# CHAPTER 1

# GENERAL INTRODUCTION

## 1.1 Introduction

The coastline of India has been undergoing physical change throughout the geological time. Although the last tectonic phase in the Indian Peninsula has been one of general emergence, the present coastal geomorphology of India has evolved largely in the background of the post-glacial transgression over the pre-existing topography of the offshore, shore and coastal zones. The Holocene sea level fluctuated in the course of the last 6,000 years and the marked regression is indicated between 3,000 and 5,000 yrs B.P.

Kerala coast is generally described as a submergent coast though Bekal and Paiyambalam at Kasaragod, Dharmadam and Azhikode at Kannur, and Varkala at Kollam have been assigned as emergent coasts. Lateritic cliffs, rocky promontories, offshore stalks, long beaches, estuaries, lagoons, spits and bars are characteristics of Kerala coast. The sand ridges, extensive lagoons and barrier islands are indicative of a dynamic coast with transgression and regression in the recent geological past. The central Kerala coast around Kochi is of recent origin. There are about 700 land-locked islands (including barrier islands) in Kerala. Though there are 41 rivers bringing enormous quantity of sediments, deltas are not formed due to the high wave energy condition of the coast. However, Narayana et al. (2001) have identified a small palaeo-delta near the mouth of Periyar river. The Vembanad is one of the largest estuarine systems in the country.

Coastal and near shore sediments have been studied over the past few decades by several researchers on various aspects, such as sea level changes, sedimentation, neotectonics, coastal geomorphology, and paleo-environment in off-shore and on-shore areas and rivers basins .The sedimentological, micropaleontological, stable isotope, radiometric and calcium carbonate records in ocean sediments provide the best evidence of rapid climatic and sea level changes during the Late Quaternary period (Chappell, 1947; Fairbanks, 1989; Charles et al., 1996; Naidu and Malmgren, 1999; Thamban et. al., 2001).

Over the years advanced sedimentological studies using modern techniques have evolved, especially in applying it to the sedimentation aspects of beaches and river networks. Morphodynamic processes that occur in response to changes in external conditions guide the coastal evolution (Stanley et al., 1972; Wright and Thom, 1977). The Holocene lake level and the role of paleowinds in the geomorphic expression, the shoreline and beach architecture and the role of lake-level variation in the development of beach ridges along southern Michigan area have been studied by Thompson et al. (2004), Johnson et al. (2002) and Thompson (1992), respectively. Larsen (1994) emphasizes the role of isostasy in the uplift of the coastal region and the usefulness of beach ridges in monitoring the isostatic changes. The origin of the beach ridges have been studied by many workers who emphasize the action of wind and the winnowing effect of the sea wave in their formation (Fox et al., 1966; Fraser et al., 1991; Komar, 1998). The consequences of fluctuations in boundary conditions, which produce event beds that ultimately form lithofacies units (Swift et al., 1991). Exogenous inputs from the environment, which comprises climatic and geological controls, are responsible for the geographic variation among coasts (Davies, 1980). The criteria for recognizing the transgressive and post-transgressive sand ridges have been discussed for the New Jersey continental shelf area (Stubblefield et al., 1984).

In India the first major attempt to study the coastal and near shore sediments of India was made by the Andhra University, under the guidance of La Fond in 1952. The study of upper Quaternary sea level record along the east coast of India gathered momentum since 1970 (Meijerink, 1971; Prudhvi Raju and Vaidyanadhan, 1978; Sambasiva Roa and Vaidyanadhan, 1979; Bruckner, 1988, 1989; Loveson and Rajamanickam, 1987; Banerjee, 1993;

Banerjee et al. 1997; Vaz and Banerjee, 1997). Ahmad's (1972) was the first book on coastal geomorphology of India, which contains data collected from large-scale maps, and inferences on the nature of the coasts based on such data. Near shore sediments especially on the mineralogical regimes off Mangalore (Siddiquie and Mallik, 1972; Mallik, 1972) and off Ratnagiri (Rajamanickam et.al., 1986; Rajamanickam and Gujar, 1984) are available. Thamban et.al. (2001) have studied the fluctuations in hydrography along the southwestern continental margin of India. Rao et al. (1996) studied the neotectonic activity and sea level changes during Late Quaternary, along the western continental margin. Banerjee (2000) identified Late Pleistocene-Holocene sea level high stands (+4 m) in the Rameswaram –Tuticorin sector and Godavari deltaic region of east coast of India. Kale and Rajaguru (1985) and Hashimi et al. (1995) used estimated and inferred ages and constructed sea level curves for the Late Quaternary for the western continental margin of India. Available information on the Quaternary sea level changes along the Indian coasts has been summarised by Merh(1992). An account of Quaternary sea level and its impact on shoreline displacement and coastal environment can be found in Rajamanickam (1990) and Rajamanickam and Tooley (2001). The works by Wagle et.al., (1994), Subrahmanya (1996) and Pandarinath et al. (2001) provide additional information of sea level changes. The Gujarat and Sourashtra coasts, which according to Pant and Juial (1993), is an ideal location to demonstrate both eustatic and tectonic features. Coastal landforms are strongly affected by sea level changes and tectonism. Paleo-shore lines have been identified as narrow (white) bands, running parallel to the coast of Saurashtra, Gujarat by Baskaran et al. (1987).

