.11-2.29 microns). The eighth band is panchromatic (0.50-0.68 microns) and ninth band (1.36-1.38 microns) is for clouds, especially cirrus. A path-row based full scene product covers an area of 170 x 185 km. The details of the satellite data are given in the table 2.1.

Table: 2.1 Details of satellite data

SATELLITE	***SENSOR***	***PATH/ ROW***	***YEAR OF PASS***
IRS-P6	LISS IV	102/127 102/134 103/041 201/148 201/149 201/150 101/152 101/151 102/123	2005
Landsat-7	ETM+	144/53 144/54 145/52	2000
Landsat-8	OLI	144/53 144/54 145/52	2014

2.7.1 b Software

Erdas Imagine version 9.2 and ArcGIS version 9.3 were used for data processing.

2.7.2 Estimation of Erosion-Accretion

Shoreline position for Poovar to Varkala, Munambam to Chettuva and Beypore to Puthiyappa was digitized for the year 1967 from 1:25,000 toposheet and for 2000, 2005 and 2014 from satellite images (Landsat for 2000 & 2014, LISS-4 for 2005). Overlay analysis of the shoreline positions was carried out for 1967 and 2000, 2000 and 2005 and 2005 and 2014 to analyze and estimate the erosion - accretion along the coast.

CHAPTER III

BEACH DYNAMICS

3.1 INTRODUCTION

The coastal landforms are complex dynamic and delicate environment which are influenced by both terrestrial and marine forces. The shaping of coastal landforms is influenced by a range of morphogenic factors which includes the geology, tectonics and the nearshore hydrodynamics. The beach morphology changes as waves and currents move beach sediment from one sector to another. In addition to the longshore drifting, sediments are moved to and fro between the beach and the nearshore zone (onshore–offshore drifting). The coastal current systems are the most active dynamic factors in the formation and development of the sandy coast (Cai *etal,* 2007). The rise and fall of the tide is the primary factor that facilitates the onshore offshore movement of sediments. The movement of sediments either onshore or alongshore promotes erosion or accretion, contributing directly or indirectly shaping the beach morphology. Therefore, studies on the beach dynamics are important in understanding the sediment movement and other related parameters which inturn provide information on the erosion or deposition pattern of the beach itself. The processes of beach erosion and accretion are seasonal and these processes over a long time ultimately result in either building up or recession of the coastline.

3.2 REVIEW OF LITERATURE

Recent advancements in coastal research are based on comprehensive studies of morphodynamics that are related to sedimentologic, geomorphologic, and dynamic characteristics (Short and Wright, 1984; Sunamura, 1988; Short and Aagard, 1993; Cowell and Thom, 1994; Klein and Menezes, 2001; Benedet *etal,* 2004). Morphological changes of beaches are surveyed using a wide variety of methods (Crowell *etal*, 1993; Larson and Kraus, 1994; and Anfuso *etal*.2007). Ruggiero (2005); Cai *etal* (2007); Taaouati *etal* (2011) and Vousdoukas *etal* (2012) studied the dynamic interaction between environmental forcing and coastal morphology. Travers (2007) compared the characters of beaches under varying energy regimes. Andrian Stania and Ungureanu (2010) made the studies regarding beach morphology and sedimentary processes which occur in low lying coastal areas. The shoreface morphology and the variation in beach morphology were related to change in the wave regime along the beach under prevailing and dominant wind condition (Jackson *etal*, 2002; Dolique and Anthony, 2005; Eliot *etal*, 2006, Limber and Murray, 2011).Studies of Mwakumanya and Bdo (2007) deciphers that the distinct variation in beach morphology may be attributed to the differences in the grain sizes and sources of materials as well as to the local configuration of the shoreline that seems to influence the wave condition. They also described the influence of wave condition in the stability of beach thereby affecting the morphological changes of beach. Bulhoes *etal* (2013) delineated the morphodynamics of embayed beaches exposed to distinct wave directions and relate it to the morphological response of beach profiles. The study of Udhaba Dora *etal* (2012) emphasizes the need to observe the beach changes over interannual variation along different seasons before planning the coastal protection measures. The study revealed that the cross shore profiles and the textural characteristics are essential tools to estimate equilibrium beach and for planning shoreline protection strategy. Micromorphology of sandy beaches that are characterized by shorter temporal and spatial scales was explained by Masselink and Kroon (1999). The morphologies are well correlated with the daily offshore incident wave climate particularly for the moderate to high energy wave conditions (Sánchez *etal*, 2008). The morphological processes of sand bars/ spit formations and their relation to hydrodynamics were explained by Blomgren and Hanson (2000). The onshore offshore transport of sediments in the nearshore zone can be the result of these formations and the movement of sand bars (Zhi-Jun Dai *etal*, 2010).

Coastline represents a dynamic, fragile physical and biological environment that is constantly changing in response to natural processes as well as human activities. Human activities have significantly interfered the natural conditions and processes. The most common anthropogenic impacts on the littoral evolution are dredging of river mouths and canals for navigation purposes, damming of rivers, blocking of littoral longshore currents by coastal engineering interventions (groins, jetties, breakwaters *etc*), removal of beach sand and beach bypassing and nourishment (Kirk *etal*, 2000; Charker and DeMeyer, 2000; Liouv *etal*, 2009;

Voorde, *etal* 2010). Komar *etal* (1976) examined the pattern of beach erosion and accretion due to the jetty construction on the Oregon coast, which has a seasonally reversing littoral drift with an insignificant net drift. Hsu *etal* (2000) illustrated that the breakwater construction plays a major role in the erosional/accretional processes. Melissa, and Hsu (2011) pointed out that, among the factors that could adversely affect the sandy beaches, harbour structures that intercept littoral drift and create sediment deficiencies for downdrift beaches have been identified as the major causes of beach erosion. The continuous accretion of beach adjacent to the artificial structures can be attributed to the fluvial sediment input from the river mouths and the sediments brought by littoral drift (Halouani *etal*, 2012**).** Pandian, *etal* (2004) emphasized the shoreline erosion/accretion related problems after the introduction of breakwaters for the port resulting in damages to the natural setup of the coastal region. Anthropogenic activities like construction of port / harbour/ breakwater, sand and clay mining etc are responsible for erosion, reduction in width of beaches and receding of shoreline (Kumar and Jayappa, 2009).

The studies related to coastal processes and beach dynamics were carried out by many researchers (Veerayya, 1972; Murthy *etal*, 1975; Murthy *etal*, 1980; Wagle, 1987; Chandramohan *etal*, 1993, 1994; SanilKumar *etal*, 2000; Jayakumar *etal*, 2004; Shamji, 2011). The west coast of India experiences its major erosional phase during the southwest monsoon season (June–September) with a secondary but minor period of erosion during December and January and accretion during the other months (Bhat *etal,* 2003; SanilKumar *etal*, 2006). The seasonal morphologic variations and effect of oceanographic processes such as erosion or accretion along the beaches are important to understand the nature of the beach and the cyclic changes occurring during different seasons (Gujar *etal*, 2011; Ganesan and Gaonkar, 2006). The cyclic morphological changes of tropical beaches in response to annual storm and swell conditions were explained by Hedge *eta,* (2009). The monsoonal beach sedimentary dynamics of Kerala coastline is reflected in the form of sandwhich which is responsive to prevailing weather and wave condition (Black *etal*, 2008).

Earlier studies on wave characteristics and beach processes of SW coast were carried out by Baba, 1986; Baba and Harish, 1986; Baba and Kurian, 1988. They found that the wave energy at Trivandrum coast is always high, compared to other stations along the Kerala coast. The different processes on the beach along a wave dominated coast were explained by Thomas, 1990. Various studies were made related to morphological changes of different beaches of Kerala coast (Thomas and Baba, 1986; Shamsuddin and Suchindan, 1987, Kurian, 1988; Kurian *etal*, 2007; Narayana *etal,* 2008; Shamji *etal*, 2010). In 1993, Sajeev delineated the physical processes along the different types of beaches of the Kerala coast. Factors responsible for the recession of coastal cliffs of Varkala were described by Avinash Kumar *etal* (2009).

The granulometry of beach sediments play a vital role in documenting the depositional history of a region. In the past 4-5 decades, there have been numerous attempts to differentiate environments of deposition using granulometric analysis. Pioneering studies were undertaken by Passega (1957), Friedman (1961); Passega (1964); Visher (1969), Bryant (1982). The sedimentary environment, the dynamics of the transport and depositional process, the density of the transport medium, the duration of the process and several other data can be reconstructed on the basis of granulometric characteristics (Edward, 2001; Elzbieta Mycielska, 2011; Leonardo *etal*, 2013).The studies by Self (1977); Engstron (1978);Lokman *etal*, (1998) and Rosnan and Saadon, (1989) highlighted the importance of a variety of sedimentological trends in interpretation of littoral drift direction and their depositional environment.

A statistical analysis of beach sediments is relevant to identify the sedimentary environments. Careful examination of statistical analysis revealed that proper combination of different textural attributes could be successfully used to discriminate various depositional environments of ancient and recent origin (Pettijohn, 1957; Griffiths, 1967; Alien, 1970; Goldberg, 1980). Several studies on the size distribution of sediments revealed the existence of statistical relationships between the different size parameters such as mean size, sorting (standard deviation), skewness and kurtosis (Folk and Ward, 1957and Mason and Folk, 1958; Blott and Pye, 2001; Malvarex *etal*, 2001, Shagude, 2004 and Yesim Celikoglu *etal*, 2006; KarunaKarudu, 2013). Nordstrom (1975), Flemming, 2000 has used grain size statistics to distinguish between high and moderate energy environments.

Grain size statistical parameters can be used to discriminate various environments of deposition of ancient as well as recent sediments (Seralathan and Padmalal, 1994; Mohan, 2000; Yacob and Hussain, 2005; Aboudha, 2003; Kumar *etal*, 2006; Angusamy and Rajamanickam, 2007., Viveganandan *etal*, 2013). Chakraborti (1977); Chaudri *etal*, (1981); Rajamanickam and Gujar (1985); Hanamgond and Chavadi (1993). The significance of the grain size studies were endorsed by Bhat *etal (*2002); Rao*etal* (2005); Kakinoki *etal* (2011) and others. Many studies has been carried out on textural attributes from south west coast of India (Veeraya and Varadachari, 1975; Samsuddin, 1986,Purandara *etal.*, 1987; Narayana and Pandarinath, 1991; Prakash *etal*, 2007; Saravanan and Chandrasekar. 2010, Venkataramanan *etal*, 2011; Sugunraj *etal*, 2013). Apart from environmental implications, the particle size distribution is related to the source materials, processes of weathering, abrasion and corrosion of the grains and sorting processes during transport and deposition (Samsuddin, 1990; Joseph *etal*., 1997; Majumdar and Ganapathi, 1998; Rajaguru *etal*., 1995, Anitha Mary *etal*, 2011). Correlations between the statistical parameters throw light on information regarding the depositional environment of sedimentation and demarcate the fields of overlapping of related depositional environments (Srinivas Reji and Kurian Sajan, 2010; Babu *etal*, 2013 and Devi, 2014).

3.3 RESULT AND DISCUSSION

For better understanding and explanation of the results the coasts were considered under (1) beaches without any structure (open beaches) (2) beach with structures (3) beaches between the headlands (pocket beaches).

3.3.1 SOUTHERN SECTOR

The Poovar–Varkala sector which is of 60 km length consists of different morphologies such as tidal inlet, backwaters, sandy coast, pocket beaches, earth cliff and rocky cliff/headland. The coastal morphology along the sector has been substantially modified with the construction of breakwaters for fishing harbours and coastal protection structures such as seawalls, groins etc.

The sector is characterized by:

(a) Tidal inlets at Poovar, Panathura, Veli and Muthalapozhi in which the rivers emptying are Neyyar, Karamana, Parvathyputhan *Ar* and Vamanapuram respectively.

(b) Harbours at Vizhinjam and Muthalapozhi

(c) A pier at Valiathura.

(d) Seawalls along Kovalam - Sankumugham (12km), and Thazhampally – Poothura (2km).

(e) Revetments in the seasonal beaches in Sankumugham and Kovalam.

(f) Groins at Panathura (2 no.s), Poonthura (8 no.s) and Chilakkur (25 no.s).

(g) Rocky headlands between Vizhinjam - Kovalam coast.

(h) Lateritic cliffs at Chowara and Varkala.

3.3.1 a Beach Profiling

Beach profiling has been carried out for the various seasons at different locations and the seasonal profile variations in the sector are given in Fig. 3.1 (a-n). Here the open beaches include Poovar-Adimalathura (9km), Veli-Pudukurichi (18km) and Anjutengu-Neduganda (6km) (Plate 3.1). The Poovar-Adimalathura stretch which is at the south of Azhimala headlands, characterize a wide beach ranging from 125-180m during fair season, whereas 65-90m in monsoon (Fig. 3.1 a and b). The beaches on the average loses a volume of 85.75 m^3/unit area at Poovar while at Adimalathura it is 305.76 m^3/unit area during monsoon and it regains back almost the same volume during fair weather season. This observation is reiterated in the chapter 4 (Geospatial studies). The Veli-Pudukurichi and Anjutengu – Nedunganda coastal stretch characterises a beach width ranging 75–90m with steeper foreshores during fair season and monsoonal erosion minimises the beach to a width of 50-60m [Fig. 3.1 (h–l)]. From the profile studies, it is evident that the beaches along this region are accreting during the transition from monsoon to fair season. Beach eroded during monsoon loses an average volume of 88.95m^3/unit area at Veli-Pudukurichi stretch and about 90.25m^3/unit area at Anjutengu-Neduganda and redeposit almost the corresponding quantity during the fair season thus attaining a stable nature.

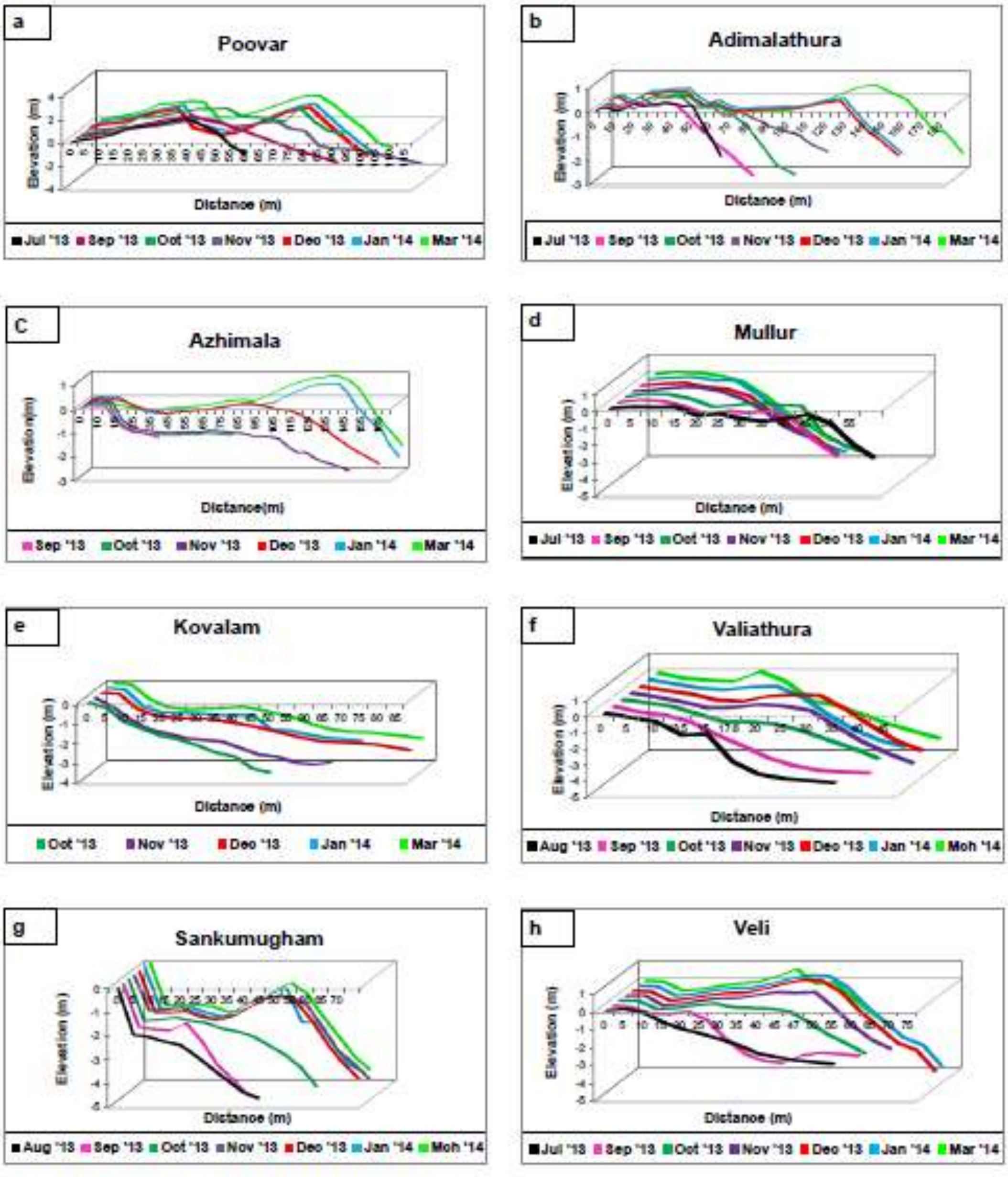


Fig 3.1(a-h) Beach profiles in Southern sector

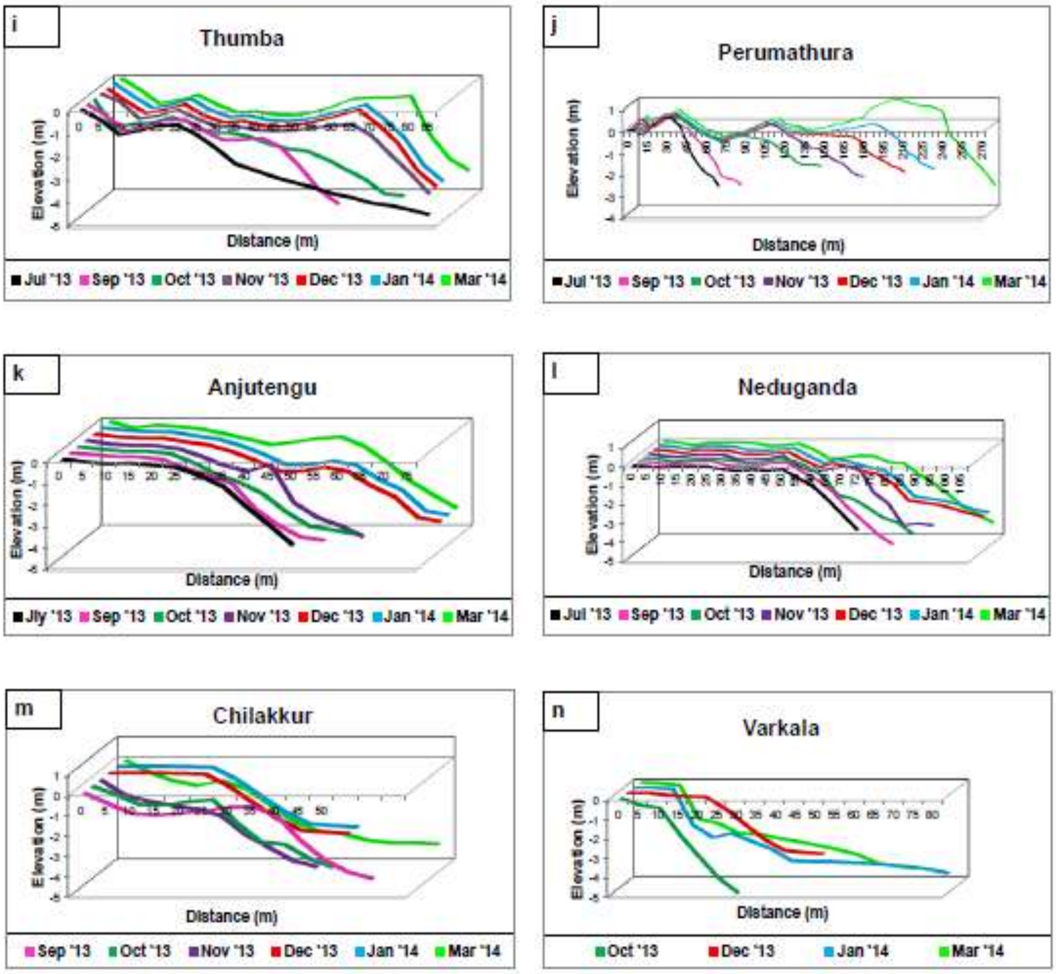


Fig 3.1(i-n) Beach profiles in Southern sector

Plates 3.1 Open beaches in Southern sector

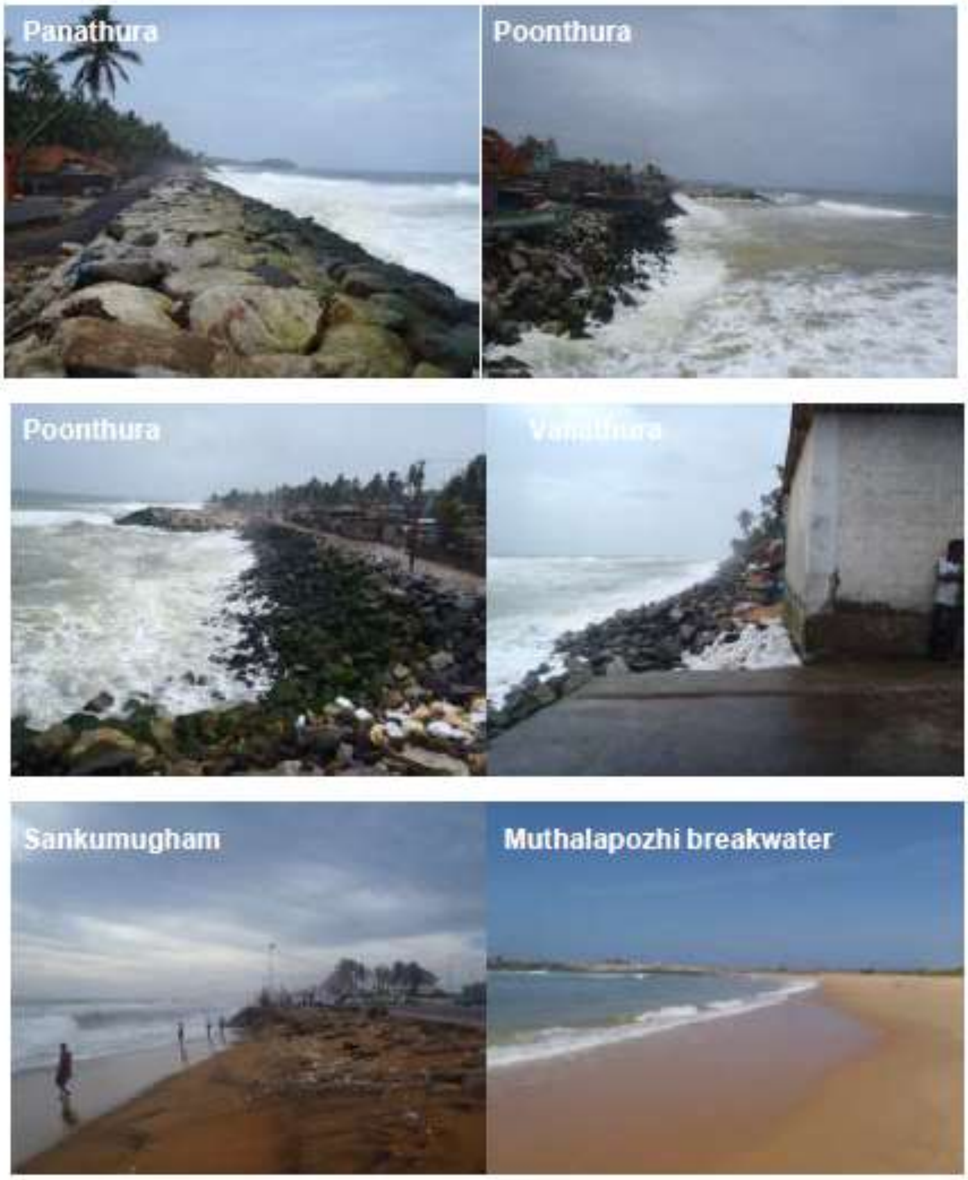
Berms and beach cusps of about 30-35m wide is a common geomorphologic feature observed along the coast during fair season. Long period swell waves during the fair season causes the formation of depositional features whereas the short period storm waves cause erosion during monsoon.

Another common geomorphologic feature along the sector is the pocket beaches/headlands/cliffs at Azhimala, Kovalam and Varkala (Plate 3.2). The Azhimala–Vizhinjam coastal stretch comprises eight pocket beaches, backed by rocky terrains. The Azhimala pocket beach which is of 170m width is present during fair season and it disappears during monsoon when waves break against the headlands (Fig. 3.1c). Gentle foreshore slopes and beach cusps are the common geomorphologic feature observed. Mullur which is at the south of Vizhinjam harbour possesses a maximum width of 60m during fair season and a minimum of 40m exists even during monsoon unlike other pocket beaches (Fig. 3.1d). The pocket beaches of Kovalam are in between the lateritic headlands. Loss of beach is a major impediment to the coastal stability, which becomes acute during monsoon. No beaches are observed during the monsoon at Kovalam. These pocket beaches exhibits a maximum width of 75-80m during fair season (Fig. 3.1e). The lateritic cliffs/promontories at Varkala encompasses pocket beach and exhibits similar nature of Kovalam. A maximum width of 80m is observed during the fair weather period at Varkala beach (Fig. 3.1n). The formation of these seasonal pocket beaches are the resultant of the deposition of sediments which is due to the obstruction of longshore currents by these

Plates 3.2 Pocket beaches in Southern sector

promontories. Monsoonal waves affect these pocket beaches more severely by the encroachment of waves, thereby exhibiting a vulnerable condition.

The seawall covers about 14km of the sector from Kovalam to Sankumugham (12km) and from Thazampally to Anjutengu (2km). The coastal plain extending from Kovalam to Sankumugham is a seawall dominated coast with a 220m long pier at Valiathura. Monsoonal erosion is the major hazard affecting this coastal area. High monsoonal waves, overtopping the seawall (2-3.5m) carve away the entire beach of this region, thereby affecting the inhabitants in the coastal area (Plate 3.3). Towards north of Valiathura pier, seawall continues up to Sankumugham (3km) after which no seawall exists. The northern part of the pier exhibits a beach of about 80m in front of the seawall during the fair weather period and no beach during monsoon (Fig. 3.1f - g). After the monsoon the beach reappears in original form by showing accretion and widens with steep slopes. The common geomorphologic feature observed during fair season is the beach cusps of about 30-35m width. Longshore bars and rip currents characterize the coast frequently during the monsoon period. The formation of nearshore bar is the result of onshore-offshore sediment transport. Nearshore bar morphology is highly dynamic and tends to move onshore under fair conditions and offshore during storms. Rip currents which are strong narrow currents that flow seaward through the surf zone by means of rip channels is an important mechanism of storm erosion on many beaches. The occurrences and configuration of rip currents are strongly linked to the bar morphology (Komar, 1988).



