5. SUMMARY AND CONCLUSIONS

A coastline represents a dynamic, fragile physical and biological environment that is constantly changing in response to natural processes as well as human activities. It holds great attraction for man as it provides him with a variety of resources for food, construction, recreation, transportation and aesthetics. It also provides a natural protective barrier for inland areas against violent storms as well as daily or seasonal attacks by wind and waves. For many years, studies of coastal processes and landforms were attempted to gain a better understanding of the complex interaction between land, air and water.

The nature and behavior of a coastal system depend on the character, frequency and intensity of the input energy and on the configuration and composition of the subaquous and subaerial boundaries. Regional and local scale variations in coastal dynamic regimes and resultant morphologies reflect the complex mutual interactions between these energy inputs and boundary configurations.

Beach dynamics of the Kerala coast has been studied to delineate the physical processes along the different types of beaches representing the open coast beaches, beaches with headlands, barrier types, beaches exposed to high and low energy environments and beaches protected by the occurrence of mudbanks. Each type has been viewed as a representative entity for estimating different coastal processes.
The high energy beach at Kasargod, shows maximum variability in the foreshore region. The E.O.F analysis as well as the beach volume changes show that the beach exhibits cyclic episodes of erosion and accretion in response to the monsoon and fair weather seasons. The storage volume of the beach is maximum (765 m³/m) at the beginning of the study, during March 1990 and shows the least storage volume (704 m³/m) in September 1990 when it is subjected to maximum erosion. However the erosion to which the beach is subjected to, occurs in three phases. After the cessation of south-west monsoon, the beach builds up gradually. By the end of the study period (February 1991), the beach regains to only 738 m³/m in storage volume. The mean grain size of the sediment sample, collected from the low water line sample of Kasargod beach, shows that it belongs to coarser grade sand size class, moderately sorted and negatively skewed. Coarsest material occurs during August, coinciding with the erosion during the south-west monsoon period. The skewness is directly related to the erosional/accretional pattern of the beach (King, 1972). The negative skewness values observed most of the time, indicates the erosional phase of the beach. The symmetrical skewness seen during September to November indicates the accretional phase of the beach. Monthly littoral drift values show that the drift values are maximum compared to the other locations and are oscillatory in nature. The maximum southerly drift is about $2.95 \times 10^5$ m³ during June. Incidentally, this is the time when the beach
starts eroding considerably. This maximum drift is brought about by the prevailing high wave energy at this location associated with the south-west monsoon which is also evident from the LEO data discussed in (Section 4.1.2). The magnitude of the annual net drift is $0.73 \times 10^6 \text{ m}^3$ and is towards north.

The Payyambalam beach at Cannanore in the vicinity of Ezhimala promontory is a straight long beach with seawall at the backshore. The beach exhibits typical monsoon response by way of erosion during both south-west (June-July) and north-east (October) monsoons. Maximum erosion occurs during July when the storage volume is least ($412.5 \text{ m}^3/m$). Over the period of one year the beach almost regained its initial storage volume of $442 \text{ m}^3/m$ by March 1990. In general, though the beach has undergone seasonal erosion during monsoon, it receives its lost material thereby maintaining an equilibrium state. For most of the time, the beach sediment is in the medium sand class. The moderately well sorted sediments with negatively skewed occurring during the south-west monsoon indicates the erosion and the symmetrical skewness with poor sorting during the fair weather season indicates building up. The monthly littoral drift values show a maximum southerly direction during August ($1.38 \times 10^5 \text{ m}^3$) when it is southerly. Annual net littoral drift is towards south with a magnitude of $0.019 \times 10^6 \text{ m}^3$.