On the west coast, Tipper (1914) carried out the first studies on the beach sands of Kerala. Viswanathan (1949) studied the beach sands for the economic importance of titanium bearing minerals. According to Mathai and Nair (1988), the present coastal landscape in Central Kerala is the combined result of sea level fluctuations and various fluvio-marine processes during the recent geological past. Sabu and Thrivikramaji (2002) emphasizes that the evolution of coastal plains and their environments of Kerala are controlled by marine transgression and regression during the Tertiary time.

The coastal plain sediments of Kerala received little attention on the variation of down core sedimentological and geochemical aspects. It is in this context present work has been undertaken in the study area, i.e., the coastal tract between Kodungallur in north and Chellanam in south (Fig1.1), with the following objectives.

1. To document the variation in texture with depth of the coastal plain sediments.
2. To study the mineralogical variation (heavy and clay minerals) of sediments.
3. To investigate the geochemical distribution of major and trace elements and organic carbon of the sediments.

## 1.2 Geology and Geomorphology of Central Kerala

The Kerala region is an important segment of the South Indian Precambrian terrain bounded by the Western Ghats on the east and Arabian Sea on the west. The area is mainly covered by four major rock units (Fig. 1.2). They are (i) Precambrian crystalline rocks - which include charnockites, garnet biotite gneisses, hornblende gneisses, and other unclassified gneisses, which occupy a considerable area of Kerala. (ii) Tertiary sedimentary rocks, which unconformably overlie the Precambrians, which extend as a narrow belt along the major part of Kerala coast, comprise continental (Warkalli beds) and marine (Quilon beds) facies. The continental facies is made of carbonaceous clays with lignite/ coal seams, china clays and friable sandstones and the marine facies is composed of sandstones and carbonaceous clays with thin bands of fossiliferous limestones (Poulose and Narayanaswami, 1968) (iii) Laterites, the third major litho-unit covering about 60 % of the surface of Kerala and (iv) Recent to sub recent sediments, which extends from Kasaragod in the north to Kanyakumari in the south, which

