

# Chapter I

## Tsunami

### 1.1 Introduction

The Tsunami which struck the Kerala coast on 26<sup>th</sup> December 2004 has created wide spread havoc on human life and property. It took away many valuable life and coastal destruction and damages to life supporting structures all along the coastal belt of Thiruvananthapuram, Kollam, Alappuzha, Eranakulam and Thrissur. It has completely destroyed the rhythm and livelihood and coastal population. Further, it has created irrecoverable havoc on different elements of the environment, i.e., land, water, air and biota. Houses have been razed to the ground, castle perished, fishing boats, nets and fishing equipments washed away, landing center washed away, landing centers flattered and fishing harbours sifted up and break waters and armour stones seriously damaged. Extensive damages to water supply systems, electric installations and road communication have resulted in disruption of life along the coastal region.

Scientific studies have been conducted by number of agencies for understanding the impact of Tsunami in various elements of the environment and produced their own reports. KSCSTE has decided to consolidated such study reports made by various agencies. In this respect, KSCSTE has conducted a series of meetings and persuaded a number of agencies for obtaining the study made by them. The primary objective was to assess the impact of Tsunami and scientific evaluation of its influence on environment which would enable us to combat such disasters in the future.

Tsunamis are waves generated in the ocean due to earthquake, landslides or volcanoes. Large impulsive displacement of the ocean floor generates tsunami. The word 'tsunami' is Japanese and made up of two characters 'tsu' (meaning harbour) and 'nami' (meaning wave) thus meaning 'harbour wave'.

Tsunami, which struck on 26th December 2004, was one of the greatest calamities that the present generation has ever witnessed in terms of the loss of human life and material damage. The dynamics of earth and science of tsunami was vividly explained,

any mechanism in timely predicting the disaster is not yet emerged out. It is understood that earthquakes trigger tsunamis, especially, if the epicentre of which lies within the sea or near shore area. Other natural process like volcanic eruptions, extensive landslides, and meteoritic impact etc. can also generate gigantic waves in the sea resulting to tsunamis.

A vertical movement along a break in earth's crust causes most tsunamis. A tsunami is generated when a large mass of earth on the bottom of the ocean drops or rises, thereby displacing the columns of water directly above it (tectonic activity). Volcanoes have generated significant tsunamis in the world. The most efficient methods of tsunami generation by volcanoes include disruption of water by the collapse of all or part of volcanic edifice, subsidence, an accompanying or preceding the eruption. Submarine eruptions may also cause minor tsunamis.

Sub-aerial and submarine landslides may generate locally destructive tsunamis. These may not be as destructive as that of a tectonic earthquake, generated tsunami.



The plate tectonics explains the dynamics of earthquakes reasonably with clarity; plate boundaries and their alignments within the ocean bottom are clearly demarcated. It is also possible to predict the nature of waves generated out of tsunamis and their likely impact and extent of waves on the near shore areas through modelling studies. Large

vertical movements of the earth's crust can occur at plate boundaries. The subduction zones where the margin of the ocean plates slips under continental plates and deciphering such locations are very important part of the study. In the recent incident the subduction zone at the Indonesian plate boundary near the Java trench had generated the earthquake waves resulting into release of total energy, which generated the killer waves. Tsunamis are characterised by shallow water waves, with long periods and wave lengths. In the Indian Ocean where the water depth is about 2500m, a tsunami may travels nearly 575 km/hr.

Velocity of a tsunami wave depends on the depth of water through which it travels. Tsunami wave velocity based on depth and its wavelength is tabulated in Table 1.

**Table 1. Velocity of Tsunami wave with reference to depth and wavelength.**

Depth (m)	Velocity (km/h)	Wavelength (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

The height of the tsunami wave ranges from few centimetres to about 30m. Most tsunamis are less than 3 meters in height. Tsunami waves are not noticed in deep waters. The wave height increases when it reaches the shore. The bathymetric features and shoreline controls the height of the wave reaching the shore.

The receding of sea waves are usually noted prior to the tsunami. Ocean floor may be exposed and then wave crest approaches the coast with a high speed. These approaches the shore like flasher and causes destruction on the coast.

It is possible to predict a tsunami at various places by knowing the source characteristics of the earthquake that generated the tsunami and the characteristics of the sea floor along the paths of those places. The impact of tsunami was determined by the offshore and coastal features. The reefs, bays, river estuaries, under sea features, slope of the beach occurrence of backwater system etc. control the impact of tsunami. Though it

is difficult to predict the occurrence of earthquakes and tsunami the post tsunami studies are helpful in predicting future tsunami impact and flooding limits at specific coastal stretches.

## **1.2 Elements At Risk**

All structures located within 200 m of the low lying coastal area are most vulnerable to the direct impact of the tsunami waves as well as the impact of debris & boulders brought by it. Settlements in adjacent areas will be vulnerable to floods & scour. Structures constructed of wood, mud, thatch, sheets and structures without proper anchorage to foundations are liable to be damaged by tsunami waves & flooding. Other elements at risk are infrastructure facilities like ports & harbours, telephone and electricity poles, cables. Ships & fishing boats/nets near the coast also add to the destruction caused by tsunami waves.

