CHAPTER 3
3. BEACH DYNAMICS

3.1. Beach morphology

Beach is the most dynamic zone of the coastal environment which is subjected to a wide range of variations. The changes in beach profile are caused, to a large extend, by the variations in the incident wave energy and fluctuation in the position of the mean water level induced by tidal oscillations. Seasonal changes of the beaches constitute an important aspect of the coastal environment and hence data on beach profiles along with constituent sediment provide vital information on the energy levels to which this environment is subjected to. Though our understanding of such changes improved qualitatively over the past few decades, quantification of these changes still needs attention. In view of this, the dynamics of the beaches bordering the Kerala coast, which falls under different environmental settings, has been addressed through a comprehensive field measurement program initiated during March 1990 - February 1991.

3.1.1. Materials and methods

Beach profiling

Beach profile measurements were taken at 5m interval, from backshore to seaward during low tide using dumpy level, metric staff and a measuring tape at 8 locations (Fig. 1.5, Table 3.1). The profiles were taken over a period of 13
months at monthly intervals during spring low water level when the maximum beach emerged above the waterline. The seaward end of the profiles were terminated near the low water point as estimated from tide table. This data were then reduced with reference to the bench mark.

Empirical Orthogonal Function Analysis

The beach profile data is further subjected to Empirical Orthogonal Function (E.O.F) analysis to delineate the spatio-temporal variations of the beach, at each of the location.

E.O.F analysis is a statistical technique for effectively representing variability in an array of geophysical data. It facilitates representation of a large quantity of data in terms of small number of orthogonal components which accounts for a large fraction of total variance in the original data. Conceptually the objective of the analysis is to separate the temporal and spatial dependence of the data so that it can be represented as a linear combination of corresponding functions of time and space which best accounts for the variability in the original data. E.O.F analysis has been applied to beach profile data by many researchers to bring out the variability and seasonality of the beaches (Winant and Aubrey, 1976; Aubrey, 1978; Winant et al., 1975).
Table 3.1. Description of beach profile location and bench marks.

<table>
<thead>
<tr>
<th>Stn.No.</th>
<th>Location</th>
<th>Survey Interval</th>
<th>Bench mark Description</th>
<th>Width of the beach from bench mark (m)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kasargod beach</td>
<td>Monthly</td>
<td>Yellow painted concrete stone</td>
<td>85 - 100</td>
<td>South of Kasargod light house. Relatively wide beach. No sea wall.</td>
</tr>
<tr>
<td>2</td>
<td>Cannannore (Payyambalam beach)</td>
<td>Monthly</td>
<td>Concrete stone</td>
<td>55 - 75</td>
<td>North of Payyambalam crematorium. Mostly all the 7 km beach is protected by sea wall. South of Ezhimala promontory.</td>
</tr>
<tr>
<td>3</td>
<td>Calicut (Konad beach)</td>
<td>Monthly</td>
<td>Concrete mile stone</td>
<td>145 - 150</td>
<td>Long and wide beach, no sea wall. A fresh water channel was present in the early stage of the study and subsequently disappeared.</td>
</tr>
<tr>
<td>4</td>
<td>Nattika beach</td>
<td>Monthly</td>
<td>Marking on the back wall of a cemeteri</td>
<td>60 - 85</td>
<td>Moderately wide beach with fishing activity. Sea wall exist well behind the backshore. Beach built up considerably. Surrounded by many casurina trees.</td>
</tr>
<tr>
<td>5</td>
<td>Andhakaranazhi beach</td>
<td>Monthly</td>
<td>Marking on a vertical coconut tree surrounded by many coconut trees, in front of the church</td>
<td>65 - 90</td>
<td>Short beach with sea wall, fishing gap of about 50-75m is present. Coast is protected by seawall. A small seasonal opening is present north of this station (SW monsoon).</td>
</tr>
<tr>
<td>6</td>
<td>Alleppey beach</td>
<td>Monthly</td>
<td>Yellow painted concrete mile stone</td>
<td>110 - 125</td>
<td>Wide and long beach north of the pier, no sea wall.</td>
</tr>
<tr>
<td>7</td>
<td>Quilon (Eravipuram beach)</td>
<td>Monthly</td>
<td>Marking on a vertical coconut tree in front of the ice factory</td>
<td>55 - 80</td>
<td>Short beach backed by continuous seawall.</td>
</tr>
<tr>
<td>8</td>
<td>Trivandrum (Sankumukham beach)</td>
<td>Monthly</td>
<td>Marking on the backsde of the bus shelter</td>
<td>55 - 60</td>
<td>Wave dominated sandy beach, north of the pier, steep foreshore and free from sea wall.</td>
</tr>
</tbody>
</table>
The beach profile data obtained at each location were set into a data matrix \( H \), with row containing a time series of the beach elevation / depression at a particular station along the profile and column containing beach profiles at a particular time. The variability of the data matrix \( H \) could be explained in terms of few simple eigen functions of the matrix \( H \). These eigen functions were obtained by normalizing and decomposing the data matrix \( H \) using Singular Value Decomposition (SVD) technique.