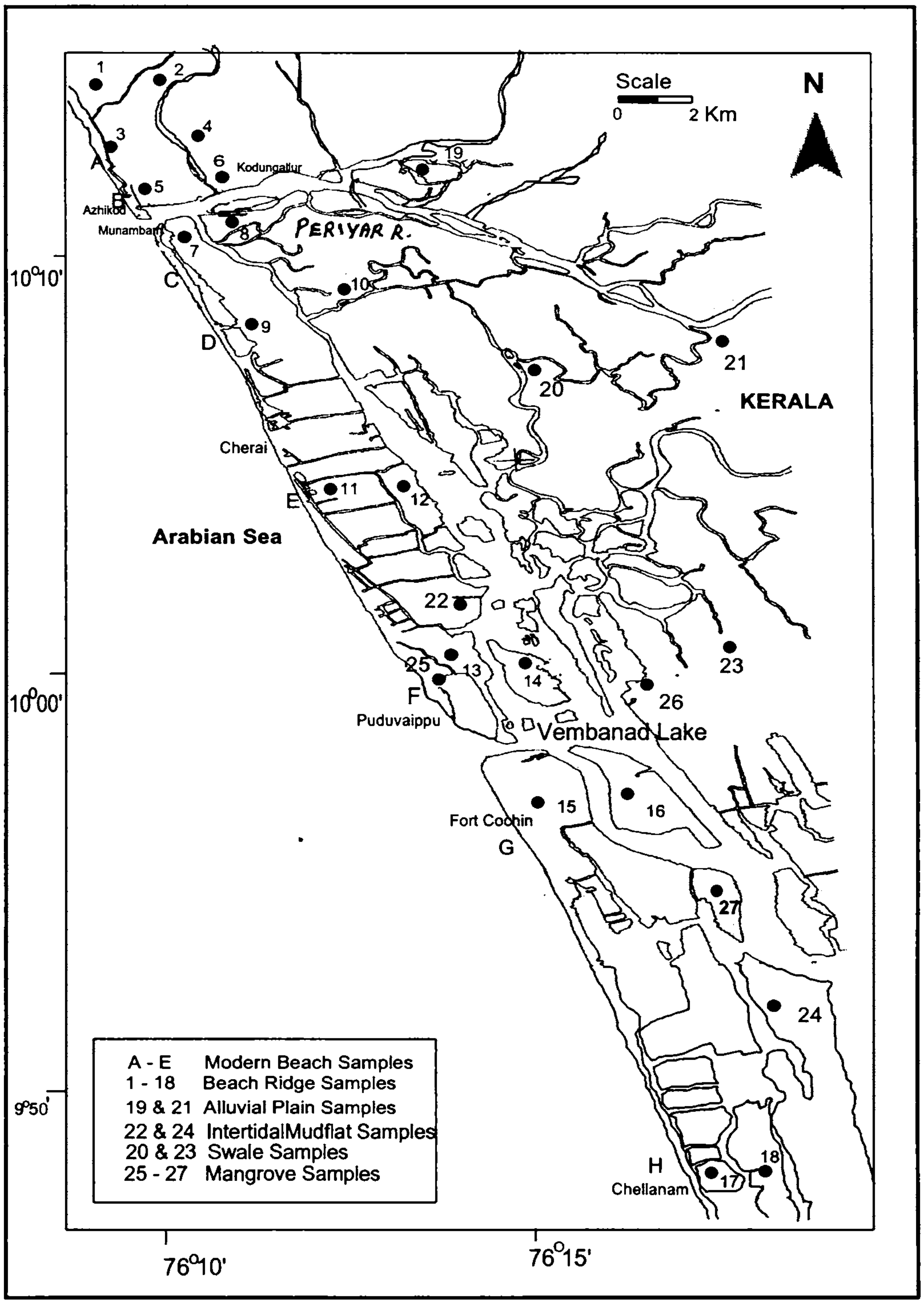


**Fig 1.1 Study area and sampling locations**

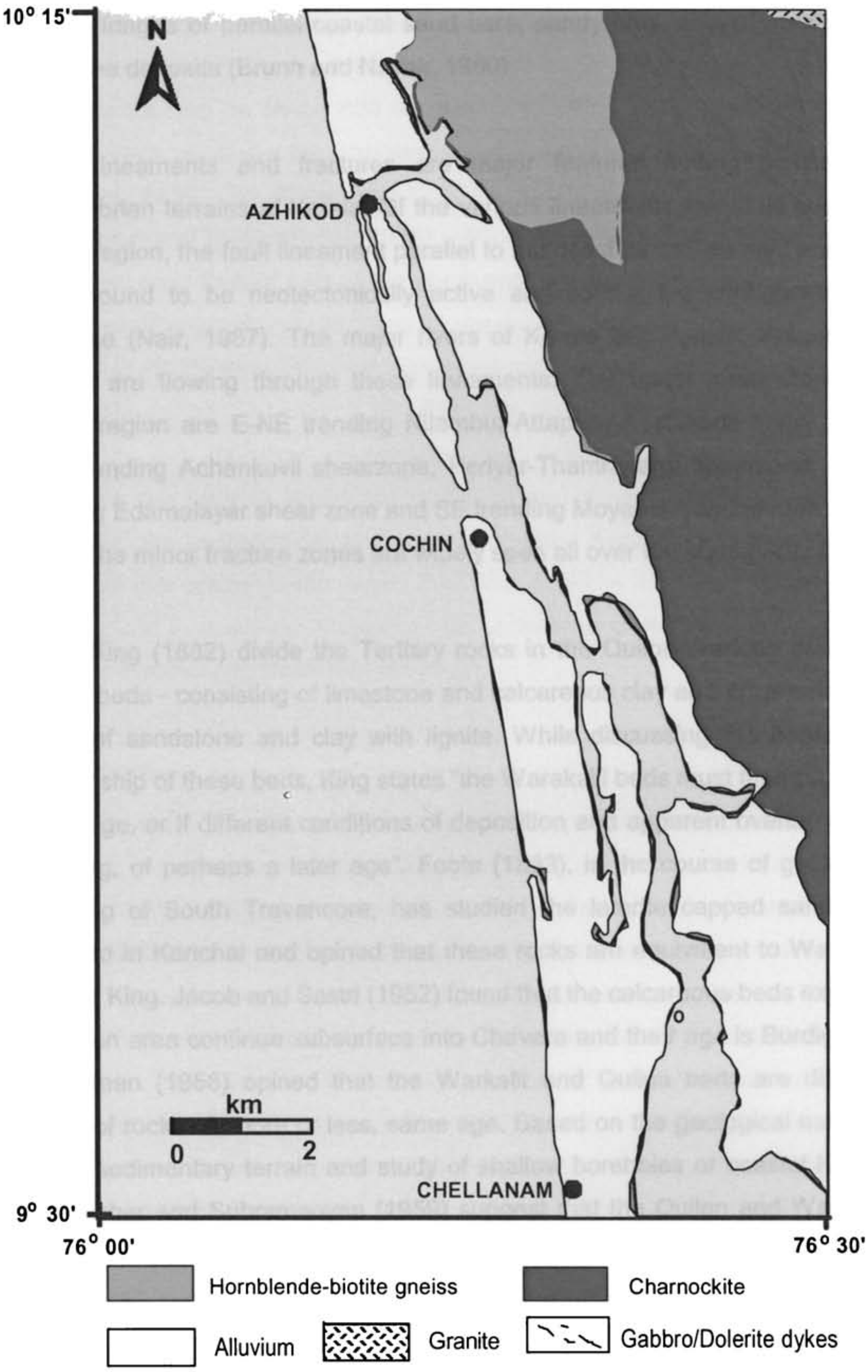


**Fig 1.2. Geological map of the study area (compiled after GSI, 1995)**

include fringes of parallel coastal sand bars, sandy flats, alluvial sands and lacustrine deposits (Brunn and Nayak, 1980).

