CHAPTER 4
4. SEDIMENT TRANSPORT

4.1. Littoral Environmental Observations

The surf zone is of primary importance in forming the final pattern of sediment movement and thereby shaping the coasts. The Littoral Environmental Observation (LEO) programme provides data on wave period, breaker height, angle of breaking waves to shoreline, breaking type, width of surf zone and longshore current speed and direction. The data collection in this zone using gauges or other instruments is difficult due to cost and inaccessibility. In the present study, visual observations were carried out once in a day, for a period of one year at 8 selected stations using regular measurement techniques.

4.1.1. Materials and methods

Breaker wave characteristics

Heights of 10 consecutive breakers were estimated and the average was noted as the significant wave height. The wave period was measured using a stop watch by observing the time required for 10 consecutive wave crests to pass a fixed point and taking the average. The breaking wave angle with respect to the coastline was measured using a surveyor's magnetic compass. Most of the observations were made between 0600 & 0900 hrs irrespective of the tidal phase.
Longshore current

Longshore current velocity and direction were measured by releasing neutrally buoyant floats in the surf zone and the distance traveled by the floats in 2 minutes was recorded and represented in m/s. The measurement was repeated twice and the average is noted. The approximate width of the surf zone was visually estimated.

4.1.2. Results

Littoral Environmental characteristics

Monthly average variations of surfzone width, breaking wave height, breaking period, breaking angle and longshore current velocity and direction at stations 1 to 8 are presented in (Figs. 4.1 to 4.8). Surfzone is seen to be wider during the monsoon and post-monsoon seasons. It shows a seasonal tendency in most of the study locations except at stations 4 (Nattika) and at station 8 (Trivandrum). At Nattika, the surfzone width is >10m during most of the time irrespective of season due to gently sloping foreshore of this beach. At Alleppey beach, the surfzone width is more during the pre-monsoon period and post monsoon season than during the monsoon season when it was <6m. The formation mud bank during the south-west monsoon period of the year 1990, (Joseph, 1992) provides calm conditions in the nearshore sea and causes the low value of the surf zone width.
Fig. 4.1. Monthly littoral environmental parameters at Stn. 1 (Kasargod)
Fig. 4.2. Monthly littoral environmental parameters at Stn. 2
(Cannannore)
Fig. 4.3. Monthly littoral environmental parameters at Stn. 3 (Calicut)
Breaker height is maximum in the monsoon months and gradually decreases towards the other seasons with a secondary peak of comparatively lesser magnitude during the post-monsoon season except at stations 6 (Andhakaranazhi). The average breaker height shows a progressive increase from fair weather season to south-west monsoon season for all the eight stations. Maximum breaker height is observed during July at stations 1, 2, 3 and 6 and during June at the other stations (4, 5, 7 and 8). Trivandrum shows higher breaker heights (>0.6 m) throughout the year. Kasargod shows breaker heights >0.6 m except during the post monsoon.

The breaker period varies between 5 sec. and 15 sec. during an year at all stations. Frequency of breakers shows increase towards the south-west and north-east monsoons and decrease towards the other seasons. The breakers are mostly plunging or surging type and sometimes characterized the collapsing nature.

The breaker angle also shows a seasonal change in the direction of approach. It is reported that, depending upon the locations, the breaking direction are found to vary between 210° to 300° N along the Kerala coast (Baba, 1988). At stations 2, 4, 5, 6 and 8, breaker direction is from north-north-west to westerly during the fair weather period and it gets reversed during south-west monsoon season to south-south-west and again shifts to north-north-west after the cessation of the south-west monsoon. The longshore current measurements are spot observations representing the average
Fig. 4.4. Monthly littoral environmental parameters at Stn. 4 (Nattika)
Fig. 4.5. Monthly littoral environmental parameters at Stn. 5
(Andhakaranazhi)
conditions persisting across the surf zone. The field observations on longshore currents at selected locations along Kerala coast spanning over a period of one year reveals high variability in their direction and speed. The wave induced longshore current values show significant temporal and spatial variations along the beaches under study. The longshore current directions vary in response to the changes in wave direction both in time and space. The sudden changes in wind direction sometimes generate short period waves, which break on the beach at an angle larger than the long period waves causing strong longshore currents (Anonymous, 1975).