## **1.3 Typical Effects**

*Physical damage* - Local tsunami events or those less than 30 minutes from the source cause the majority of damage. The force can raze everything in its path. It is the flooding effect of a tsunami, however, that most greatly effects human settlements by water damage to homes and businesses, roads, bridges and other infrastructure. Ships, port facilities, boats/trawlers, fishing nets also get damaged.

*Environmental damage* - There is evidence of ever increasing impact upon the environment on account of the effects of tsunamis. The range varies from generation of tonnes of debris on account of structural collapse of weaker buildings, release of toxic chemicals into the environment on account of chemical leak/spillage/process failure/utility breakages/ collateral hazards and negative impact on the already fragile ecosystems.

*Casualties and public health:* Deaths occur principally from drowning as water inundates homes or neighbourhoods. Many people may be washed out to sea or crushed by the giant waves. There may be some injuries from battering by debris and wounds may become contaminated.

*Water supply:* sewage pipes may be damaged causing major sewage disposal problems. Drinking water shortage arises due to breakage of water mains and contamination. Open wells and ground water may become unfit for drinking due to contamination of salt water and debris.

*Standing Crops and food supplies:* flooding by tsunami causes damage to the standing crops and also to the food supplies in the storage facilities. The land may be rendered infertile due to salt water incursion from the sea. All these effects are dealt in detail in the following sections.

#### **1.4 Tsunami and India**

Tsunamis are frequent occurrences in certain locations bordering the Pacific ocean, especially Japan. Tsunamis in Indian Ocean are, however rare. But the tsunami on 26<sup>th</sup> December 2004 due to a massive earthquake with a magnitude of 9.3 in Richter scale off north Sumatra coast (3.316°N latitude and 95.854°E longitude) generated devastating waves and affected several countries in South East Asia and in Africa. The number of human lives lost was recorded as 186983 and missing as 42883 by United Nations. In India it was affected in Andaman and Nicobar Island, Tamilnadu, Pondicheerry, Andra Pradesh and Kerala. As per records of Ministry of Home affairs the death toll in India is 12400 and missing is 5604. Many were injured and massive destruction to coastal areas were recorded. Some of the Historic Tsunamis are tabulated in Table 2.

**Table 2. Tsunamis affected in India**

<b>Date</b>	<b>Remarks</b>
12 April, 1762	Earthquake in bay of Bengal. Tsunami wave of 1.8 m at Bangladesh coast
19 <sup>th</sup> Aug. 1868	Earthquake Mag. 7.5 in Bay of Bengal. Tsunami run-up 4.0 m at Port Blair
31 <sup>st</sup> Dec. 1881	Earthquake of mag 7.9 in the Bay of Bengal reported tsunami run-up level of 0.76 m at Car Nicobar, 0.3 m at Nagapattinam, 1.22 m at Port Blair
27 <sup>th</sup> Aug. 1883	Karakatoa, 1.5 m Tsunami at Madras, 0.6 m at Nagapattinam, 0.2 m at

	Arden
1884	Earthquake in the western part of the Bay of Bengal Tsunamis at Port Blair, Doublet (mouth of Hoogly River)
26 <sup>th</sup> June 1941	8.1 quake in the Andaman Sea at 12.9 <sup>0</sup> N, 92.5 <sup>0</sup> E Tsunamis on the east coast of India with amplitudes from 0.75 to 1.25 m. Some damage from East Coast was reported.
27 <sup>th</sup> November 1945	Mekran Earthquake (Magnitude 8.1). 12 to 15 m wave height in Ormara in Pasi (Mekran coast) Considerable damage in Mekran coast in Gulf of Cambay of Gujarat wave heights of 11-11.5 meter was estimated. Damage report from Gujarat coast was not available. The estimated height of waves at Mumbai was about 2 meters, boats were taken away from their moorings and causality occurred
26 <sup>th</sup> December 2004	In India, Andaman & Nicobar Island, Tamil Nadu, Pondichery, Andhra, Kerala affected about 12400 people lose their lives & 5604 missing.

### 1.5 Tsunami and Kerala

There is no historic record of Tsunami in Kerala. Only Tsunami that has affected the State of Kerala was that on 26<sup>th</sup> December 2004. The lost estimated in terms life loss was 176 and 1600 were injured. Loss of property estimated to Cores of Rupees. Although the entire Kerala coast experienced the effects of tsunami waves at a stretch of 10 km along the coast off Azhikkal (9°2' N to 9°5'N) in Kollam district was the most affected in terms of inundation, run up and erosion. Alappuzha, and Eranakulam districts too had extensive damage due to this killer waves. The tsunami waves that hit Kerala coast were three to five meters in height, according to the National Institute of Disaster Management.



Plate 2. Tsunami waves in Allapad, Kollam district

It was also estimated that the tidal upsurge had affected 250 Kilometres of the Kerala coastline and entered between one to two kilometres inland. The tsunamis pounded 187 villages affecting 24.70 lakh persons in Kerala. As many as 6280 dwelling units were completely destroyed and 11175 were partially damaged in the tsunami onslaught. As many as 84773 persons were evacuated from the coastal areas in Kerala and were accommodated in 142 relief camps after tsunami

The impacts of tsunami in various sectors are discussed in detail in the report. Kerala coast being prone to hazards like Tsunami, Erosion, and cyclone needs a comprehensive approach for dealing with these hazards.