Lineaments and fractures are major features cutting across the Precambrian terrains of Kerala. Of the various lineaments identified over the Kerala region, the fault lineament parallel to the coast as well as right angle to it are found to be neotectonically active and control the configuration of shoreline (Nair, 1987). The major rivers of Kerala like Periyar, Achankovil, Pamba are flowing through these lineaments. The major shear zones of Kerala region are E-NE trending Nilambur-Attapady-Kozhikode shear zone, E-W trending Achankovil shearzone, Periyar-Thamraparni shearzone, NNW trending Edamalayar shear zone and SE trending Moyar-Bavali-Mercara shear zone. The minor fracture zones are widely seen all over the state (GSI, 1995).

King (1882) divide the Tertiary rocks in the Quilon-Warkala area into Quilon beds - consisting of limestone and calcareous clay and Warakalli beds made of sandstone and clay with lignite. While discussing the homotaxial relationship of these beds, King states "the Warakalli beds must then be of the same age, or if different conditions of deposition and apparent overlap go for anything, of perhaps a later age". Foote (1883), in the course of geological mapping of South Travancore, has studied the laterite capped sandstone exposed in Karichal and opined that these rocks are equivalent to Warakalli beds of King. Jacob and Sastri (1952) found that the calcareous beds exposed in Quilon area continue subsurface into Chavara and their age is Burdigalian. Narayanan (1958) opined that the Warkalli and Quilon beds are different facies of rocks of, more or less, same age. Based on the geological mapping of the sedimentary terrain and study of shallow boreholes of coastal Kerala, Desikachar and Subramanyan (1959) suggest that the Quilon and Warakalli beds continue far into the north up to Kainakari and Ambalapuzha.

Bose et al. (1976) suggested that the deepest part of the sedimentary basin is between Chellanam and Chavara, and around Alleppey the thickness of sediments may be about 600 m. Rao and Datta (1976) opined that the Wrakalli beds could be the continental equivalents of Quilon beds, a view expressed earlier by Narayanan (1958) and doubted by King (1882). Varadarajan and Balakrishnan (1976) were of the view that the laterite along the coastal area formed part of the continental shelf and their occurrence as terraces of different elevations could be due to Neogene and Quaternary uplift. Desikachar (1976) identified four formations and these in the ascending order are (i) Mayyanad Formation, (ii) Azheekal Fromation, (iii) Ambalapuzha Formation, (iv) Kainakari Formation; the Azheekal and Ambalapuzha formations are roughly equivalent to Quilon and Warkalli beds. Desikachar highlighted the hydrocarbon prospects of offshore Kerala Basin. Murty et al. (1976) felt that greater sedimentary thickness could be expected northwest of Alleppey and Ponnani on account of the extension of the Achankovil shear zone and Palghat gap faults into the basin.

### 1.3 Drainage

The state of Kerala is drained by 44 rivers, of which 3 are east flowing. The streams originating from the Western Ghats are short and swift flowing, showing various stages of gradation. Cascades and waterfalls mark these streams in the upper reaches, although in the plains they show evidences of maturity of development. Some of these rivers have steep gradients (1/250 or more) in their initial reaches. In the case of Periyar and Chalakudi rivers, this extends for three-fourths of their course, while such gradients are also discernible in the upper reaches of Chaliyar, Valapattanam river, Vamanapuram Ar. and Karamana Ar, suggesting their youthful stages of development (cf. Resource Atlas of Kerala, 1984). Rejuvenation of the catchment area, closely linked with the west coast faulting and later adjustments may, in all probability, be the reason for the youthful behaviour of the rivers, while high-energy shoreline might have prevented delta formation in the river mouths.

The general drainage pattern of the rivers of central Kerala is dendritic, although in places, trellis, sub-parallel and radial patterns are also noticeable. Most river courses are straight, indicating structural control. General course of the rivers is along prominent lineaments (NW-SE and NE-SW). The five major rivers, namely Periyar, Bharathapuzha, Pamba, Chaliyar and Chalakudi together drain 40% of the geographical area of the State.

**Periyar River:** The river Periyar having a length of 244 km is the longest river in Kerala (Table 1.1). It has a drainage area of 5398 $km^2$ (cf. Water Resource of Kerala, 1974), of which 114$km^2$ lies in Tamil Nadu. The catchment area spreads over the districts of Idukki and Ernakulam. Formed by the confluence of a large number of streams originating from the Sivagiri hills in the Western Ghats at an elevation of 1800 m, it finds its source from the south and east of the Periyar reservoir and Periyar wild life sanctuary areas. From the exit point of the Periyar dam, the river flows almost in NNW direction with occasional meanders up to the Idukki dam area. From Idukki the river flows northwards up to the Mudrapuzha confluence. The main tributaries of the Mudrapuzha originate from the Mattupatti, Anamudi areas and flows through Munnar town, which is a junction of three arms of the river. It passes through several gorges, the important one being the Idukki gorge. Major reservoirs like Idukki, Periyar, Anairangal, Mattupetti and Setuparvatipuram are within the basin area.The Periyar river takes a straight NW course up to Bhutathankettu reservoir. The main branches, Edamala Ar and Puyamkutty Ar debouch their sediments into Bhutathamkettu reservoir. From there, the Periyar river and its distributaries join the Vembanad lake at Azhikod. The sinuosity of the river is 1.75, which is moderate and decreases towards the downstream direction. The river flows through a metamorphic terrain consisting of charnockite, khondalite, garnet-biotite and hornblende-biotite gneisses, besides migmatite and granite.