Konad beach at Calicut, sheltered by the mud bank is wide and sandy with least variability compared to the rest of
the beaches. This beach also responds, though to a lesser degree, to the south-west and north-east monsoons undergoing erosion both during July and October. Accordingly, the changes in storage volume also are minimal to the tune of 10 m$^3$/m during the south-west monsoon and 5 m$^3$/m during the north-east monsoon. The beach regains its initial storage volume of 1302 m$^3$/m (April 1990) by the end of January 1991. The stable nature of the beach is very clearly depicted in the E.O.F analysis also. The mean size of the beach sediment belongs to medium sand class without much variations over this period showing the low energy environment. Coarser grain size class, which is highly sorted and negatively skewed shows the erosional behavior of the beach during the north-east monsoon. The low values of the medium grain size during south-west monsoon along with small volume changes are caused by the calm conditions provided by the dampening of waves under the influence of the Calicut mud bank. The breaker height distribution also confirms the results. The monthly drift at this location shows that the magnitude of the littoral drift is low compared to the other northern locations. The maximum drift occurs during March (0.76 X 10$^5$ m$^3$) and is southerly. The low values observed during the south-west monsoon is due to the occurrence of mud bank. The minimum monthly drift value of 0.11 X 10$^5$ m$^3$ is observed during the north-east monsoon season (November). The annual net drift is southerly with a magnitude of 0.011 X 10$^6$ m$^3$ indicating the stable nature of the beach. The supply of
sediments from the rivers on either side of the beach also provides stability to the beach.

The Nattika beach is an open straight beach backed by seawall well inside the backshore. The storage volume shows that the beach has maximum material in the beginning of March 1990 (548 m³/m) with a rapid erosion during the onset of the south-west monsoon. The beach loses about 34 m³/m of the material within two months of south-west monsoon (June and July). It takes about six months for the beach to recover its lost material reaching 544.7 m³/m by January 1991. Then onwards the beach continues to accrete to a storage volume of 557.0 m³/m in February 1991. In contrast to the other beaches, this beach does not show any erosion during north-east monsoon. Thus, in general, the beach shows an accretional trend over the period of study. The existence of an old seawall well behind the backshore is a good indication of the building up nature of the beach during the past years. The mean grain size shows that the beach material belongs to fine sand class during most part of the year with some exceptions during September-October when it shows medium sand. The sediment shows well sorted to moderately sorted nature with symmetrical skewness indicating the accretional trend of the beach. The monthly drift at this beach shows a southerly direction during the monsoon months with the maximum drift occurring during September (0.78 X 10^5 m³/month). This beach depicts the typical monsoon sediment drift pattern. However, during November to February, the
Drift is towards north. In general, the monthly drift values at this beach are higher than at the Calicut beach. This may be due to the wide surf zone which causes to set more sand in motion. Annual net drift shows a northerly drift with values of $0.19 \times 10^6 \, m^3$.

Andhakaranazhi beach is a barrier type short beach. The storage volume shows that before the onset of south-west monsoon, the beach has a storage volume of $587 \, m^3/m$ (April) which rapidly decreases to $35 \, m^3/m$ during June under the action of high monsoonal waves. The accretion is also rapid and the beach regains its material by the end of October 1991 ($582 \, m^3/m$). The influence of the north-east monsoon also is seen in the beach volume during November-December which shows a loss of material to the tune of $7 \, m^3/m$. However, the beach regains this material by the end of February. Thus the storage volume as well as the results of the E.O.F analysis shows the near-stable nature of the beach during this period. The average grain size shows the presence of medium grade sand. Beach shows fine sand class till the end of July. The presence of medium sand during north-east monsoon indicates the eroding phase of the beach. The sediments show a well sorted nature during the south-west monsoon period and poorly sorted nature during north-east monsoon. The symmetrically skewed nature of the sediment during most of the time shows almost stable nature of the beach. The monthly littoral drift values along this beach also shows a monsoon trend of southerly drift with a maximum value of $1.11 \times 10^5 \, m^3$ in
June. In all the other months, except during March and January and monsoon months, the drift is towards north. Annual net drift shows a southerly drift with a magnitude $0.2 \times 10^6 \text{ m}^3$.