Plates 3.3 Artificial structures constructed in Southern sector

The breakwater at Muthalapozhi is another important artificial structure along the coast. Immediately south of the breakwater at Perumathura, the beach is accreting during fair weather period. Here the building up is both horizontal and vertical and are significant. The profile studies during 2008 shows the presence of beach to about 170m during fair season and it reduces to 115m during monsoon (Fig. 3.2). Beach accretion at Perumathura during the fair season indicates the interruption of northerly longshore sediment transport by the breakwater. The sediment carried by the northerly longshore sediment transport during fair season is not fully interrupted by the breakwater but a part gets bypassed and deposited as bar. Formation of bar in the harbour mouth hinders the free passage of fishing boats to sea. Subsequently the reconstruction and modifications of breakwater to rectify this problem by way of extending the length of breakwater started in 2009. The 250m long southern arm of the breakwater was extended to 530m and the 280m northern arm to 520m to circumvent the sand bar formation. As a consequence, the width of the beach at Perumathura increased to about 240m during fair period and retards to 170m during monsoon (Fig. 3.1j). This is due to the impediment caused by the modified structure leading to the subsequent accumulation of sediments at the immediate south of breakwater as reported in the similar studies of Mohanty *etal* (2012). Further south of the breakwater (Thumba), the beach face is steeper and narrower indicating the natural high energy character of the sector. The region north of Muthalapozhi breakwater is subjected to severe erosion during monsoon and hence this coastal stretch is protected by seawall. During monsoon period, the

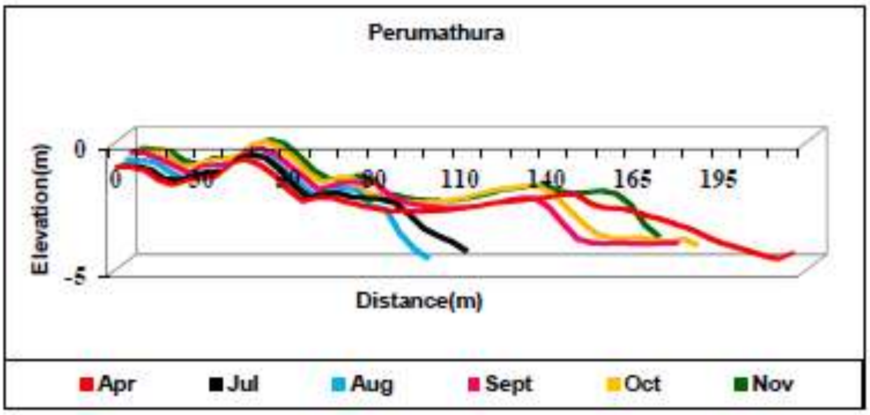


Fig 3.2 Beach profiles at Perumathura during 2008

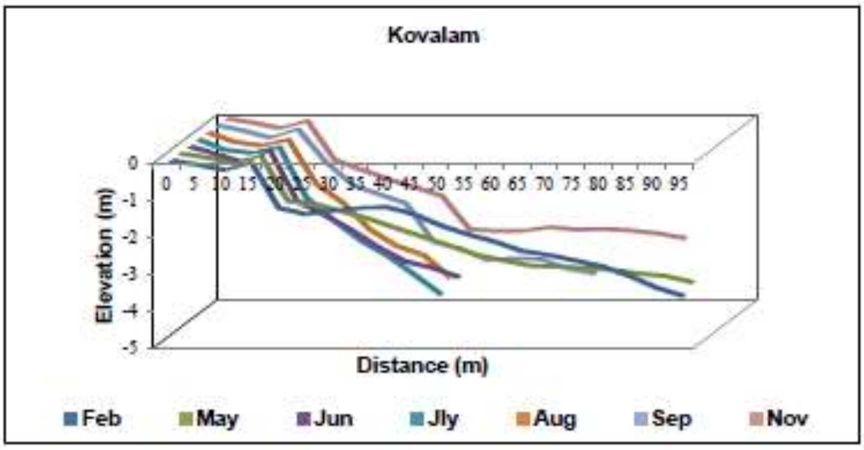


Fig 3.3 Beach profiles at Kovalam during 2010

longshore current on the south of breakwater is northerly and at the north of the breakwater, it is southerly and this may be due to the presence of breakwater. During the period, the waves are of W and WSW direction and will not reach the southern part of breakwater, hence called a shadow zone. While on the northern part of the breakwater, the southerly longshore currents are deflected by the breakwater. Similar studies of Halouani *etal* (2012) revealed that the magnitude of erosion is due to the disruption of sediment transport through the harbour.The reconstruction of breakwaters shows no considerable variation in beach width towards the northern part of the breakwater, except the immediate north. This reveals that the reconstruction does not bring any fluctuation here. But the immediate north of breakwater, at Thazampally, which was facing intense erosion before reconstruction has procured a better condition. The formation of sand bar within the harbour came to extinct after reconstruction.

Beach erosion is seasonal and cyclic with negligible net erosion along most of the sandy coasts. But the net erosion rate increases when human activities interfere with natural coastal processes. Initially the Kovalam beach was a continuation of the natural coastal zone extending from the coconut plantations on the landward side. As a part of improving aesthetic appearance and beach facilities, a walkway and retaining wall was constructed. Large volume of beach materials were used for this construction works, thus reducing the sediment availability in this pocket beach. Thus erosion of the coast became a serious issue in Kovalam beaches during monsoon and the beach is vulnerable from the month of June to September. To foster the beaches of Kovalam, the Government of Kerala recognized the benefits of offshore multipurpose reef for sustainable coastal protection, improved ecology and tourism. As a mitigation measure, multipurpose reef was placed in the nearshore of Kovalam in 2010. Prior to the construction of multipurpose reef during 2005 - 2006, the beach experienced severe erosion during monsoon period. Beach shifts from a wide normal profile to storm profile (with minimum beach width) and back to normal profile along with a shift in the wave condition from fair to rough season and back to fair season. The beach eroded during the monsoon rough season is rebuilt by the next fair season (January– March) and it attains a width of 75-80m.The profile taken after the reef construction (2010-2011) represented the erosion/accretion cycle throughout the year with a wide beach of 95-110m (Fig. 3.3). Monsoonal waves reduce the beach to 40m and they get accreted back during the fair season. The profile studies during 2013-2014 exhibited a beach of only 80m during fair season (as discussed in 3.2.1) (Fig. 3.1e). The beach shows extensive erosion during monsoon and the foreshore with gentle slope rebuilds after the monsoon erosion. From the studies, it is evident that the width of the beach showed a considerable increase immediately after the reef construction even during monsoon season i.e., 2010-2011. But recently, waves encroaches the pocket beaches intensely during monsoon resulting in complete disappearance of beach (Plate 3.4). Monsoonal waves are enhancing the erosional nature of the beach, making it unreliable for tourism purposes.

Plates 3.4 Impact of Artificial reef in Kovalam

3.3.1b Nearshore observations

The wave-tide recorder and recording current meter to measure waves and currents were deployed at a depth of 4m and 6m in Thumba and Nedunganda during different seasons (Table 3.1). Ocean waves are not monochromatic and the sea surface at any time comprises of groups of waves of different heights, periods and directions. To describe such a random wave field, defined statistical parameters such as the significant wave height (H_s), Zero Crossing wave period (Tz), Average height (H_{avg}) and mean wave direction are measured.

The significant wave height (H_s) observed during fair season is between 0.39 to 1.2 m and wave period (Tz) has a range from 6.13 to 11.3 sec. General wave direction is of 230-240^0 where the direction shows large variability from 190 to 305^0 N after monsoon . Waves are generally high during monsoon and the significant wave height (H_s) varied between 1.24 to 2.73 m. The wave periods are low and ranges from 7.6 to 9.2 sec. The wave direction is mostly confined to SW to WSW which is typical of monsoon waves. Measurements have shown that during fair season the current speed is in the range 0.29 to 34.9cm/s and it varies between 0.29-68.05cm/s after monsoon. Current speed during monsoon is in the range 0.29-54.85cm/s.

3.3.2 CENTRAL SECTOR

The coastal stretch that has been considered under central sector extends from Munambam to Chettuva extending for a total length of 40km. (Fig. 1.2). Both

Table 3.1 Nearshore characteristics of Southern, Central and Northern sectors

Southern sector	Premonsoon	Monsoon	Post monsoon
Wave height (m)	0.39 - 1.03	1.24 - 2.73	0.40 - 1.20
Wave Period (s)	6.13 - 10.82	7.60 - 9.20	6.18 - 11.30
Beaker Direction (degree)	230 - 240°	250 - 260°	190 - 305⁰
Longshore current (cm/s)	0.29 - 34.90	0.29 - 54.85	0.29 - 68.05
Central sector	**Premonsoon**	**Monsoon**	**Post monsoon**
Wave height (m)	0.39 - 1.00	0.15 - 1.25	0.41 - 1.53
Wave Period (s)	8.40 - 12.80	6.40- 7.80	4.00 - 9.00
Beaker Direction (degree)	236 - 256°	250 - 263°	234 - 270°
Longshore current (cm/s)	0.29 - 41.06	0.29 - 50	0.29 - 48.92
Northern sector	**Premonsoon**	**Monsoon**	**Post monsoon**
Wave height (m)	<0.60	0.90 - 1.20	<0.60
Wave Period (s)	6.00 - 9.00	6.00 - 9.00	-
Beaker Direction (degree)	-	240 - 260°	-
Longshore current (cm/s)	0.29 - 41.06	0.29 - 55.43	0.29 - 48.00

Munambam and Chettuva are noticed for the presence of tidal inlets having a tidal range of <2m. A breakwater has been constructed at Munambam in the year 2000 to facilitate a fishing harbour. Seawalls exist from Munambam to Peringanam (13 km) and Vadanapally to Chettuva (8km) with spacing for the country boat for fishing. Another important feature observed is the formation of mudbanks, during the southwest monsoon season. Beach profiles in the following sessions at different stations were prepared and discussed [Fig. 3.4(a-g)].

3.3.2a Beach Profiling

The profiles reveal an accreted beach with berms on the north of Munambam breakwater throughout the year with a little sediment loss during monsoon. The beach width at Munambam shows a maximum width of 230m during fair period and a minimum of 180m during monsoon (Fig. 3.4a). The beach loses an average volume of 22.4m^3 of sediment per unit area during monsoon and it regains to about 81.1m^3/unit area in fair season. Accretion of beach is seen on the northern side of the breakwater throughout the year, which is likely a result of the interruption of southerly littoral currents. The southerly longshore drift in this sector during the period differs from the general direction of these currents along south west coast of India. Here the change in orientation of the coastal line (4^0) results in a broad, gentle concavity (Fig. 1.2), setting up local littoral cells that may vary from the regional trend. From Munambam, the beach gradually tapers

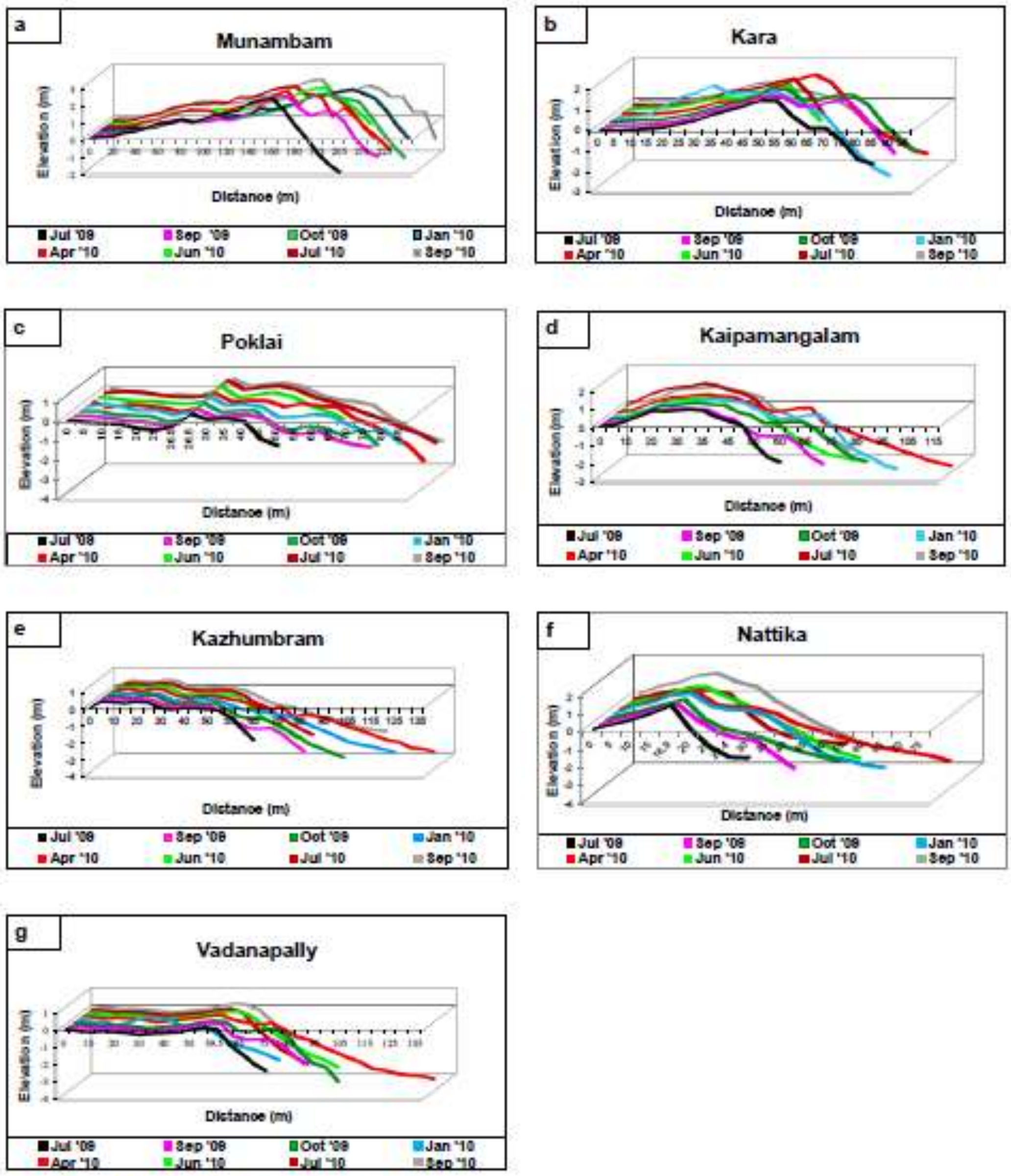


Fig 3.4(a-g) Beach profiles in Central sector

down towards north for a distance of 5 km, after which seawalls begins from Azhikode to Peringanam (13km) and Vadanapally to Chettuva (8km). The area is identified as seawall dominated region and with no beaches in front of seawall irrespective of the season. The change in orientation of the coastline as referred above cause wave convergence on either side of the concavity due to wave refraction resulting in erosion at Azhikode-Peringanam and Vadanapally–Chettuva stretch (Plate 3.5). Subsequently accretion occurs on concave side where the wave diverges. The width of the beach from Kaipamangalam to Vadanapally (19km) is of about 90-135m during fair season and during monsoon the beach width reduces to 55-80m (Fig. 3.4 d-g). Here the beach lose during monsoon is on the average of 27.22m^3 to 55.01m3/unit area and a redeposition of 14.67 to 45.05m^3/unit area during fair season. Accretion of foreshore occurs along the sector during fair season with the development of berms (Plate 3.5). The stability of the beach can be explained by the erosion/ accretion cycle and it can be attributed to the oceanographic processes operating in the area. Similar observations were made by Ganesan and Gaonkar (2006)**.**

Mudbanks are another reason for this erosional/accretion trend during the southwest monsoon. It is a major morphologic feature that has a close and direct impact on erosion-accretion of the beach. Mudbanks can be defined as those areas of the sea adjoining the coast, which have a special property of dampening the waves resulting in clearly demarcated areas of calm water even during the roughest monsoon conditions of the sea (Gopinathan and Qasim, 1974). They

Plate 3.5 Various morphologies in Central sector

are patches of calm, turbid water with high load of suspended sediments appearing close to the shore during southwest monsoon season (Silas, 1984). The wave induced bed erosion process weakens the bed and causes subsequent fluidization under severe wave action. The fluidized mud is transported to the nearshore by waves and currents. This expanse of fine suspended sediments in water results from the interactions of suspended material concentrations, near bottom current velocity and wave activity in the coastal zone. In the nearshore zone the fluid mud plays a significant role in absorbing and dissipating surface wave energy. Their morphological significance is the dampening effect of waves and currents. This results in the sediment accumulation and severe erosion is observed at south of the mudbanks. The length of the mudbanks along the coast varies from 6km to 10km and the width upto 4km.They migrate with the seasons but the predominant direction of movement is towards south. An examination of historical evidences and field observations made by Moni (1970) indicated that the mudbank provide key to the shore stability. Mudbanks affect the coastal processes in the following ways: 1) Traps the littoral material from the updrift side and thereby prevent its downdrift movement 2) Causes refraction of waves on its sides 3) Causes accretion within the mudbank area. The portion of the coast from Kozhikode to Trivandrum where the mudbanks are confined is coincident with the presence of alluvial belt backed by lateritic deposits. The occurrence of mudbanks along the study area were already reported by Gopinathan (1974) and Joseph and Baba (1991). Mudbanks are generally reported from different places in the sector viz., Chettuva, Vadanapally, Nattika, Edamuttom and Kaipamangalam over the years. The occurrence of mudbanks during the period 2009 along Peringanam-Kaipamangalam region led to the erosion in the southern side.

3.3.2b Nearshore Observations

Instruments to measure waves, tides and currents were deployed at Kara, Kaipamangalam and Vadanapally at depths 8.5m and 4m at Kara, 6m and 4m at Kaipamangalam and 6.5m and 4 m at Vadanapally (Table 3.1).

The wave data collected during fair season shows that wave heights are low with significant wave height (H_s) and in the range being 0.39 – 1.53m. The wave period (Tz) is in the range 8.4-12.8s and the wave direction is of 234 to 270^0. During monsoon wave heights are higher than pre monsoon season and significant wave height (H_s) is in the range 0.15-1.25m. At the same time it was observed to be very low value at some locations along this sector which was due to the presence of mudbanks during monsoon months. The wave period (Tz) during monsoon is in the range 6.4-7.8s and wave direction is of 250 to 263^0.The current meters deployed beyond the surf zone mostly represent the coastal currents. The current speed during fair and monsoon seasons consecutively are of the range 0.29- 48.92 cm/sec and 0.29-50cm/sec.

3.3.3 NORTHERN SECTOR

The Kozhikode coast comprising the northern sector extends from Beypore to Puthiyappa for a distance of 20km. The tidal height is of 1.5m which remains more or less same as that of other sectors. The section is marked by 3 breakwaters which are at Beypore, Kallai and Puthiyappa. Seawalls start from Beypore to Valiyangadi along a distance of 9km. In addition, groins were also constructed between Kallai and Valyangadi. From Valiyangadi to Kozhikode the beach is identified as stable. Towards north, from Kozhikode beach, revetments are observed at certain locations. Mudbanks, though not prominent occur in the coastal waters of Kozhikode coast at Puthiyappa-Vellayil area.

3.3.3a Beach Profiling

Beach profiling were carried out during fair and monsoon seasons [Fig. 3.5(a-f)]. Profile stations were selected to identify the impact of both natural and artificial structures along the study region so as to understand the beach dynamics. An abrupt and distinct inflection of the coastline would check the longshore transport leading to a depositional regime. This is very marked at the breakwaters in the northern sector, which is known to favour sediment deposition by obstructing the littoral drift (Plate 3.6). As expected for sandy beaches along the south west coast of India, the coast here experiences erosion/accretion process corresponding to monsoon and fair season. The erosion/accretion pattern and the related longshore currents of the northern sector were studied by Samsuddin *etal* (1991). The breakwaters at Beypore, Kallai and Puthiyappa show sediment deposition on their southern side (Fig. 3.5 a, e, f). The width of the beach ranges from 140-150m during fair season. During monsoon the beach width decreases to 80-110m, the erosion being in foreshore. Seawall dominated coast from

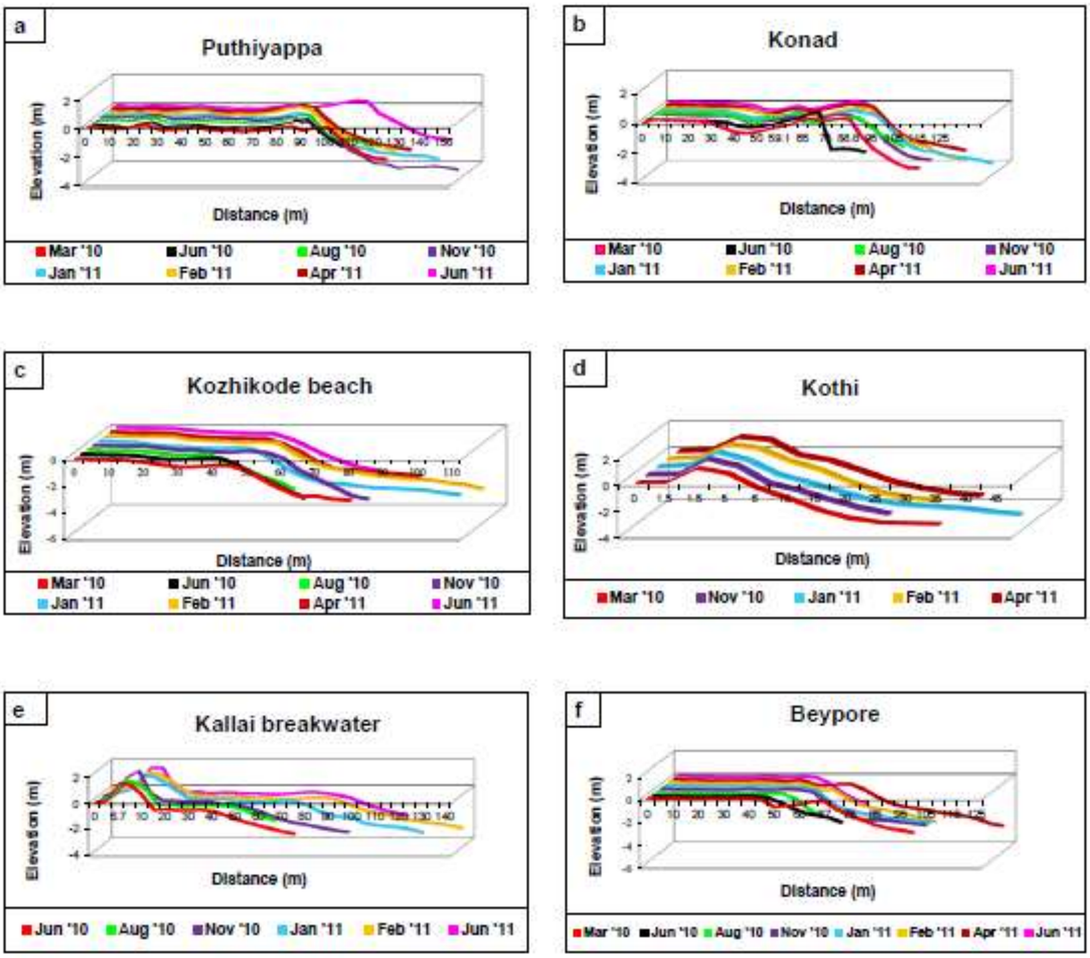


Fig 3.5(a-f) Beach profiles in Northern sector

Plate 3.6 Various morphologies in Northern sector

Beypore to Valiyangadi (9km) faces severe erosion during monsoon resulting in the complete loss of beach (Plate 3.6). Beaches of 35-50m are observed along this part during fair season. From Kozhikode to Puthiyappa (11km), a beach of 110-140m width occurs during fair season and reduces to 65-70m during monsoon (Fig. 3.5 b and c). The beach on the average loses 22.3 to 30.07 m^3/unit area during monsoon which regains almost the same volume of about 39.9 m^3/unit area during fair season. During monsoon, the foreshore erodes and the berms get shifted towards backshore while during fair season, the waves along with the longshore currents bring back the eroded beach sediments. In short the net effect is that the area witness neither erosion nor deposition reflecting the most stable part of the beach (Plate 3.6). Beach cusps of width 26-30m were noticed during fair season and scarps were observed during monsoon. Mudbanks were also observed along Puthiyappa-Vellayil region. As per information gathered from local inhabitants, mudbanks did not form at Puthiyappa for about 10 years and reappeared from 2010 onwards. The presence of mudbank was noticed during the latter half of monsoon at Puthiyappa and it migrated along Puthiyangadi - Vellayil region triggering erosion at down drift side. Mallik *etal* (1988) described the northern sector as an open coast low energy beach where it is calm enough for occurrence of mud banks during monsoons.

3.3.3 b Nearshore *observations*

The instruments were deployed at Beypore, Kallai and Puthiyappa during fair and monsoon seasons. Deployments were made close to shore at 4 m depth and further offshore at 7.5 m depth both at Puthiyappa and Beypore. At Kallai the instrument was deployed at a depth of 7 m (Table 3.1).

Data collected during fair season shows that the wave height (Hs) is mostly below 0.60m and wave periods (Tz) are generally of 6 to 9 sec.The dominating wave direction is 240 - 260^0.Observed significant wave height during monsoon ranges between 0.9- 1.2m and the wave direction is 240 - 260^0. Wave period ranges from 6-9 sec. Wave data collected during the latter half of monsoon indicated that the wave height in the nearshore at Puthiyappa is abnormally low because of the presence of mudbanks which dampens waves. Current speed during the fair season and monsoon are 0.29-48cm/sec and 0.29 -55.43cm/sec respectively.

3.4 BEACH SEDIMENTS

The energy inputs such as waves, tides and currents are linked to the landforms of the coast by coastal sediments. Grain size is the most fundamental properties of sediment particles, affecting their entrainment, transport and deposition and this provides important clues to the sediment provenance, transport history and depositional conditions.

3.5 RESULTS AND DISCUSSIONS

The following session discusses the textural attributes in the 3 sectors of different energy regimes. The various grain size statistical parameters are furnished in the tables in respective sectors.