**Table1.1 Details of the rivers discharging into the Vembanad Estuary (Water Resources of Kerala, 1974; Soman, 2002)**

| River | Length (km) | Catchment Area ($km^2$) | Annual Run-off (1000 MC ft.) |
|---|---|---|---|
| Karuvannur | 48 | 1054 | 42.00 |
| Chalakudi | 130 | 1704 | 42.00 |
| Periyar | 244 | 5398 | 434.00 |
| Muvattupuzha | 121 | 1554 | 93.68 |
| Meenachil | 78 | 1272 | 96.27 |
| Manimala | 90 | 847 | 72.67 |
| Pamba | 176 | 2235 | 222.80 |
| Achankovil | 128 | 1484 | 76.00 |

**Muvattupuzha River:** Muvattupuzha River is one of the major perennial rivers in central Kerala. It has a length of about 121 km and a catchment area of about 1,554 $km^2$ (cf. Water Resource of Kerala, 1974). The river originates from the Western Ghats and drains mainly through highly lateritised crystalline rocks. It debouches into the Vembanad estuary near Vaikom. Two major tributaries namely Thodupuzha and Kaliyar join the Muvattupuzha river near Muvattupuzha town. The Thodupuzha river has two main tributaries i.e., Vazhipuzha and Kudayathoorpuzha. The streamlets flowing down from the area north of Uppukunnu hills, west of Kuilimala hills i.e., Komb Ar and Toni Ar join to form the Kaliyar river, which flows towards northwest. After flowing as a single stream up to Vettukattumukku, the river branches into two distributaries namely Ittupuzha and Murinjapuzha. The river exhibits dendrite drainage pattern. The river discharge ranges from $50m^3$/sec (premonsoon) to $400m^3$/sec (monsoon). Peak discharge is recorded during June to October. Considerable changes have taken place in the flow characteristics of the Muvattupuzha river after the commissioning of the Idukki hydroelectric project in 1976, across the adjoining Periyar river. The tailrace water

(19.83-78.5$m^3$/sec) was directed into the Thodupuzha tributary from Moolamattom power station.

**Pamba River :** The river Pamba is the third longest river (176 km) in Kerala, and has the fourth largest catchment area (2235 $km^2$). It rises in the hill ranges of Pathanamthitta district and the adjoining Pirmed plateau, and is formed by the confluence of Pambiyar Ar, Kakki Ar, Arudai Ar, Kakkad Ar and Kal Ar. Pamba and Kakki are the major reservoirs in the basin. From Vadasserikkara to Chengannur, the river flows through midland terrain with minor meanderings down stream of Payipad, the Pamba river coalesces with other river distributories, which flow in the NNW direction to join the Vembanad lake. A paleochannel drainage basin is observed between Puthenkavu and Arattupuzha. Flowing through the crystalline rocks the basin displays dendritic to sub-dendritic and rarely rectangular and trellis drainage patterns.

**Chalakudy River:** The Chalakudy river has a length of 130 km and a drainage area of 1704 $km^2$. Five streams – Parambikulam, Kuriakutty, Sholayar, Karapara and Anakkayam form the Chalakudy river. Of these, Parambikulam and Sholayar rise in the Anaimalai hills at elevations above 1733 m and 1332 m, respectively. The river flows through thick forests and the channel has many waterfalls until it reaches the plains at Kanjirapally. The river debouches into the right arm of the Periyar at Puthenvelikkara. Poringalkuttu, Sholayar and Parambikulam are the major reservoirs in the basin. Charnockites and migmatitic gneisses are encountered along the river course.

**Achankovil River:** The river Achankovil has a length of 128 km and a catchment area of 1484 $km^2$. It originates from the border of Kerala and Tamil Nadu to the ESE of Achankovil. The Achankovil river has no prominent tributaries, other than small streamlets. The river has a straight northwesterly course from the Western Ghats to Konni and then it deviate to west. The Achankovil shear zone coincides with the drainage basin of the Achankovil river. This river joins with the river Pamba near Chennithala, before entering into the Vembanad estuary. The Achankovil river has again connection with Pamba river at Payipad and the main stream (local name, Puthan Ar) flows to the sea through Thottappalli spillway.