## **1.6 Marine and Coastal Environment of Kerala**

**1.6.1 Introduction :** The Coastal Zone in Kerala is the low land fringing the sea extending over 560km, with a height of less than 8m from the MSL, covers about 15% of the state's total area of 38,863 sq.km.

A chain of water bodies, locally known as *kayals* running parallel/oblique to the coastline is a characteristic feature of Kerala coast. These are mostly interconnected by natural or man-made canals, facilitating internal navigation almost for the entire length of

the coast. Numerous perennial rivers discharge into these kayals. Southern half of the Kerala coast harbours more of larger backwaters. The kayals of the Kerala coast are mostly separated from the sea by elongated sandbars and based on this they can be treated as “coastal lagoons”. The Kerala Public Works Department (cf. Water Resources of Kerala, 1974) has identified 27 estuaries and 7 lagoons in Kerala (Table 3).

**Table 3 Estuaries and lagoons in Kerala (Water resources of Kerala-PWD)**

Estuaries	Lagoons
1. Uppala	1. Kavvayi
2. Kumbala	2. Agalapuzha
3. Mogral	3. Enamakkal-Manakkodi
4. Chandragiri	4. Muriad
5. Kalnad	5. Kodungallur
6. Bekal	6. Sasthamkotta
7. Chittari	7. Vellayani
8. Karingote	
9. Ezhimala	
10. Valapattanam	
11. Dharmadam	
12. Tellicherry	
13. Mahe	
14. Kottakkal	
15. Elathur	
16. Kallai	
17. Beypore	
18. Kadalundi	
19. Chettuvai	
20. Ponnani	
21. Vembanad	
22. Kayamkulam	
23. Ashtamudi	
24. Paravur	
25. Edava-Nadayara	
26. Kadinamkulam	
27. Veli	

The vast low lying area fringing the coast, is not only an important physiographic unit of the state, but also important in terms of economic activity and demographic distribution. It constitutes 16.40 % of the area of the State, but also important in terms of economic activity and demographic distribution . In Central Kerala most of the area

shows elevation of 4 to 6 m above MSL, whereas it is 4 to 10m north and south Kerala, except the coastal cliffs, promontories and sloping platforms. Beach dunes, ancient beach ridges, barrier flats, coastal alluvial plains, flood plains, river terraces, marshes and lagoons constitute this unit. It has the maximum width in the Alappuzha and Aluva-Kaladi regions. A characteristic feature of this unit is the existence of numerous beach drive ridges, parallel and sub-parallel to the coast, especially in the Alappuzha-Cherthala regions. Their orientation indicates that the strandlines belong to at least two ages, and 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 (Soman, 1997).

The west flowing rivers meander in the level flats of the coastal plain, and sometimes strike a northerly direction as they flow into the backwaters. The characteristic formation of parallel sandy ridges along the coast, and the persistence of the system towards the east indicate a history of repeated marine transgressions and regressions. It has been assumed that there have been at least three significant phases of such processes within 5000 years before present, of varied intensity and intervals. It is continuing even now, these areas are extensively covered by coconut plantations, paddy lands, marshy areas and a high density of human populations. Table 4 presents the wetland categories along with their area of coverage along the Kerala coast.

**Table 4 Wetland categories along the Kerala coast (Source-Space Applications Centre, 1992)**

Category	Area (sq. km)
Beach and strand plain	1,378.5
Spit	0.8
Reclaimed land -1	512.9
Reclaimed land -2	24.0
Estuary	251.2
Flood plain	7.1
Islets	22.4
Lagoon	5.9
Total	2,202.8

The major renewable resources available along this coastal zone are water, agriculture and fisheries and non-renewable resource such as placer minerals, soils, subfossil deposits, etc. The average marine fish production from Kerala is 25% of India.

Kerala contributes around 20% of the total marine products exported from the country which earns 1200 crores per annum while the domestic turn over from fisheries is around 12,000 crores. The unique mud banks, which appear at some locations during the monsoon season, also contribute to the rich monsoon fishery along this coast. The Chavara coast of Kerala is well known world over for its rich heavy mineral deposits.

The coast is well known for several places of historical importance, heritage areas and areas of outstanding natural scenic beauty (Tables 5, 6, 7). Anjengo Fort, Bekal Fort, and Sankumukham palace are among the important historical areas declared by the Archaeology Dept. There are several places of outstanding natural beauty along the Kerala coast, which probably is one of the main reasons that make Kerala an important tourist destination. Sankumugham, Vettukad, Papanasam(Varkala), Pozhikkara-Paravur, Neendakara and Arthungal are some of the heritage areas.