3.5.1 SOUTHERN SECTOR

The Poovar-Adimalathura and Veli–Varkala beaches along the sector characterizes moderately well sorted, medium to coarser sand with a mean size of 0.80-1.84φ (Table 3.2a). The coarser grain size indicates the presence of river input at Poovar, which is fed by Neyyar river. The sediments here are fine to symmetrically skewed and are of leptokurtic to mesokurtic in nature. The seawall dominated coast from Valiathura to Sankumugham characterizes medium sand of 1.10 to 1.66φ (Table 3.2a). The sediments are moderately well sorted to well sorted, symmetrical to fine skewed and are very mesokurtic to very leptokurtic. Perumathura, the southern side of Muthalapozhi breakwater also exhibits moderately sorted to moderately well sorted, medium to fine sand (1.11φ to 2.03φ). The sediments adjacent to the breakwater show a lesser grain size compared to other areas and specifies no considerable variations before or after the reconstruction. As discussed in 3.3.1a, before reconstruction of breakwater, a sand bar formed within the inlet during fair season. The grain size of this formation was similar to that at Perumathura. It revealed that the sediment carried by the northerly longshore sediment transport is not fully interrupted by

Table: 3.2(a) Textural parameters of beach sediments in Southern Sector

LOCATIONS	MEAN (Φ)			SORTING (Φ)			SKEWNESS (Φ)			KURTOSIS (Φ)		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Open beaches												
Poovar												
BS	1.02	0.80	1.15	0.57	0.65	0.53	0.13	-0.03	0.23	1.10	1.54	1.05
BM	1.06	1.43	1.27	0.53	0.49	0.57	0.20	0.32	0.18	0.97	1.35	1.06
FS	0.80	0.90	1.31	0.85	0.38	0.56	0.14	0.00	0.15	0.73	0.99	1.03
Adimalathura												
BS	1.18	1.34	1.41	0.61	0.72	0.52	0.30	-0.01	-0.07	0.97	1.14	1.19
BM	1.47			0.64	-	-	0.18	-	-	0.90	-	-
FS	1.17	1.55	1.24	0.63	0.70	0.47	0.19	0.15	0.01	1.13	0.92	0.90
Vettukad												
BS	-	1.27	-	-	0.52	-	-	0.19	-	-	1.28	-
FS	-	1.05	-	-	0.40	-	-	0.07	-	-	0.92	-
Veli												
BS	1.53	1.59	1.30	0.59	0.48	0.57	0.16	0.09	0.10	0.96	0.97	0.97
FS	1.24	1.67	1.39	0.54	0.49	0.52	0.15	0.16	0.12	0.98	0.82	1.04
Thumba												
BS	1.29	1.10	1.79	0.54	0.42	0.58	0.12	0.08	0.16	0.94	1.02	0.89
Bm	1.30	1.32	1.43	0.56	0.42	0.55	0.18	0.20	0.14	0.99	1.61	0.98
FS	1.13	1.28	1.29	0.62	0.32	0.66	-0.02	0.07	0.10	1.34	1.42	0.94
Anutengu												
BS	1.28	1.00	1.03	0.58	0.60	0.46	0.19	0.21	0.06	0.93	1.30	1.21
FS	1.14	1.10	1.79	0.73	0.71	0.59	0.12	0.24	-0.06	1.17	1.26	0.93
Neduganda												
BS	1.59	1.24	1.12	0.57	0.54	0.65	0.21	0.17	-0.22	1.01	1.08	1.02
FS	1.19	1.42	1.84	1.07	0.58	0.85	-0.05	-0.01	0.09	1.05	0.95	0.98
Breakwater												
Perumathura												
BS	1.52	1.46	1.42	0.51	0.78	0.76	0.18	-0.04	0.19	0.97	0.86	0.79
BM		1.56	1.90	-	0.57	0.66	-	0.25	-0.14	-	1.10	0.91
FS	1.11	1.61	2.03	0.63	0.69	0.73	0.22	-0.04	-0.15	1.07	0.94	0.86
Seawalls												
Vallathura												
BS	1.44	-	1.61	0.49	-	0.59	0.29	-	0.40	1.37	-	1.03
BM		-	1.66	-	-	0.65	-	-	0.42	-	-	1.00
FS	1.16	-	1.30	0.44	-	0.54	0.04	-	0.17	0.93	-	1.28
Sankumugam												
BS	1.62	-	1.60	0.59	-	0.76	0.25	-	0.28	1.02	-	0.89
BM	-	-	1.27	-	-	0.57	-	-	0.23	-	-	1.30
FS	1.27	-	1.10	0.56	-	0.55	0.20	-	0.09	1.30	-	1.05
Pocket beaches												
Azhimala												
FS	-	1.67	2.26	-	0.60	0.52	-	0.08	-0.09	-	0.91	1.03
Mullur												
BS	1.26	0.75		0.50	0.73	-	0.07	-0.02	-	0.99	0.96	-
Bm	0.84	0.91	1.45	0.73	0.64	0.60	0.04	-0.08	0.03	1.18	1.19	0.96
Fs	0.36	0.71	1.58	0.92	0.78	0.60	0.03	-0.14	-0.05	0.71	0.96	0.94
Kovalam												
BS	2.55	2.72	2.71	0.51	0.31	0.47	-0.25	0.05	0.02	1.22	1.60	1.54
BM	-	2.91	-	-	0.40	-	-	0.22	-	-	1.06	-
FS	2.63	2.79	2.04	0.42	0.29	0.67	-0.24	0.21	0.05	1.68	1.32	0.78
Chilakkur												
BS	1.55	-		1.03	-	-	-0.14	-	-	0.91	-	-
FS	2.03	-	1.61	0.61	-	0.90	-0.02	-	-0.24	0.96	-	1.01
Varkala												
FS	-	1.62	-	-	0.89	-	-	-0.01	-	-	0.75	-

BS - Backshore; BM - Berm; FS - Foreshore

Pre - premonsoon; Mon - monsoon; Post - postmonsoon

the breakwater but a part get bypassed and deposited within the harbour making it non-functional.

The pocket beach at Azhimala, the northern part of Poovar-Adimalathura stretch possess moderately well sorted, medium to fine sand (1.65- 2.26φ). Towards north at Mullur, a small pocket beach exists in between headland and Vizhinjam breakwater. Here the sediments show a medium to coarser grade (1.56-0.72φ) which may be due to the high energy condition existing in between the headlands. The sub-bottom topography and the resultant wave energy at Mullur enhance the churning up of sediments which subsequently results in coarser sand accumulation. The pocket beaches at Kovalam possess well sorted to very well sorted fine grade sediments ranging 2.04 to 2.91φ with higher percentage of black sands. This is also due to the high energy conditions causing the finer sediments to be winnowed away leading to the accumulation of heavy minerals of a finer size grade. Further north, the pocket beaches at Varkala characterizes moderately to moderately well sorted sediments of medium to fine size (1.60-2.26φ). The pocket beaches are generally characterized by moderately well sorted to well sorted, coarsely skewed sediments (Table 3.2a).

The sand, silt and clay percentage ranges from 62.40 to 99.83%, 0.76 to 24.44% and 0.28 to 16.12% respectively (Table 3.2b). The innershelf to a depth of 20m are largely (99%) carpeted with, medium to very fine sand (0.86 to 4φ) which are of moderately well sorted (Table 3.2c). The southern sector which is of high energy condition possesses higher sand percentage in the innershelf region.

Table 3.2b Percentage of sand, silt and clay of nearshore sediments in Southern Sector

Location	SAND (%)			SILT (%)			CLAY (%)		
	pre	mon	post	pre	mon	post	pre	mon	post
Thumba (6m)	98.35	-	99.33	1.00	-	0.38	0.65	-	0.28
Thumba (15m)	97.01	82.12	83.88	1.81	11.00	9.59	1.18	6.88	6.53
Muthalapozhi (15m)	97.69	74.26	62.2	1.40	15.84	23.1	0.91	9.91	14.71
Neduganda (6m)	68.20	-	83.59	19.04	-	9.87	12.76	-	6.54
Neduganda (12m)	76.83	59.74	98.75	14.20	24.14	0.76	8.97	16.12	0.49

Table 3.2c Textural parameters of nearshore sediments in Southern Sector

Location	MEAN (Φ)			SORTING (Φ)			SKEWNESS			KURTOSIS		
	pre	mon	post	pre	mon	post	pre	mon	post	pre	mon	post
Thumba (6m)	1.27	-	1.92	0.67	-	0.54	0.13	-	-0.09	1.35	-	1.01
Thumba (15m)	1.72	3.89	3.55	0.69	0.50	0.62	0.12	0.23	-0.22	1.05	1.97	1.65
Muthalapozhi (15m)	0.86	4.00	3.99	0.59	0.47	0.61	0.07	0.42	0.14	1.34	0.82	1.32
Neduganda (6m)	3.80	-	3.52	0.71	-	0.64	-0.03	-	-0.23	1.48	-	1.48
Neduganda (12m)	1.26	3.69	1.46	0.77	0.57	0.88	0.15	-0.08	0.12	1.52	2.29	1.39

Pre - premonsoon; Mon - monsoon; Post - postmonsoon

3.5.2 CENTRAL SECTOR

The general direction of longshore currents along the west coast of India reverses to southerly during monsoon and their velocity is much stronger than in other seasons. This accounts for the high rate of erosion and sediment transport along the coast during the monsoons as reported earlier by Baba and Kurian (1988). As discussed in 3.3.2a, the change in orientation of the coastal line ($\sim 4^0$) results in a broad, gentle concavity setting up local littoral cells that may vary from the regional trend. The refraction of wave energy and the subsequent littoral sediment transport is controlled by the shoreline curvature of the coast. Earlier studies of Petersen *etal* (1986) and Chernicoff and Whitney (2006) revealed similar pattern of wave divergence for the coast of Oregon. These processes give rise to a calmer zone favouring deposition of even finer sediments all through the year in a low energy environment. The mean values suggest that most of the sediments are medium to fine sand (1 to 2.74φ) (Table 3.3a). The sediments are moderately to well sorted and symmetrical to fine skewed. The fine skewed sediments generally imply the introduction of finer material or removal of coarser fraction (Friedman, 1961).The kurtosis show that the sediments are mostly of platykurtic to mesokurtic with values clustered between 0.73φ to 1.24φ. The foreshore sediments along the accreting beach are finer than those in backshore. The deposition of finer sediments in beaches of lower energy condition is corroborated by the general strong wave divergence in the region. Samsuddin (1990) emphasized that under the influence of the differing wave energy

Table: 3.3(a) Textural parameters of beach sediments in Central Sector

LOCATIONS	MEAN (Φ)			SORTING (Φ)			SKEWNESS (Φ)			KURTOSIS (Φ)		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Kara												
BS	0.97	1.25	1.69	0.64	0.50	0.69	-0.09	0.22	0.05	0.99	1.22	0.89
BM	1.47	-	-	0.52	-	-	0.14	-	-	1.12	-	-
FS	1.64	1.43	1.74	0.61	0.64	0.79	0.13	-0.01	-0.09	1.08	1.25	0.87
Poklai												
BS	0.94	1.09	1.79	0.72	0.69	0.68	0.12	-0.01	-0.11	1.14	0.92	0.90
BM	1.74	-	-	0.67	-	-	-0.01	-	-	1.03	-	-
FS	1.47	1.69	1.89	0.75	0.71	0.62	-0.12	-0.05	0.02	1.15	0.91	1.01
Kaipamangalam												
BS	1.74	2.00	2.00	0.59	0.60	0.58	0.00	0.04	-0.13	1.24	0.95	0.94
BM	1.89	2.00	-	0.55	-	-	0.10	-	-	1.02	-	-
FS	2.74	2.56	2.56	0.41	0.55	0.39	-0.13	-0.03	0.03	1.49	0.95	0.92
Kazhumbram												
BS	2.40	1.64	2.32	0.53	0.84	0.45	-0.09	-0.29	-0.01	1.00	0.87	1.09
BM	-	1.84	-	-	-	-	-	-	-	-	-	1.13
FS	2.84	1.47	2.47	0.44	0.51	0.77	-0.06	-0.05	-0.27	1.26	0.94	-
Vadanapally												
BS	1.79	1.74	1.60	0.47	0.76	0.58	0.15	-0.05	0.18	0.98	0.88	0.99
BM	-	1.89	-	0.56	0.64	-	0.14	0.10	-	1.03	0.87	-
FS	1.89	1.29	1.51	0.86	0.61	0.77	-0.15	0.13	0.06	0.73	0.95	1.02

BS - Backshore; BM - Berm; FS - Foreshore

Pre - premonsoon; Mon - monsoon; Post - postmonsoon

conditions, the textural parameters exhibits distinct differences in the distribution pattern. The major hydrodynamic feature that has a close and direct impact on erosion/accretion of the beach, is the formation of mud banks during the southwest monsoon. The wave induced bed erosion process weakens the bed and causes its subsequent fluidization under severe wave action. The fluidized mud is transported to the nearshore by waves and currents. This expanse of fine suspended sediments in water results from interactions of suspended material concentrations, near bottom current velocity and wave activity in the coastal zone. In the nearshore zone the fluid mud plays a significant role in absorbing and dissipating surface wave energy. Their morphological significance is their role as dampening the effect of waves and currents. This results in sediment accumulation and severe erosion at the south of the mudbanks. The occurrence of mudbanks along the study area were already reported by Gopinathan (1974) and Joseph and Baba (1991). Low values of mean grain size during monsoon are caused by the calm conditions formed by dampening of waves where mud banks hold sway (Sajeev *etal*., 1997). The beach sediments at mudbank locations appeared to be comparatively finer (1.74 to 2.74φ) (Table 3.3a). The presence of mud bank influences the shore stability of that region and induces coastal erosion immediately south of the mudbanks.

The sand, silt clay percentages ranges from 0.40 to 17.3%, 63.38 to 76.50% and 18.93 to 32.95% respectively (Table 3.3b). The offshore sediments along the central sector are poorly sorted and predominated by coarse silt to very fine silt

Table 3.3b Percentage of sand, silt and clay of nearshore sediments in Central Sector

Location	SAND (%)			SILT (%)			CLAY (%)		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Kara (5m)	5.41		0.40	65.19	-	72.72	29.40	-	26.88
Kara (12m)	-	1.35	0.97	-	67.32	73.77	-	31.33	25.26
Kaipamangalam (5m)	0.45	-	14.84	66.60	-	63.38	32.95	-	21.78
Kaipamangalam (12m)	-	-	1.58	-	-	74.51	-	-	23.91
Vadanapally (5m)	3.34	-	17.03	65.49	-	64.04	31.16	-	18.93
Vadanapally (12m)	-	-	1.89	-	-	76.50	-	-	21.61

Table 3.3c Textural parameters of nearshore sediments in Central Sector

Location	MEAN (Φ)			SORTING (Φ)			SKEWNESS			KURTOSIS		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Kara (5m)	7.72	-	7.22	2.24	-	1.96	-0.04	-	0.15	0.83	-	0.88
Kara (12m)	-	8.00	7.16	-	1.69	1.92	-	0.05	0.16	-	1.10	0.89
Kaipamangalam (5m)	8.77	-	6.38	1.68	-	2.46	-0.16	-	0.26	1.13	-	0.79
Kaipamangalam (12m)	-	-	7.75	-	-	2.05	-	-	0.22	-	-	0.79
Vadanapally (5m)	8.48	-	5.83	1.74	-	2.13	-0.21	-	0.39	1.40	-	0.88
Vadanapally (12m)	-	-	7.22	-	-	1.66	-	-	0.12	-	-	0.82

Pre - premonsoon; Mon - monsoon; Post - postmonsoon

(~76%), with a mean size ranging from 5.83φ to 8φ (Table 3.3c). The accumulation of these silty sediments represents the low energy environment and the influence of mudbanks existing in the area.

3.5.3 NORTHERN SECTOR

The sector exhibits medium to fine sand with sediment size varying from 1.15 to 2.94φ. They are of moderately well sorted to well sorted (0.38φ to 0.73φ) and are symmetrical to finely skewed indicating mesokurtic to leptokurtic in nature (Table 3.4a). The sediments along the beaches adjoining to breakwater are finer than the other locations (1.47 to 2.94φ). An abrupt and distinct inflection of the coastline would check the longshore transport leading to a depositional regime. This is very marked at the breakwaters at Beypore, Kallai and Puthyappa in the northern sector, which is known to favour sediment deposition by obstructing the littoral drift. The presence of fine sediments is a reflection of the depositional environment and this is corroborated by the strong wave divergence prevailing in the region as reported by Angusamy *etal* (2006) in their studies. The study sector is an open coast low energy beach, frequently sheltered by the occurrence of mudbank. Low values of mean grain size during south west monsoon are caused by the calm conditions provided by the dampening of waves under the influence of the mudbank (Sajeev *etal*., 1996).

Being a mudbank area, silt fractions forms the major component (76%) and the offshore comprises very fine sand to very fine silt. The Beypore-Puthyappa coast also shows the dominance of sandy silt where the silt content ranges up to

Table 3.4(a) Textural parameters of beach sediments in Northern sector

LOCATIONS	MEAN(Φ)			SORTING(Φ)			SKEWNESS(Φ)			KURTOSIS(Φ)		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Puthiyappa												
BS	2.64	-	2.06	0.38	0.40	-	-0.03	0.06	-	0.99	0.95	-
BM	2.94	-	-	-	-	-	-	-	-	-	-	-
FS	-	2.47	2.64	0.41	0.47	0.80	0.07	0.06	-0.29	1.26	1.11	1.31
Konad												
BS	1.15	1.47	1.60	0.61	0.66	0.62	0.14	0.17	0.23	0.95	0.96	0.93
BM	1.94	1.56	-	0.58	0.55		-0.19	0.10	-	0.97	1.01	-
FS	2.12	1.36	1.25	0.62	0.52	0.81	0.00	0.14	0.14	0.87	0.96	1.11
Kallai												
BS	2.32	-	2.56	0.63	0.53	0.50	-0.09	0.15	0.03	1.06	1.10	1.05
BM	-	2.74	-	-	0.54	-	-	0.05	-	-	1.07	-
FS	2.64	2.84	2.06	0.44	0.47	0.63	-0.04	0.09	0.20	0.98	1.03	0.87
Gotheswaram												
BS	2.32	1.94	2.18	0.73	0.67	0.72	0.03	-0.05	0.00	0.89	0.86	0.88
BM	1.74	2.32	1.60	-	-	0.76	-	-	0.23	-	-	0.90
FS	1.74	2.18	1.64	0.88	0.59	0.74	-0.02	0.04	0.02	1.05	0.97	0.91
Beypore												
BS	2.12	1.47	2.12	0.70	0.64	0.60	0.06	0.15	0.01	0.90	0.90	1.02
BM	2.12	2.00	1.84	0.58	0.62	0.61	-0.07	0.00	0.10	0.97	1.05	0.86
FS	2.47	2.25	1.69	0.67	0.48	0.65	-0.15	0.05	-0.07	1.22	1.07	0.95

BS - Backshore; BM - Berm; FS - Foreshore
Pre - premonsoon; Mon - monsoon; Post - postmonsoon

73.2%. The sand and clay percentage ranges from 0.6 to 87.3% and 0.6 to 34.6% respectively (Table 3.4b). The mean size of the innershelf sediments varies from 3.28φ to 7.93φ representing very fine sand to fine silt (Table 3.4c). The textural parameters show a disparity in both space and time and this suggest the prevalance of temporal and spatial variation in energy condition.

The Southern sector with the highest energy level is characterized by comparatively coarser grains except at the south of breakwater and the northern sector with the lowest energy regime with accreting beach of finest sediments. The central sector with intermediate energy condition and accreting nature shows a sediment range in between. The size of the sediment is observed to be decreasing from south to north in accordance with the wave climate (Baba, and Kurian, 1988). In the high energy regime the sediment size during monsoon seems to be coarser than fair season. The sediments appear to be in the same grade during monsoon and fair season in central and northern sector is due to the presence of mudbanks. The accreted beach adjacent to breakwater show comparatively finer sediments all over the year.

The innershelf of southern sector is carpeted with sandy sediments representing a high energy condition whereas the central and northern sectors shows the predominance of silt fractions representing a low energy environment. The variation in mean size reveals the differential energy conditions that lead to erosion /deposition of sediments in different locations. The grain size distribution

Table 3.4b Percentage of sand, silt and clay of nearshore sediments in Northern Sector

Location	SAND (%)			SILT (%)			CLAY (%)		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Puthyappa (5m)	0.6	0.7	-	64.8	73.2	-	34.6	26.1	-
Puthyappa (10m)	20.7	-	34.8	54.6		46.7	24.7	-	18.5
Kallai (5m)	87.3	52.6	51.2	12.0	32.0	33.3	0.6	15.5	15.5
Kallai (10m)	13.8	-	-	69.5	-	-	16.8	-	-
Beypore (5m)	30.0	52.7	-	50.7	32.6	-	19.3	14.7	-
Beypore (8m)	12.4	28.0	11.7	62.5	52.6	65.6	25.1	19.4	22.7

Table 3.4c Textural parameters of nearshore sediments in Northern Sector

Location	MEAN (Φ)			SORTING (Φ)			SKEWNESS			KURTOSIS		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Puthyappa (5m)	7.93	7.75	-	1.76	1.45	-	-0.40	0.22		1.08	2.44	-
Puthyappa (10m)	5.20	-	4.70	1.74	-	1.43	0.47		0.58	1.24	-	1.96
Kallai (5m)	3.28	4.00	4.09	0.77	1.17	1.42	0.27	0.39	0.42	2.00	1.72	1.17
Kallai (10m)	5.58	-	-	1.78	-	-	0.51	-	-	1.00	-	-
Beypore (8m)	5.20	3.98	-	1.76	1.15	-	0.33	0.34	-	0.96	1.37	-
Beypore (8m)	5.92	4.76	5.84	1.90	1.60	1.94	0.12	0.21	0.34	0.89	1.45	0.99

Pre - premonsoon; Mon - monsoon; Post - postmonsoon

of beach sediments provides enormous information about the properties and depositional environment which helps to understand the various processes affecting erosion and deposition (Saravanan, 2010).

CHAPTER IV

GEOSPATIAL STUDIES

4.1 INTRODUCTION

Remote sensing and Geographic Information System (GIS) are powerful tools which have revolutionized our understanding and approach to the Earth's resources, its environment and their management. Remote sensing can be interpreted as the science and art of obtaining information about an object, area or phenomena through the analysis of data acquired by a device that is not in contact with the object, area or phenomena under investigation (Lillesand and Keifer, 1994). Hence the term remote sensing is commonly used to identify earth features by detecting the characteristics of electromagnetic radiation that is reflected/emitted by the earth's surface. Remote sensing techniques promised a great deal in mid seventies of last century. In the last century, the routine satellite monitoring of marine and coastal parameters had been limited primarily to sea surface temperature monitoring (Advanced Very High Resolution Radiometer-AVHRR) and to a lesser degree, chlorophyll (Coastal Zone Colour Scanner-CZCS) and Seasat(Synthetic Aperture Radar-SAR). High-resolution satellite images are now increasingly being used by countries to identify areas of coral reef, seagrass, mangroves, estuary, geomorphological classes and coastal vegetation types in their particular areas of jurisdiction. This work is often complemented by digitized high-resolution aerial photography and by the use of Landsat and IRS archive which is now available. The remote sensing data has been proved to be useful in providing information on various components of the coastal environment, shoreline changes and suspended sediment dynamics, wetland conditions, mangrove development and degradation etc. Due to intense human activity on coastal plains and as rivers serve as natural conduits in transporting materials to the seas, estuary and coastal zones have become repositories of wastes/dumping grounds. Shoreline is one of the rapidly changing landform in coastal area and hence the accurate detection and frequent monitoring of shorelines are very essential to understand the coastal processes and dynamics of various coastal features

4.2 Digital Image Processing (DIP)

Digital Image Processing is a collection of techniques for the manipulation of digital images by computers. The computer is programmed to insert the data into an equation, or series of equations, and then store results of the computation for each pixel. These results form new digital images that may be displayed or recorded in pictorial format. The raw data received from the imaging sensors on the satellite platforms contains flaws and deficiencies. To overcome these flaws and deficiencies in order to get the originality of the data, it needs to undergo several steps of processing. This will vary from image to image depending on the type of image format, initial condition of the image and the information of interest and the composition of the image scene. Digital Image Processing consists of three general steps:

- Pre-processing /Image restoration;
- Image enhancement and
- Information extraction

4.2.1Pre-Processing / Image restoration

The operations carried out in the preprocessing as are follows:

- Atmospheric Correction;
- Radiometric Corrections;
- Geometric Corrections and
- Feature Extraction

Some techniques has to be applied so as to remove the unwanted and distracting elements such as image/system noise, atmospheric interference and sensor motion from an image data occurred due to limitations in the sensing of signal digitization, or data recording or transmission process. Thus image restoration includes the efforts to correct for both radiometric and geometric errors.

4.2.2 Image Enhancement Techniques

These processes aim to correct distorted or degraded image data and to create a more faithful representation of the original scene. Image enhancement techniques are employed for making satellite imageries more informative and to achieve the goal of image interpretation. The term enhancement is used to mean the alteration of the appearance of an image in such a way that the information contained in that image is more readily interpreted visually in terms of a particular need. The image enhancement techniques are applied either to single-band images or separately to the individual bands of a multi band image set. These techniques can be broadly categorized into two:

- **Spectral Enhancement Techniques:** Density Slicing, Contrast Stretching, Linear Contrast Stretch, Histogram Equalization and Gaussian Stretch.

- **Multi-Spectral Enhancement Techniques:** Band Ratioing, Principal Component Analysis, Canonical Components, Hue, Saturation and Intensity (HIS) Transform and Fourier Transformation.

4.2.3 Information Extraction

4.2.3.1 Visual Analysis of Data

Visual interpretation methods have been followed for extracting information on various natural resources. The elements of image interpretation include colour, tone, texture, shape, size, drainage pattern and association. Success in visual image interpretation varies with the training and experience of the interpreter, the nature of objects or phenomena being interpreted and quality of the images being utilized.

4.2.3.2 Image Classification

It involves automatic categorisation of pixels in an image in to different themes by analysis of multispectral data and application of statistical algorithms. When these algorithms are based on the spectral pattern present in the data, the classification procedure is called spectral pattern recognition. This pattern is a set of radiance measurements obtained in various wavelength bands for each pixel and it is manifested by the inherent spectral reflectance and emittance properties of different feature types. The spectrally based image classification comprises supervised and unsupervised approaches. In the supervised classification a numerical interpretation key is compiled from representative samples of known feature types to describe the spectral attributes for each feature type. Each pixel in the image is then compared to each category in the interpretation key and labelled. The unsupervised approach involves aggregation of image pixels in to natural spectral groups and assigning them in to different feature types by comparison with ground reference data. When the classification algorithms are based on geometric size, shapes and patterns in the image, the classification procedure is called spatial pattern recognition while time is used as an aid for feature identification in temporal pattern recognition. The current state-of-the-art procedures for spectral pattern recognition are more advanced compared to the spatial and temporal approaches.

4.3Remote Sensing and Geographic Information System

Remote sensing systems produce large volumes of spatial data, which can be processed further only by efficient geographic handling and processing systems that will transform these data into usable information.

Geographic information system has been defined as a set of tools for collecting, storing, transforming and displaying geographically referenced spatial data with its corresponding attribute information to meet a specific requirement (GeetaVaradan, 1992). Advancement in computer graphics and high speed and low cost microcomputers has dramatic impact on the development of Geographic information systems in1980s (Taylor, 1991). Geographic information system is normally considered to include spatially referenced computer data base and appropriate application software.

Geographic information systems are being used widely for natural resources management, environmental monitoring and planning and socio-economic and demographic research. The use of GIS provides wide scope for designing strategies for sustainable development and monitoring of environmental resources. Geological research often calls for combination, comparison, and correlation of different kinds of data known as analysis. A GIS is, undoubtedly, a versatile system that can aid in decision making for better planning and management of natural resources.

