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# Longshore Sediment Transport along the Coast of Kerala in Southwest India

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**Abstract**

Accurate estimation of longshore sediment transport (LST) along the entire coastal stretch of Kerala is challenging as the sediment transport pattern varies both spatially and temporally depending on the nearshore wave climate, nearshore bedslope, shoreline orientation, coastal morphology, presence of hard structures etc. While majority of the locations show a net northerly drift, there are certain stretches of the coast which are dominated by southerly transport. For the estimation of longshore sediment transport the three commonly used formulae viz. CERC (SPM (1984)), Van Rijn (1991) and Kamphuis (2002) were considered. After detailed analysis of the computed LST results for different sectors of the coast using these formulae, the formula of Kamphuis (2002) which considers all the important parameters like the nearshore bed slope, sediment grain size and peak wave period in addition to the usual input parameters like the wave breaker height and wave breaker angle was selected as the most appropriate one. To understand the spatial and temporal variation in the LST pattern along the Kerala coast, the LST rates for eight important locations - viz. Trivandrum, Quilon, Aleppey, Andhakaranazhi, Nattika, Calicut, Kannur and Kasargod spread along the Kerala coast were computed adopting the Kamphuis (2002) formula. For computation of the LST rates for the eight locations, the one year site specific nearshore wave data derived from numerical model studies was used. For validation, the results were compared with that of the earlier estimations available in literature. It was observed that even though the net magnitude was of the same range, there were deviations in the direction. However, when the results were compared with field observations (where morphological indicators were used) a reasonable agreement could also be established for the directions. The net annual longshore sediment transport was found to vary between $0.32 \times 10^5$ $m^3$ and $2.3 \times 10^5$ $m^3$ along the Kerala coast and the net transport direction was pre-dominantly northerly for almost all the locations selected for the study. The maximum gross sediment transport of $12.85 \times 10^5$ $m^3$ was obtained for Trivandrum but the net transport for this station was much less, and therefore comparable with other locations.

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*Keywords:* *Longshore sediment transport; shoreline orientation; nearshore bedslope; coastal processes; sediment cell*

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## 1. Introduction

Different methods are available for the estimation of longshore sediment transport in the surf zone region. Many of the formulae proposed by earlier researchers were developed on the basis of experimental work for a short duration or field conditions that existed along a particular stretch of the coast which may be unique. Hence, for proper assessment or estimation of the Longshore Sediment Transport (LST) for a coast, it is essential that the underlying processes and factors responsible for the changes are critically examined. Studies that combine both field and empirical results, however, are limited. The present study is an attempt made in this direction to select the most appropriate method for reliable estimation of longshore sediment transport along the Kerala coast.

## 2. Review of the existing methods and its application for the Kerala coast

For an accurate estimation of the longshore sediment transport, it is essential that the boundaries both in the alongshore and offshore directions have to be defined appropriately so that the nearshore coastal processes are represented well. The maximum alongshore extent or length of the coastal stretch that can be considered depends on several factors which includes variation in shoreline orientation, nearshore bathymetry, presence of artificial or natural projections like breakwaters/headlands, other hard structures like seawalls, groins, offshore breakwaters which are usually provided as part of shore protection or harbour/port development activities. Apart from these, the nearshore hydrodynamic data, viz., waves, wind, current and tides also are major deciding factors. The cross-shore extent of the segment to be considered also depends on all these factors as mentioned above. For the present study the entire Kerala coast was broadly divided into four major Sediment Cells as shown in Fig. 1 adopting the sediment cell concept of Van Rjin (1997). The orientations of the four sediment cells (SC) designated as SC - I to SC- IV with respect to North as well as their respective beach slopes and sediment characteristics are presented in Table 2. The southernmost cell SC-I represents a high energy sector with the Poovar inlet in Trivandrum, and Thangassery headland at Kollam as the southern and northern boundaries respectively. For the second cell, SC - II with medium to low energy conditions, the southern and northern boundaries are the Thangassery headland and Munambam inlet in Cochin respectively. Similarly, the third and fourth Sediment Cells - SC III and SC - IV which again represent a combination of medium to low wave energy conditions have the Nandhi Hills headland in Calicut and the Manjeswar inlet in Kasargod as their respective northern boundaries; whereas the southern boundary of these cells are same as the northern boundary of the previous cell. Each of this Sediment Cell can be further divided into sub-cells again based on the same criteria for accurate estimation of LST, particularly at locations where there is a significant change in shoreline orientation and nearshore bed slope.

In the present study, initially the CERC formula (Shore Protection Manual, 1984), the formulae proposed by Van Rijn (2001) and Kamphuis (2002) were considered. To test the reliability of the results computed using the above mentioned formulae for the Kerala coast, the LST rates were calculated for certain pre-defined locations for which field data were available. The results were then compared with the field observations and also with the data quoted in literature. On comparing the results with the field data, the formula proposed by Kamphuis as presented in the next section (Eqn. 1) gave reliable results both for magnitude and direction, whereas the LST rates estimates made using the other two formulae (results not presented) were considerably high (of the order of 2 to 5 times in magnitude). This may be due to the fact that several parameters such as bed slope, peak wave period and sediment grain size that can influence the LST, are not being considered in the formula. The accuracy of the LST transport estimated using CERC formula is believed to be ± 30-50 percent (Smith et al., (2004)). However the direction predicted by CERC was found to be more reliable compared to that obtained using the formula of Van Rijn (1991).