**Table 5 List of historical locations along the Kerala coast (CZMP, 1995)**

Sl. No.	Place name	District	Remark
1.	Kottukal	Trivandrum	Vizhinjam Bhagavathy temple
2.	Sankumugham	“	Palace, mandapam
3.	Anjengo fort	“	Fort
4.	Thangasseri	Kollam	Fort & lighthouse
5.	Karunagapally	“	Budha image
6.	Ambalapuzha	Alappuzha	Budha image, Karumadi
7.	Vaikom	Kottayam	Temple with fine panels of mural paintings
8.	Mattancheri	Ernakulam	St. Francis Church
9.	Chennamangalam	Ernakulam	Granite stone, Hebrew inscriptions
10.	“	“	Pallipuram fort
11.	“	“	Manjapra temple
12.	“	“	Kottayil Kovilakam palace site of Raja of Villaravattath
13.	“	“	Vaipikkota Seminary built by Portugese in 18 <sup>th</sup> century
14.	Parur	“	Stone inscription
15.	Chemanchery – Quilandy	Kozhikode	Kappad pillar monument of the arrival of Vasco de Gama
16.	Bekal	Kasargod	Bekal Fort

The 690km length Kerala coast faces the Arabia Sea. The coastline of Kerala is more or less straight trending in NNW-SSE direction from north till the Thangassery

headland near Kollam. The coastline orientation south of Thangassery is in the NW-SE direction. The offshore continental shelf bathymetry is steeper to the south. While the 100m contour is at a distance of around 40 km off Thiruvananthapuram from the shore, it is 58km off Kasargode. The variation in the slope of the inner shelf is more pronounced. While the inner shelf is very steep with the 50m contour distant only 11 km off Thiruvananthapuram, it is very gentle off Kozhikode with a distance of 42 km. This change in the bottom slope has lot of implications in the hydrodynamic and sedimentological characteristics of the inner shelf of Kerala. Based on the bottom slopes Kurian (1987) categorised the Kerala coast into different wave energy zones which is found to be fully endorsed by the field data from different locations (Baba et al., 1988).

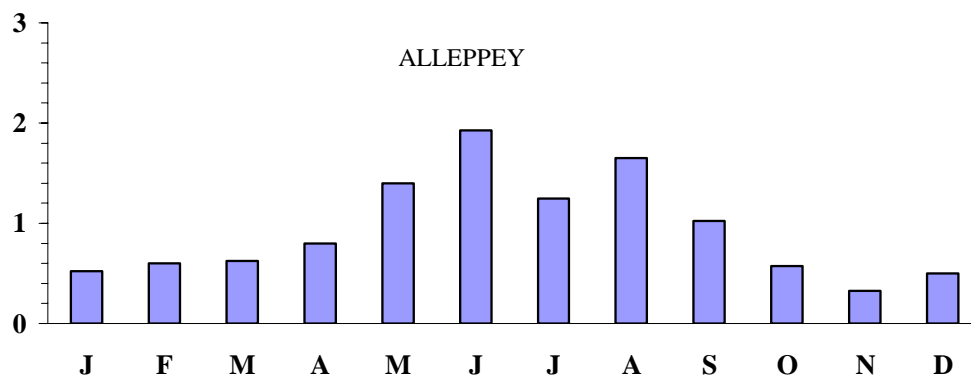
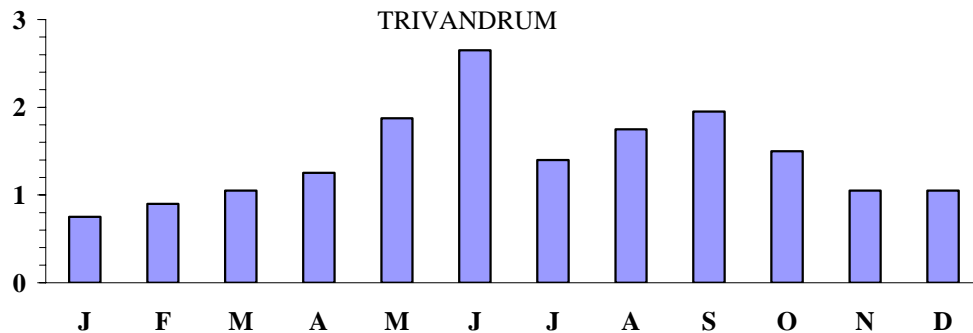
**Table 6 Areas of outstanding natural beauty along the Kerala coast (CZMP, 1995)**

No	Place name	District	Remark
1.	Puvar south	Trivandrum	Wide beach, backwater
2.	Pulinkudi – Kovalam	“	Rocky cliff, extensive stable beach
3.	Sankumugham	“	Beach, archaeological sites, palace, park
4.	Veli	“	Tourist Village, backwater, beach tourism, park
5.	Papanasam – Varkala	“	Cliff & beach, artician springs, temple
6.	Edava	Kollam	Barrier beach & backwater at close proximity, coconut groves
7.	Kappil	“	Barrier beach, extensive backwater, coastal road
8.	Pozhikkara	“	Pozhi (permanently connected to sea) with canal, temple, coconut groves
9.	Mundakkal (Jonnapuram)	“	Park, extensive stable, beach
10.	Thirumullavaram	“	Bay, beaches, coconut groves, temple, pond
11.	Palliyamturuth	“	Uninhabited island (islet) with beautiful backwater surroundings
12.	Alappuzha	Alappuzha	Extensive stable beach, park, pier suitable for recreational fishing
13.	Fort Kochi	Ernakulam	Wide beach backed by backwater
14.	Cherai	“	Extensive beach with sea and backwater frontage, park
15.	Bekal	Kasargod	Fort on high cliff, wide beaches around backwater at the vicinity
16.	Kottikulam	“	Promontory and pocket beaches around