4.4 Integration of Remote Sensing and Geographic Information System

Whereas remote sensing systems are powerful tools for the collection of the classified spatial data, the GIS are powerful tools for the management and analysis of spatial data. Most of the GIS utilize maps as their primary source of spatial data and remote sensing systems produce such spatial data in the form of maps. The interpreter generally utilizes these complex maps for visual search and retrieval but when the same data are digitized, GIS is best for their integration. Maps produced with conventional field surveys and through remote sensing techniques can provide basic geometrical data. Combining the different sources of data either in the production phase or in the analysis phase could increase the value of the information that can be derived from these data. By combining the analysis functions of the GIS system with the image manipulation functions of the remote sensing, new possibilities in information can be generated. There are two points of view for integration, one from the remote sensing side and one from the GIS side. For remote sensing, a GIS offers possibilities for use and distribution of the output. Remote sensing images themselves are mostly useful for the specialists and not for users such as managers and decision-makers. Moreover, display of data and production of output can easier be customized with the GIS techniques. However, remote sensing gives advantages in the updating of geo-database and for the monitoring of processes. Also for some specific requirements remote sensing data can give locally more information than a map can.

4.5 Review of Literature

Remote sensing is increasingly being considered as one of the elements of an integrated GIS environment rather than simply as an important source of the multispectral data to be moved from the remote sensing domain into the GIS domain (Jackson & Mason, 1986; Star and Estes, 1990; Parker 1996). For the application of remote sensing and GIS to planning, there are two hosts of consideration necessary to ensure that multispectral data can be successfully converted to information useful for planning. Included in this consideration are issues of temporal facility, scale and resolution, quantitative versus qualitative model integration and linkage, operational linkage, costs, training, competency computational overhead and standards.

Advances in sensor design and data analysis techniques are making remote sensing systems practical and attractive for use in research and management of coastal ecosystems, such as wetlands, estuaries, and coral reefs. Multispectral and hyperspectral imagers are available for mapping coastal land cover, concentrations of organic/inorganic suspended particles, and dissolved substances in coastal waters. Since coastal ecosystems have high spatial complexity and temporal variability, they frequently have to be observed from both satellite and aircraft in order to obtain the required spatial, spectral, and temporal resolutions (Klemas, 2011). Several studies were made to elucidate coastline change detection from remotely sensed images (Alesheikh, *etal,* 2007; Hussain *etal,* 2013). The shoreline, occurring between land and sea, is dynamic in nature. It undergoes frequent changes, short term and long term, caused by hydrodynamic changes (*e.g.,* river cycles, sea level rise), geomorphological changes (*e.g.,* barrier island formation, spit development) and other factors (*e.g.,* sudden and rapid seismic and stormevents) (Scott, 2005). Shoreline change analysis and prediction are important for integrated coastal zone management, and are conventionally performed by field and aerial surveys. Wei-Wei Chen and Hsien-Kuo Chang, 2009 presented the one-line shift method of determining mean sea level datum-based shoreline positions from three sequential satellite images that take into account tidal variations. The study of the rate of change in shoreline position is important for a wide range of coastal studies, such as development of setback planning, hazard zoning, erosion-accretion studies, regional sediment budgets and conceptual or predictive modeling of coastal morphodynamics (Al-Hatrushi, 2012; Mahmoud and Hereher, 2009). Shoreline changes and erosion/ accretion patterns using satellite images and hydrographic profiles were earlier carried out by El-Raey *etal,*1999 elsewhere.

Sabyasachi Maiti and Amit, 2009 demonstrated that combined use of satellite imagery and statistical methods can be a reliable method for shoreline related studies. The location of the shoreline and the changing position of this boundary through time are of elemental importance to coastal scientists,engineers, and managers (Douglas and Crowell,2000). Both coastal management and engineering design require information about where the shoreline is, where it has been in the past,and where it is predicted to be in the future. The position of the shoreline can provide information in regard to shoreline reorientation adjacent to structures (Komar, 1998) and beach width and volume (Smith and Jackson, 1992), and it is used to quantify historical rates of change (Dolan,*etal* 1991; Moore, 2000). Analysis of shoreline variability and shoreline erosion-accretion trends is fundamental to a broad range of investigations undertaken by coastal scientists, coastal engineers, and coastal managers. Though strictly defined as the intersection of water and land surfaces, for practical purposes, the dynamic nature of this boundary and its dependence on the temporal and spatial scale at which it is being considered results in the use of a range of shoreline indicators. The most common shoreline detection technique has been subjective visual interpretation. Recent photogrammetry, topographic data collection, and digital image-processing techniques now make it possible for the coastal investigator to use objective shoreline detection methods. The remaining challenge is to improve the quantitative and process-based understanding of these shoreline indicator features and their spatial relationship relative to the physical land–water boundary (Boak and Turner, 2005). Shoshany and Degani, 1992 carried out the shoreline detection by digital image processing of aerial photography. Digital image processing techniques applied to digitized aerial photography allow significant improvements in the process of shoreline detection.

Accurate detection and proper monitoring of the coast is very essential to understand the coastal process and dynamics of various coastal features which will be helpful in accessing the dynamic nature of coast (Vinayraj *etal*, 2011; Padmakumari *etal,* 2012). Poornima and Sravan, 2014 studied the detection and future prediction of coastal changes in Chennai using remote sensing and

GIS techniques. Mani Murali *etal,* 2006 made studies to detect changes in the coastal zone of Goa using remote sensing and digital image classification techniques. According to them both natural and anthropogenic processes along the coast modify the shoreline configuration and control the erosion and accretion of coastal zones (Kumar and Jayappa, 2009; Kumaravel *etal,* 2012, Mahapatra *etal*, 2013, Chentamilselvan *etal,* 2014).Sreekala *etal,* 1998 studied the long term erosional/accretional trend along Kerala coast using satellite imageries and aerial photographs. Kumar *etal*, 2013, compiled the geospatial information to evaluate longterm morphological changes in Cochin estuary.

4.6 Result and Discussion

The shoreline change detection of three energy regimes during the period 1967-2000, 2000-2005 and 2005-2014 were studied. The areal extend of erosion/accretion (Table 4.1) was calculated to decipher the long term geomorphological changes. As discussed in Chapter 3, for the convenient explanation of the results, all the sectors were considered under (1) coast without any structure (Open beach) (2) coast with structures (3) beaches between the headlands (Pocket beaches).

Southern Sector

The areal extend of accretion during the period 1967-2000 is 1.288 sq.km. The net change during the period 2000-2005 is 0.072 sq.km erosion and that for the period 2005-2014 is 0.181 sq.km accretion. In the open beaches of Poovar-Adimalathura, Veli–Pudukurichi and Anjutengu-Nedunganda the long term

Table 4.1 Area of erosion/accretion in Southern, Central and Northern sectors

	Change Period	Erosion (sq.km)	Accretion (sq.km)	Net change (sq.km)
Southern sector	1967-2000	0.893	1.288	0.396
	2000-2005	0.596	0.524	0.072
	2005-2014	1.001	1.181	0.181

	Change Period	Erosion (sq.km)	Accretion (sq.km)	Net change (sq.km)
Central sector	1967-2000	0.152	3.688	3.536
	2000-2005	0.128	0.437	0.309
	2005-2014	0.317	0.410	0.093

	Change Period	Erosion (sq.km)	Accretion (sq.km)	Net change (sq.km)
Northern sector	1967-2000	0.149	0.701	0.551
	2000-2005	0.150	0.201	0.051
	2005-2014	0.110	0.200	0.090

shoreline changes obtained during the entire period exhibited accretional nature [Fig. 4.1(a),(b); 4.2(a),(b); 4.3(a),(b)]. From 2km south of Nedunganda upto Varkala an erosional nature is observed during 1967-2000 [Fig. 4.1(b)]. Hence to prevent erosion a series of groins were constructed during the period 1980. As a result the areal extend of erosion decreased and accretion is observed during 2000-2005 and 2005-2014 (Fig. 4.2b). The coastal stretch from Kovalam-Sankumugham (12km) faced intense erosion during the period 1967-2000 and 2000-2005 [Fig. 4.1(a),(b)]. While the rate of erosion decreased during 2005-2014 due to the construction of seawalls and groins in the region. The rate of changes in erosion/accretion can be altered by the construction of shore protective measures (Dhewidar and Frihy, 2007). From Muthalapozhi to Poothura an accreted beach was observed during 1967-2000. A breakwater was constructed at Muthalapozhi during the period 2000-2005 and as a consequence erosion occurred at the north of Muthalapozhi breakwater, i.e Thazampally to Poothura (2km). To prevent the erosion in the area seawalls were constructed. The construction of Muthalapozhi breakwater faced some discrepancy and to resolve the problem reconstruction was done during 2009-2014 (discussed in chapter 3). As a result accretion of beach took place in the area (Fig. 4.4). The pocket beaches from Azhimala–Kovalam and Varkala showed severe erosion during the period 1967-2000 and 2000-2005. To nourish the beaches in Kovalam and to promote tourism an artificial multipurpose reef was placed during the period 2009-2010 and subsequently accretion occurred here during fair season.