\[
x_{mxn} = H/ (mxn)^{1/2} = U_{mxr} \Gamma_{rnx} V_{txn}^{T}
\]

where \( m \) and \( n \) are the number of rows and columns of the data matrix respectively and \( T \) indicates the transpose of the matrix. The column vectors of \( U \) and \( V \) are orthogonal, ie. \( U^T U = I \) and \( V^T V = I \) and \( \Gamma \) is a diagonal matrix with diagonal elements called the singular values of \( H \), and \( r(r < \min(m,n)) \) is the rank of the matrix \( H \).

\( U, \Gamma \) and \( V \) satisfying equn. (3.1) are obtained by solving the eigen value problem

\[
(B - \lambda I) V = 0 \quad (3.2)
\]
\[
(A - \lambda I) U = 0 \quad (3.3)
\]

where \( B = x^T x \) and \( A = x x^T \). Values of \( \lambda \) is obtained by solving the characteristic of equn. (3.2), ie, \( \det(B - \lambda I) = 0 \) and its substitution in equn. (3.2) leads to a system of equations which are solved following the standard Gaussian elimination method (McCormick and Salvadori, 1968) to obtain values of \( V \).
Knowing $V$ and $\lambda$, $U$ is determined from equn. (3.3).

The ratio between the sum of the squares of the elements of the factor model and that of the data matrix is considered as the measure of closeness of the model data

\[
\text{Measure of closeness} = \frac{\sum_{i=1}^{K} \lambda_i}{\sum_{i=1}^{r} \lambda_i}
\]

where $K$ is the number of factors and $r$ is the rank of the data matrix.

The eigen functions are ranked according to the percentage of mean square value of the data they explain. These percentages as accounted by each function, enable evaluation of the relative importance of each function in explaining the observed beach variability.

**Beach volume computation**

To quantitatively estimate the beach volume changes associated with each of the beaches under study, the relative changes in volume of the sediments per unit length of the beach (storage volume) at each location were computed in cubic metres using an arbitrary defined base line.

**3.1.2. Results**

In this chapter, the seasonal changes of the beach morphology inferred from monthly profile data, E.O.F analysis and storage volume changes at 8 selected beaches are presented. The storage volume calculated for different months and different locations are given in Figs. 3.2a & 3.2b.
Kasargod beach

The beach located south of Kasargod lighthouse is a moderately wide beach backed by casurina trees. It is free from any protective structures like sea wall. Three minor rivers drain into Arabian sea north of this beach. One major river Chandragiri having a total annual run-off \((3118.6 \times 10^6 \text{ m}^3)\) (Anonymous, 1974), debouches into the sea within 2 Km south of the study region. Beach vegetation like casuarina trees are present on the backshore. This beach falls in the category of straight open coast beach. The beach has a wide backshore and a gently sloping foreshore. The width of the beach varies between 85-100 m, having a berm present at a distance of 50 -60 m from the bench mark (Fig. 3.1a). The beach shows maximum variability in the foreshore and it is almost stable in the backshore region. The beach responds to the monsoonal forcing with seasonal episodes of erosion and accretion.

The E.O.F analysis of the profile data shows that, at Kasargod the first eigen function accounts for 97.5 % of the mean square value while the second and third accounts 1.5 % and 0.4 % respectively (Table 3.2). In general, the contribution from the higher order function is insignificant. Since most of the variations in the profile are accounted by the first three eigen functions corresponding to largest eigen values, in the following discussions only the first three eigen functions are considered.
Table 3.2. % Variance explained/contained by each eigen functions.