During the onset of south-west monsoon, a prominent reversal of longshore current direction towards south is noted in most of the stations with an increase in speed. It shows that during south-west monsoon, the longshore current shifts its direction towards south. (June-September). Changes in wind direction during the onset of monsoon cause the change in wave direction which results in the reversal of longshore current direction in most part of the Kerala coast. The obliquely approaching swell waves generate intense southerly longshore currents during the monsoon season causing southerly littoral drift along the beaches of Kerala.

A reversal in longshore current direction (towards north) with high magnitude is observed during north-east monsoon season. The longshore current direction is seen to be
Fig. 4.6. Monthly littoral environmental parameters at Stn. 6 (Alleppey)
Fig. 4.7. Monthly littoral environmental parameters at Stn. 7 (Quilon)
Fig. 4.8. Monthly littoral environmental parameters at Stn. 8 (Trivandrum)
transitional and inconsistent during March, December and January. A progressive increase in current velocity occurs from November through January and February along the studied locations. Current speed upto 0.88 m/sec is observed in the Trivandrum beach during November, which is highest among the recorded values on the beaches studied along the Kerala coast during this period. Current speeds of 0.2 - 0.6 m/sec. are frequently recorded at many locations. Negligible current velocity (0.02 to 0.05 m/sec.) values are also recorded at stations 3 and 6, ie. at Calicut and Alleppey, frequently during the period of study.

4.2. Longshore sediment transport

The longshore movement of beach sand poses a potential littoral problem. The important factor governing the beach erosion is the longshore sediment transport which is controlled predominantly by waves and nearshore topography. An understanding of sediment transport on beaches is also necessary for the analysis of formation of the geomorphic features such as sand spits and barrier islands, to examine the tidal inlet processes and to understand the irregularities in the shoreline. Interruptions of these natural movements of sands by man made barriers like groins, breakwaters, jetties etc. result in sediment deposition on the updrift side and removal of sediments on the downdrift side. This results in the necessity to study the longshore sediment transport around inshore coastal areas, which is of
fundamental interest to coastal engineers in the planning of structures, dredging activities of ports and spoil disposal. A proper understanding of the seasonal littoral transport trend is important for the efficient management and development of coasts. Beach erosion problems along this coast have been the initial motivation for this study on sand transport by estimating the rate of sand movement.

Since estimation of the rate of littoral sand drift is one of the essential items necessary for the field investigation in regard to beach protection and sedimentation problems, much effort has been made in establishing a method of estimation by coastal engineers for a long time. The dynamics of sediment movement in the littoral zone is governed primarily by the wave induced currents. Specific knowledge of these currents and associated circulation patterns are helpful in better utilization of the coastal environment.

In the nearshore area, waves arriving from offshore continuously bring in momentum, energy and mass. Since the shoreline provides a fixed boundary, the momentum and energy fluxes are dissipated in the surfzone. Most of the energy is converted to turbulence in the breaker zone but enough is left to drive a nearshore current system and move loose bed material. The momentum brought in by the waves will drive the littoral current system and cause a local set-up or set-down of the mean water level.
The dynamics of sediment movement in the littoral zone depends mainly on four factors: the nature of the material available for transport, orientation and other geomorphic features of the shore, the angle of wave approach and the wave induced currents. Waves arriving at the shore are the primary cause of sediment transport in the littoral zone. Higher waves break further offshore, widening the surfzone and setting more sand in motion. Changes in wave period or height result in moving sands onshore or offshore. The knowledge about the wave climate - the combined distribution of wave height, period and direction during different seasons - is required for an adequate understanding of movement of sand in any specific area. The cellular circulation patterns in the surfzone depend on the longshore gradient in wave setup. Because of the turbulence due to breaking and surging of waves, large volumes of sediments are placed in suspension or rolled along the bed in the surfzone.