**Table 7 List of heritage areas along the Kerala coast (from CZMP, 1995)**

Sl. No.	Place name	District
1.	Sankumugham	Thiruvananthapuram
2.	Vettukad	Thiruvananthapuram
3.	Papanasam	Thiruvananthapuram
4.	Pozhikkara – Paravur	Kollam
5.	Neendakara	Kollam
6.	Arthungal	Alappuzha

The hydrodynamic regime of the coastal marine zone of Kerala depicts the typical features of a monsoon dominated tropical coast. The highest wave and current intensity occurs during the peak monsoon months of June-July. The highest wave recorded is 9m off Kavaratti in the Lakshadweep sea (Baba et al., 1992). The waves approaching the coast are mostly the swells except during the peak monsoon period. The highest wave intensity is seen during the peak monsoon months of June and July due to proximity of the coast to the wave generating zones in the Arabian Sea. The nearshore wave intensity decreases from south to north (Fig 3). While the maximum wave height (Hmax) recorded is 6m at Valaithura near Trivandrum it is only 2.6m at Tellichery. Incidentally Trivandrum coast has the highest wave intensity along the Indian (excluding islands) coast. The longshore currents generated by the waves are generally southerly during monsoon and northerly during the rest of the year (Baba and Kurian, 1988)



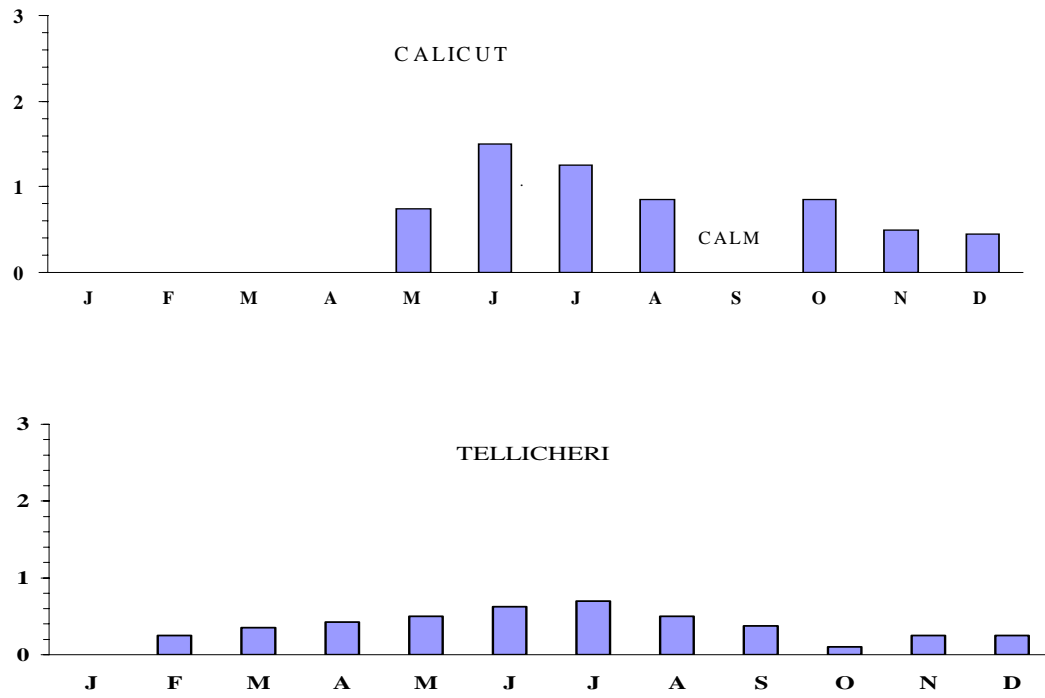


Fig. 3 Monthly mean  $H_s$  at different nearshore locations of Kerala coast in the year 1981 (after Kurian et al., 2004)

The coastal currents observed in the coastal marine zone are a resultant of wind-driven circulation together with tidal currents, continental shelf currents and coastal-trapped waves. Coastal currents are generally known to be southerly during monsoon and northerly during the fair weather period. Deviations to this generally understood pattern of coastal currents are observed and are attributed to the formation of an anticyclonic eddy off the southwest coast during the north-east monsoon and cyclonic eddy during the (southwest) monsoon (Shahul Hameed et al., 2004). Like the other parts of the west coast, the coastal marine zone of the Kerala coast is also known for the occurrence of upwelling which is strong during the monsoon. The coast is in general microtidal with the tidal range decreasing from north to south (Table 8). While the parts of the coast north of Kozhikode have a tidal range of around 1.5m, the tidal range is around 0.50 m in the south along the Trivandrum coast.