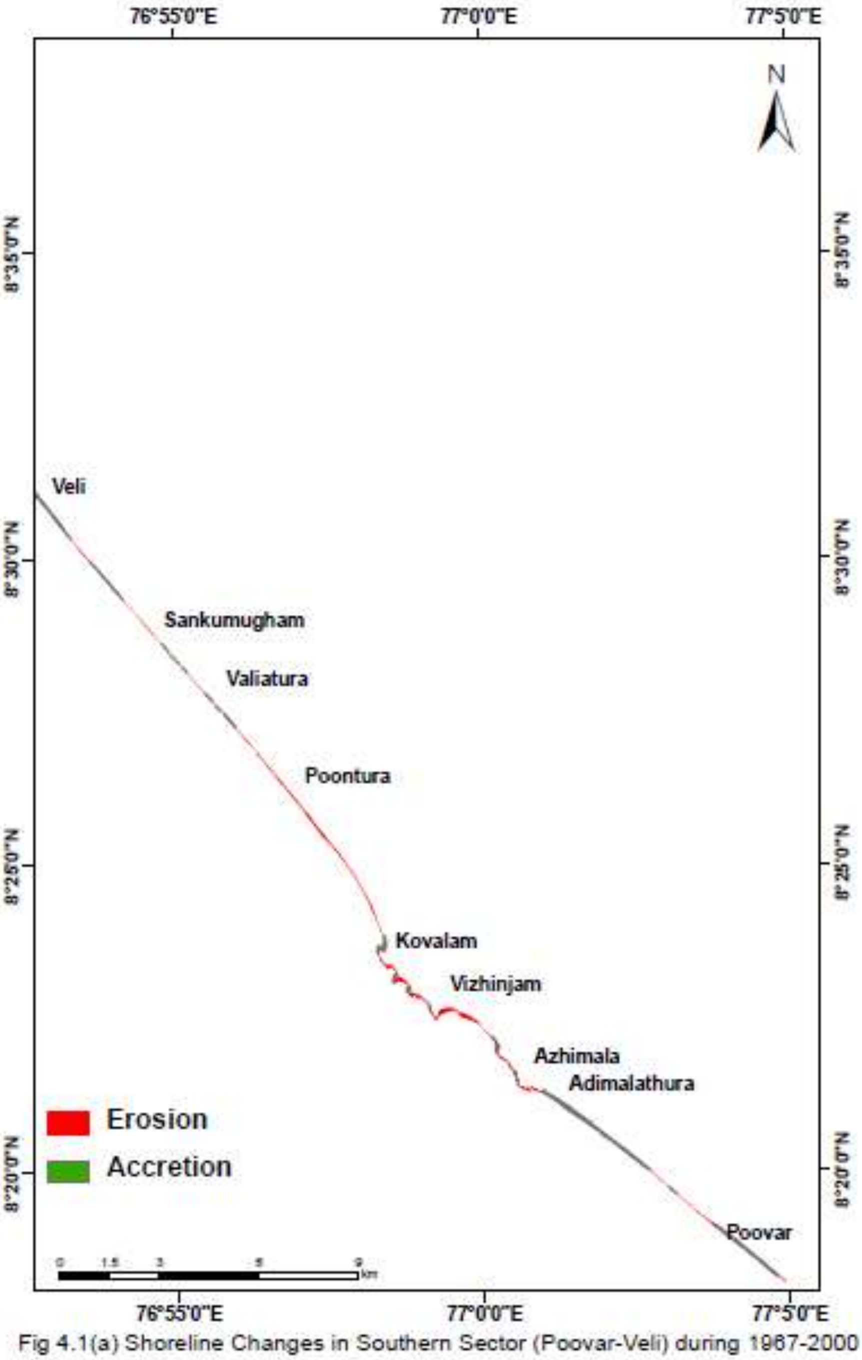


Fig 4.1(a) Shoreline Changes in Southern Sector (Poovar-Veli) during 1967-2000

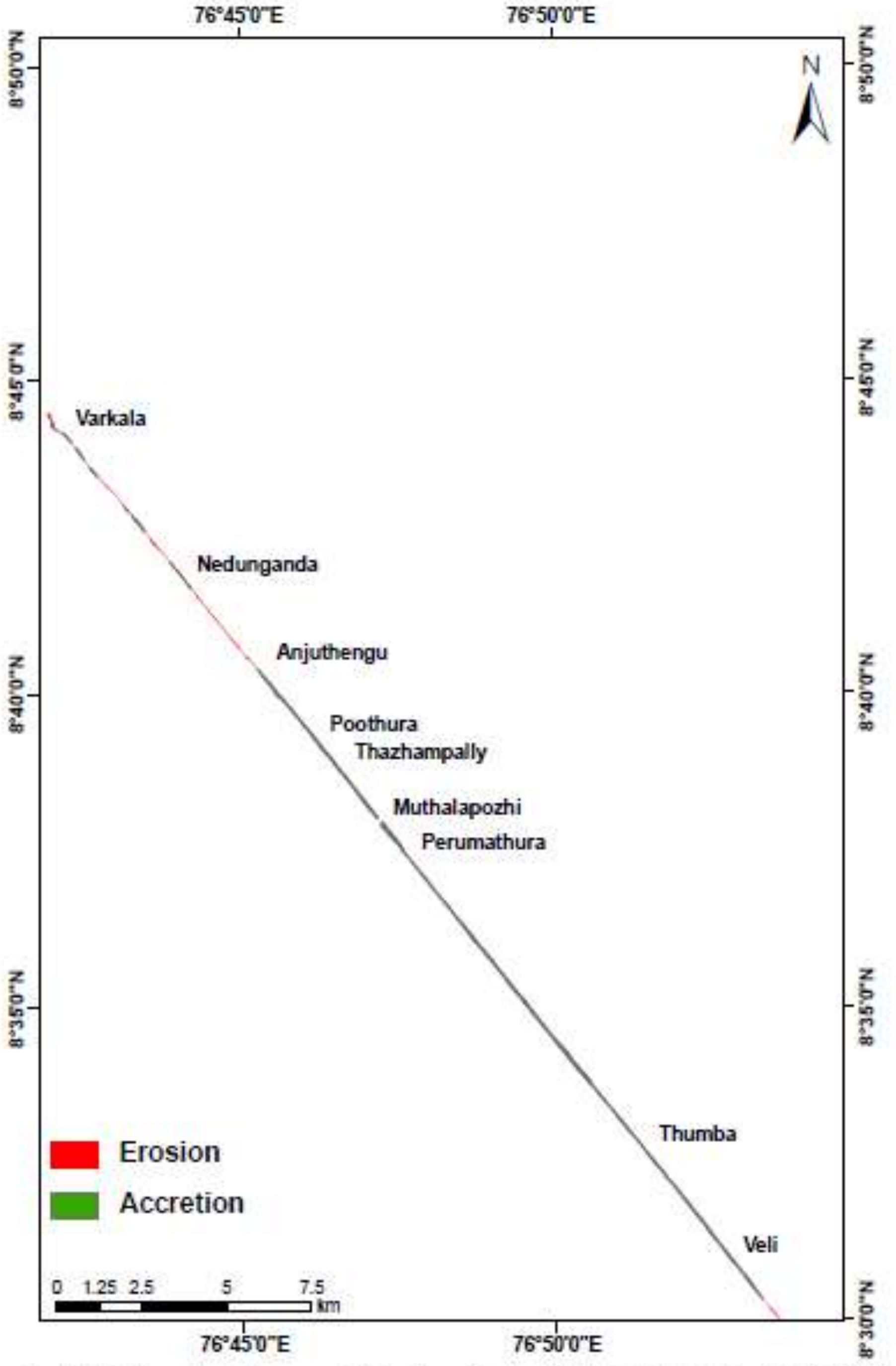


Fig 4.1(b) Shoreline Changes in Southern Sector (Veli-Varkala) during 1967-2000

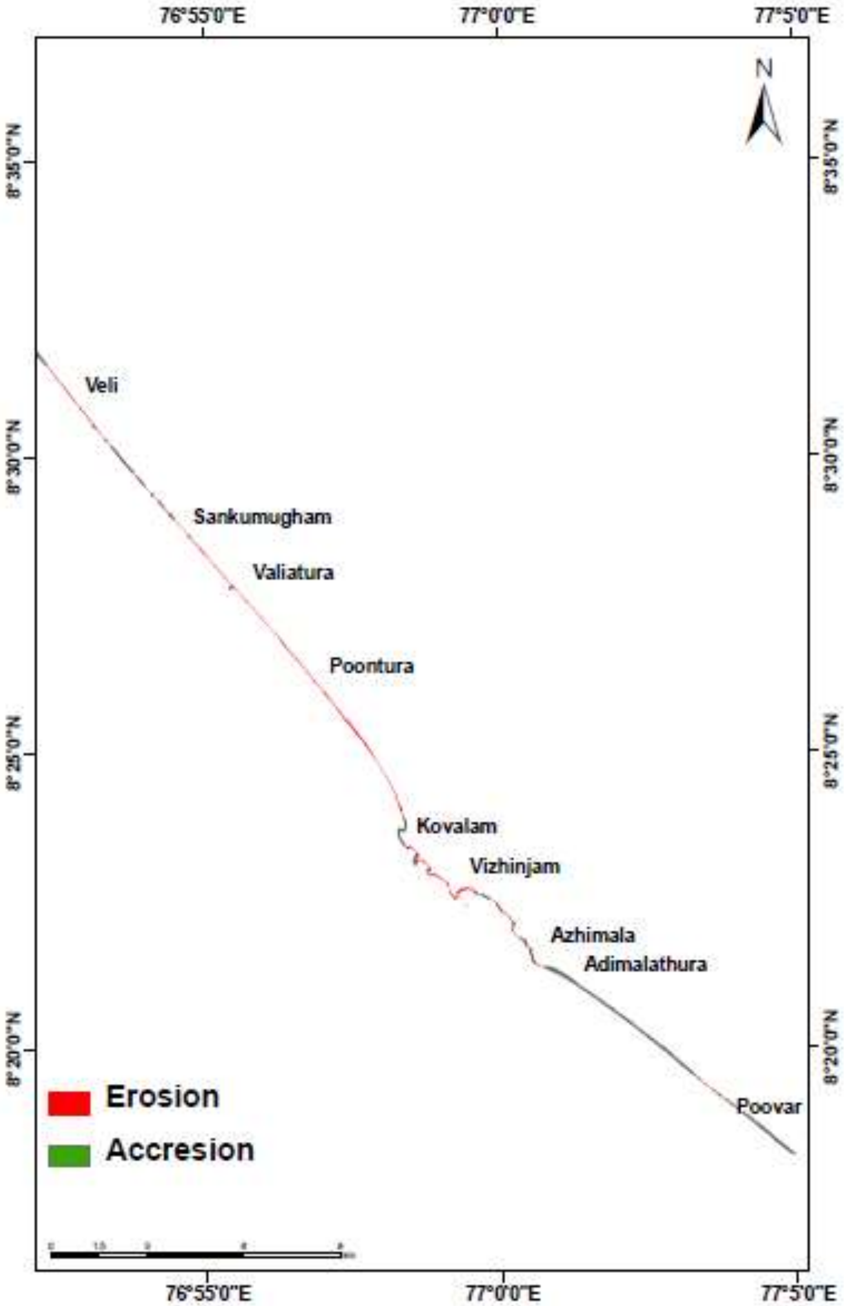


Fig 4.2(a) Shoreline Changes in Southern Sector (Poovar-Veli) during 2000-2005

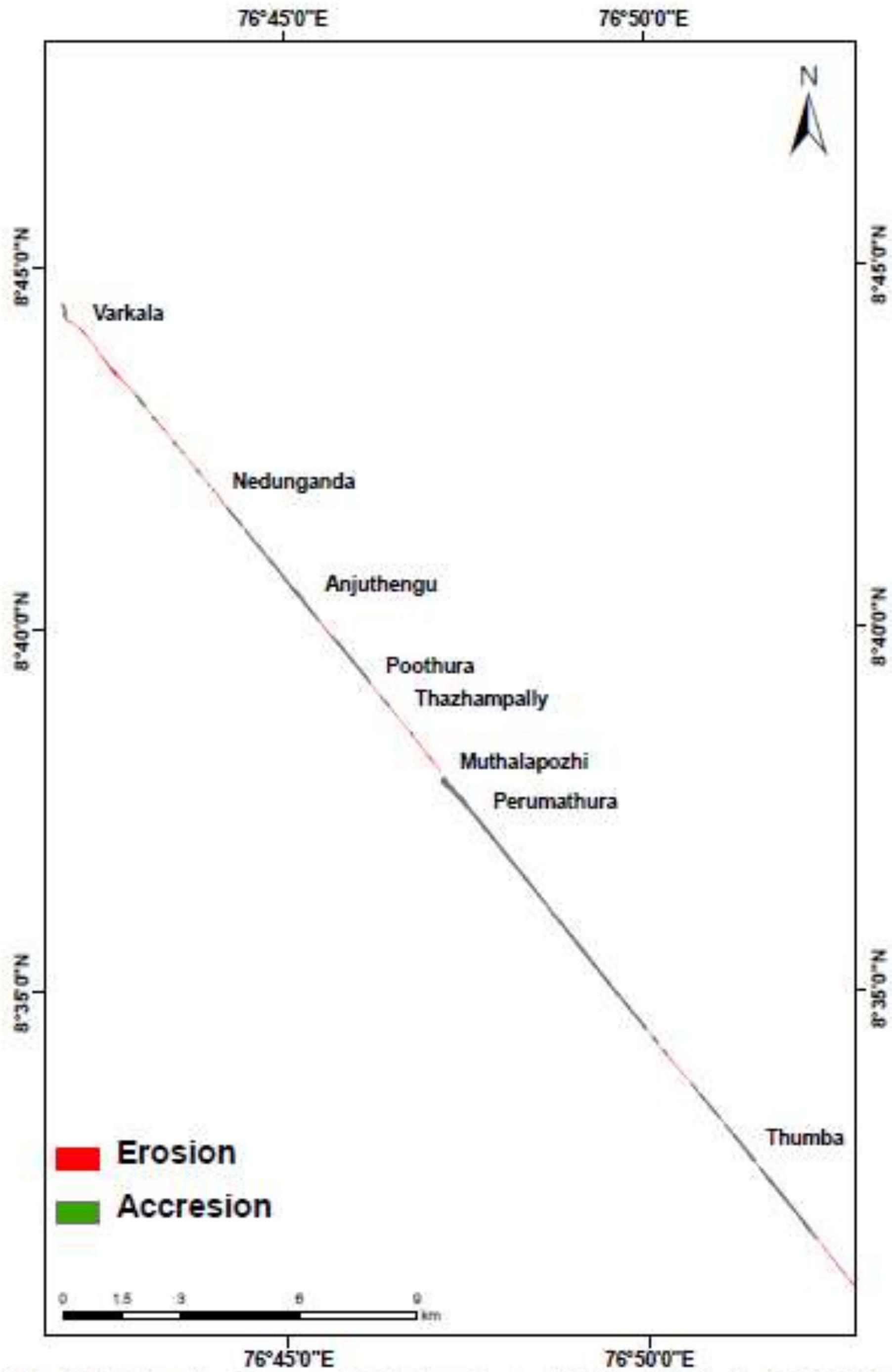


Fig 4.2(b) Shoreline Changes in Southern Sector (Veli-Varkala) during 2000-2005

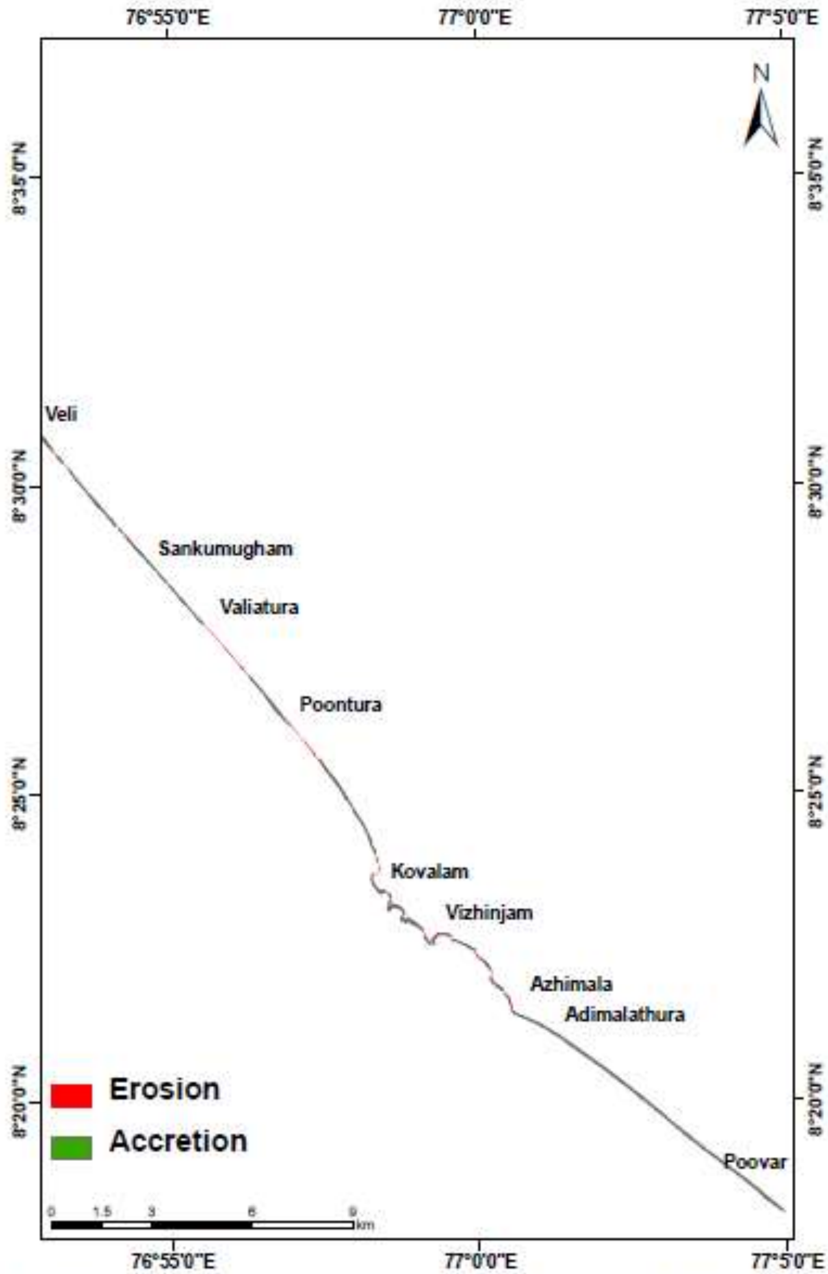


Fig 4.3(a) Shoreline Changes in Southern Sector (Poovar-Veli) during 2005-2014

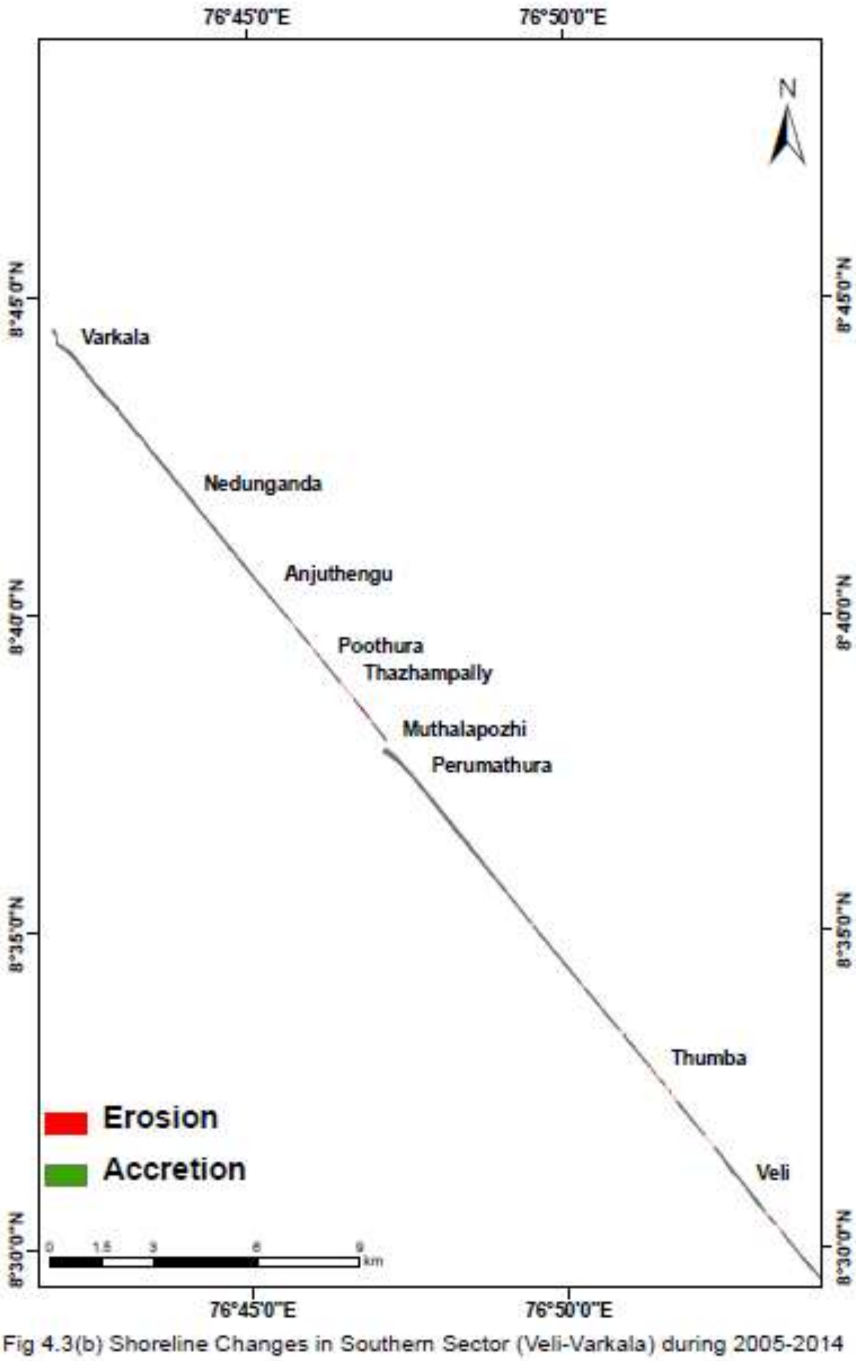


Fig 4.3(b) Shoreline Changes in Southern Sector (Veli-Varkala) during 2005-2014

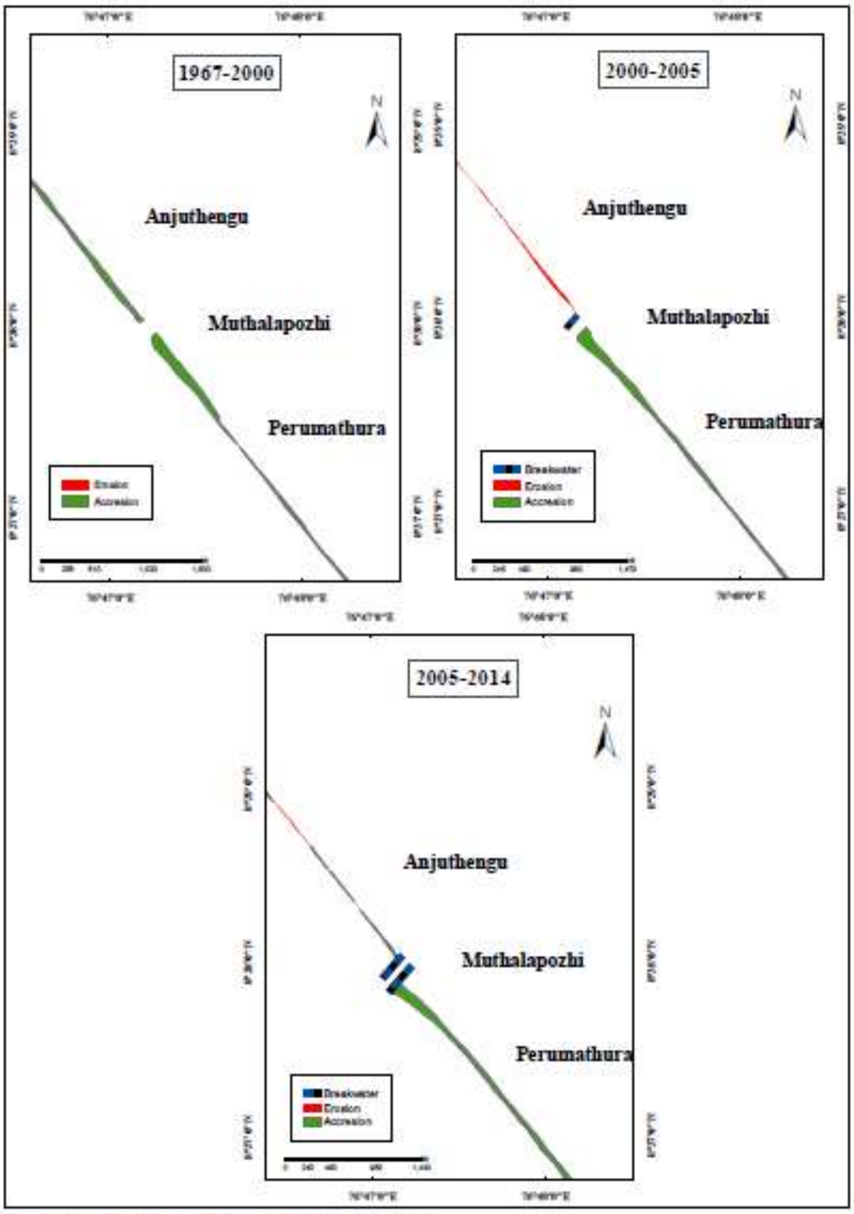


Fig 4.4 Impact of Muthalapozhi Breakwater

Central sector

Accretion observed as the net change in the central sector during the period 1967-2000, 2000-2005 and 2005-2014 with an areal extent of 3.536 sq.km, 0.309 sq.km, and 0.093 sq.km respectively. In the open beaches from Kaipamangalam to Vadanapally (19km) extensive accretion is seen during 1967-2000 (Fig. 4.5). Mudbanks were formed at Chettuva, Vadanapally, Nattika, Edamuttom and Kaipamangalam for several years during the period and the presence of this mudbanks enriched the beach. While during 2000-2005 and 2005–2014 the areal extend of accretion decreased due to the shifting of mudbanks towards south (Fig. 4.6 and 4.7), this observation is supported by the studies done in beach profile (chapter 3).

The seawall dominated coast from Azhikode-Peringanam (13km) and Vadanapally-Chettuva (8km) showed dominant accretion during 1967-2000 (Fig. 4.5). The construction of Munambam breakwater in 2000 facilitated accretion in the north of breakwater also. As discussed in Chapter 3, the change in orientation of the coastal line (4^0) results in a broad, gentle concavity in the sector, setting up local littoral cells and this enhanced accretion on the northern side of the breakwater. While the areal extend of accretion decreased in Azhikode-Peringanam stretch during 2000-2005 and 2005-2014 (Fig. 4.6 and 4.7). The change in orientation of the coastline as referred above cause wave convergence on either side of the concavity due to wave refraction resulting in erosion at Azhikode-Peringanam and Vadanapally–Chettuva stretch.

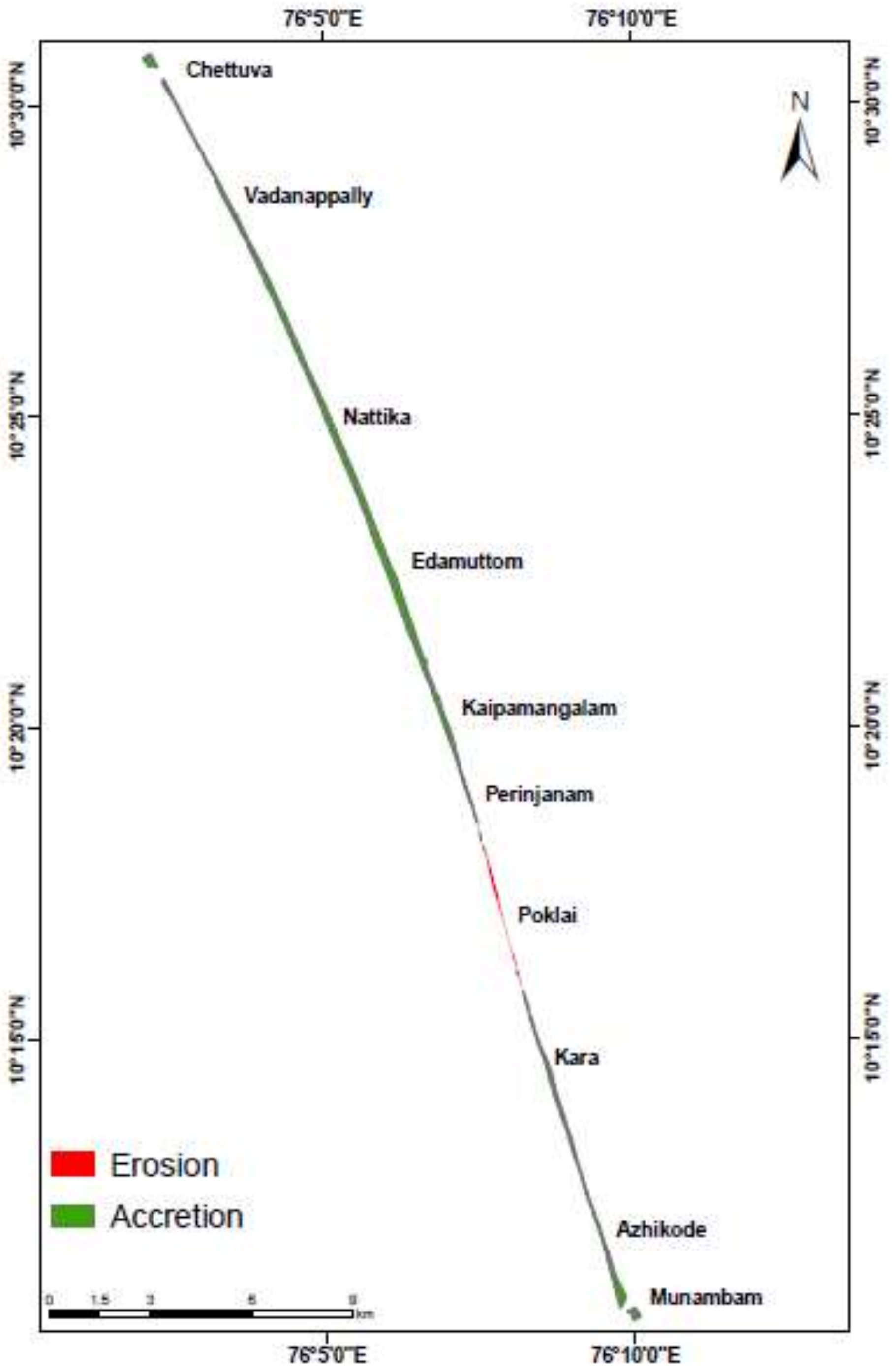


Fig 4.5 Shoreline Changes in Central Sector during 1967-2000

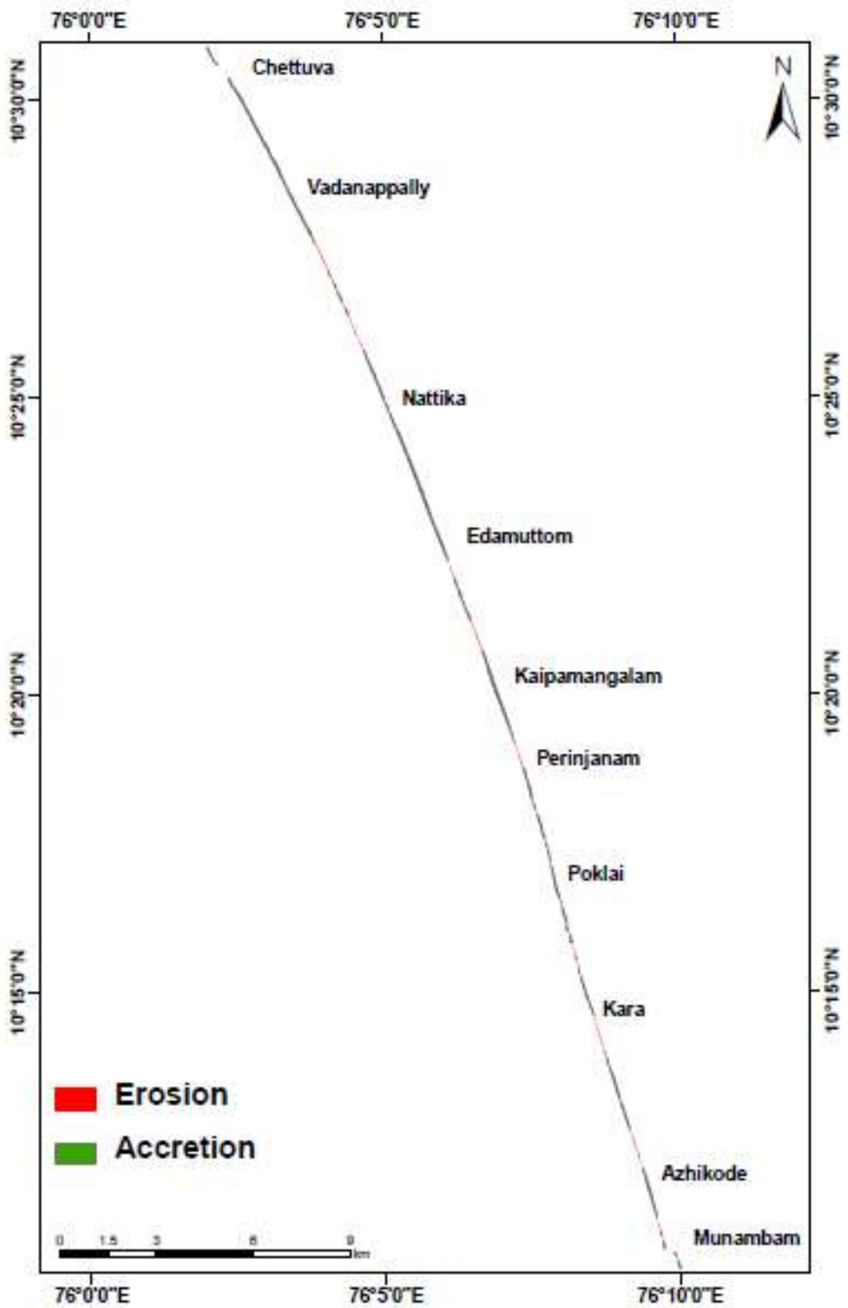


Fig 4.6 Shoreline Changes in Central Sector during 2000-2005

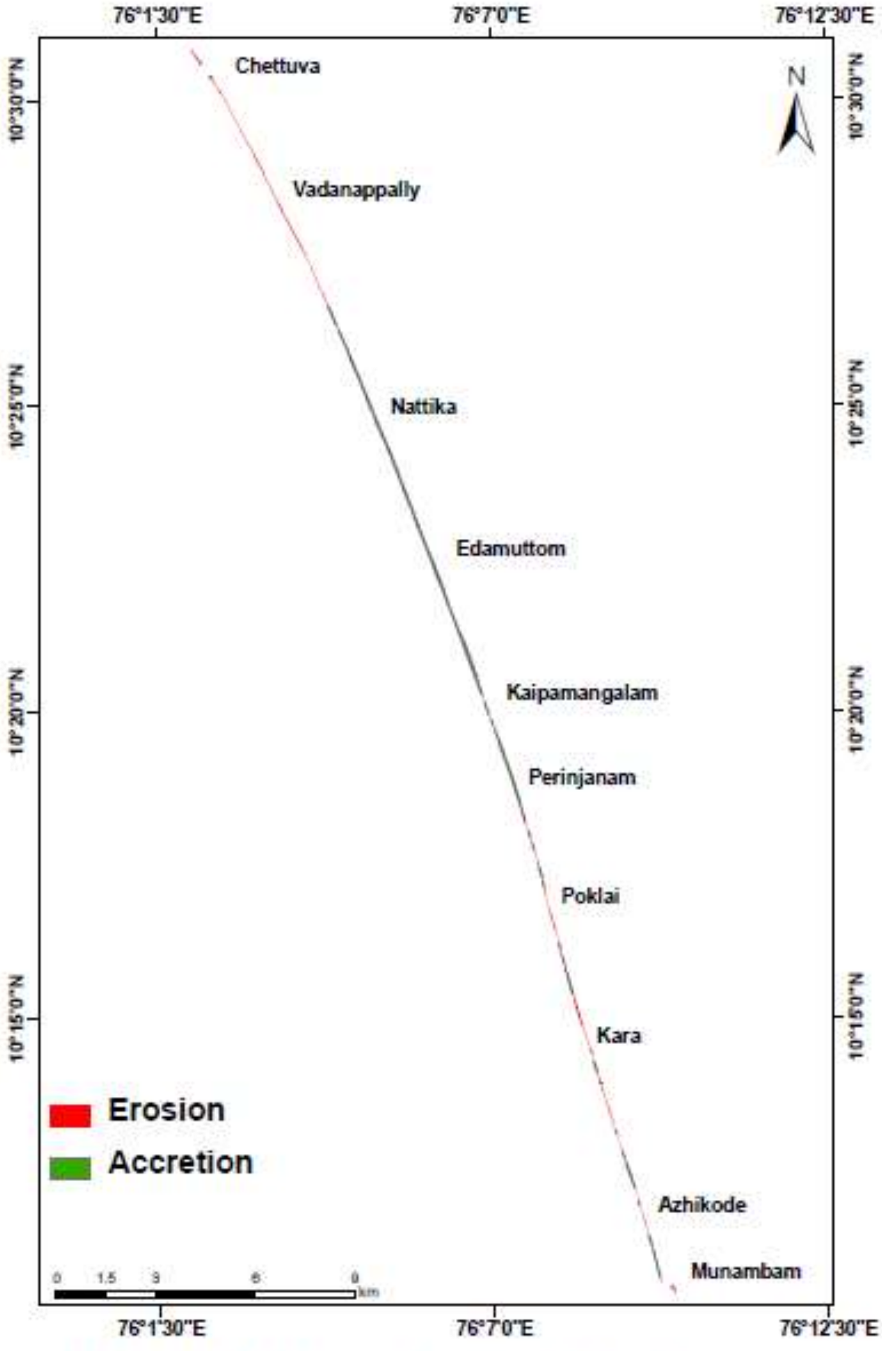


Fig 4.7 Shoreline Changes in Central Sector during 2005-2014

The construction of breakwater at Chettuva during 2010-2013 also enhanced erosion along Vadanapally–Chettuva region. Moreover, the shifting of mudbank significantly influenced the shoreline morphology of the sector. During this period the occurrence of mudbanks was along Kaipamangalam-Peringanam region and this facilitated erosion in the southern side of mudbank.

Northern Sector

The areal extend of erosion during the period 1967-2000 in the northern sector is 0.149 sq.km and the net change during 2000-2005 and 2005-2014 are 0.051 and 0.090 sq.km accretion respectively. In the open beaches from Kozhikode to Puthiyappa (11km) accretional nature is noticed during 1967-2000 (Fig. 4.8). The presence of mudbank and the construction of breakwater in Puthiyappa at early 90's enhanced accretion in the region. The beaches experience progressive erosion because of sediments being trapped by human structures resulting in the formation of wide beaches on the updrift side and erosion downdrift (MartínezdelPozo and Anfuso, 2010). While the rate of accretion decreased during the period 2000-2005 and 2005-2014 due to the mudbank shift and extensive sand mining at Puthiyappa harbour area (Fig. 4.9 and 4.10). Local information says that mudbank did not form at Puthiyappa for the last ten years and reappeared in 2010. The reappearance of mudbanks may be the reason for the beach build up along the stretch and consecutive erosion in the downdrift side.