The Alleppey beach is a wide and long beach with the sheltering provided by the mud bank during the south-west monsoon period. During the period of survey Alleppey mud bank was active with calm waters and heavy load of mud in suspension. (Joseph, 1992). The storage volume shows that the beach continuously builds from its March level of $895 \text{ m}^3/\text{m}$ to $942 \text{ m}^3/\text{m}$ during August. Thus about $47 \text{ m}^3/\text{m}$ of material is accreted during these six months. The north-east monsoon effect is seen during October when the beach volume reduces by about $15 \text{ m}^3/\text{m}$. The occurrence of mud bank in this region during the south-west monsoon dampens the high monsoonal waves and makes this nearshore very calm. The southerly drift from the beaches north of Alleppey gets trapped by the mud bank leading to the observed accretion. The E.O.F analysis and grain size composition also show the accretional nature of the beach. The poorly sorted distribution along with negative skewness during the north-east monsoon indicates an erosional trend. However the symmetrical skewness during the rest of the period indicates accretional nature of the beach. The monthly littoral drift shows lesser values even during the peak monsoon months substantiating the results obtained from beach volume and grain size studies. It shows the low energy environment prevailing over this location brought in
by the mud bank. The maximum northerly drift of $0.13 \times 10^5$ m$^3$ is observed during April. Subsequently the drift shows southerly direction during the south-west monsoon season. During the north-east monsoon season the drift becomes negligible with a value of $0.0011 \times 10^5$ m$^3$/month during November. The annual net littoral drift ($0.016 \times 10^6$ m$^3$/year) is the least and is directed northerly.

The Quilon beach, south of Thankasseri headland, is a narrow beach. During the south-west monsoon, the beach erodes rapidly loosing about $54$ m$^3$/m of the beach material from it's initial storage volume of $425$ m$^3$/m in April 1990. By the end of the survey the beach has only $404$ m$^3$/m of storage volume, indicating a net deficiency of about $21$ m$^3$/m of the material. Thus the beach at Quilon undergoes erosion as also evident from the E.O.F analysis. The mean grain size shows the presence of coarser sand most of the time. It shows coarsest sediment during the south-west and north-east monsoon seasons with poor sorting. The intensive sand mining activity, for black sand, along this stretch of the beach could be a factor affecting the long-term equilibrium of this beach. The littoral drift shows higher values compared to Alleppey beach with a maximum drift of $3.91 \times 10^5$ m$^3$ towards south in June. It shows a typical monsoonal character with southerly drift during south-west monsoon period and northerly drift during rest of the year. The annual net drift is southerly with a magnitude of $0.38 \times 10^6$ m$^3$. 
Shankhumukham beach at Trivandrum is an open beach exposed to high wave energy. This beach shows typical monsoon response by way of erosion during June-July. From the storage volume, it is seen that the beach loses 67 m$^3$/m of the material during monsoon period when the beach is subjected to very high wave energy environment. The erosion is rapid while the accretion is gradual and steady taking about 4 to 5 months to recover the material lost during the south-west monsoon. By the end of the survey the beach shows considerable building up (478 m$^3$/m) compared to its initial volume of 466 m$^3$/m before the onset of monsoon. The average grain size shows the presence of medium grade sand during the entire study period. Sorting value shows moderately well sorted material to moderately sorted during south-west monsoon. The sediment is symmetrically skewed throughout the entire period which shows that the beach accretes during the survey period. The monthly littoral drift values show comparatively higher magnitudes compared to the beaches at central part, which is due to the prevailing high energy environment at this location. The beach show monsoonal behaviour of southerly drift with a maximum value of 2.87 X 10$^5$ m$^3$ in July. Annual net drift along this beach was northerly with a magnitude of 0.09 X 10$^6$ m$^3$. The the volume changes as obtained from the storage volume studies also indicate this.

It is observed that the wave heights are high at some locations and lower at other locations along the coastline of
Kerala. This kind of wave height distribution is associated with the formation of zones of convergence of wave energy at locations with higher waves and zones of divergence of wave energy at locations with lower wave heights.