<table>
<thead>
<tr>
<th>STATION NO.S</th>
<th>FUNCTIONS</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>97.5</td>
<td>1.5</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>99.5</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>99.2</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>4</td>
<td>96.3</td>
<td>2.8</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>5</td>
<td>98.2</td>
<td>1.3</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>6</td>
<td>98.1</td>
<td>1.1</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>7</td>
<td>98.6</td>
<td>0.8</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>8</td>
<td>96.5</td>
<td>2.7</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>MEAN GRAIN SIZE</td>
<td>92.1</td>
<td>3.9</td>
<td>1.6</td>
<td>1.1</td>
</tr>
</tbody>
</table>
The first eigen function (U1), representing the mean beach profile (Winant et al., 1975) shows a wide backshore and a berm located between 50-60m from the bench mark with moderately sloping foreshore (Fig. 3.1c). The associated temporal function (V1), shows the erosional tendency of the beach during the period of study.

The spatial configuration of the second function (U2) indicates the locations of the beach subjected to maximum variabilities. In the present case, the maximum variability occurred at about 70 m from the bench mark, as could be inferred from the peak of the curve. A lesser variability is seen at about 55 m from the bench mark, coinciding with the berm crest. In other words, the foreshore region of the beach undergoes greater changes while the berm is subjected to lesser variability. The distribution of the second temporal eigen function (V2) shows the erosional/accretional episodes to which the beach is subjected. The beach at Kasargod experiences a slight accretion from March to April followed by an erosion till September. The erosion has three phases: an initial rapid rate from April to May, a slow rate from May to August and then again a rapid erosion from August to September. Then the beach started rapid accretion from September to December indicating that the beach has regained some of the material lost due to erosion. Once again, the beach shows a slight erosion from December to February followed by an accretional phase towards the end of the survey.
Fig. 3.1a. Beach profiles at station - 1 (Kasargod)

Fig. 3.1b. Monthly variation of low water mark from benchmark (m)

Fig. 3.1c. Spatial and temporal distribution of eigen functions at station - 1 (Kasargod)
The third function (U3), shows a more complex nature of distribution with a broad maxima around 60-65 m from the bench mark. This coincides with the mean low water mark encountered during the period of one year. In order to understand the temporal distribution of the third eigen function (V3), the position of the mean low water line from the bench mark during each survey has been presented in Fig. 3.1b. A close examination of this figure with the distribution of V3 shows that, V3 depicts the temporal fluctuations of the low water line. Further, the lowest positive peak in the distribution of V3 occurs during October which coincides with the minimum distance of the position of the low water line which is at about 60 m from the bench mark. Similarly the lowest value occurs during March, coinciding with the maximum distance (95 m) of the position of mean water line from the bench mark.

The storage volume of beach material per metre length of the beach calculated for different months are presented in Fig. 3.2a. The beach has a maximum storage volume during March which decreases till May. During June to August the volume changes are marginal. The storage volume decreases from July onwards and the beach attains a minimum storage volume during September which is 704 m$^3$/m. From September onwards the storage volume indicates a build up. The pre and post monsoon periods indicate a maximum accreted phases.
FIG. 3.2a. VOLUME OF BEACH SEDIMENT/METRE LENGTH
The Payyambalam beach at Cannanore is situated about 5 km south of Ezhimala promontory. Valapattanam river with an annual run off of $2764.9 \times 10^6 \text{ m}^3$ drains into the sea about 10 km north of this beach. It is a short beach (7 km), protected by sea wall. The upper backshore is covered by beach grass. The beach has a moderately steep foreshore and gentle backshore with a total width of 55-75 m. From the profiles (Fig. 3.3a), it is clear that the beach has a stable backshore while the foreshore is subjected to changes seasonally.

The mean beach function ($U_1$) shows a narrow backshore with a well developed berm and a moderately sloping foreshore with a step-like feature at 20 - 30 m from the bench mark. (Fig. 3.3b). The corresponding temporal eigen function ($V_1$) shows almost stable nature of the beach during the study period. The second function $U_2$ indicates maximum variability in the upper foreshore where the step-like feature is noticed. The distribution of the second temporal function ($V_2$) shows that the beach is subjected to continuous erosion from March till July with a high rate of erosion during June-July. Thereafter the beach starts building up rapidly, regaining its lost material till December. Once again the beach undergoes erosion from December to till the end of the survey. The third spatial function ($U_3$) shows a maximum around 40-45 m from the bench mark. The lowest positive peak associated with the third temporal function occurs during
Fig. 3.3a. Beach profiles at station-2 (Cannanore)

Fig. 3.3b. Spatial and temporal distribution of eigen functions at station-2 (Cannanore)
July coinciding with the nearest position of the low water mark at about 35 m from the bench mark. The lowest value during March-April coincides with the farthest position of mean water line which is 55 m from the bench mark during March.