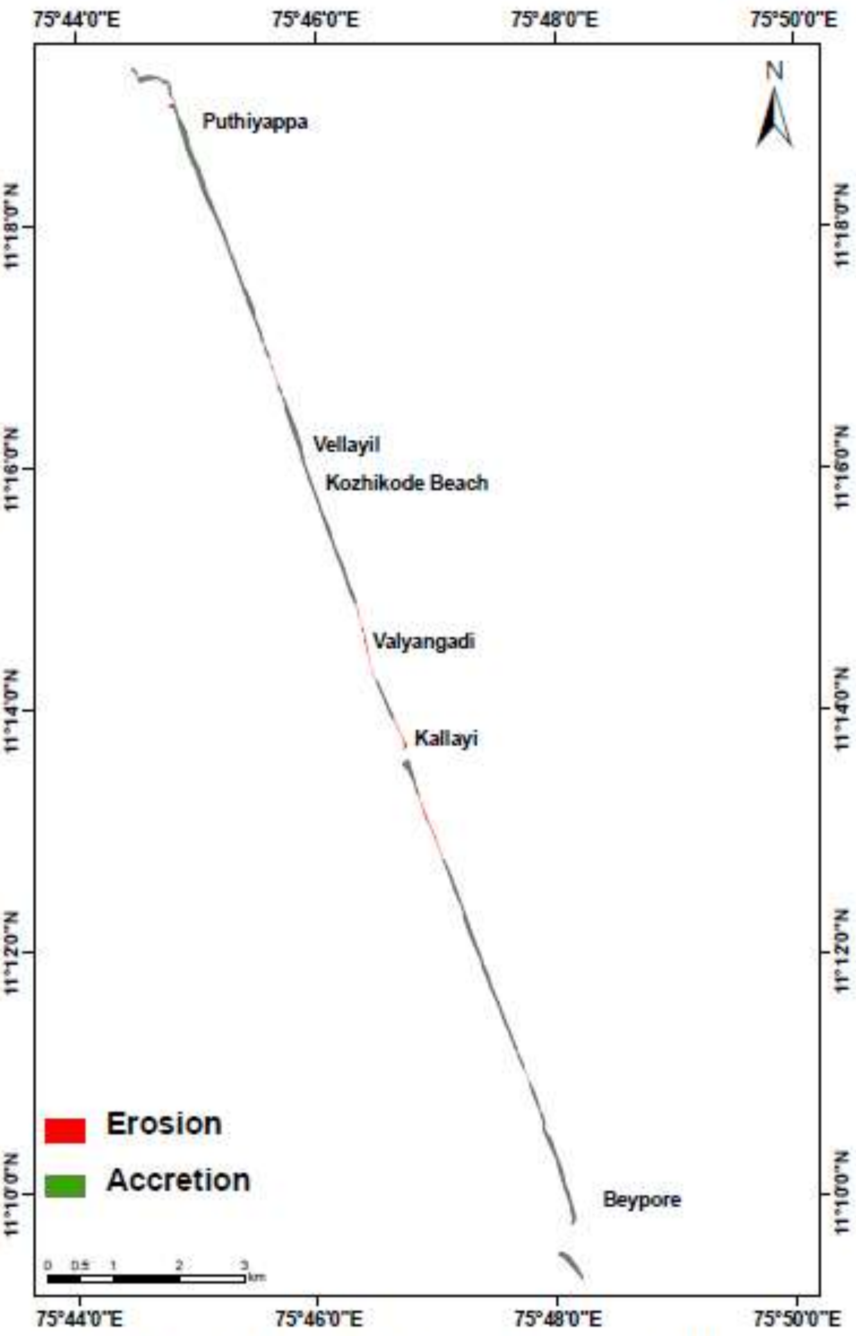


Fig 4.10 Shoreline Changes in Northern Sector during 2005-2014

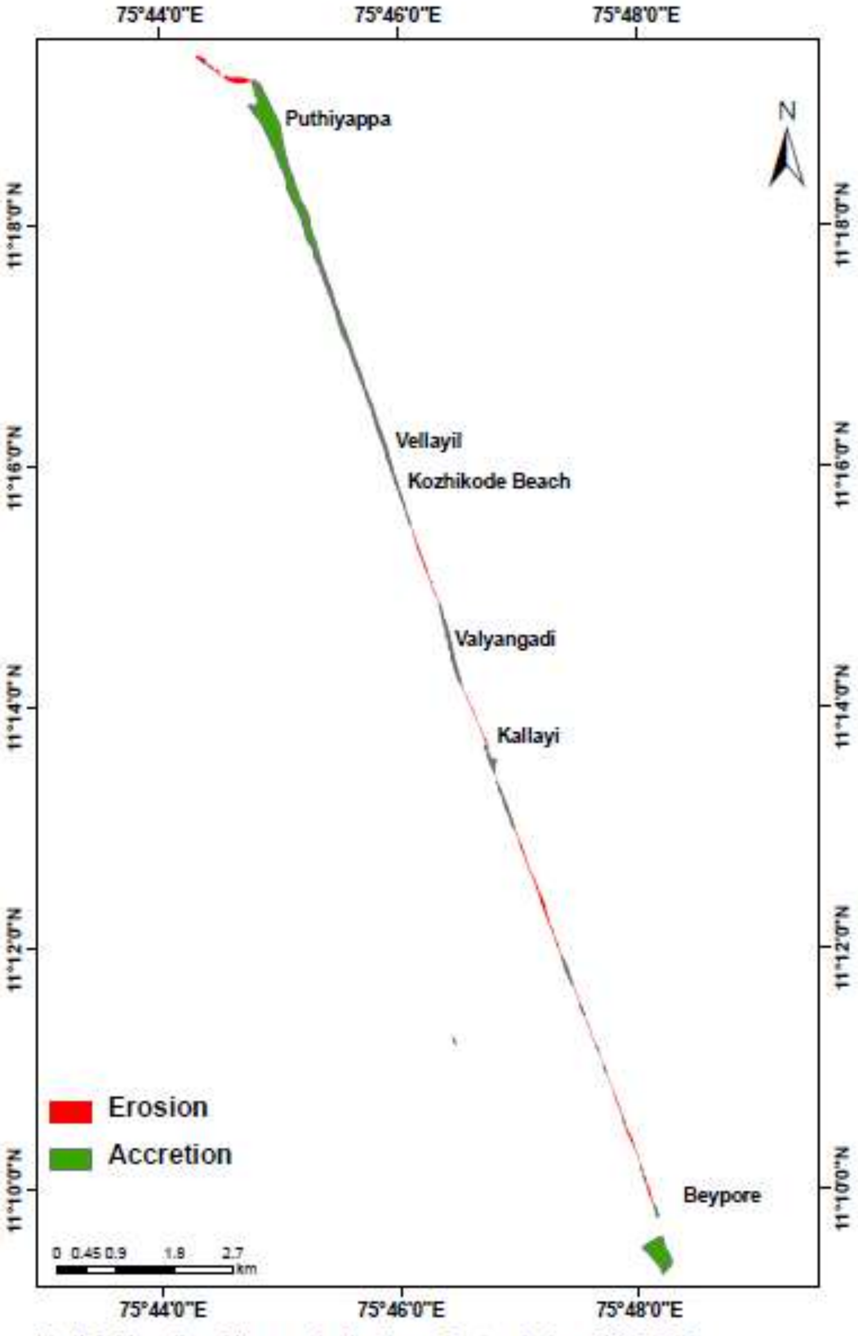


Fig 4.8 Shoreline Changes in Northern Sector during 1967-2000

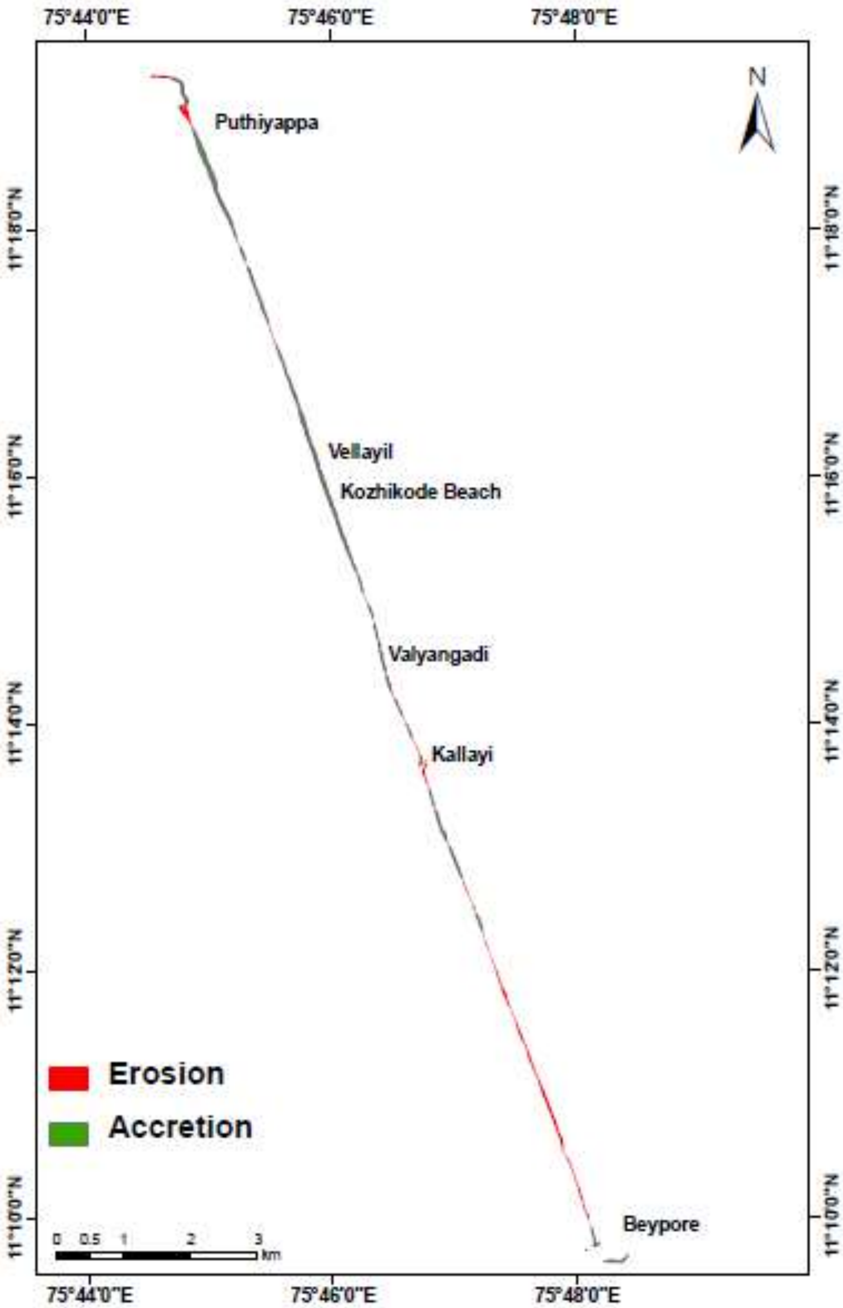


Fig 4.9 Shoreline Changes in Northern Sector during 2000-2005

The coastal stretch from Beypore to Valiyangadi (9km) was dominated by erosion during 1967-2000 and 2000-2005. The construction of breakwater at Kallai and the subsequent seawalls which were maintained continuously through regular repair reduced the erosional rate during 2000-2005. Construction of seawalls north of Beypore harbour could have been necessitated due to erosion as a consequence of breakwater construction. As auctioned by the harbour engineering department, a large quantity of beach sand is being mined from the accreting beach immediately south of Puthiyappa breakwater every year. Beach sand is thus continuously lost from the area which has an adverse impact on shoreline stability.

The three energy regimes possessed stable beaches where the rate of erosion decreased during 2000-2005-2014 compared to the earlier periods. The implementation of artificial structures deduced the erosional rate. At the same time, these structures also reduced the accretion rate at the nearby stable beaches. The central and northern sectors having low energy condition and mudbank effects showed more stability than the high energy regime. The results obtained through the geospatial studies supports the beach dynamics discussed in chapter 3.

CHAPTER V

SEDIMENT CHARACTERIZATION OF THE VIZHINJAM PORT - A PILOT STUDY

5.1 INTRODUCTION

Port terminals and harbours play a key role in the worldwide economy through the transportation and storage of traded goods. On the other hand, their operating activities are extremely harmful to marine and coastal environments. Since the activities of marine ports are associated with the contamination of aquatic environment, they are the significant sources of pollution. The construction of ports may also adversely affect the coastal zone environment, such as the construction of jetties: which can interrupt the normal sediment transport, pollution due to the generation of waste, the discharge of contaminants: such as sewage and waste water, etc. Contaminants get in to the aquatic environment through shipping, traffic, loading, repairs and dredging as well as rainwater runoff, effluent discharge, dust etc. The physical and chemical parameters and their dynamics in the harbour water area depend on human activity (Stakeniene *etal*, 2011)

Pollution by heavy metals in natural environments has become a global problem (Irabein and Velasco, 1999). The concentration of heavy metals in the aquatic environment need considerable ecological concern due to their toxicity, wide sources, non-biodegradable properties and accumulative behaviours. With the rapid industrialization and economic development in coastal region, heavy metals are introduced to the estuarine and coastal environment through rivers, land runoff and land based point sources where metals are produced as a result of metal refinishing byproducts (Ruilian *etal*,2008). When metals enter into the marine environment, most of them will settle down and be incorporated into sediments together with organic matters, Fe/Mn oxides, sulfides and clay (Chen,2000). Marine sediments act as scavengers for trace metals and often provide an excellent proof of man's impact (Guevara *etal*, 2005).

Kerala has a coastline serviced by 17 intermediate and minor ports and one major port at Cochin with container terminal (https://en.wikipedia.org: Ports and harbours of Kerala). As the maximum transportation of the state is through sea, it is inevitable for the state to develop a container terminal to crater traded goods. As part of this the Government of Kerala has been motivated to develop the Vizhinjam port in to a fully-fledged Vizhinjam International Deepwater Multipurpose Seaport for a long time. The proposed port at Vizhinjam is just 10 nautical miles from the International Shipping Lane and it is endowed with a natural seawater depth of up to 24 m as close as one nautical mile from the seacoast. Due to this natural depth, Vizhinjam can attract the largest container vessels currently in operation and also the future mega container carriers. Since the operating activities of the port terminals/harbours are recognized to be extremely harmful to the coastal environment an Environmental Impact Assessment (EIA) is inevitable. Therefore an attempt has been made to create a baseline data for Vizhinjam Sea port with respect to sediment and chemical characterization.

The Adimalathura–Kovalam coastal area has earthy/rocky cliffs fronted by narrow sandy beaches. The coastal stretch of Adimalathura which is at south-east of the proposed port is a sandy beach which develops during the non monsoon period and erodes with the onset of monsoon. The Vizhinjam- Kovalam coastal stretch possesses headlands. Towards north of Kovalam, seawall is provided to protect the settlements lined close to the shore from erosion. Total 14 samples were collected from 3 transects T1, T2 and T3 at a depth of 3m, 5m, 10m, 15m and 20m. The locations were represented as T1, T2 and T3 represents Adimalathura, Mullur and Kovalam respectively (Fig 5.1).

5.2 REVIEW OF LITERATURE

Interrelationship between grain-size frequency, distribution and processes has been used successfully in many earlier studies to identify the depositional environment. Heavy minerals often serve as the best tool for the reconstruction of provenances. It has also proved to be an important contributor to the analyses of sedimentation associated with tectonically active hinterlands. Wong *etal* (2013) carried out the heavy mineral analysis for assessing the provenance of sandy sediment in the San Francisco Bay Coastal System. Hedge *etal* (2006) studied the provenance of heavy minerals with special reference to ilmenite of the Honnavar beach, central west coast of India. Gandhi and Raja (2014) studied the heavy mineral and the grain size distribution within the coastal sediments

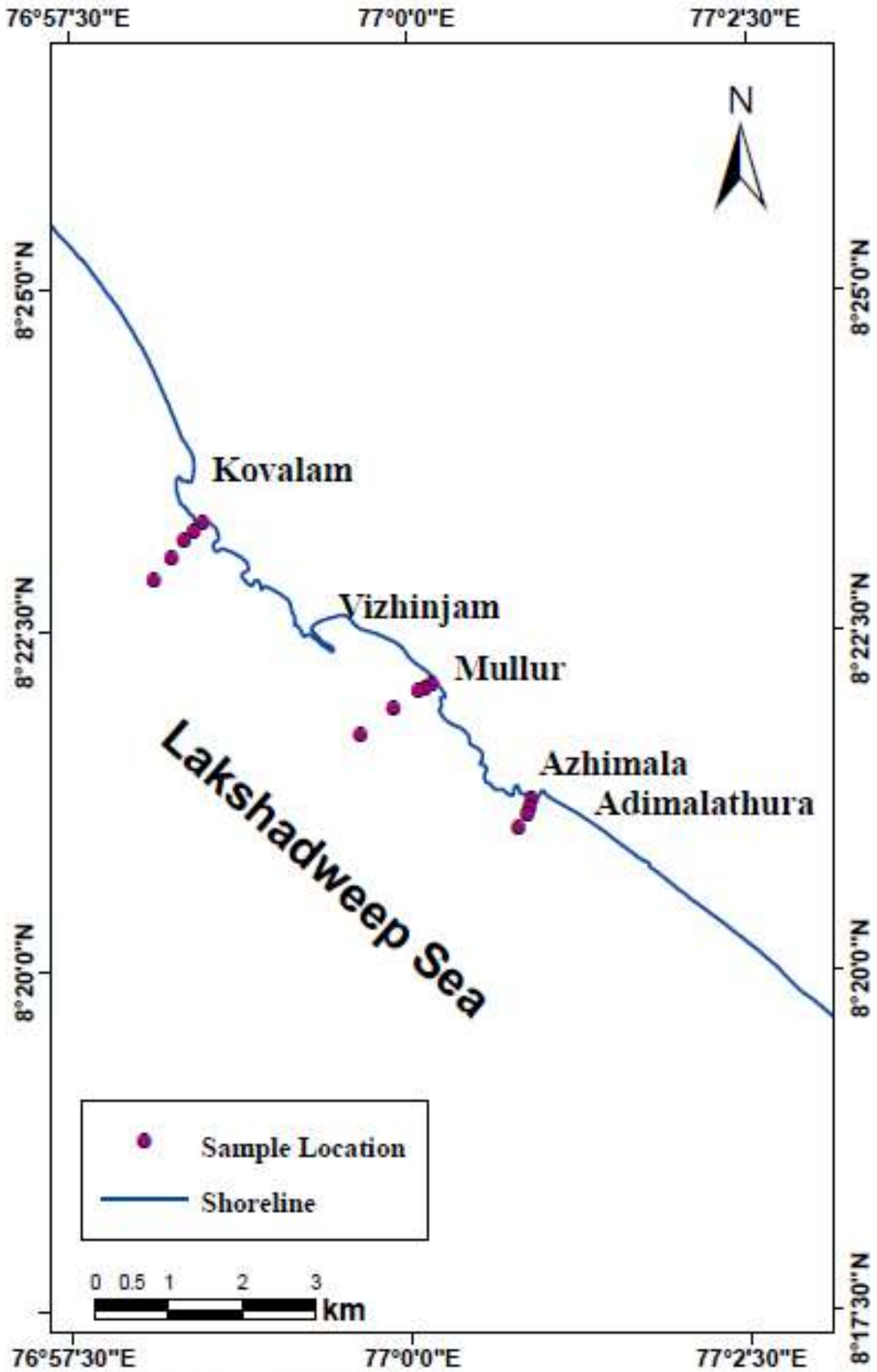


Fig 5.1 Location Map of Vizhinjam Port Area

between Besant Nagar and Marakkanam, Tamil Nadu and their study indicated that the wave energy conditions are contributors to the formation of heavy minerals in the region. Kumar and Asaithambi (2013) investigated the seasonal impact on the status of heavy mineral distribution along the Tamil Nadu coast and they concluded that the heavy minerals associated with sediments indicate that they are derived from metamorphic terrain dominated by Precambrian gneiss and quartzite of Indian Peninsular Shield. Anooja *etal (*2013) studied the provenance and depositional history of the late quaternary sediments including heavy mineral placers in the coastal lands of Quilon.

Studies on heavy metal pollution especially in the coastal zones increased over a last few decades at global scale taking into account of the coastal developmental activities. Many studies have been carried out world over to understand the geochemical behavior of elements moving from land to sea through various fluvial systems, where in addition to natural inputs, concomitant activities such as harbour, industrial, residential and agricultural activities can release heavy metals to the environment. The geochemical investigations were undertaken to understand the distribution, sources and processes by which various major and trace elements are incorporated in the sediments (Paropkari, 1990). There has been a great spurt of renewed activity to identify the source and sinks of heavy metals in rivers, estuaries and nearshore environments. The fate of heavy metals in these environments is of extreme importance due to their impact on ecosystem (Vale, 1986; Mance, 1987; Klomp, 1990; Windom, 1990). The concentration of elements in sediments not only depend on anthropogenic and lithogenic sources but also upon the textural characteristics, organic matter content, mineralogical composition and depositional environment of sediments (Tefry and Presely, 1980). Fulya Yucesoy and Mustafa Ergin, (1999) studied the heavy metal geochemistry of surface sediments from the Southern Black sea shelf and upper slope and the metal concentration in the area indicates the terrestrial sources. Zubair *etal* (2014) carried out the heavy metal distribution and contamination indicator in the sediments of coastal areas **of** Karachi, Sindh, Pakistan. Imo *etal*, (2014) revealed that, contamination of heavy metals in coastal areas at the commercial and fishing ports in Samoa is a serious exotoxicological and environmental problem due to direct runoff from anthropogenic wastes, commercial vessels and discharge from industrial effluents which may accumulate in the suspended particulate matter and settle on the bottom sediments. Garcia and Gomez (2005) assessed the pollution levels in the harbour of Ceuta, North Africa, to discuss the origin of contaminants in the harbour, and to evaluate the environmental implications. Buruaem *etal* (2012) estimated the contamination of port zone sediments by metals from Large Marine Ecosystems of Brazil and concluded that sediment contamination by metals poses risks to coastal ecosystems. Fatoki and Mathabatha, (2001) carried out an assessment of heavy metal pollution in the East London and Port Elizabeth harbours and their results indicated that the contribution of heavy metal pollution are from storm water drains and streams which carry runoff from industrial, urban and residential sources. They also concluded that the levels did not exceed the guidance level but a close monitoring is needed due to the increasing activities at the ports.

The physico-chemical properties such as texture, organic content, pH, Eh etc. affect the behaviour of metals in sediments (Machado *etal*, 2008). Nisha and Achyuth, (2014) studied the geochemical evaluation of the continental shelf sediments, south east coast of India and reveals insignificant pollution along the entire coast of TamilNadu. Sudarsan *etal* (2013) and Anitha and Sugirtha (2014) focused on the heavy metal distribution, textural pattern and organic carbon inorder to assess the extent of environmental pollution. Mallik *etal* (1997) carried out an integrated study to understand the sediment mobility and wave climate in the area to throw light on the siltation problems faced due to construction of breakwater. Anilakumary *etal* (2001) studied the sediment characteristics of Poonthura estuary in relation to pollution. Angusamy and Rajamanickam (2006) inferred that the variation in sedimentological parameters is governed by fluvial input, wave dynamics and littoral transport of the sediments

5.3 RESULT AND DISCUSSION

5.3.1 Sediment characteristics

Grain size characteristics of sediments play a significant role in coastal dynamics. They are controlled by several factors such as sediment source, hydrodynamics, and biological factors that modify erosion/accretion processes. The sediments are important sinks for various pollutants like heavy metals and also play a major part in the remobilization of contaminants in aquatic systems under favourable conditions (Naji *etal*, 2010).The sediments were nomenclature by plotting the percentages of sand, silt and clay on a triangular coordinate paper following Folk and Ward (1957) and are provided in Fig 5.2. The sand, silt and clay proportions as determined for the study are given in Table 5.1 and the sediments are of sandy nature. The percentage of sand ranges from 99.3% to 99.7% at Adimalathura, 89.9% to 99.6% at Mullur and 97.4% to 99.5% at Kovalam respectively. The silt percentages vary from 0.69% to 1.24% at Adimalathura, 0.88% to 8.62% at Mullur and 0.45% to 1.34% at Kovalam whereas the percentages of clay at these locations are 0.02% to 0.75%, 0.02% to 1.39% and 0.04% to 0.94% respectively. The mean values ranges from 2.19 to 3.57φ indicating a predominant distribution of fine to very fine sand in the area (Table 5.2). The sediments are moderately well sorted to very well sorted and are symmetrical to coarse skewed. The winnowing action of the waves aided by the steep bathymetry may be a reason for the high concentration of sand in the region. High percentage of sand may be explained in terms of tidal currents and wave action which prevent the settling of fine material from suspension (Neto *etal*, 2000). The higher sand content in the area indicates that currents from the abrasion zone transport the finer sediments once they reach the coast (Szefer and Skwarzec, 1988).

A distinct variation in the total heavy mineral percentage of bulk sediments of the three transects (Adimalathura, Mullur and Kovalam) is given in Table 5.3. The percentage of heavy minerals vary from 1.1% to 15.6% at Adimalathura, 5.84% to 17.74% at Mullur and 8.54% to 29.74 at Kovalam where the highest

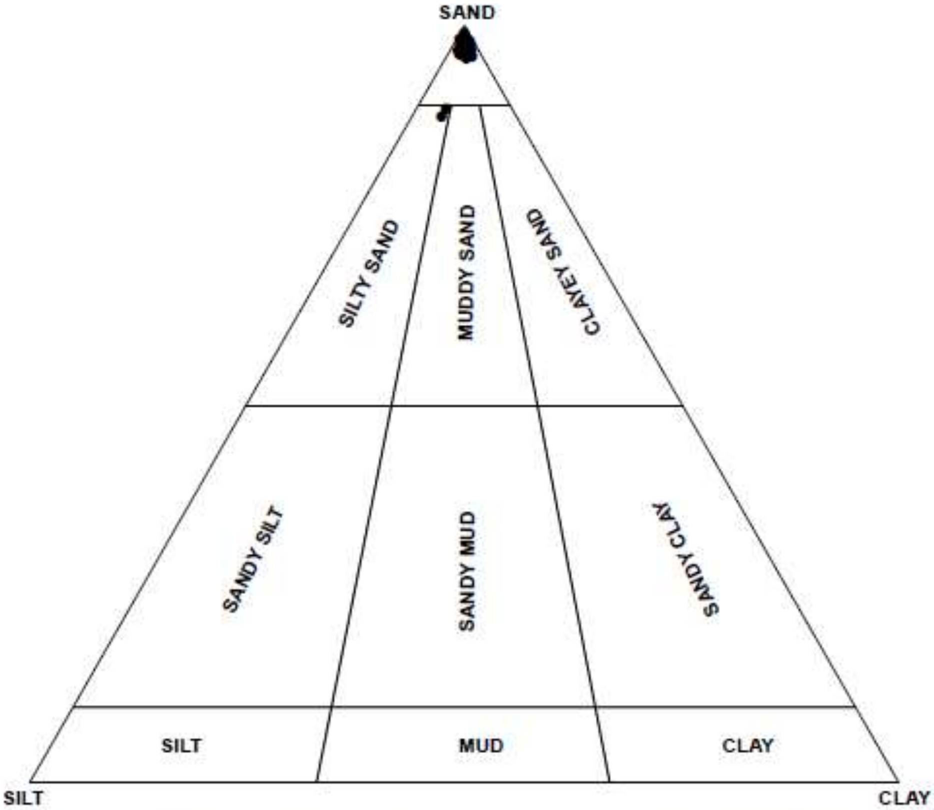


Fig. 5.2 Textural nomenclature of the nearshore sediments from Vizhinjam Port area

Table: 5.1 Percentage of sand, silt and clay of nearshore sediments of Vizhinjam Port area

Locations	Sand %	Silt %	Clay %	Sediment type
T1 (3m)	99.63	0.69	0.02	Sand
T1 (5m)	99.30	0.97	0.05	Sand
T1 (10m)	99.40	1.24	0.75	Sand
T1 (15m)	99.73	0.83	0.07	Sand
T2 (3m)	99.33	1.18	0.03	Sand
T2 (5m)	99.67	0.88	0.02	Sand
T2 (10m)	89.99	8.62	1.39	silty Sand
T2 (15m)	90.92	7.69	1.39	silty Sand
T2 (20m)	97.43	1.92	0.65	Sand
T3 (3m)	98.72	1.34	0.04	Sand
T3 (5m)	99.51	1.06	0.13	Sand
T3 (10m)	97.99	1.34	0.67	Sand
T3 (15m)	98.11	0.95	0.94	Sand
T3 (20m)	99.32	0.45	0.24	Sand

Table: 5.2 Textural parameters of nearshore sediments of Vizhinjam Port area

Locations	Mean (φ)	Sorting (φ)	Skewness (φ)	Kurtosis (φ)
T1 (3m)	2.56	0.47	-0.18	1.14
T1 (5m)	2.60	0.45	-0.17	1.20
T1 (10m)	3.04	0.51	-0.02	1.05
T1 (15m)	1.14	0.50	0.10	1.86
T2 (3m)	2.46	0.41	0.14	0.97
T2 (5m)	2.20	0.46	0.05	0.96
T2 (10m)	3.57	0.52	-0.13	1.63
T2 (15m)	3.45	0.61	-0.01	1.69
T2 (20m)	2.35	1.07	0.08	0.61
T3 (3m)	2.86	0.47	-0.13	1.18
T3 (5m)	2.73	0.53	-0.16	1.24
T3 (10m)	3.07	0.42	-0.06	1.02
T3 (15m)	2.91	0.43	0.11	1.13
T3 (20m)	2.23	0.56	0.09	0.97

Table: 5.3 Weight percentage of heavy and light minerals in the nearshore sediments of Vizhinjam Port area

Locations	Heavy mineral %	Light mineral %
T1 (3m)	7.06	92.93
T1 (5m)	5.33	94.67
T1 (10m)	15.67	84.33
T1 (15m)	1.10	98.90
T2 (3m)	11.44	88.55
T2 (5m)	5.84	94.16
T2 (10m)	15.75	84.25
T2 (15m)	17.74	82.26
T2 (20m)	8.62	91.38
T3 (3m)	9.87	90.13
T3 (5m)	15.82	84.18
T3 (10m)	29.74	70.26
T3 (20m)	8.54	91.46

concentrations are observed at a depth of 10-15m. The light mineral percentages at Adimalathura, Mullur and Kovalam are 84.4% to 98.9%, 82.2 to 94.1% and 70.2 to 90.1% respectively.

The heavy mineral percentage in different size fractions of the three transects is shown in the Table 5.4. Among the three transects, Kovalam shows a higher heavy mineral percentage with an average value of 1.07 in medium, 10.24 for fine and 35.95 in the very fine sand.

The number percentages of different size fraction (medium, fine and very fine) were identified. In the nearshore sediments collected at varying depths from Adimalathura, the opaques and sillimanite are the dominant minerals in the medium fraction ranging from 19% to 32.2% and 28.6% to 53.4% respectively (Table 5.5). The other minerals are topaz and garnet which constitute less than 10%. Hypersthene, biotite, monazite and rutile are found only in negligible amount. Whereas in the case of fine fractions, opaques range from 18.1% to 43.8% and sillimanite ranges from 47.7% to 82.8% and amongst the very fine fractions, the opaques range from 30.7% to 47.4% and sillimanite ranges from 41.7% to 55.1%. In the fine and very fine fractions, minerals like zircon, hypersthene and biotite are found less than 5%.

In Mullur, among the medium size fractions, the dominant minerals are opaques and sillimanite. They range from 13.5% to 53.6% and 15.9% to 45.3% respectively (Table 5.5). In this fraction biotite ranges from 1% to 45% and other minerals like topaz, garnet, zircon, hypersthene and monazite are less than 10%.