4.2.1. Materials and methods

There have been many investigations in the littoral zone for the quantitative and qualitative estimation of sediment drift, making use of the relationship between wave forces and transport of sediment. Many studies have been carried out on the theoretical estimation of the longshore sediment transport using laboratory and field experiments. Longshore sediment transport is generally estimated by using empirical equations which relate the longshore energy flux in
the breaker zone to the longshore transport rate. (Graff and
Overeem, 1979; Willis, 1980). Empirical equations, using
results of the wave refraction studies and progressive
changes in grain size distribution have also been used to
indicate sediment transport direction. Some analyses are more
sophisticated by taking into account the frictional factors
and bed permeability. These also assume for convenience, a
constant mean sediment size. It has been shown later that
these assumptions were far from reality during the short
periods when the bulk of the littoral drift takesplace.

Komar (1976) presented graphically, various data
indicating relationships between the longshore transport rate
and the longshore component of wave energy flux. Komar and
Inman (1970) made extensive field measurements and proposed
an approach of longshore transport with the immersed weight
of longshore transport of sand proportional to the longshore
component of wave energy flux. Shore Protection Manual
(Anonymous, 1975), presents different equations for
estimating the longshore transport using the relationship
between longshore energy flux factor (Pls) and the longshore
transport rate (Q).

Almost all studies have attempted to relate, the
longshore sediment transport with longshore energy flux in
the form,

\[ Q = K \cdot Pls \]  \hspace{1cm} (4.1)

where \( Q \) = volume rate of longshore sediment transport.

\( K \) = dimensional constant
Pls = longshore component of wave power at breaking

\[ = P \cos \alpha_b \sin \alpha_b \] where

\( P \) = wave power at breaking = \( (E C_n)_b \)

\( \alpha_b \) = breaking angle

\( E \) = wave energy

\( C_n \) = group celerity and suffix b denotes at breaker zone

Using the value of Pls in equn. (4.1)

\[ Q = K (E C_n) \cos \alpha_b \sin \alpha_b \quad (4.2) \]

Walton (1980) established a computing technique for longshore energy flux factor (Pls) using the longshore current and breaking wave height.

By radiation stress principle, the longshore current is given by the relation (Longuet-Higgins, 1970)

\[ V_b = \frac{5 \pi}{8} \left( k_a \frac{\beta}{C_f} \right) (g d_b)^{0.5} \sin \alpha_b \cos \alpha_b \quad (4.3) \]

where

\( V_b \) = longshore current velocity at breaker zone

\( \beta \) = a mixing parameter

\( d_b \) = breaking depth

\( C_f \) = bottom friction factor

\( m \) = beach slope

\( k_a \) = breaking wave amplitude/water depth

Using the relationship \( 2k_a = H_b/d_b \) in equn. (4.3)

\[ V_b = \frac{5 \pi}{16} k_a \frac{\beta}{C_f} (1/2k_a)^{0.5} m (g d_b)^{0.5} \sin \alpha_b \quad (4.4) \]

The longshore current velocity at any point in the surf zone can be defined as

\[ V = V_b \left( V_o/V_b \right) \left( V/V_o \right) \quad (4.5) \]

where
\[ V = \text{longshore current velocity within the surfzone} \]

\[ V_0 = \text{theoretical Longshore current velocity at breaking (no mixing)} \]

using (4.3) and (4.4)

\[ V = \frac{(V/V_0)(5\pi/16)(k_a/C_f)(1/2 k_a)^{0.5} m (gd_b)^{0.5} \sin 2\theta_b}{(4.6)} \]

The relationship for longshore energy flux factor at surface is given by

\[ P_{ls} = \rho \frac{H_b^2}{16} (b \sin 2\theta_b) \]

(4.7)

For breaking zone, substituting \( C_b = (g \frac{d_b}{H_b})^{0.5} \) in equn. (4.8)

\[ P_{ls} = \frac{\rho H_b^2}{16} \left( \frac{d_b}{H_b} \right)^{0.5} (g H_b)^{0.5} \sin 2\theta_b \]