The storage volume of beach material for this location (Fig. 3.2a), indicates that the beach does not undergo much changes from March to May while during July to October, it gains material. The lowest storage volume level of the beach is during July (412 m$^3$/m). From July end to September beach experiences accretion and receives some part of the lost material. From September end, the beach once again passes through a state of erosion till the end of October and again shows a building up tendency. In general the storage volume shows that the beach loses material during monsoon months of June-July and regains the materials during the rest of the year except an erosional tendency during October (416.6 m$^3$/m).

KONAD BEACH

Konad beach at Calicut is a long and very wide sandy beach free from any protective structures like sea walls. A fresh water channel was present in the early stage of the study which has been subsequently disappeared. There are two small rivers, on either side of the beach, Elattur river on the south and Kallai river on the north. The beach width varies between 145-150 m from the bench mark. From the beach
profiles (Fig. 3.4a), it is clear that the beach profile variations are the least for this beach as compared to the other 8 locations.

The first spatial function (U1) shows that the beach has a very wide gently sloping backshore and a moderately steep foreshore (Fig. 3.4b). The backshore contain two berms, one at 30-40 m which is a permanent berm while the other at 120-130 m is a seasonal one. The almost straight line of the distribution of the temporal function (V1) associated with the first eigen function, shows the stable nature of the beach during the period of study. The spatial configuration of the second function (U2) shows the maximum variability associated with the second berm and lesser variability at 100-110 m from the bench mark. The second temporal eigen function (V2) shows that the beach undergoes an initial slow accretional phase during March-April followed by an eroding phase till the end of June. From July onwards the beach started building up at a very slow rate till January. The maximum value associated with the third spatial function (U3) around 140 m from the bench mark indicates the position of low water mark. Its corresponding temporal function (V3) shows lowest positive peak during January-February at 145 m which indicated the farthest position of the low water line while the lowest value at 30-35 m during November-December indicates the closest position of the mean low water line from the bench mark.
Fig. 3.4a Beach profiles at station-3 (Calicut)

Fig. 3.4b Spatial and temporal distribution of eigen functions at station-3 (Calicut)
The variations in storage volume along this beach is minimal (of the order of 10 m³/m) (Fig. 3.2a). The beach shows the highest storage volume in March-April and lowest storage volume in June-July. There is a gradual increase of storage volume towards September and a decrease in the north-east monsoon period followed again by an increasing tendency.

NATTIKA BEACH

Nattika beach is a straight beach with comparatively wide back shore and a gently sloping foreshore. This beach with considerable fishing activity is backed by casuarina plantations. There are no rivers in the near proximity of this beach. An old sea wall exists well behind the backshore indicating that the beach has built during the past years. The width of this barrier beach varies between 60-85 m from the bench mark. The beach is composed of fine sand mixed with silt. The profiles shows the presence of a seasonal berm in the foreshore (Fig. 3.5a).

The first spatial eigen function (U1), shows the presence of a berm situated at 5m from the bench mark (Fig. 3.5b). It shows a wide, gently sloping foreshore. From the distribution of the associated temporal eigen function (V1), it is seen that the beach shows slight accreting tendency. The second eigen function (U2) shows that the maximum variability of the beach occurs in the upper foreshore. The second temporal function (V2) shows that the beach undergoes slight accretion initially (March-April) and a rapid erosion
Fig. 3.5a. Beach profiles at station-4 (Nattika)

Fig. 3.5b. Spatial and temporal distribution of eigen functions at station-4 (Nattika)
till June. This is succeeded by a fast rate of accretion till October and then a gradual tendency of erosion. The third spatial eigen function (U3) shows a maxima at about 50 m from the bench mark, which coincides with the mean water level. The corresponding temporal function V3 shows that during June the low water level is closest (30 m), while during February-March it is farthest (80 m).