Table 5.4 Weight percentage of heavy and light minerals in the different size fractions in Vizhinjam Port area

Location	Size fractions	Heavy Mineral %	Light Mineral %
T1 3	very fine	33.24	66.76
	fine	3.96	96.04
	medium	0.23	99.77
T1 5	very fine	23.07	76.93
	fine	2.83	97.17
T1 10	very fine	24.54	75.46
	fine	4.52	95.48
	medium	0.25	99.75
T1 15	very fine	14.32	85.68
	fine	7.32	92.68
	medium	0.06	99.94
T2 3	very fine	53.75	46.25
	fine	6.55	93.45
	medium	0.28	99.72
T2 5	very fine	52.78	47.22
	fine	5.91	94.09
	medium	0.35	99.65
T2 10	very fine	8.69	91.31
	fine	7.55	92.45
	medium	0.08	99.92
T2 15	very fine	15.45	84.55
	fine	10.12	89.88
	medium	0.89	99.11
T2 20	very fine	18.87	81.13
	fine	9.16	90.84
	medium	0.22	99.78
T3 3	very fine	19.05	80.95
	fine	12.84	87.16
	medium	0.51	99.49
T3 5	very fine	30.53	69.47
	fine	10.24	89.76
	medium	0.76	99.24
T3 10	very fine	38.15	61.85
	fine	14.79	85.21
	medium	2.29	97.71
T3 15	very fine	31.47	68.53
	fine	6.52	93.48
	medium	1.47	98.53
T3 20	very fine	60.57	39.43
	fine	6.82	93.18
	medium	0.31	99.69

Table: 5.5 Number percentage of heavy minerals in Vizhinjam port area

MEDIUM FRACTION											
Location	**Depth (m)**	**Opaqes**	**Sillimanite**	**Zircon**	**Topaz**	**Garnet**	**Hypersthene**	**Biotite**	**Monazite**	**Rutile**	**Others**
Adimalathura	3	28.8	45.4	1.2	2.4	4	0.9	17	0	0.3	0
	10	19	28.6	4.6	7.1	1	1.5	37.2	1	0	0
	15	32.2	53.4	0	2.1	12.3	0	0	0	0	0
Mullur	3	53.6	15.9	0	2.6	4.2	0	23.7	0	0	0
	5	16.6	45.3	1.5	2.1	7.9	1.8	24.5	0	0.3	0
	15	34.2	40.9	3	9.6	10	0.3	1	0	1	0
	20	13.5	24.9	0	9.6	7	0	45	0	0	0
Kovalam	3	14.5	58.8	0.9	5.9	12.2	3.6	4.1	0	0	0
	5	38.2	51.4	0.3	4	4.3	0.9	0	0.6	0	0.3
	10	30.1	40.3	1.3	4.2	9	3.2	11.9	0	0	0
	15	42.1	44.4	5.1	1.5	4.8	1.8	0.3	0	0	0
	20	16.5	52	0.5	23.1	5.1	2.3	0.5	0	0	0
	Average	*28.3*	*41.8*	*1.5*	*6.2*	*6.8*	*1.4*	*13.8*	*0.1*	*0.1*	*0.0*
FINE FRACTION											
Location	**Depth (m)**	**Opaqes**	**Sillimanite**	**Zircon**	**Topaz**	**Garnet**	**Hypersthene**	**Biotite**	**Monazite**	**Rutile**	**Others**
Adimalathura	3	8.1	82.8	1.2	2.2	3.8	1.9	0	0	0	0
	5	10.4	77.6	0	4.7	4.1	1.6	1.6	0	0	0
	10	19.3	72.8	0.6	1	3.8	0.6	1.9	0	0	0
	15	43.8	47.6	0.9	1.7	5.1	0.9	0	0	0	0
Mullur	3	60.5	29.9	1.5	0	7.5	0.3	0.3	0	0	0
	5	52.5	37.9	1.7	2.5	4.8	0	0.3	0.3	0	0
	10	56	36.7	0.6	0	4.5	0.3	1.9	0	0	0
	15	13.3	81.1	0.6	1.3	3.1	0.6	0	0	0	0
	20	29.6	58.5	0.5	7.3	3.5	0.3	0.3	0	0	0
Kovalam	3	33.5	43.7	1.2	18.6	2.7	0	0	0.3	0	0
	5	38.6	55.6	1	2.6	1.6	0.3	0	0.3	0	0
	10	64	24.1	4.8	5.8	1.3	0	0	0	0	0
	15	52.7	36.1	1.7	6.1	2.8	0.3	0	0	0.3	0
	20	50.9	41.7	1.5	3.1	2.5	0.3	0	0	0	0
	Average	*38.1*	*51.9*	*1.3*	*4.1*	*3.7*	*0.5*	*0.5*	*0.1*	*0.0*	*0.0*
VERY FINE FRACTION											
Location	**Depth (m)**	**Opaqes**	**Sillimanite**	**Zircon**	**Topaz**	**Garnet**	**Hypersthene**	**Biotite**	**Monazite**	**Rutile**	**Others**
Adimalathura	3	46.1	41.7	0	7.8	2.2	2.2	0	0	0	0
	5	30.8	55.1	0	7.5	4.9	1.4	0	0	0.3	0
	10	30.7	47.6	0.6	14.6	4.9	1.6	0	0	0	0
	15	47.4	43.9	1.1	4.6	1.4	1.6	0	0	0	0
Mullur	3	50	32.9	2.6	7.9	6.3	0	0.3	0	0	0
	5	50.1	34.5	2.4	6	6.2	0	0	0	0.8	0
	10	46	35.4	0	14.4	1	2.9	0	0	0.3	0
	15	27.6	32.4	2.6	33.8	2.4	0.3	0	0	0.9	0
	20	27.4	28.4	1.3	40.1	2.2	0	0	0.6	0	0
Kovalam	3	34.7	54.8	3.6	5.1	0.3	0.3	0	0.9	0.3	0
	5	51.8	35.6	4.2	4.5	3	0	0	0.9	0	0
	10	63.6	11.8	8.9	10.7	1.2	0	0	3.8	0	0
	15	36.4	35.8	4.5	21.1	1.3	0.6	0	0.3	0	0
	20	50.9	17.5	2.1	28.6	0.6	0.3	0	0	0	0
	Average	*42.4*	*36.2*	*2.4*	*14.8*	*2.7*	*0.8*	*0.0*	*0.5*	*0.2*	*0*

In the case of fine fractions, opaques and sillimanite are ranging from13.3% to 60.5% and 29.9% to 81.1% respectively. Topaz, zircon, hypersthene and biotite together sum upto less than 10%. In very fine fractions, opaques and sillimanite range from 27.4% to 50.1% and 28.4% to 35.4% respectively. In this fraction topaz ranges from 6% to 40.1% and other minerals like garnet, zircon and hypersthene are not more than 10%.

In Kovalam, the opaques and sillimanite are the dominant minerals in the case of medium fractions ranging from 14.5% to 42.1% and 40.3% to 58.8% respectively (Table 5.5). In addition to the above, topaz and garnet range from 1.5% to 23.1% and 4.3% to 12.2% respectively. The other minerals like zircon, hypersthene, biotite and monazite are less than 10%. Among the fines, opaque and sillimanite constitute 33.5% to 64% and 24.1% to 55.6% respectively. Topaz, zircon, hypersthenes and biotite are less than 5%. Very fine fractions show the presence of opaque and sillimanite in the range of 34.7% to 63.6% and 11.8% to 54.8% respectively and minerals like topaz, garnet, zircon and hypersthenes constitute less than 10%.

The higher concentrations of heavy minerals are observed at Kovalam during monsoon period. The concentration of heavies is the result of strong winnowing action of waves rather than selective transport by longshore currents. Moderate to high energy conditions facilitate winnowing action of the waves and removal of lighter minerals leading to concentration of heavies. The presence of headlands may form another reason for the concentration of placers at Kovalam. The presence of headlands interrupts longshore drift and therefore the transportation of sediments by longshore current to the beach is a distant possibility. The offshore reservoir sands may form another source for the formation of beach placers which is in conjunction with the observation of Hedge *etal* (2006). Presence of heavy mineral around 15m depth off the coast of Kerala leads support to this interpretation (Mallik, 1974). Machado, 1995 inferred that the promontories at Kovalam act as barriers to the dominant southerly current and force the heavies to settle on the upstream side of these headlands.The seasonal variation of longshore currents, steepness of shelf and high wave energy may initiate panning of sediments (Baba and Kurian, 1988: Prakash *etal,* 1999). The concentration of heavy minerals depends on the hydrodynamic conditions like sediment in the flux from the hinterland, wave energy and its velocity, longshore current and wind which controls littoral transport, sorting and deposition of placer minerals in suitable locations (Rao *etal*, 2001). It can be concluded that the heavy mineral distribution at Vizhinjam area is the culmination of the above referred factors.

5.3.2 Geochemistry

Geochemical studies of surface sediments along the coast have been intensified in the last few decades due to the growing awareness of coastal contamination from various sources discharged in the coastal environment. It is determined to a large degree by their interaction with sediments. As a result, sediments act as integrators and amplifiers of concentration of many hazardous elements in the waters, which pass over and transport them to the shallow coastal areas (Jonathan *etal*, 2004). The sediments are both carrier and potential source of natural geochemical constituents, derived principally from rock weathering. The sediment particles can either absorb/adsorb many contaminants, such as toxic metals, pesticides and radio nuclides that are transported and deposited as a part of the sedimentary component. The natural sources like soil erosion, rock weathering and the dissolution of water soluble salts, and anthropogenic activities such as industrial effluence, domestic and agricultural waste water are the major basis of enrichment of metals in an aquatic system (Al- Juboury *etal*. 2009).

The geochemical constitution of the sediments and their relative abundance in and around Vizhinjam port are given in the Table 5.6 and 5.7 and it's inter elemental correlation matrix is provided in Table 5.8 and 5.9. The inter elemental correlation matrix ascertains the relation between the elements and their behaviour pattern. Likewise the results can also be used as an effective tool for demarcating the zones of maximum and minimum variation.

5.3.2a Organic carbon

Organic matter is an important factor that has to be considered in geochemical evaluation of any environment as it is being considered as the major agent of retention and transportation of heavy metals. (Hunt, 1981; Davies, *etal*., 1991).The important factors affecting the accumulation of organic matter in the sediment depends on the supply of organic matter, texture of sediments, rate of

Table: 5.6 Concentration of C-org and major elements (%) in the nearshore sediments of Vizhinjam Port area

Locations	C-org	Na	K	Ca	Mg	Fe	Mn	Ti	Si	Al	P
T1 (3m)	0.67	1.23	0.75	3.67	0.14	0.99	0.03	0.39	38.22	3.69	0.03
T1 (5m)	0.78	1.33	0.84	3.89	0.24	1.07	0.04	0.29	37.59	3.75	0.03
T1 (10m)	0.65	1.10	0.82	3.57	0.16	1.06	0.05	0.92	37.32	4.14	0.03
T1 (15m)	0.63	1.13	0.52	0.69	0.12	0.65	0.04	0.15	42.80	2.83	0.02
T2 (3m)	0.82	1.15	0.73	3.43	0.03	1.16	0.01	0.94	38.06	3.61	0.03
T2 (5m)	0.76	1.24	0.77	3.03	0.09	1.04	0.04	0.52	38.82	3.56	0.03
T2 (10m)	0.10	1.39	1.09	3.23	0.46	1.76	0.07	0.86	36.41	4.69	0.04
T2 (15m)	0.15	1.31	0.92	3.02	0.41	1.93	0.07	1.09	35.97	4.75	0.05
T2 (20m)	0.53	1.16	0.71	1.80	0.21	1.12	0.05	0.55	39.95	3.54	0.03
T3 (3m)	0.30	1.19	0.61	2.69	0.07	0.73	0.02	0.65	39.42	3.42	0.03
T3 (5m)	0.44	1.13	0.53	1.53	0.08	1.15	0.03	1.29	39.54	3.88	0.03
T3 (10m)	0.17	1.19	0.72	2.99	0.33	2.62	0.02	2.45	35.06	4.39	0.07
T3 (15m)	0.14	1.17	0.61	0.09	0.08	1.17	0.06	1.66	40.70	3.87	0.02
T3 (20m)	0.62	1.10	0.52	0.33	0.11	0.90	0.06	0.69	42.26	3.28	0.02

Table: 5.7 Concentration of trace elements (ppm) in the nearshore sediments of Vizhinjam Port area

Locations	Cu	Ni	Pb	Zn	Zr	Cr
T1 (3m)	38	12	3	8	251	50
T1 (5m)	57	28	8	14	122	29
T1 (10m)	26	38	13	37	2897	88
T1 (15m)	29	33	16	31	111	15
T2 (3m)	12	16	7	21	974	60
T2 (5m)	37	23	4	29	477	38
T2 (10m)	29	45	16	61	2467	97
T2 (15m)	27	42	12	53	3643	93
T2 (20m)	40	22	9	51	1786	48
T3 (3m)	17	31	11	24	1597	62
T3 (5m)	9	46	15	53	2509	92
T3 (10m)	25	62	18	74	8550	136
T3 (15m)	31	51	23	66	4518	86
T3 (20m)	37	30	14	48	697	56
Average	30	34	12	40	2096	66

Table 5.8 Inter-elemental correlation matrix of major elements in the nearshore sediments of Vizhinjam port area

	C-org	*Sand %*	*Silt %*	*Clay %*	*Na*	*K*	*Ca*	*Mg*	*FeO*	*Mn*	*Ti*	*Si*	*Al*	*P*
C-org	1.00													
Sand %	0.68	1.00												
Silt %	-0.60	-0.99	1.00											
Clay %	-0.75	-0.86	0.80	1.00										
Na	-0.33	-0.70	0.71	0.42	1.00									
K	-0.22	-0.73	0.76	0.60	0.81	1.00								
Ca	0.20	-0.18	0.26	0.00	0.54	0.72	1.00							
Mg	-0.56	-0.85	0.83	0.77	0.72	0.76	0.35	1.00						
FeO	-0.61	-0.57	0.51	0.62	0.41	0.49	0.29	0.74	1.00					
Mn	-0.35	-0.62	0.59	0.71	0.33	0.38	-0.29	0.49	0.06	1.00				
Ti	-0.62	-0.16	0.08	0.43	-0.10	-0.01	-0.10	0.23	0.76	-0.14	1.00			
Si	0.31	0.49	-0.51	-0.45	-0.59	-0.77	-0.80	-0.66	-0.77	0.09	-0.44	1.00		
Al	-0.62	-0.75	0.74	0.80	0.58	0.76	0.45	0.78	0.81	0.34	0.56	-0.85	1.00	
P	-0.49	-0.45	0.41	0.49	0.42	0.52	0.50	0.73	0.93	-0.10	0.64	-0.85	0.75	1.00

Table 5.9 Inter-elemental correlation matrix of minor elements in the nearshore sediments of Vizhinjam port area

	C-org	*Sand %*	*Silt %*	*Clay %*	*Cu*	*Ni*	*Pb*	*Zn*	*Zr*	*Cr*
C-org	1.00									
Sand %	0.68	1.00								
Silt %	-0.60	-0.99	1.00							
Clay %	-0.75	-0.86	0.80	1.00						
Cu	0.29	0.04	-0.08	-0.03	1.00					
Ni	-0.78	-0.36	0.30	0.58	-0.28	1.00				
Pb	-0.69	-0.24	0.16	0.51	-0.27	0.86	1.00			
Zn	-0.76	-0.47	0.38	0.71	-0.24	0.84	0.79	1.00		
Zr	-0.71	-0.28	0.20	0.56	-0.30	0.84	0.62	0.79	1.00	
Cr	-0.72	-0.44	0.39	0.62	-0.47	0.77	0.53	0.74	0.89	1.00

decomposition, oxygen content of water and depth of water. Study of organic carbon in the marine environment is an important area of investigation, which can throw light on the biogeochemical cycling of elements, ecosystem energy and transport of pollutants. The organic carbon in the sediment is mainly derived from the terrigenous runoff and to some extend primary production. The high inputs of terrigenous material from the adjacent land mass and discharge of nearby industrial effluents may enhance the organic carbon (Rajamanickam and Shetty, 1973). Organic carbon increases with increasing finer fraction and its enrichment suggests the co-deposition of finer sediments (Kumar *etal*, 2009).

The percentage organic carbon at Adimalathura, Mullur and Kovalam varies from 0.63 to 0.78%, 0.10 to 0.82% and 0.14 to 0.62% respectively (Table 5.6). The lower values of organic carbon indicate the predominance of sand. The southern Kerala coast (Paravur and Veli) recorded low organic carbon with high percentage of sand and the irregularity in the behaviour of the sediment organic carbon could be attributed to the biological utilization of detrital matter (Robin *etal*, 2012). The sandy and shallow nature of the coastal region supports the above inference (Rozonov *etal*, 1974). Low organic carbon values might be related with the poor absorbability of organics by sand dominant regions and constant flushing activity by tides along with the input of waves (Anitha *etal*, 2014). The low organic carbon in the study area can be attributed to the coarse nature of the sediments and high tidal and wave activity.

5.3.2b Major Elements

Distribution of grain size and organic matter are the two critical factors influencing the metal distribution in sediments (Aloupi and Angeleder, 2001; Huang and Lin, 2003). Fine sediments are considered to be an important carrier as well as a sink of heavy metals in the hydrological cycle (Celo *etal*, 1999). Weathering and erosion of bedrocks are the natural sources of heavy metals in sediments near the coast. Generally the harbours get contaminated as they are the point source for the discharge materials, fishing activities, antifouling paints and drainage sewage. Recently the anthropogenic contribution of heavy metals into the coastal environment far exceeds the natural inputs. The majority of heavy metal emissions from anthropogenic activities accumulate in river and ocean sediments when they are absorbed in to clays and other fine grained materials (Kamau, 2002). Natural concentrations of major and trace elements are strongly influenced by the nature of the inorganic matter that results from physical and chemical weathering. The rock forming silicate minerals with smaller contributions from metal oxides and sulfides that make up the material is transported in the coastal zone (Carvalho *etal*, 2002). The concentrations and the averages of all the measured metals in the Vizhinjam nearshore surface sediments are depicted in table 5.6.

Sodium (Na) and Potassium (K)

Sodium and Potassium mainly comes into sediments as a weathering product of minerals like feldspars, feldspathoids, amphiboles and pyroxenes. Sodium and

Potassium behaves similarly with depth indicating their close affinity. Sodium is a volatile and lithophile alkali element. It is the second most abundant element in seawater and the most abundant cation. Its concentration is limited mostly by interaction of seawater with seafloor through diagnetic and hydrothermal fluids. In contrast with potassium, there is no major Na rich clay mineral of major geological importance and most sedimentary Na resides in detrital feldspar. The carbonates, sulphates, nitrates and chlorides of sodium are found abundantly in nature. Na is a trace nutrient and one of the essential elements for living tissues and for human life. Although sodium is tied to chloride, it is also ion of silicate involved in the formation of silicate minerals and in cation exchange with clay sediments. In silicates the Na^+ ions normally occupies octahedral sites. Na ions set free by the weathering of feldspars are transported by rivers in to the sea in the dissolved load. The world average shale value of Na is 0.59%.

Like sodium, potassium is also a naturally occurring constituent in the sediment. Potassium is an alkali element, i.e. both volatile and lithophile. The prime K repositories in igneous rocks are alkali feldspars, amphibole, and micas. In sedimentary rocks, most of the K inventory is sequestered as clay minerals, notably in smectite, illite and in detrital feldspars. During weathering, feldspars react with water to produce clay minerals. The K rich clay mineral illite is left as a residue and its umbiquitous presence keeps the concentration of K in low temperature hydrous fluids (rivers, seawaters) at very low levels. K is therefore transported to the sea with the suspended load. The K^+ ion is very large. Although it may enter octahedral sites, it often fits 12 coordinated sites as in feldspars and micas. As a nutrient element to plants K plays a vital role in the productivity of aquatic environments. The potassium budget of the ocean is not well understood. The element is unusual in that only about 60% of its input is by rivers; the remainder is believed to come from newly formed undersea basalt (Hammer, 2008). Generally, a major portion of Na and K will be fixed within the lattice of clay minerals (Sajan, 1988). The world average shale value of K is 2.66%.

The percentage of Na content varies from 1.10 to 1.33% at Adimalathura, 1.15 to 1.39% at Mullur and 1.10 to 1.19 at Kovalam, while the concentration of K at Adimalathura, Mullur and Kovalam are 0.02 to 0.34%, 0.21 to 0.59% and 0.02 to 0.22% respectively. Na and K concentrations in the surface sediments of Gulf of Mannar, South east coast of India are low with mild enrichment in the southern part of the area indicating the influence of river input (Jonathan *etal*, 2004). The surface sediments of central south Yellow Sea also possess lower concentration of Na and K (Yang and Youn, 2007). The contents of Na and K are higher in the shelf samples of southern and western coast of Korea (Cho, *etal* 1999). Ho *etal* (2010) recognized higher concentration of K in the estuarine sediments of CuaHong harbour and reasoned that the low hydrodynamic energy facilitated high deposition of fine grains. The present study indicates that the Na and K mainly comes from the detrital minerals and are lower than the world average shale value.

Calcium (Ca) and Magnesium (Mg)

Calcium is one of the most abundant elements existing in different forms in natural water and soil. It is a refractory and lithophile alkaline earth element and is the third most concentrated cation of seawater. It is mainly associated with feldspar, clay minerals and also occurs in carbonate forms. Calcic plagioclase and amphibole are the major hosts for Ca in igneous rocks. The low temperature Ca rich phases in calcium carbonate are calcite and aragonite. Ca ions occupy octahedral sites in silicates. The source of calcium carbonate is the shells of deceased organisms lying all along the shores of south west coast (Anitha *etal*, 2014). The Ca concentration level in fresh water and seawater is controlled by the solubility of calcite and aragonite. Calcite is less soluble than aragonite. The world average shale value of Ca is 1.6%.

In the study area, the concentration of Ca at Adimalathura ranges from 0.69 to 3.89% where the minimum value is observed at a depth of 15m. In Mullur, it ranges 1.80 to 3.23%. Here the minimum value is observed at a depth of 20m and in Kovalam it is of 0.09 to 2.69% with the least amount at 15m. The maximum concentrations observed are due to the leaching of dead shelled organisms. Ca is inversely correlated with other major elements except K, P and Na. In marine sediment Ca is found in associated with oozes, fish bones and other biogenic debris. Another source of Ca is the plagioclase mineral (Sirocko *etal*, 2000). The carbonate materials have a coarse texture and as a result the Ca contents are very high in coarse sediments (Cho *etal*, 1999). Studies of

Jonathan *etal*, 2004 reveals that the Ca are abundant in the southern side of Tuticorin, East coast of India where the shelf is widest and shell debris is main constituent. The Ca levels of Abu-Qir Bay and the Eastern Harbour of Alexandria, Egypt ranges from 0.99% to 13.925% and from 2.17% to 39.81% respectively (Ghani *etal*, 2013) which is higher than the study area.

Mg is another abundant element in the earth crust which is primarily derived from hydrolysis of rocks. It is also a refractory and lithophile alkaline earth element. After oxygen, Mg is the second most abundant element in the mantle where it is hosted in minerals like olivine, pyroxene, garnet etc. Its concentration in crust is relatively low and hence amphiboles, micas, Mg rich clays and carbonates normally remain in minor mineral phases. Mg rich calcite is a major form of carbonate which is precipitated by marine organisms. In silicates, Mg ions occupy octahedral sites. In igneous and sedimentary carbonates Mg substitutes for Ca. It is liberated from silicates by weathering and transported to the sea in the dissolved load. The present day magnesium budget seems to have been balanced for the past 100 million years (Hammer, 2008). Most of the extensive dolomite deposits were formed prior to this time and so the longer time magnesium budget is poorly understood. The world average shale value of Mg is 1.5%.

The concentration of Mg in Vizhinjam Port area varies from 0.12 to 0.24%, 0.03 to 0.21% and 0.07 to 0.33% at Adimalathura, Mullur and Kovalam respectively. At Adimalathura, the lowest concentration is observed at a depth of 15m whereas at Mullur and Kovalam it is of 3m. On comparing with the Ca (1.60 to 4.20%) and Mg content (0.48 to 2.05%) in the nearshore sediments of Quilandy mudbank area, south west coast of India (Ramachandran, 1992), the study area records a lower concentration. Karageorgis *etal*, 1997 stated that the distribution of elements like Ca and Mg in the surface sediments of the South Evvoikas and Petalian Gulfs is due to their common origin which is principally the skeletons of marine organisms. Similar observations were also observed in our study area. Ca and Mg concentrations reveal a higher average in the surface sediments of Gulf of Mannar (Ca: 0.4-13.6%; Mg: 1.12-8.32%) than for other coastal regions along the southeast coast of India due to the abundance of skeletal components. (Jonathan *etal*, 2004). From the above results, it can be inferred that the main source for the Ca and Mg is mainly from the shell fragments and to lesser extend from the detrital grains.

Iron (Fe) and Manganese (Mn)

Iron, the fourth most common element in the earth crust is refractory and siderophile. In most silicate mineral phases, ferrous iron (Fe^{2+}) substitutes for Mg^{2+}. In the upper mantle ferrous iron is found in olivine, pyroxene, garnet and amphibole. In igneous rocks it is hosted in amphibole and biotite. (Hammer, 2008). When exposed to the atmosphere or seawater at low temperatures, Fe is normally oxidized to Fe^{3+}. It is found in different forms of iron hydroxide in soils and sediments, and as ferromanganese nodules and encrustations in the deep sea. Iron can be combined with a variety of anions to form complexes and minerals. The common mineral forms are oxides, sulphides and to a lesser extend silicates and phosphates. Under natural conditions, Fe changes its oxidation state steadily with changes in the amount of oxygen and variations in pH conditions. Hence this element provides useful information on the present and past depositional and environmental conditions (Albarede, 2003).

Adimalathura, lower concentration of Fe content is observed at a depth of 15m whereas at Mullur and Kovalam it is at 3-5m depth. The Fe content in the sediments of nearshore region may result from the reduction of Fe during the oxidation of organic matter (Francois, 1988). Fe shows good correlation with Al, Mg, P, Ti and clay. Fe is found in lithogenous alumino silicate and other detrital minerals. Fe is transported partly in solution and partly in colloidal form to the depositional environment. In oxygenated alkaline water iron gets oxidized and precipitated as ferric hydroxide complex. The negatively charged colloids reacts with cations of seawater and gets precipitated (Sajan, 1992). Correlation between Fe and clay is due to the high cation exchange capacity and absorption of clay minerals (Srinivas, 2004). The Fe content in the sediments of Quilandy mudbank area is of higher concentration (5.02 to 10.91%) (Ramachandran, 1992) when compared to our study area. Nisha *etal*, 2014 reported a concentration of 5.8% Fe at Tarangapadi, south east coast of India as due to the supply of detrital grains through adjacent rivers. The concentration of Fe in the study area can be attributed to detrital mineral composition in particular to heavy minerals.

Manganese is an element of low toxicity but by the usage of manganese bearing fertilizers contributes air and water pollution. It is one of the biogeochemical and active transition metals in aquatic environment (Nadia *etal*, 2009). Mn is mostly found in trace elements in the lattice structure of most rock forming silicates or it occurs as a major element in oxides. It is precipitated as hydroxides in the estuarine and nearshore areas as the river water rich in Mn mixes with sea water (Anitha *etal*, 2014).

The concentration of Mn at Adimalathura, Mullur and Kovalam varies from 0.03 to 0.05%, 0.01 to 0.07% and 0.02 to 0.06 respectively. The lower percentage of Mn content is noticed at a depth of 3m in these areas. When compared with the average shale value (Fe-4.72% and Mn-0.85%) their concentration along the sector is enormously low. The lower concentration of Mn (158 to 2203 µg/g) in the coastal sediments between Besant Nagar and Marakkanam, TamilNadu attributes their lithogenous origin (Gandhi *etal*, 2014). The distribution and geochemical behavior of Fe and Mn in aquatic environments have received wide attention among scientific community because of the understanding of these redox sensitive elements as a prerequisite in the assessment of toxic contaminants causing disastrous effects to organic life (Forstner and Wittmann, 1983 and Sajan 1992). Fe-Mn oxy hydroxides are observed to be a major controlling factor for trace metal accumulation when compared to organic carbon (Banerjee *etal*, 2005). From the above studies it can be inferred that the Mn content in the study area owes to detrital mineral composition.