(4.9)

Using equn. (4.7) and assuming \( m = d_b/W \)

\[ P_{ls} = \frac{\rho H_b W V C_f}{0.78 (5\pi/2) (V/V_o)} \]

(4.10)

Equn. (4.1) become

\[ Q = K P_{ls} \]

ie \[ Q = K \frac{\rho g H_b W V C_f}{0.78 (5\pi/2) (V/V_o)} \]

(4.11)

where \( Q \) is the annual longshore sediment transport rate in \( \text{m}^3/\text{yr} \) and the value \( K = 1288 \) is a dimensional constant.

\[ \rho = 1025 \text{ kg/m}^3 \]

\[ g = 9.81 \text{ m/s}^2 \]

\[ C_f = 0.01 = \text{frictional coefficient dependent on bottom excursion and bottom roughness.} \]

\[ H_b = \text{breaking wave height in m} \]

\[ W = \text{surfzone width in m} \]

\[ V = \text{longshore current velocity} \]
theoretical dimensionless longshore current
\[ V = \frac{V_0}{\sqrt{1 + p^2}} \]
velocity, (Longuet-Higgins, 1970), assumed
mixing parameter \( p = 0.4 \) and is dependent on the
parameter \( X/W \).

For the estimation of sediment transport rate using
the daily data of LEO, only Walton's equation can be well
suited, as it takes into consideration the measured values of
longshore current. Chandramohan et al. (1993) have used this
equation for the estimation of longshore sediment transport
along the south Maharashtra coast. The primary concern for
such studies is to make estimations on breaker height,
breaker period and longshore current direction and speed.
Monthly averages of the daily LEO data for one year made at
each station have been used in equation (4.11). The net
transport (difference between the amount of littoral drift
transported to the north and south across the surfzone for a
given period) has been calculated.

4.2.2. Results

Monthly longshore sediment transport rates were
estimated using Walton's equation (4.11) from the littoral
environmental parameters on breaker height, surfzone width
and longshore current direction and speed at all 8 stations.
(Figs. 4.9 to 4.16 and Table. 4.1). The negative sign in the
table indicate the drift towards south and the positive sign
towards north. Annual net transport for each location is
presented in Fig. 4.17.
Table 4.1. Monthly drift values at different stations (× 10^5 m^3)

<table>
<thead>
<tr>
<th>Months</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>-0.60998</td>
<td>1.26592</td>
<td>-0.76541</td>
<td>0.32845</td>
<td>-0.07624</td>
<td>-0.01906</td>
<td>-0.07918</td>
<td>0.56795</td>
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<tr>
<td>April</td>
<td>0.03421</td>
<td>0.03128</td>
<td>0.19238</td>
<td>0.05132</td>
<td>0.11887</td>
<td>0.12903</td>
<td>0.08211</td>
<td>0.68115</td>
</tr>
<tr>
<td>May</td>
<td>0.80061</td>
<td>-0.47782</td>
<td>0.35191</td>
<td>0.34311</td>
<td>0.35191</td>
<td>0.01173</td>
<td>-0.80060</td>
<td>0.32845</td>
</tr>
<tr>
<td>June</td>
<td>-2.95609</td>
<td>-0.18768</td>
<td>-0.48877</td>
<td>0.38319</td>
<td>-0.26393</td>
<td>-0.15054</td>
<td>-3.91017</td>
<td>-1.97952</td>
</tr>
<tr>
<td>July</td>
<td>-1.88861</td>
<td>-0.83091</td>
<td>-0.39590</td>
<td>-0.68428</td>
<td>-1.11440</td>
<td>-0.05718</td>
<td>-0.61585</td>
<td>-2.87398</td>
</tr>
<tr>
<td>August</td>
<td>-1.21997</td>
<td>-1.38909</td>
<td>-0.16422</td>
<td>-0.67743</td>
<td>-1.00100</td>
<td>0.00117</td>
<td>0.05474</td>
<td>-0.80647</td>
</tr>
<tr>
<td>September</td>
<td>-0.03128</td>
<td>-0.01955</td>
<td>-0.03665</td>
<td>-0.78008</td>
<td>-0.95799</td>
<td>0.00439</td>
<td>-0.53960</td>
<td>1.02153</td>
</tr>
<tr>
<td>October</td>
<td>0.06256</td>
<td>0.52787</td>
<td>-0.00586</td>
<td>-0.19550</td>
<td>-0.07820</td>
<td>0.00195</td>
<td>1.17305</td>
<td>1.93553</td>
</tr>
<tr>
<td>November</td>
<td>0.21115</td>
<td>0.21994</td>
<td>0.00117</td>
<td>1.21215</td>
<td>0.07624</td>
<td>-0.00117</td>
<td>0.30792</td>
<td>0.40822</td>
</tr>
<tr>
<td>December</td>
<td>-0.13685</td>
<td>0.07038</td>
<td>0.15249</td>
<td>0.24634</td>
<td>1.11440</td>
<td>0.00264</td>
<td>0.02346</td>
<td>0.06451</td>
</tr>
<tr>
<td>January</td>
<td>-0.68037</td>
<td>0.49268</td>
<td>0.00879</td>
<td>0.87978</td>
<td>-0.51614</td>
<td>0.07038</td>
<td>0.34409</td>
<td>0.22679</td>
</tr>
<tr>
<td>February</td>
<td>-0.95310</td>
<td>0.10264</td>
<td>0.00342</td>
<td>0.82113</td>
<td>0.32552</td>
<td>0.17595</td>
<td>0.12219</td>
<td>1.41743</td>
</tr>
</tbody>
</table>