**Table 8 Tidal range at different tide recording stations in/near Kerala (from CZMP, 1995)**

Port	Lowest Low Water Springs at Solstices (LLWS)(m)	Highest High Water at Solstices (HHWS) (m)	Tidal Range (m)
Mangalore	0.03	1.68	1.65
Bey pore	0.18	1.51	1.33
Kochi	0.20	1.05	0.85

The surficial sediments of the continental shelf and slope of Kerala can be divided into terrigenous, biogenous and chemogenous sediments. In the shelf and slope of Kerala, terrigenous sediments mostly occur as sands in the nearshore (up to 10 -12 m water depth) followed by a zone of silty clays on the inner shelf. An admixture of abundant terrigenous and biogenic constituents carpets the outer shelf. The continental slope sediments are clayey silts with abundant carbonate tests. The surface sediment distribution in the inner continental shelf also shows considerable diversity with respect to the bottom slope conditions. For example, when the shallow northern parts of this coast have fine-grained sediments dominated by silt and clay, the southern parts off

Kollam and Thiruvananthapuram have a sandy bottom (Prakash, 1991; Ramachandran, 1992; Hashimi et al., 1981).

Pleistocene sea level variations have affected shelf sedimentation and Nair (1974) inferred that this shelf could be considered as an example of a drowned coast, formed due to transgressive and regressive episodes. Thus, sediment facies in the shelf embodies mixed distribution of both ancient and modern sediments presently remain inundated by reworking processes. Nair et al. (1978) and Hashimi et al. (1978) identified three distinct sedimentary facies, the first two facies consisting of sand and mud are of recent origin, while the outer shelf relict carbonate sand facies are of late Pleistocene (8,000-11,000 year BP) formed at the time of marine regression. From the study of carbonate sediments and size of quartz grains, Nair and Hashimi (1980) inferred a warmer climate and low terrestrial run off during the Holocene. Further, feldspar content in the sediments has also been used to infer the climatic aridity over India 11,000 years ago (Hashimi and Nair, 1986). Therefore, these evidences indicate contrast in climate between the carbonate and clastics on the shelf suggesting rapid change from arid to humid climate.

The coastal marine zone of the Kerala is well known for the occurrence of mudbank which is a unique phenomenon. During the southwest monsoon period when the sea is very rough, very calm sea conditions prevail in the mud bank zones adjoining the shorelines. Some of the locations well known for the occurrence of mud bank are Koilandy, Njarakkal, Puthuvype, Alleppey and Purakkad. Unlike the mud banks reported from other muddy coasts of the world (Wells and Coleman, 1981; Rine and Ginsberg, 1985), the Kerala mud banks do not show regular relief forming features. Their transient nature, unpredictable periodicity, calmness and turbid nature of the water column are unique. Ramachandran and Mallik (1985) reported an offshore sediment source and rapid sedimentation in the mud bank region during the monsoon season. Baba et al. (1994), Mathew and Baba (1995) and Mathew et al. (1995) examined in detail the wave climate of a mud bank location, sediment characteristics during different stages of mud bank and the wave-mud interaction processes. According to the conceptual model proposed by them, the offshore sediments resuspended by high waves during the monsoon form a fluid mud layer, which is transported *en masse* to the nearshore by the combined action of waves and currents and cause the formation of mud bank. The duration of the mud bank

is determined by the ability of waves and currents in keeping the fluid mud without much settling and also in overcoming its down slope movement due to gravitational force, which controls the dissipation of mud banks.

Kerala is the most densely populated state in India with a population of 318 lakhs in 2001. In this about 30% live in the coastal zone. The coastal population density at the major urban centers like, Cochin, Thiruvananthapuram, Kozhikode, Alleppey and Kollam is more than 2000 persons per sq. km. The figure is extremely high at some pockets near the major cities like Cochin, Thiruvananthapuram and Kozhikode and at some other places like Tellicherry, Neendakara etc.

Due to the high density of population compared to the other parts of the state the coastal zone has undergone substantial development. Out of the total 14, 7 district headquarters are located in the coastal zone. They are Kasaragod, Kannur, Kozhikode, Ernakulam, Alleppey, Kollam and Thiruvananthapuram. All the four municipal corporations, Kozhikode, Cochin, Kollam and Thiruvananthapuram and 19 municipal towns (including the district headquarters) are situated in this zone. Easy water transport and shipping facilities and availability of abundant water resources also attracted the industrial and other related development projects to this zone.

Most of the industries of Kerala are situated in and around the coastal zone. In addition to this, the bulk of the state's wood and clay based industries, fish processing plants, boat building yards, coir industries etc. are situated here. Most of the coastal areas are connected by roads, railway or water transport systems. A good inland water transport facility exists along this coast. There is substantial scope for improvement of water transport system, which will be cheaper and more harmonious to the coastal environment. There are three international airports in the state at Thiruvananthapuram, Kochi and Kozhikode which are situated in the coastal zone.