**Manimala River:** The major stream and its feeding streamlets originate from the mountainous regions at Uppanmala, Melethadom hills (1140 m above MSL) and areas around Endayar hills. Many small streamlets like Talungal Thodu, Kokkayar Ar joins the main stream. Two other tributaries join the main stream at Mundakkayam. Two other major tributaries join together and flow for a length of approximately 4 km before it joins the Manimala river. From there the river flows in the northwesterly direction and finally joins the Vembanad lake. Tidal action is noted up to Tirumoolapuram . This river is comparatively narrower than the Pamba and other major rivers. The Manimala river has a length of 90 km and has a catchment area of 847 $km^2$ out of this approximately 20 km runs through high land region, 45 km through midland and the rest (25 km) through low land areas.

**Meenachil River:** The Meenachil river has a length of 78 km and a catchment area of 1272 $km^2$. Major part (38 km) of this stream runs through midland terrain, 21 km through the highland and the rest (16 km) is seen to flow through the low land terrain. The river assumes its name after the confluence of its two important affluents at Erattupetta , one coming from Poonjar and the other from Tikkoi area. The Poonjar branch has two main tributaries and many small streamlets joining it. The other main branch has two tributaries i.e. the Kalattukadavu Ar and Tikkoi Ar. The Meenachil flows in the westerly direction from Erattupetta to Palai . Kudamuruti Thodu is a tributary of this. Before reaching the town of Kottayam, seven other tributaries join the main stream. The Meenachil river drain into Vembanad lake at Kumarakam .

**Karuvannur River:** The streamlets Kurumalipuzha and Manali Ar, which originate from the Western Ghats join to form the Karuvannur River. The Manali Ar collects its headwaters from the Vaniamparakunnu hills (400 m above MSL) and reaches the Peechi reservoir. From Peechi it flows in a southwesterly direction and joins the Kurumalipuzha at Pudukad area. The Chimonipuzha has three tributaries, which arise in the Payampara and Chimoni hill. Now a dam has been put here. Before joining the Vembanad Lake, one distributory goes towards north and joins the sea and the other main river channel trends south and reaches the Vembanad lake near Kodungallur. This river drains an extensive area of more than 1000 km$^2$ having a total length of 90 km.

### 1.4 Geomorphology of the coast

The width of the coastal plain in the State of Kerala varies from 35 to 120 km with an average of 65 km. Within this small width, the physiographical and topographical features change considerably. Kerala has a coastline of 560 km. Of this a cumulative 360 km length of coastline is very dynamic and fluctuates seasonally. Based on vulnerability and dynamism, the shoreline is divided into (1) permeable, gently sloping sandy shoreline (2) semi permeable, cliffed sedimentary shoreline and (3) impermeable crystalline shoreline arranged in order of intensity of erosion.

The central Kerala coast is described as a submerged coast, falling under the terrigenous coast of primary morphologic disequilibrium. Accordingly the long-term tendency of coastal evolution is to increase the linear extent of erosional coastal segments at the expense of intervening depositional areas and when the process completes a coast of equilibrium results. The coastal features include beaches, beach cliffs, stacks, islands, shore platforms, spits, bars, beach ridges, estuaries, lagoons, mud flats, tidal flats and deltaic plains (Nair, 1987; Thrivikramaji, 1987).

The characteristic features of Kerala coast are the backwaters and the estuaries. They include lakes (kayals) and sea inlets, which stretch irregularly along the coast (Joseph and Thrivikramaji, 2002). The biggest one is the Vembanad Lake, with about 230 km$^2$ in area, opens into the Arabian Sea at Fort Cochin. The other important backwaters are at Ashtamudi, Veli, Kadhinam-Kulam, Anjego, Edava, Nadayara, Paravur, Kayamkulam, Kodungallur and Chetuva. Coastal inlets play an important role in the exchange of water between bays/estuarys and ocean. There are about 48 inlets in Kerala, out of which 20 shows permanent nature of opening, whereas the remaining 28 open only during the monsoon season (Nair et al., 1993). Munambam inlet is a major permanent inlet just north of Cochin inlet, through which Periyar River joins the sea. Island and islets are major landforms seen along the lagoon.

The shoreline of Kerala is generally straight, trending NNW-SSE, with minor variations. Even though the straight-line configuration is apparent in a synoptic view, the shoreline is highly irregular and indented especially around promontories comprising of crystallines and sedimentaries. Stretches of shoreline between promontories are usually depositional in nature with sandy beaches and are locally straight. Long shore drift deposits straighten out the shore features over long stretches (Nair, 1987). The coastal landforms are generally elongated parallel to the coast. They are mainly made of sand and alluvium. Strandlines are seen along these elongated coastal landforms and are considered to be ancient shorelines by most geomorphologists. As an ancient shoreline strandline refers collectively to the assemblage of various features characteristic of former coastal area. Strandlines in this sense may be either above or below the actual water level. Strandline need not necessarily refers to marine features. Ancient lake shorelines are occasionally called strandlines (Smith, 1968). Coastal erosion is a major problem along the Coast of Kerala. In the central Kerala region, considerable stretches of shoreline from Fort Cochin to Manaccadum are reported to undergo severe erosion

(Murthy et al., 1980). Shore protection structures such as seawalls and groins have been constructed to check erosions of alarming proportions.