Titanium (Ti)

The ninth most abundant element in the earth's crust is titanium and is occurring mainly as TiO_2, which is present in most of the igneous rocks and sediments. The heavy minerals such as ilmenite, leucoxene and rutile are the important titanium bearing minerals that are widely distributed on the south west coast of India. The moderately high concentration of titanium in comparison with the world average value throughout the study area could be attributed to the heavy minerals present in the area. The world average shale value of titanium is 0.46%.

In the study area, the concentration of titanium at Adimalathura ranges from 0.15 to 0.92% with the least value observed at 15m depth. When it reaches Mullur the concentration varies from 0.52 to 1.09%. Whereas in Kovalam, the concentration of titanium ranges from 0.65 to 2.45%. At Mullur and Kovalam the lowest concentrations are observed at a depth of 3-5m. The distribution of titanium indicates maximum percentage at Kovalam where heavy mineral assemblages dominate. The heavy minerals are highly enriched in the beach sand along the west coast of India. Paul, (2001) reported the TiO_2% for Cochin innershelf as 0.93% and it coincides with the study are. Al and Ti are the index element for the terrigenous source and are immobile in marine environment (Nath *eta*l, 1989). Ti is having positive correlation with Fe, P and Al. Positive correlation between Al and Ti suggests the source as detrital alumino silicates. This enrichment of titanium in an environment can be explained by two processes: (1) winnowing of the sediment by the current activity that concentrates Ti rich minerals (Shimmield *etal,* 1990) and (2) rapid settling of heavy minerals from the area adjacent to source rocks which are rich in Ti (Turekuian and Wedepohl, 1961). The Ti content in the bulk sediments off the Cochin, Alleppey areas are 0.7% and 0.5% respectively (Prakash, 1991 and Ramachandran, 1992) which are lower when compared with our study area. Machado, 1995 reported that the higher content of Ti in the surficial sediments of Veli (1.4%) could have been derived from the industrial sludge which is being disposed off the Veli beach. In light of the above discussion it can be stated that the main source of Ti in the study area reflects its source as detrital minerals besides the effluents from the titanium factory (Travancore Titanium Ltd).

Silica (Si) and Aluminium (Al)

Silica, the third most abundant element in the earth is essentially lithophile and refractory. It forms the major minerals in both felsic and mafic igneous rocks in the crust. Silicon is a major constituent of clastic sediments. Most dominant portion of silicate minerals are seen with silt and sand fractions in the sediment. The sources of silica may be of either detrital quartz or siliceous skeletons (Shankar *etal*, 1987; Nath *etal*, 1989). The world average shale value of Si is 27.5%.

From Adimalathura to Kovalam the concentration of Si varies from 37.32 to 42.80%, 35.97 to 39.95% and 35.06 to 42.26% respectively and it can be attributed to the higher sand content in the study area. The higher percentage of sand implies that Si is related to terrestrial input of quartz (Karageorgis *etal*, 2009).The Si content in the nearshore sediments of Quilandy varied from 15.46 to 30.11% (Ramachandran, 1992) which is lower than our study area and it is due to the dominance of mud at Quilandy. Jonathan *etal*, 2004 stated that the higher sand content indicates the availability of larger proportions of free quartz. The abundance of Si in the study area is of detrital origin.

Aluminium is the sixth most abundant element in the earth. The element is normally seen with ultra basic rock. Al usually found as oxides and is known for its low density and ability to resist corrosion. The major mineral that hosts Al in igneous rocks is feldspar, where plagioclase occurs in basalts, while plagioclase and alkali feldspar may occur together in felsic rocks. Biotite mica may occur in both types of rocks. In sedimentary rocks, Al is hosted in clay minerals such as kaolinite and illite. Aluminium can be tetrahedrally coordinated and in this coordination it replaces Si in the centre of oxygen tetrahedral. It can also be octahedrally coordinated and form solid solutions with elements such as Ca, Mg and Fe. Concentration of aluminum in the sediments could be due to the contribution from detrital mineral grains supplied through the river in addition to the precipitation of their dissolved species (Anitha *etal*, 2014). The world average shale value of Al is 8.8%.

The concentration of Al in Adimalathura, Mullur and Kovalam ranges from 2.83 to 4.14%, 3.54 to 4.75% and 3.28 to 4.39% respectively. The lowest values in the study area are observed at a depth of 15-20m. A maximum concentration of Al is observed at Mullur. The concentration of Al (5.05 to 9.42%) in the nearshore sediments of Quilandy mudbank area (Ramachandran, 1992) is higher when compared with the Vizhinjam port area and it can be attributed to the occurrence of muddy sediments at Quilandy. Cho *etal* (1999) stated that the sand sized mineral assemblages such as quartz and feldspar and carbonate shell debris are responsible for the lower concentration of Al (5.74%) in the surface sediments of southern and western coast of Korea. Similar observations were noted for the lesser Al content in the study area.

Phosphorus (P)

The key limiting element in the development of oceanic biomass is phosphorus, which is in the form of the phosphate ion. Phosphorus is a lithophile and moderately siderophile element. It is almost exclusively hosted in Ca phosphate (apatite). Biogenic (fish teeth and bones) and diagenetic apatites are the essential repositories of sedimentary phosphorus (Hammer 2008). Crustal rock weathering and biological process are the main source of phosphorus in the environment. Usually the content of organic phosphorus is higher than that of inorganic phosphorus. About half of the phosphorus input is in the form of suspended material, both organic and inorganic, the latter being in a variety of forms including phosphates adsorbed on to clays and iron oxide and calcium phosphate eroded from rocks.

The concentration of P at Adimalathura, Mullur and Kovalam are 0.17 to 0.35%, 0.26 to 0.48% and 0.17 to 0.74% respectively. The higher concentration of P in a sedimentary environment may occur due to the transportation of allogenic apatite by terrestrial agents, organic associates or precipitates from inorganic complexes (Padmalal, 1992).The high concentration of phosphorus (266 to 1350µg/g) together with high values of organic matter measured inside the Ceuta harbour, North Africa indicates the pollution of urban influence (Garcia *etal*, 2005). The phosphorus content in the study area is due to the supply of detrital minerals and from biogenic materials found in the form of shell fragments.

5.3.2c Trace elements

The granulometry and organic matter are the important controlling factors in the abundance of trace metals. The sand dominated sediments registers less concentrations of trace metals than mud. The fine grained sediments possess relatively high metal contents, due to the high surface area of these smaller particles and this enrichment is mainly due to surface adsorption and ionic attraction (Horowitz and Elrick, 1987). Also, coatings of organic matter are relevant in fine grained sediments, and these coatings bind a variety of trace elements (Wangersky, 1986). On the other hand, high carbonate contents are associated with low concentration of trace metals. These relationships are clearly evident in the studies of Rubio *etal* (2000) where variations in absolute metal concentrations are linked clearly with variations in grain size or carbonate content. The average concentrations of trace elements in the nearshore sediments of Vizhinjam port area are provided in the Table 5.7

Copper (Cu) and Nickel (Ni)

Copper is a chalcophile element which is mostly found in sulphide deposits. It is one of the essential elements for plants and animals. At higher concentrations the metals turns to be highly toxic (Flemming and Trevor, 1989). Copper pollution in aquatic region can occur by the discharge of Cu based agrichemicals. Copper enters the aquatic environment from paints on the hulls of ships (Seshan *etal*, 2010). Copper- and Zinc-based antifouling paints and cathodic protection devices which have been identified are important sources of these metals in estuaries and harbour sediments (Uncles *etal 2000* and Turner 2010). Nickel is a siderophile element and its associations are with Mg and Co in mafic and ultramafic rocks (Sundararajan and Natesan, 2013). This metal usually substitutes to Fe and Mg in rock forming minerals. Nickel enters surface waters from the dissolution of rocks and soils from biological cycles, atmospheric fall out and especially from industrial processes and waste disposal (Dara, 1993).

The average concentration of Cu along Adimalathura, Mullur and Kovalam are 37.5ppm, 29ppm and 23.8ppm respectively, the general average being 30.01 ppm. As compared to the average shale value (45ppm), the concentration of Cu in the study area is lower. The maximum concentration of Cu is observed at Adimalathura where intense fishing activities are going on. The boating activities in particular, paint chips or flakes resulting from the annual cleaning or less frequently, complete scraping of automobiles may increase the concentration of Cu in sediments.

The average concentration of Ni along Adimalathura, Mullur and Kovalam are 27.75ppm, 29.6ppm and 44ppm respectively, the general average being 33.78 ppm. The average Ni content seems to be lower than the average shale value (50ppm). The maximum concentration is observed in Kovalam. Even though the values of Ni are of low concentration in the study area, they show a maximum range of 30-62ppm in Kovalam suggesting the anthropogenic contribution. Cu and Ni enrichment are commonly observed in a region where harbour and petroleum-related activities are intense (Algarsamy and Zhang, 2010). The moderate to highly elevated concentrations near to the sites of intense industrial, shipping and commercial activities suggest a direct influence of these sources (Chouba *etal*, 2013). Transportation to and fro from the harbour can increase the metal level in this region. Ravichandran *etal* (2012) reported that the concentration of Cu (48.8µg/g) and Ni (71.1µg/g) recorded at the nearshore sediments of Ennore may be due to the industrial and petroleum related activities. The sediments from large marine ecosystem of Brazil showed an enrichment of Cu and Ni due to the urbanization, industrial and harbour activities that occur in the area (Buruaem *etal*, 2012). From the above inferences it can be assured that the concentration of Cu and Ni does not show much variation in the study area and this indicate the source of these metals either from detrital minerals or fishing activities.

Lead (Pb) and Zinc (Zn)

Lead is a chemical element in the carbon group and is also the heaviest no radioactive element. The ability of many organisms to accumulate lead poses a potential threat to mankind through ingestion of contaminated products. It enters in aquatic environment through precipitation, dust fall out, erosion and leaching of soil as well as municipal and industrial waste disposals. Lead values in estuarine and other coastal sediments have been much augmented by man's activities (Alagarsamy, 2006).

Zinc is a chalcophile element and an essential trace metal for animal and plants but in higher concentration it is hazardous to living organisms. During weathering these elements are mobilized easily and find their way into oceans. The high concentration of Pb and Zn in nearshore sediments can be due to the heavy input of industrial effluents from the industrial regions which are dominated by the petrochemical, painting, thermal plant and other chemical industries (Ravichandran and Manickam, 2012). These metals are also used in the construction of water pipelines and other pipes, tanks and reservoirs (Garcia and Gomez, 2005). The vehicle emissions represent another major source of Pb (Matthai and Birch, 2001; Padmalal, 1992). Municipal refuse, automobiles and agricultural use of pesticides and fungicides containing ZnSO4 is another source of pollution (Dara, 1993).

The average concentration of Pb along Adimalathura, Mullur and Kovalam are 10ppm, 9.6ppm and 16.2ppm respectively. The average concentration of Pb is

11.93ppm which is lesser than the average shale value (20ppm). The average concentration of Zn along Adimalathura, Mullur and Kovalam are 22.5ppm, 43ppm and 53ppm respectively, with a general average of 39.75ppm. The Zn content in the area seems to be lesser than the average shale value (95ppm). The studies of Balachandran *etal* (2003) revealed that the trace metals do not seem to constitute a threat to the marine environment of central south west coast of India and this supports the results of our study area. The higher concentration of metals like Pb and Zn along the Gulf of Mannar indicates that the area has been contaminated by the input from riverine sources and the industries nearby (Jonathan *etal*, 2004). Gracia *etal* (2005) explained the higher abundance of Pb and Zn in the sediments from Ceuta harbour due to sewage effluents, antifouling paints and oil spills since there is no industrial activity in and around the harbour. The present study shows a lower concentration of these metals in Vizhinjam port area reflecting the source as to that of detrital mineral composition, vehicle emissions and antifouling paints.

Zirconium (Zr) and Chromium (Cr)

Zr is a strong transition metal and zircon being the most important source of zirconium. It is mainly used as a refractory and opacifer although it is used in small amounts as an alloying agent for its strong resistance to corrosion. The average concentration of Zr along Adimalathura, Mullur and Kovalam are 845.25ppm, 1869.4ppm and 3574.2ppm respectively. The general average is 2096 ppm which is higher than the global average shale value (160ppm). The maximum concentration of Zr is observed at Kovalam where the sediments are enriched with Zircon.

Cr is the seventh most abundant element on earth but 21st in abundance in crustal rocks with an average concentration of 100ppm (McGrath and Smith, 1990). Chromium is an essential nutrient for plants and animal metabolism. However when accumulated at high levels, it can generate serious trouble and diseases such as nausea, skin ulcerations, lung cancer etc. and is the most toxic form for bacteria, plants and animals (Anilkumar,1988). Cr indicate the anthropogenic influence in the marine sediments due to the occupational exposure of numerous processes including chrome plating baths, chrome colours and dyes, cement, tanning agents, wood preservatives, anticorrosive agents, welding fumes, lubricating oils and greases, cleaning materials, textures and furs (Gandhi *etal*, 2014). The average concentration of Cr along Adimalathura, Mullur and Kovalam are 45.5 ppm, 67.2ppm and 86.4ppm respectively, the general average is 66.36ppm. When compared with the present study, Sany *etal*, 2011 reported higher concentration of Cr in the surface sediments of West port Malaysia due to the presence of industrial waste from the industrial outlet. In light of the above results it is inferred that the concentration of Zr in the study area is mainly due to the presence of zircon in the heavies while for Cr it is from the dyes, tanning agents, anticorrosive agents, welding fumes, lubricating oils and greases etc.

Rare earth elements like La, Nb, Sm and Ce are of very negligible concentration and as of now it is not at all alarming.

Most of the trace metals analysed show positive correlation with mud and negative correlation with organic carbon and sand (Table 5.9). This indicates that finer particles are the carriers of elements rather than organic carbon. Al and Fe are positively correlated with majority of the elements studied. Hydrous oxides of Al and Fe readily sorbs and co precipitate elements when they sink to the bottom of water. This association may be due to the large surface area, extensive cation exchange and wide availability of the elements. In the present study trace elements show positive correlation with Fe than Mn. Similar correlation was reported by Muraleedharan and Ramachandran in Beypore estuary and its innershelf. The correlation of Fe/Mn hydroxides with trace element was also reported in Cochin estuary (Paul, 2001).Significant correlation between Cu and Zn is primarily due to uptake of these elements by micro organisms as these elements are the micronutrients for plankton growth (Pratt and Avis, 1992, Ergin *etal*, 1996). Lack of correlation of Cu with other elements and finer particles may be due to desorption capacity of this element when they get in contact with seawater. Similar relation was reported by Padmalal *etal* (1997) in central Vembanad estuary. Correlation of Cr with clay indicates that illite traps Cr in strong reducing environment (Alagasamy and Zhang, 2010). Saager *etal* (1992) reported that Cu concentration in ocean water depends on the nutrient content and the chemical composition of plankton. The concentration also increases with water depth. Cu enrichment is found associated with clay and high organic matter. The lack of correlation in the present study also proves this association. Correlation of Ni with Cr and mud indicates that these elements are either absorbed/adsorbed by mud rather than organic carbon.

Contamination Factor (CF) is used to evaluate the extent of metal contamination and also anthropogenic inputs. Trace metals like Cu, Ni, Pb, Cr, Zn etc. are used in the marine contamination studies for evaluating anthropogenic activities (Munuz *etal*, 2004). The values of CF for almost all the trace elements except Zr in the study area are less than 1 indicating low contamination (Table 5.10). Zr shows highest contamination due to the presence of zircon in the heavy minerals. The pollution load index values (PLI) (<1) also supports the CF values indicating no pollution in the Vizhinjam seaport area (Table 5.10). The obtained I_{geo} value for the trace elements shows that the Vizhinjam port area is polluted with Zr and this is due to the concentration of heavy minerals (Table 5.11). Also from the result, it is inferred that sampling stations T3 (10m) and T3 (15m) is under moderately polluted condition.

The concentrations of most of the elements in the study area are generally low compared to those of average crustal and average shale value and anthropogenic effect was identified at Kovalam. The elements like Si, Ca and Ti shows a higher concentration in Vizhinjam port area when compared to average shale value. Kovalam exhibited the enrichment of Ti indicating the accumulation of heavy minerals. The high energy condition and presence of heavy minerals form reason for the greater percentage of these elements in Vizhinjam. The

Table 5.10 Contamination factor (CF) and pollution load index (PLI) of minor elements of nearshore sediments in Vizhinjam port area

Location	Cu	Ni	Pb	Zn	Zr	Cr	PLI
T1 (3m)	0.84	0.24	0.15	0.08	1.57	0.56	0.35
T1 (5m)	1.27	0.56	0.40	0.15	0.76	0.32	0.46
T1 (10m)	0.58	0.76	0.65	0.39	18.11	0.98	1.12
T1 (15m)	0.64	0.66	0.80	0.33	0.69	0.17	0.48
T2 (3m)	0.27	0.32	0.35	0.22	6.09	0.67	0.55
T2 (5m)	0.82	0.46	0.20	0.31	2.98	0.42	0.55
T2 (10m)	0.64	0.90	0.80	0.64	15.42	1.08	1.31
T2 (15m)	0.60	0.84	0.60	0.56	22.77	1.03	1.26
T2 (20m)	0.89	0.44	0.45	0.54	11.16	0.53	0.91
T3 (3m)	0.38	0.62	0.55	0.25	9.98	0.69	0.78
T3 (5m)	0.20	0.92	0.75	0.56	15.68	1.02	1.04
T3 (10m)	0.56	1.24	0.90	0.78	53.44	1.51	1.84
T3 (15m)	0.69	1.02	1.15	0.69	28.24	0.96	1.57
T3 (20m)	0.82	0.60	0.70	0.51	4.36	0.62	0.88

Table 5.11 Geo accumulation index of minor elements of nearshore sediments in Vizhinjam port area

Location	Cu Igeo	Ni Igeo	Pb Igeo	Zn Igeo	Zr Igeo	Cr Igeo
T1 (3m)	0.17	0.05	0.03	0.02	0.31	0.11
T1 (5m)	0.25	0.11	0.08	0.03	0.15	0.06
T1 (10m)	0.12	0.15	0.13	0.08	3.63	0.20
T1 (15m)	0.13	0.13	0.16	0.07	0.14	0.03
T2 (3m)	0.05	0.06	0.07	0.04	1.22	0.13
T2 (5m)	0.17	0.09	0.04	0.06	0.60	0.08
T2 (10m)	0.13	0.18	0.16	0.13	3.09	0.22
T2 (15m)	0.12	0.17	0.12	0.11	4.57	0.21
T2 (20m)	0.18	0.09	0.09	0.11	2.24	0.11
T3 (3m)	0.08	0.12	0.11	0.05	2.00	0.14
T3 (5m)	0.04	0.18	0.15	0.11	3.15	0.21
T3 (10m)	0.11	0.25	0.18	0.16	10.72	0.30
T3 (15m)	0.14	0.20	0.23	0.14	5.67	0.19
T3 (20m)	0.17	0.12	0.14	0.10	0.87	0.12

decrease in concentration of trace metals along the study area indicates that the area is not contaminated neither by the input from riverine sources nor the industries nearby. The heavy metal contents in sediments varied between stations and it could be due to the resuspension phenomenon induced by wave and tide currents and anthropogenic activities as mentioned by Chouba *etal* (2013) in their studies. In nearshore environment of South Brazil Neto *etal (*2000) identified a zone of higher energy condition with sediments low in metal content and organic carbon but rich in sand. Similar observations were noted in the study area. Lower metal concentration in the area can be understood interms of the low proportion of fine material in the sediments. The studies of Robin *etal* (2012) revealed that along the southern Kerala coast (except Cochin) the heavy metal concentrations are below the threshold levels and regulatory limits. Metal enrichments were observed close to the major urban areas of coastal waters, mostly associated with large scale industrialization. The coastal environment remains free from contaminants as the metals are rapidly removed by the coastal currents and biogenic association (Balachandran *etal,* 2007). The prevalent longshore currents are capable of dispersing the deposition in the coastal region (Shetye *etal,* 1991).

CHAPTER VI

SUMMARY AND CONCLUSION

The present study on the beach morphodynamics under three different energy regimes along the Kerala Coast has thrown light on the short and long term beach morphological changes and the associated processes and that has been summarised and concluded in the present Chapter. The organisation of the summary and conclusion is for the study on the Southern, Central and Northern sectors of the Kerala coast.

In the open beaches of southern sector, the monsoonal waves reduces the beach to a considerable extent and regains the earlier status by redepositing almost the same quantity of sediment during fair season, thus attaining a stable nature. The formations of depositional features are due to the long period swell waves during the fair season whereas during monsoon the short period storm waves cause erosion. The formation of pocket beaches is the resultant of the deposition of sediments due to the hindrance of longshore currents by the promontories. The encroachment of monsoonal waves affects these pocket beaches severely thereby making it vulnerable. The artificial structures constructed along the coast have the potential to change the morphology of the coast. High monsoonal waves, overtopping the seawall carve away the entire beach of this region thereby affecting the inhabitants in the coastal area. After the monsoon the beach reappears in original form by showing accretion and widens with steep slopes. The formation of longshore bars along the coast during monsoon period indicates the dominance of onshore-offshore sediment transport rather than longshore sediment drift. Another important artificial structure in the southern sector that influences the coastal morphology is the construction of breakwater at Muthalapozhi. The construction of Muthalapozhi breakwater faced an incongruity by the formation of bar in harbour mouth and reconstruction was done to resolve the problem. The reconstruction of breakwaters though prevents the formation of bars, no considerable variation in beach width has been noticed except the immediate north. But the immediate north of breakwater, at Thazampally, which was facing intense erosion before reconstruction has procured a better condition. Erosion of the beaches became a serious issue in Kovalam during monsoon. To nurture the beaches and to endorse tourism, an artificial multipurpose reef was sited. From the studies it is evident that the width of the beach showed a considerable increase immediately after the reef construction even during monsoon season. But recently, waves encroaches the pocket beaches intensely during monsoon resulting in complete disappearance of beach.

The longshore drift in the central sector differs from the general direction of the currents along south west coast of India. The southerly longshore drift during fair season differs from the common path of the currents. The change in orientation of the coastal line (4^0) results in a broad, gentle concavity setting up local littoral cells that may vary from the regional trend. The seawall dominated region faces no frontal beaches irrespective of the season. The change in orientation of the coastline as referred above cause wave convergence on either side of the concavity due to wave refraction resulting in erosion. Subsequently accretion occurs on concave side where the wave diverges resulting in the formation of open beaches. The stability of the beach can be explained by the seasonal erosion/accretion and it can be attributed to the oceanographic processes operating in the area. Mudbanks also form another reason for this erosional/accretion trend during the southwest monsoon and noticed that there is accretion on the northern side and erosion on southern side.

As expected for sandy beaches along the south west coast of India, the northern sector also experiences erosion/accretion process corresponding to monsoon and fair season. During monsoon, the foreshore erodes while for fair season, the waves along with the longshore currents bring back the eroded beach sediments. In short the net effect is that the area witnesses neither erosion nor deposition reflecting the most stable part of the beach.

An hasty and discrete inflection of the coastline would check the longshore transport leading to a depositional regime. This is very marked at the breakwaters in all the sectors which is known to favour sediment deposition by obstructing the littoral drift.

The beach sediment characteristics show considerable spatial variation in tune with the hydrodynamic conditions and beach morphological characteristics. The Southern sector with the highest energy level is characterized by comparatively coarser grains except at the south of breakwater where as in the northern sector with the lowest energy regime, the beach accretes with fine sediments. The central sector with intermediate energy condition shows an accreting nature but with sediment range in between. In the high energy regime the sediment size during monsoon is coarser than fair season. In the other regimes, the sediments appear to be in the same grade during monsoon and fair season. This is due to the presence of mudbanks, which is the characteristic feature of central and northern sector. The accreted beach adjacent to breakwater show comparatively finer sediments all over the year. Similar results were observed on the other two regimes also. This reveals that the breakwater influences the morphology of the coast and this morphological change are reflected approximately 1 km on either south or north of the breakwater. Thus artificial structures have the potential to modify coastal morphology. The innershelf of southern sector is carpeted with sandy sediments representing a high energy condition whereas the central and northern sector shows the predominance of silt that favours the formation of mudbanks representing a low energy environment. The variation in mean size reveals the differential energy conditions that lead to erosion / deposition of sediments in different sectors.

Based on the morphology, the study area can be broadly divided into two as (1) Stable and (2) Vulnerable beaches. The stable beach comprises open beaches whereas vulnerable beaches are those which have artificial or natural interventions. In the southern, central and northern sectors, the stable beaches are of 60%, 50% and 55% respectively. In the southern sector, which is of high energy condition only 36-55% beach exist in monsoon where as in the central, it is 50-67% and that of northern, it is 46-61%. Mud banks also form another reason for the existence of beach in the central sector during monsoon.

From the studies it is evident that the coastal morphology primarily depends on the sediment characteristics and nature of beach, add to that, the currents and waves. Besides, the study could also reiterate the southern, central and northern sectors respectively as high, medium and low energy regimes.

The changes in shoreline and the extent of erosion and accretion in all the sectors over a time span ranging from 1967-2000, 2000-2005 and 2005-2014 were studied using geospatial techniques. The results point to varying magnitude of the erosional and accretional processes in all the sectors in different periods which can be attributed to various processes influencing the coastal zone discussed in detail in chapter 3. The three energy regimes possessed stable beaches with accretional nature during 1967-2000 periods. The rate of erosion decreased during 2000-2005-2014 compared to the earlier periods. However, it is seen that the implementation of artificial structures deduced the erosional rate. At the same time, these structures also reduced the accretion rate at the nearby stable beaches. The central and northern sectors having low energy condition and mudbank effects showed more stability than the high energy regime. More accreting beaches are seen adjacent to the breakwaters and also at the open beaches where no artificial structures are present. The results obtained through the geospatial studies supports the beach dynamics discussed in the chapter 3.

The pilot study on the Vizhinjam port area reveals that, as of now, is not under stress nor environmentally degraded. The present study indicates that the major and minor elements comes from the detrital minerals and are lower than the world average shale values. A slight variation is noticed in Kovalam and it may due to the anthropogenic activity. The higher concentrations of heavy minerals are observed at Kovalam during monsoon period. The concentration of heavies is the result of strong winnowing action of waves rather than selective transport by longshore currents. Moderate to high energy conditions facilitate winnowing action of the waves and removal of lighter minerals leading to concentration of heavies. The presence of headlands may form another reason for the concentration of placers at Kovalam. The presence of headlands interrupts longshore drift and therefore the transportation of sediments by longshore current to the beach is a distant possibility. There is no uniqueness either in the distribution of sediments or heavy metals which is indicative of pristine coastal environment.

Any sort of coastal developmental activities if not monitored meticulously will turn to be threat for coastal ecosystem. Hence the data generated through the study can be utilized as the baseline data for future monitoring and other port development activities.

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