+ Northerly - Southerly
Fig. 4.9. Monthly surfzone drift at Kasargod

Fig. 4.10. Monthly surfzone drift at Cannanore
Along Kasargod beach (Fig. 4.9), the littoral drift shows higher values compared to all other beaches. In the pre-monsoon season southerly drift is observed during March and northerly drift during April-May. During May, the drift magnitude amounts to $0.8 \times 10^5 \text{ m}^3$. With the onset of south-west monsoon, a shift to southerly direction is observed in June and continues in the same direction till the end of south-west monsoon. Maximum southerly drift is observed in June ($2.95 \times 10^5 \text{ m}^3$). During post-monsoon season, the drift is low and inconsistent in direction. During January to March the drift is southerly. The annual net transport shows a southerly drift of $0.73 \times 10^6 \text{ m}^3$ which is the highest compared to the other locations. The higher drift magnitude along this beach is due to the high energy conditions prevailing along this beach. (Chapter 4, Section 4.1.2).

Along Cannanore section (Fig. 4.10), it is seen that, during pre-monsoon period the drift is northerly with a maximum value of $1.26 \times 10^5 \text{ m}^3$ in March. The beach shows southerly littoral drift during May - September and it is northerly during the other months. A decrease in magnitude is observed during June ($0.19 \times 10^5 \text{ m}^3$) followed by an increase towards August ($1.38 \times 10^5 \text{ m}^3$). From September onwards the drift is consistently directed towards north. The annual net drift is southerly with a magnitude of $0.019 \times 10^6 \text{ m}^3$.

Along the Calicut beach (Fig. 4.11), the littoral drift values show lesser magnitude compared to the locations on the north. The monthly drift is southerly during March
Fig. 4.14. Monthly surfzone drift at Calicut

Fig. 4.12. Monthly surfzone drift at Nattika
with the highest value of $0.76 \times 10^5 \text{ m}^3$. The drift is northerly during April-May. During the south-west monsoon season the drift is southerly with comparatively lower values contributed by the occurrence of mud bank in this region. The littoral drift shows a decrease during the post monsoon season reaching a minimum value of $0.001 \times 10^5 \text{ m}^3$ in November. From the beach profile studies (Chapter 3, Section 3.1.2), this beach is seen to be a stable beach among the beaches studied along the northern coast of Kerala. This region represents a case in which the interaction between wave, current and the topography have reached a state of dynamic equilibrium. The annual net drift is southerly with very small magnitude ($0.11 \times 10^6 \text{ m}^3$).