### 1.5 Climate and Rainfall

Kerala region experiences the tropical climate and the dominating feature is the monsoon. Subtropical type of climatic regime is seen in certain areas in the eastern part of the state due to the high variation in relief from west coast to the hilly regions of the Western Ghats in the east. Through Palghat gap and Ariankavu pass the heat waves from the plains of Tamil Nadu enters Kerala.

According to Indian Meteorological Department the seasons of Kerala can be grouped into a) the hot weather period (the pre-monoon season, during March-May), b) the south – west monsoon (June – September), c) the retreating monsoon (September-November) and d) the winter (December-February). The atmospheric temperature is maximum (37°C) during the premonsoon period and from June it gradually comes down due to heavy rainfall. Land and sea breezes influence the coastal area and here the seasonal and diurnal variations of temperature and almost of the same range (5° - 70° C). Kerala experiences two monsoons, namely the Southwest (June to September) and northeast (October – December) monsoon. The State of Kerala receives highest annual rainfall among other states of India, which is three times the average rainfall of India. The average annual rainfall varies from 100-500 cm with an average of about 300cm. The northeast monsoon is generally weak along the West Coast and the average annual rainfall is about 60 cm (Pisharody, 1992; Sampath and Vinayak, 1989).

### 1.6 Waves, Currents and Tides

West coast of India is under the influence of the SW monsoon between June and September, which is considered as the rough weather season from wave climate point of view. The wave activity is very strong during June and

July but the intensity reduces by August and September. The sea remains relatively calm during October to May (fair weather season). During fair weather season, long swells often mixed with the local sea winds prevail along the coast. The dominant energy along near shore is composed of gravity waves and mean currents of circulation. Far infra-gravity wave energy is about two orders of magnitude larger than that of gravity waves and evidence of edge waves in the infra-gravity band was demonstrated by Tatavarti et al. (1996). Far infra-gravity waves may be a common feature in the nearshore oceans in the presence of longshore currents (Bowen and Holman, 1989).

The wind and current systems along the coast play an important role in the dynamics of mud banks of the southwest coast if India. The important feature of the wind system in the Indian seas is the seasonal reversal of direction associated with two monsoons. Along the west coast of India, during the southwest monsoon the winds blow southwards from May to September and attain a northerly direction during the northeastern monsoon. Thus, the seasonally reversing wind pattern influences the southward littoral drift during the southwest monsoon, while a northward drift occurs during the northeastern monsoon. By the middle of May, the southwest monsoonal winds of oceanic origin are established. These winds continue to increase gradually until June when there is a 'burst' or sudden strengthening of the southwest winds. During July and August, the winds have their highest strength, and in September the wind force decreases ahead of the fall transition, which lasts through October and November (Sharma, 1978).

Estuarine hydrography plays an important role in the sedimentation and geochemical processes of this environment. The quantum, duration, transport and settlement of the particulate sediments depend directly on estuarine hydrography. The hydrography of the Vembanad estuary has been investigated by several researchers (Quasim and Reddy, 1967; Quasim et al., 1968; Sankaranarayanan et al., 1986; Anirudhan, 1988; Rasheed et al., 1995). Processes like exchange of heat with atmosphere and other localised phenomena are also likely to influence the hydrographic conditions of the system. The temperature of water in estuary varies between 25 -31 C. Low salinity values ranging from 0 to 10 x $10^3$ psu at the surface and 0 to 12 x $10^3$ psu at the bottom are observed during monsoons. This is brought by the combined effect of land drainage from the prevailing monsoonal rains causing high freshwater discharge from the river and intrusion of saltwater from the sea. As the season advances to post and premonsoon, higher salinity values ranging from 10 to $22x10^{-3}$ psu at the surface and 12 to $24x10^{-3}$ psu at the bottom were observed (Anirudhan, 1988). The estuarine waters considerably get diluted near the Muvattupuzha river confluence. The pH values of the surface and bottom water vary from 6.6 to 7.4 and slight increase is observed seasonally up to postmonsoon period.

### 1.7 Area of Study

The study area extends between latitudes 9°47" to 10°13" N and longitude 76°10" to 76°23" E, from Kodungallur in the north to Chellanam in the south for a length of 42 km. In the eastern part, the area extends beyond the swales, at times as far east as 15 km. The Arabian Sea forms the western limit. Vembanad estuary, which fringes the study area on the eastern side is the largest backwater system in the west coast of India and is the largest water body in Kerala extending parallel to the coast from Alleppey in the south to Munambam in the north (latitudes 9°28" – 10°10" N and longitudes 76°13" - 76°25" E). It has a length of about 113 km and the breadth varies from a few hundred meters to 14.5 m, covering an area of about 233 $km^2$. It is elongated and oriented in NW-SE direction. This estuary system has two openings with the Lakshadweep sea; one at Fort Cochin and other at Munambam (northern part of the study area). Seven major rivers (five from south of Cochin; Achankovil, Pamba, Meenachil, Manimala and Muvattupuzha and two from north; Periyar and Chalakkudi) debouch into the estuary. The area of Vembanad kayal in 1912 was 315 $km^2$and by 1983 it shrank by 43.09% to 179.25$km^2$ (Nair et al. 1987), essentially due to reclamation and