The storage volume of the beach material (Fig. 3.2a), shows that the beach undergoes gradual erosion from March (547 m$^3$/m) reaching the minimum storage volume in June (514 m$^3$/m). Afterwards the beach gradually build up regaining all the lost material by the end of February (557 m$^3$/m).

ANDHAKARANAZHI BEACH

Andhakaranazhi beach is a short and narrow barrier beach protected by sea wall with a fishing gap of 50-75 m width. A small seasonal opening to the sea is present north of the station during the south-west monsoon season. The beach has a narrow backshore and a moderately steep foreshore. The beach width varies in between 65-90 m. A seasonal berm is present in the foreshore and a permanent berm in backshore (Fig. 3.6a). The sand size is in the range of fine to coarse sand.

The first eigen function (U1), representing the mean beach profile (Fig. 3.6b), shows that the beach is very narrow with two berms at 10 m and 25 m from the bench mark.
Fig. 3.6a. Beach profiles at station-5 (Andhakaranzhi)

Fig. 3.6b. Spatial and temporal distribution of eigen functions at station-5 (Andhakaranzhi)
The temporal function (V1) shows the near-stable conditions of the beach during the period of study. The second spatial function (U2) shows a broad maximum at around 35 m, clearly identifying the location where the beach profile experienced maximum variation. The distribution of the corresponding temporal function V2 shows that the beach is subjected to rapid erosion during April and May followed by slight accretion during June–July. Once again the beach is eroded till August. From August to September, the beach builds up rapidly followed by a slow rate of accretion till December. The beach undergoes another cycle of erosion and accretion, at a much lesser rate till the end of March. The third spatial function (U3) shows maximum variability in the lower foreshore. From the distribution of the third temporal function (V3), it is clear that low water mark is at about 30 m which is closest during May and farthest during October (55 m).

The storage volume computed from the monthly beach profile (Fig. 3.2b), shows that from March there is a little increase in volume reaching maximum of 587 m$^3$/m during April, but suddenly there is a drop in volume as monsoon intensified and the storage volume reaches a minimum in June (551.6 m$^3$/m). Subsequently there is a rapid increase in volume during September followed by a gradual decrease till January. After that it again shows a depositional tendency and the beach almost regains its lost material back by the end of February (588 m$^3$/m).
FIG. 3.2b: VOLUME OF BEACH SEDIMENT/METRE LENGTH
ALLEPPEY BEACH

The beach at Alleppey is a wide and long barrier beach situated south of Alleppey pier and is free from any protective structures. There are no rivers in the proximity of this beach. The width of the beach ranges between 110-125 m. The beach is composed of fine size sands. The profiles (Fig. 3.7a), show a stable backshore and a foreshore which gets built up even during the peak monsoon months. The mud bank occurring in this region during the south-west monsoon season (Kurup, 1977; Kurian et al., 1984, 1985) dampens the high monsoonal waves and makes this nearshore region very calm. The observed accretion of the beach during the monsoon months is brought in by the presence of the mud bank.

The distribution of mean beach function (U1) shows the presence of a very wide backshore and a gently sloping foreshore (Fig. 3.7 b). A seasonal berm is situated at 80 m from the bench mark. The associated temporal function (VI) shows an overall accretional tendency of the beach. The second spatial function (U2), shows a maximum near the lower foreshore where the beach undergoes large variations. The temporal function (V2) shows that the beach is subjected to accretion throughout the period of study except during May-June, September-October and February-March. The distribution of the third spatial function (U3), shows the position of mean low water mark at 90 m from the bench mark. The third temporal function (V3) shows that the mean water line fluctuates between 90 m during May and 110 m during November.
Fig. 3.7a. Beach profiles at station - 6 (Alleppey)

Fig. 3.7b. Spatial and temporal distribution of eigen functions at station - 6 (Alleppey)
The storage volume shows (Fig. 3.2b), that the beach continues its building up tendency rapidly till August when it attained a storage volume of about 940 m$^3$/m, followed by a slight erosion during September and October reaching a minimum storage volume at the end of October (927 m$^3$/m). Then the beach again shows an accretional tendency till the end of February (964.6 m$^3$/m).