A major port at Cochin, and 14 minor ports and fishing harbours are situated in this coastal zone. Utilizing the dredged material from the shipping channel, the land area in the vicinity of the Cochin port has been considerably enlarged; eg. Wellington island, Candle island, Marine drive, Vallarpadam, etc. In addition to the ports mentioned above, a series of fishing harbours and fish landing centers are established along this coast. Out of the total length of 560km, about 260km of the coast is under varying degrees of

erosion (Sreekala et al., 1998). In order to combat this erosion, shore protection measures are being taken along this coast for the last 100 years. The shore protection structures made along the coast are broadly classified into three: (1) seawalls, (2) seawall & groin assembly and (3) groins. Accreted beaches are being developed into tourist destinations. Even though the dams constructed on the rivers do not come under the coastal zone, they have considerable influence on the sediment budget of the coastal zone. The major schemes like Thanneermukkam bund and Thottappally spillway are constructed in the coastal zone with a view to achieve agricultural development in the Kuttanad area. These have created various environmental problems in this area.

In addition to the major reclamation works undertaken at the Cochin port with dredged material, there are major governmental schemes for reclamation at Kattampally, Kayamkulam, Paravoor, Trichur, Ponnani, Korappuzha, etc. In addition to this, private agencies and individuals also have undertaken this activity all along the coast of Kerala. The high density of population in this zone has necessitated a large-scale housing development in the coastal zone. Near the urban centers the density of housing has reached such an alarming proportion that the people of the lower strata (mainly fisherman) even encroach the newly accreted beaches.

**2.6.2 Bibliography :** An account of bio-diversity of Kerala's marine and coastal zone is given in Chattopadhyay et al. (2003) based on a technical note prepared by M.P. Nayar (2002). Compared to terrestrial biodiversity, the marine biodiversity and their ecological interactions are poorly studied. Tropical marine ecosystem of Kerala coast includes lagoons, mangrove swamps, sandy and rocky shores and open sea front. Studies on microorganisms, phytoplankton's, zooplanktons and micro algae are done in individual groups. The CMFRI (Central Marine Fisheries Research Institute), Kochi conducts studies on marine biodiversity.

A close relationship between the abundance of Oil Sardines (*Sardinella longiceps*) and abundance of *Fragilaria Oceanica* in the west coast was reported. About 291 species of phytoplankton were listed in the Kozhikode coast. *Fragilaria oceanica*, *Coscinodiscus gigas*, species of *Chaetoceros*, *Rhizosolenia*, *Bacteriastrum*, *Skeletonema*, *Eucampia* and *Asteronella* were the dominant diatoms. Copepods formed the largest zooplankton

community in the Kozhikode area. The other economically important groups in Protozoa are foraminifers and radiolarians. Flagellates form major groups with high productivity and high turnover. Macro algae belong to the families of Chlorophyceae, Phaeophyceae, Rhodophyceae and Cyanophyceae. Out of the total 64 families and 215 genera found in India, Kerala and Lakshadweep area have 25 families and 75 genera.

Sea grasses in the West coast are found in small shallow beds. *Halophila ovalis* is associated with mangroves. Other species are *Halophila beccari*, *Halodule pinifolia*, *Enhalus acoroides* and *Cymodocea rotundata*.

Mangrove vegetation is an important coastal ecosystem associated with tidal / mud flats and back water systems. According to one estimate in the recent past Kerala had 70,000 ha. of mangrove, which had diminished to less than 4200 ha (Mohan, 1997). Some other estimate indicates the extend of mangrove vegetation to be 1671 ha at present within a distance of 500m from the coastline. Mangroves are found in small isolated patches along the coast and back waters. The major concentrations are found in the Vallapattanam river mouth, Kannur district, Puthuvypene at Ernakulam district and Kumarakom (Vembanad lake east bank) at Kottayam district. Certain patches are also found in Kozhikode districts, Alappuzha, Kollam and Thiruvananthapuram. Table 9 provides the district wise distribution of area under mangrove vegetation in the State.

**Table 9 : District – wise distribution of mangroves in Kerala (Source: Mohan (1997))**

District	Area in hectares	Area in % to total area	Number of major species
Kasaragod	50	1.20	15
Kannur	3500	83.35	14
Kozhikode	200	4.75	17
Malappuram	100	2.40	11
Thrissur	25	0.60	11
Ernakulam	250	5.95	17
Kottayam	20	0.45	21
Alappuzha	25	0.60	13
Kollam	15	0.35	22
Thiruvananthapuram	15	0.35	14
State total	4200	100.00	32

Important mangrove species are *Rhizophora apiculata*, *Rhizophora mucronata*, *Bruguiera gymnorrhiza*, *Avicenia officinalis*, *Sonneratia caseolaris*, *Sonneratia apetala*, *Kandelia candal*. Mangrove associates are *Cerbera manghas*, *Hibiscus tiliaceus*, *Derris trifoliata*, *Pandanus tectorius*. These species grow behind the tidal mangrove zone. The fern *Acrostichum aureum* grows in degraded habitats and *Acanthus ilicifolius* colonizes saline marshes.