Along Nattika beach (Fig. 4.12), the magnitudes of the monthly littoral drift show slightly larger values compared to Calicut beach. This could be related to the increase in width of the surf zone due to the sloping nature of the beach. Here the drift direction shows a typical monsoonal trend, i.e. southerly during south-west monsoon and northerly during the other seasons. Along this beach, maximum southerly drift is observed during September with a magnitude of $0.78 \times 10^5 \text{ m}^3$ and maximum northerly drift of $1.21 \times 10^5$ during the north-east monsoon (November). Annual net transport along the beach is towards north with a magnitude $0.19 \times 10^6 \text{ m}^3$.

At Andhakaranazhi beach, (Fig. 4.13), the monthly transport shows southerly drift during south-west monsoon months with a maximum of $1.11 \times 10^5 \text{ m}^3$ in July. Subsequently
Fig. 4.13. Monthly surfzone drift at Andhakaranazhi

Fig. 4.11. Monthly surfzone drift at Alleppey
the magnitude decreases towards October. In all the other months except March and January the drift is seen towards north. Another peak value of the drift towards north is observed during the north-east monsoon season (December). Results of the earlier investigations showed similar features in this region. (Prasannakumar, 1985). The annual net drift along this stretch of the beach is southerly with magnitude of $0.2 \times 10^6 \text{ m}^3$.

Monthly drift values estimated for the Alleppey beach (Fig. 4.14), show southerly drift with low magnitudes during south-west monsoon season. These low values may be due to the occurrence of the mud bank off this location which brings out calm conditions in this region. In all other months except March, the drift is northerly. A maximum northerly drift of $0.13 \times 10^5 \text{ m}^3$ occurs in April and is followed by a reversal in direction towards south in the beginning of south-west monsoon season. The drift values are negligible during August to December ($\leq 0.005 \times 10^5 \text{ m}^3$/month). The annual net drift value shows a northerly drift ($0.016 \times 10^6 \text{ m}^3$) which is least compared to the other beaches examined. The beach profiles (Chapter 3, Section 3.1.2), also show the stable nature of the beach during the entire period of study.

At Quilon (Fig. 4.15), the estimated monthly drift values are higher in magnitude than the Alleppey beach. During pre and post-monsoon months, the monthly drift shows northerly trend, while during monsoon it is southerly with a
Fig. 4.15. Monthly surfzone drift at Quilon

Fig. 4.16. Monthly surfzone drift at Trivandrum
Fig. 4.17. Annual net transport for different locations
maximum value of $3.91 \times 10^5 \text{ m}^3$ in June. The magnitude of drift values shows a decreasing trend towards September followed by a shift in direction. The lowest northerly drift value of $0.023 \times 10^5 \text{ m}^3$ is observed during December. The annual net transport is towards south with a magnitude of $0.38 \times 10^6 \text{ m}^3$.

The estimated value of the monthly drift for the Trivandrum beach (Fig. 4.16), shows higher magnitude than at Quilon beach. The drift is southerly only during the south-west monsoon period (May-September) and northerly in other months. The higher magnitude of the drift values along this beach is due to the high energy conditions prevailing along this beach. From the monthly and daily wave breaker height analysis (Chapter 4, Section 4.1.2), it is evident that this beach has all typical characteristics of a high energy beach. With the onset of monsoon, an increase in southerly drift value is observed and shows a maximum value in July ($2.87 \times 10^5 \text{ m}^3$). As reported from earlier studies, during the onset of south-west monsoon season, breaker directions mostly vary between $230^\circ - 240^\circ$ causing a southerly longshore current and a southerly drift. During post-monsoon months an increase in drift value is observed with a maximum of $1.93 \times 10^5 \text{ m}^3$ in October and is northerly. The reversal in drift direction is very conspicuous in this beach. Annual net drift along this beach is towards north with a low value of $0.09 \times 10^6 \text{ m}^3$. 