**ERAVIPURAM BEACH**

Eravipuram beach at Quilon is a narrow curved beach south of Thankassery headland. The entire stretch of the beach is protected by sea walls. Ithikkara river falls south of this beach and a fresh water lake (Ashtamudi Lake) is present on the north. The beach width ranges between 55-80 m with a gently sloping backshore covered beach vegetation and a foreshore with maximum seasonal variations (Fig. 3.8a). The beach sediment is composed of coarse sand.

The first spatial eigen function (U1) shows a well defined berm in the backshore and a moderately sloping foreshore (Fig. 3.8b). The temporal function associated with the mean beach function (V1) shows an overall erosional tendency of the beach during the period of study. The second spatial function (U2) indicates maximum variability in the upper foreshore and a secondary maximum in the lower foreshore. The distribution of the second temporal function (V2) shows that the beach undergoes rapid erosion during April to June followed by a slow accretion till July and
Fig. 3.8a. Beach profiles at station-7 (Quilon)

Fig. 3.8b. Spatial and temporal distribution of eigen functions at station-7 (Quilon)
erosion during August to September. Subsequently the beach builds till December and shows an erosional trend during December-January. The third spatial eigen function (U3) shows the position of the low water mark at 60 m. The corresponding third temporal function (V3) indicates the closest water mark at 30 m during June and farthest at 60 m during February.

The storage volume shows that the beach has a maximum storage volume in April ($425.4 \text{ m}^3/\text{m}$), (Fig. 3.2b) and a minimum storage volume in June ($371 \text{ m}^3/\text{m}$) followed by a slight building up during July-August and erosion during September ($373.6 \text{ m}^3/\text{m}$). This is followed by an accretional trend during October-December. In general, the beach loses material over a period of the year.

**SHANKUMUKHAM BEACH**

Shankumukham beach at Trivandrum situated north of the Valiyathura pier is a sandy beach with comparatively wide backshore and is devoid of any beach vegetation. Among all the beaches studied, this beach is exposed to higher wave energy throughout the year and undergoes maximum profile changes (Fig. 3.9a). The beach has a gently sloping backshore and a very steep foreshore during the rough weather season. The beach has a width of 55-60 m and is composed of coarse sized sand.

The distribution of the mean beach function (U1) shows a berm at 20 m from the bench mark and a moderately sloping
Fig. 3.9a. Beach profiles at station - 8 (Trivandrum)

Fig. 3.9b. Spatial temporal distribution of eigen functions at station - 8 (Trivandrum)
foreshore (Fig. 3.9b). The corresponding time dependent factor, \(V_1\) indicates an annual accretional trend. The spatial configuration of the second eigen function \(U_2\) shows maximum variability in the lower foreshore and lesser variability near the berm. The second temporal function \(V_2\) shows rapid erosion from April to July followed by rapid accretion till October. The accretional trend continues till December at a much reduced rate. However from December till the end of February, the beach does not undergo much variations. The distribution of the third spatial function \(U_3\) indicates that the position of the low water level is around 35-40 m from bench mark where maximum erosion occurs. Its corresponding temporal function \(V_3\) shows that the closest position of mean low water level occurs during July (30 m) and is farthest during September (55 m).

The storage volume computed for this beach (Fig.3.2b) shows that the beach loses material from April reaching a minimum storage level in July \(400 \text{ m}^3/\text{m}\). Subsequently the beach experiences gradual accretion leading to a considerable deposition till the end of February when the beach gets built up considerably. The response of this beach depicts the typical monsoonal response of an open coast beach undergoing rapid erosion under monsoonal high waves taking away the beach material at a faster rate and regaining the material over longer period through the fair weather period.
3.2. Beach sediments

The beach is made up of unconsolidated sediments which range from very fine sands to pebbles. Wind, waves and tides are the important factors responsible for the movement of material on the beach and the resultant sediment distribution (Komar, 1976). The difference in wave energy and the period of the ocean swell are important factors that determine the nature and distribution of the foreshore sediments. The variation in grain size for any type of beach is primarily a function of variation in wave height and to a lesser degree, the wave period (Write et al., 1985). On a beach, sediment is mainly exposed to two forces of unequal strength acting in opposite directions - the incoming waves and the outgoing wash. This is the primary mechanism by which sediment get sorted. The textural parameters, in addition to the degree of sorting, also reflect the mode of transportation and the energy levels of transportation media.