The strand vegetation (sand dune vegetation) comprises mainly sand binding *Ipomoea pes-caprae*, *Spinifex littoralis*, *Indigofera spicata*, *Portulacca oleracea*. The common shrubs of the region are *Calotropis gigantea*, *Dodonea viscosa*, *Scaveola taccada*, *Hugonia mystax*. Estuarine vegetation is classified into tidal mangroves, prohaline and euhaline types. Prohaline type of vegetation is composed of salt tolerant fresh water plants such as *Ceratopteris siliquosa*, *Corchorus aestuans*, *Hygrophila quadrivalvis*, *Salviania molesta* and *Sphenoclea zeylanica*. Eury haline type consists of highly salt tolerant plants like *Acanthus ilicifolius*, *Acrostichum* and *Pandanus fascicularis*.

Kerala is endowed with a rich diversity of marine fishes with a numerical strength of more than 300. They represent mainly under clupeids, perches, elasmobranchs, leiognathids, coakers, threadfin breams, flat fishes, carangids, red mullets, etc. There are about 54 species of prawns and shrimps commercially exploited in India. The number of marine mollusks exceeds 300 species with more than 10 commercially important species. The marine echinoderm fauna comprised of around 80 species while the ancillary resources such as sea fans, gorgonids, etc. constitute another 110 species. The state is also endowed with more than 25 species of sea weeds among them 12 species are commercially very important. *Macrobrachium rosenbergii*, the giant freshwater prawn is the largest prawn seen in Kerala backwaters. Apart from this there are more than 12 species of prawn inhabit in the estuaries and backwaters of Kerala among them *M. idella* is commercially very important. Commercially important lobsters occurring in the Kerala coast are *Panulirus homarus* and *Panulirus polyphagus*. Other species are *Scyllarus sordidus* and *Panulirus ornatus*. Important crab species used in food are *Matuta lunaris*, *Matuta panpipes*, *Scylla serrata*, *Neptunus sanguinolentus*, *Neptunus*

*pelagicus*, *Charybdis cruciata*, *Charybdis annulata*, *Charybdis edwardsi*, *Charybdis natator* and *Varuna litterata*.

Five species of marine turtles are found in Indian waters. The Hawksbill (*Eretmochelys imbricata*) variety is common in tropical water. Olive Ridley (*Lepidochelys olivacea*) turtle are found to nest in Kozhikode coast near Pyyoli.

Mangrove forests in India are habitats of around 177 resident and migratory birds, of which 45 species are reported in the mangrove forests of Kerala alone. The common species are heron, kingfisher, sea eagle, kites and storks.

India has good pelagic fishery resources comprised of mainly of oilsardine and lesser sardines, mackerel, tuna, carangids, seer fishes, and demersal fishes such as cat fishes, elasmobranchs, sciaenids, silver bellies, besides shrimps and other crustaceans. About 60% of marine fish yield of the country comes from the west coast, of which Kerala contributed as high as 30%. The coastal waters in Kerala are highly productive, the mud bank formations in the Kerala coast add to the high fish turn over.

The common hydrophytes found in the wetlands of Kerala are classified as submerged and emerged types and they are further classified as free-swimming (phytoplanktons) and floating types. Some one of the common wetland flowering plants are *Eichornia crassipes*, *Pistia stratiotes*, *Monochoria vaginalis*, *Monochoria hastata*, *Limnocharis flava*, *Lagenandra meeboldii*, *L. toxicaria*, *Colocasia esculenta*, *Nelumbo nucifera*, *Nymphaea nouchali*, *Blyxa aubertii*, *Blyxa octandra*, *Hydrilla verticillata*, *Hygrophila auriculata*, *Xyris indica*, *Limnophylla chinensis*, *Limnophylla indica*, *Pandanus furcatus*, *Pandanus fascicularis* and *Pandanus thwaitesii*.

Important medicinal plants available in the coastal belt which help in local traditional medical practices are Vaymabu (*Acorus calamus*), Adalodakam (*Adhatoda vasica*), Aloe vera, Perumaram (*Ailanthus triphysa*), Koovalam (*Aegle marmelos*, Kiriath) (*Andrographis paniculate*), *Aristolochia tagala*, Sathavaari (*Asparagus racemosus*), Bramhi (*Bacopa monnieri*), Thazhuthama (*Boerhavia diffusa*), Mukkuti (*Biophytum sensitivum*), Bramhi (*Bacopa monnieri*), Kanikonna (*Cassia fistula*), Uzhinja (*Cardiospermum halicacabum*), Kodangal (*Centella asiatica*), Vayana (*cinnamomum verum*), Cheruthekku (*Clerodendron serratum*), Veluthashangupuspam (*Clitoria ternatea*), Nilapana (*Curculigo orchioides*), Karuka (*Cyperus dactylon*), Mulapalkodi (*Euphorbia*

hirta), Kaiyonni (*Eclipta prostrata*), Chakkarkolli (*Gymnema sylvestre*) Adumbuvalli (*Ipomoea per-caprae*), Neerkanthalam (*Lagenandra ovata*), Kizhanelli (*Phyllanthus amarus*), Kalluruki (*Scoparia dulcis*), Krunthotti (*Sida cordifolia*), Amrutu (*Tinospora cordifolia*), Nerinjil (*Tribulus terrestris*) Vallipala (*Tylophora indica* ) and Murikkotti (*Zornia diphylla*).