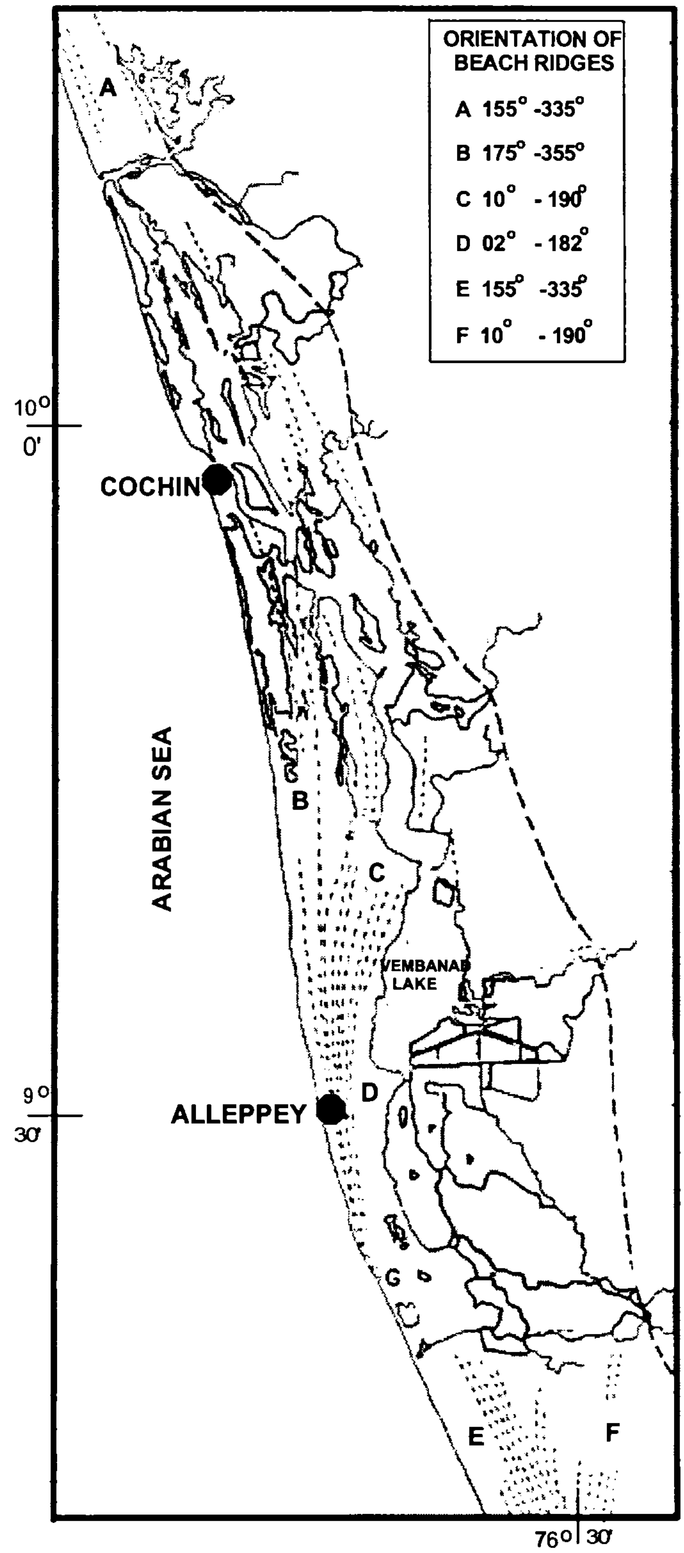


**Fig. 1.3 Orientation of palaeo-beach ridges from Central Kerala (After Mallik and Suchindan, 1984)**

encroachment. The available C14 dates indicate Holocene evolution of the estuary. Spatial disposition of the distributory system of rivers in the deltaic upper Kuttanad area, comprising Achankovil, Pamba and Manimala suggests existence of a single mighty river prior to the Holocene sea-level rise.

On the southern side of the Vembanad estuary, a barrage has been constructed near Thannermukham to prevent saltwater intrusion especially during extreme droughts (premonsoon). The backwaters are bounded by barrier islands and have numerous interconnecting canals. The bathymetry of the Vembanad estuary suggests that the depth of the water column in the estuary varies from <1m to 8.5 m. It is shallower in the northern and southern parts of the estuary as well as in the adjacent narrow channels in the central part (<1 – 2m). The central part of the estuary is deeper with the water depth generally varying from 2 – 5 m. The deepest part (8.5 m) is in its southern part, south of Thanneermukkom bund to the northeast of Varanam church. Most of the sediments in the estuary consist of different admixtures of clay, silt and sand. Based on borehole data, thickness of the sediments in the lake is found to vary from 34 to 63 m, and the sediments include mixtures of sand and clay, and occasional lignite patches. The coastal plain is marked by a number of beach ridges running parallel to the coast and lake margins (Fig1.3).