The aim of the present investigation is to determine statistically the significant variations in grain size distribution of the beach sediments along different beaches under study. In order to get a comprehensive picture about the seasonal changes in the size characteristics of the sediments along all the beaches, average moment measure statistics viz. mean, standard deviation and skewness were computed. The analysis has been done only for the samples collected from the low waterline.
3.2.1. Materials and methods

Monthly beach sediment samples were collected over a period of 12 months from each station, close to the water line during spring low water level when the beach exposure was maximum above the water line. A total of 104 samples were collected and used for the present study. The samples represent top 5 cm as on the day of sampling. Sieve analysis was carried out to study the grain size distribution.

Grain size analysis

Beach samples were subjected to size analysis by the simple sieving method. The samples were collected by scoop sampling. Approximately 1 kg in weight was washed free of salt, silt and clay and finally oven dried. From that 100 gm was separated by the conning and quartering method. Shells and shell fragments, if any present in the samples were separated by hand-picking method, 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 (mesh nos. 18, 25, 35, 45, 60, 80, 120, 170 and 230). The weight of each fraction representing a particular grain size was measured using an electronic balance. The graphic mean, median, standard deviation and skewness were calculated based on the formula of Folk and Ward (1957).
E.O.F of grain size data

Mean grain size data of each of the samples were further subjected to E.O.F analysis to understand the spatio-temporal variability of the sediments in different environments. The size distribution of all the 104 samples were represented in the form of a matrix, $L(X,\phi)$ of discrete size class with $X$ as the location and $\phi$, the grain size class. The matrix was converted to a normalized data matrix, $X(X,\phi)$ and the eigen functions were obtained as described in section 3.1.2.

3.2.2. Results

The monthly variation of graphic mean, standard deviation and skewness calculated for the samples from different location are presented in Figs. 3.10a & 3.10b for mean size, Figs. 3.11a & 3.11b for standard deviation and Fig. 3.12a & 3.12b for skewness.

At Kasargod (Fig. 3.10a), the mean size of the beach sands fluctuated generally between 0.22 mm to 0.94 mm which corresponds fine to coarser grade. During the south-west monsoon period (June to September), the sediment is mostly in the coarser sand class. Fine and medium grade sands are present during the other months. On an average, the mean grain size of the beach is of the medium sand size. The standard deviation values (Fig. 3.11a), reveal that majority of the water line samples are moderately sorted and display
FIG. 3.10a. MONTHLY VARIATION OF MEAN SIZE
FIG. 3. MONTHLY VARIATION OF STANDARD DEVIATION
FIG. 3.12a. MONTHLY VARIATION OF SKEWNESS
best sorting with an average value of 0.82 $\phi$. In August, the sorting value is maximum (1.15 $\phi$) and the mean grain size is coarsest (0.93 mm). This indicates that erosion is active till August. The samples are negatively skewed to nearly symmetrical with most of the values clustered around -0.02, -0.11 and -0.21 (Fig. 3.12a). However, during the rest of the months, it is symmetrically skewed with values around -0.21. The negative skewness indicates the erosional phase of the beach from June to September while the symmetrical skewness, the stable nature of the beach.

At Cannanore (Fig. 3.10a), the average mean size of the beach sand is 0.29 mm which belongs to medium grade sand size. Coarsest size sand is observed in June (0.58 mm) coinciding with high energy environment under the influence of south-west monsoon. In August and October the sediments shows poorly sorting nature (Fig. 3.11a), while during the rest of the year they are moderately well sorted to moderately sorted. In general, throughout the period of study, the sediments show a moderately sorted trend. The skewness parameter (Fig. 3.12a), shows that during monsoon months the sediment is negatively skewed while during the rest of the period it was symmetrically skewed indicating an erosion during June.

The beach at Calicut (Fig. 3.10a), is composed of medium grade sand (0.26 mm to 0.40 mm) with moderate sorting and symmetrical skewness except during October, November and January, when coarse material is present. During January
(0.64 mm) the material is coarsest. The coarser size class during October and November along with high sorted (Fig. 3.11a) and negatively skewed nature (Fig. 3.12a) shows that the beach undergoes erosion during these months.

At Nattika (Fig. 3.10a), the average beach grain size shows fine sand class (0.15 mm to 0.26 mm) except during September when it is medium sand class (0.48 mm) and during October when coarser sands (0.52 mm) are present. The sorting values (Fig. 3.11a), show well sorted class during monsoon and moderately sorted trend during the other seasons. The negatively skewed trend in October (post-monsoon period) (Fig. 3.12a) and symmetrically skewed nature during the other seasons indicates the erosional and accretional behavior of the beach in terms of its constituent sediment.