It is interesting to note that the wave convergence at Vypin is a permanent feature which occurs for waves from all directions.

The divergence of wave energy seen south of Ezhimala promontory for 270° and 8 S. The divergence at Cannanore, Badagara and Mahe is caused by the presence of Ezhimala promontory. The divergence at Quilon and Varkallai for wave direction 290° and period 8 S is due to the presence of headland at Thankasseri.

The presentation of refraction coefficient and net wave height graphs can be used as monograms for evaluating the wave height for different deep water wave heights along the Kerala coast.

The Kasargod beach, shows an eroding nature over the period of study and indicates the monsoon response of erosion during both the monsoons. The Payyambalam beach at Cannanore, in the vicinity of the Ezhimala promontory shows an overall stable nature. The presence of promontory seems to modify any waves approaching the coast from north and protect the beach. This beach responds to both the monsoons with erosion and with accretion during the other months. The erosion seen at Kasargod may be in part due to the effect of
promontory which prevents the northerly drift. Hence the beach at Kasargod gets only sediments which bypass the promontory. The high littoral drift value at Kasargod is indicative of larger sediment supply brought in by the high wave energy and the influx of sediments owing to the existence of rivers draining along this coast. The Konad beach at Calicut shows the least variability during the period of study. The drift values are also very low here, showing minimum variability. This beach shows monsoonal responses to a very lesser degree. Nattika beach shows monsoonal erosion during south-west monsoon and accretion during north-east monsoon. Andhakaranazhi beach shows stable nature and it shows erosion only during south-west monsoon and an accretional trend during the north-east monsoon. Alleppey beach shows accreting trend even during the south west monsoon with slight erosion during north-east monsoon season. This beach shows a typical mud bank response with accretion during the south-west monsoon season and a slight erosion during the north-east monsoon. Quilon beach shows typical monsoonal erosion during both the monsoons. Trivandrum beach, exposed to high energy environment shows high variability of beach volume. The beach responds well with erosion during south-west monsoon and during the north-east monsoon it shows a strong accretional trend.

The beach variability of the northern and southern beaches are maximum as compared to the central beaches because the former are exposed to high wave energy and the
latter are either protected by mud banks or are low energy beaches. The northern beaches show northerly net drift while the central beaches show southerly drift. The southerly beaches show an oscillatory type drift characteristics.

The temporal distribution of the third eigen function depicts the temporal fluctuations of the positions of the low water mark. The lowest positive peak of the V3 curve coincides with the minimum proximity of the position of the low water line from the bench mark and the lowest negative value coincided with the maximum distance of the low water line from bench mark, which reflects the erosional and depositional phases respectively. This temporal variability may be attributed to the spatial variability of the interplay between locally generated winds, waves, tides, currents and the bottom topography.

Four different types of relations were tested for the monthly data sets of storage volume against the corresponding drift values.

1. \( Y = -126.459075 X + 736.228955 \) (\( r=0.29, \) Variability=0.08)
2. \( Y = -71.30008 \log(X) + 550.64295 \) (\( r=0.45, \) Variability=0.20)
3. \( Y = 676.65959 e^{-0.175061 X} \) (\( r=0.30, \) Variability=0.09)
4. \( Y = 525.140731 X^{-0.096641} \) (\( r=0.46, \) Variability=0.21)

Of these, \( Y = 525.140731 X^{-0.096641} \) (Fig. 5.1), explains comparatively a better amount of variability. A major part of the variability remains unexplained which requires detailed investigations as suggested below.
5.1. Scope for future study

Though the studies on the beach changes along this coast have been conducted, it is still necessary to monitor the beaches in this region continuously over an extended period of time with an increased number of close study locations, in order to establish a more reliable quantitative predictive model for the Kerala coast. The environmental and economical significance of an improved quantitative predictive model justifies the improvement of substantial future field programs. Further studies are needed to establish the estimation of effective nearshore transport of sediments using Littoral Environmental Observation (L.E.O), under varying environmental conditions.