At Andhakaranazhi (Fig. 3.10b), the average grain size shows medium grade sand size class. During monsoon period, fine (0.16 mm - 0.22 mm) to medium sand classes (0.30 mm) are observed and maximum medium grade sand class (0.44 mm) is present in October. The sediments are well sorted (Fig. 3.11b) in July and September and poorly sorted in October. They are negatively skewed in October and symmetrically skewed during the other seasons (Fig. 3.12b).

At Alleppey, the mean grain size (Fig. 3.10b), does not show much significant changes till October when it belongs to the medium sand size class (0.27 mm - 0.46 mm) indicating almost stable nature of the beach during the
FIG. 3.10b. MONTHLY VARIATION OF MEAN SIZE
FIG. 3.11b. MONTHLY VARIATION OF STANDARD DEVIATION
FIG. 3.12b. MONTHLY VARIATION OF SKEWNESS
south-west monsoon. During the north-east monsoon season, there is a decrease in size values from 0.46 mm (October) to 0.41 mm (November). However, during December, the sediments become coarser (0.62 mm). During June, the sediments belong to fine sand class (0.22 mm) indicating the depositional phase of the beach. It is moderately well sorted (Fig. 3.11b) during the south-west monsoon season, poorly sorted and negatively skewed in December and symmetrically skewed in the other seasons (Fig. 3.12b). At Alleppey, the presence of mud bank during south-west monsoon is congenial to the accretion of the beach adjacent to it due to the wave dampening by the unconsolidated mud suspension. As a result, changes in sediment size, sorting value, skewness and beach volume changes are not seen at this location during this period. However, the changes in wave climate associated with north-east monsoon, though to a much less dynamic as compared to the south-west monsoon, are felt much more here than in any other locations. The results corroborate the earlier studies done in this beach (Hameed, 1988).

At Quilon, the average grain size, (Fig. 3.10b) shows the presence of coarse sand (>5 mm). From March to June, the sand size shows medium sand size class (0.30 mm - 0.38 mm) except in May (0.53 mm). Two peaks of coarser grain size are present, one during the south-west monsoon season and another during the north-east monsoon season with size class 0.95 mm during July and 0.96 mm during October. Medium sand is present in the other seasons. During July to August, the
sorting value shows a poorly sorted tendency (Fig. 3.11b). The samples show negatively skewed nature (Fig. 3.12b) during most of the period except during April and June when they are symmetrical. This shows that the beach in general undergoes erosion during the period of study.

At Trivandrum, the average value of the mean grain size (Fig. 3.10b) shows the presence of medium size sand (0.25 mm - 0.36 mm) except in June where fine sand class is present (0.23 mm). The maximum grain size in July shows the severe erosion during this month. The sorting values (Fig. 3.11b) show moderately well sorted to moderately sorted nature during south-west monsoon. And was symmetrically skewed (Fig. 3.12b) through the entire period of study indicating the dynamically stable nature of the beach.

The E.O.F analysis of the mean grain size data shows that the first function accounted for 92.1% of the mean square value while the second and third functions accounted for 3.9% and 1.6% respectively (Table 3.2).

The first spatial eigen function (U1) of the mean grain size (Fig. 3.13) shows that, of all the beaches under study, the beaches at Kasargod and Quilon have the highest mean grain size whereas the beaches at Nattika and Trivandrum have the least grain size values. In general, the sediments are in the medium sand class except at Kasargod and Quilon where they are coarse sized.
Fig. 3.13. Spatial and temporal distribution of eigen functions for mean grain size.
The second spatial eigen function (U2) of the mean grain size reflects the deviation in the grain size at a given station from the mean. It also follows a similar trend as that of the first eigen function indicating that the maximum variability of the mean grain size is seen at Kasargod and Quilon while at Nattika, Andhakaranazhi, Alleppey and Trivandrum it shows least variability.

The corresponding temporal functions V1 and V2 also indicate a similar profile variations as discussed under section 3.1.3. Since the third functions, both the spatial and temporal, does not depict any behavioral pattern that can be related to the physical phenomena, it has not been considered for the present study.