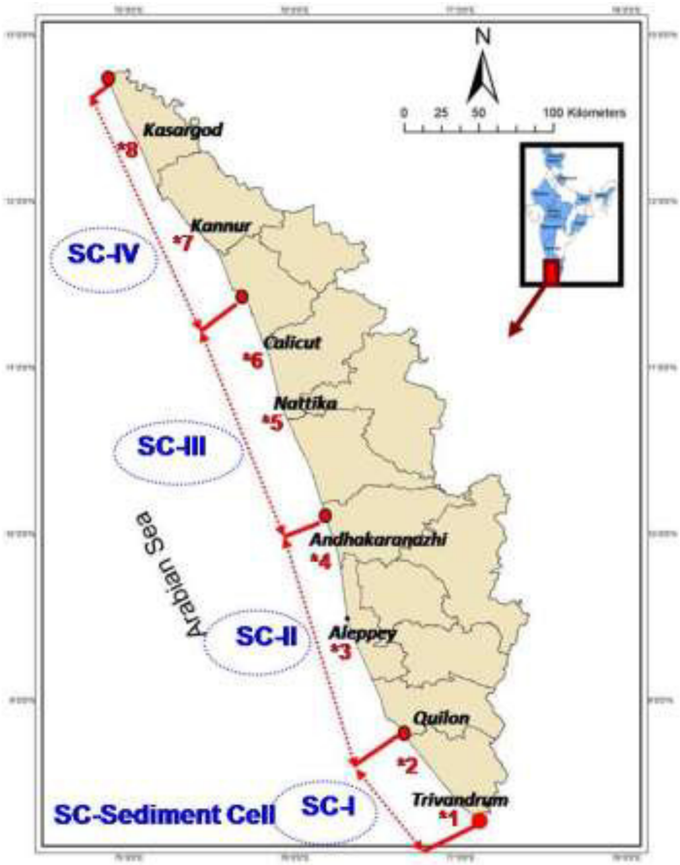


Fig. 1 Location map of the study area showing the sediment cells and coastal stations selected

Table 1 Shoreline orientation, wave condition, nearshore bed slope and grain size of each Sediment Cell

| Sediment Cell | Average Shoreline Orientation ($^{o}$w.r.t N) | Wave climate | Average nearshore slope | Average Grain size (mm) |
|---|---|---|---|---|
| I | 228 | High | 0.005 - 0.05 | 0.34 - 0.37 |
| II | 255 | Medium to low | 0.005 -0.003 | 0.24 -0.31 |
| III | 250 | Medium to low | 0.002 - 0.003 | 0.20 - 0.30 |
| IV | 248 | Medium to low | 0.002 -0.004 | 0.24 -0.3 |

## 3. Kamphuis Formula

The formula proposed by Kamphuis (2002) given in Eqn. (1) below has been used for the calculation of the LST along different stretches of the Kerala coast. The formula takes into account all the important parameters like wave breaker height, wave breaker direction, sediment grain size, bed slope and also the effect of swells (included in the form of peak wave period) which is very important for the Kerala coast as it is mostly dominated by swell waves.

$$Q_{vol} = 6.4 \times 10^{4} H_{sbr}^{2} T_{op}^{1.5} m_{b}^{0.75} D_{50}^{-0.25} \sin^{0.6}(2\theta_{br}) \qquad (1)$$

where, $Q_{vol}$ is the total immersed volume in $m^3$/year, $H_{sbr}$ - breaker wave height, $T_{op}$ is the peak wave period, $m_b$ - bottom slope up to two wave lengths offshore of the breaker line, $D_{50}$ mean grain size and $\theta_{br}$ is the breaker angle with respect to the shore normal.

## 4. Estimation of LST along the Kerala coast

The computed net longshore sediment transport rates using the Kamphuis (2002) formula for the 8 locations viz. Trivandrum, Quilon, Aleppey, Andhakaranazhi, Nattika, Calicut, Kannur and Kasargod along the Kerala coast are compared with the predictions of Sajeev et al. (1997) in Fig. 2. The difference in the magnitudes is mainly due to the adoption of visually observed data (one data per day) by Sajeev et al. (1997) and the variations in nearshore bathymetry and grain size which were not considered by the earlier researchers. For the present work, the site specific nearshore wave data (presented in Table 2) derived from numerical model studies carried out using the Spectral Wave (SW) module of the MIKE 21 modelling system for simulating the wave transformation from offshore to the nearshore region have been used. The derived wave data used for the present study was also pertaining to the same one year period of March 1991 - February 1992 as considered in the earlier studies conducted by Sajeev et al. (1997). The derived wave data obtained from the numerical model results were compared with the measured nearshore wave data available with CESS for selected locations as reported by Baba and Kurian (1988) and it was found that the range, average value and overall trend gave reasonably good match. Since the nearshore measured wave data available with CESS did not pertain to the same year one to one comparison could not be made. The computed monthly longshore sediment transport rates and the annual gross/net transport for each of the eight locations mentioned above are presented in Tables 3(a) and 3(b) respectively**.** It is observed that the direction of net LST obtained by the present study deviates from the results of earlier researchers but corroborates well with the field observations (given by morphological indicators and the monthly shoreline variation plots prepared after conducting shoreline survey). According to Sajeev et al. (1997) for all the stations except Trivandrum, Aleppey and Nattika, the net annual transport is southerly, whereas, the present study gives net northerly transport at seven stations except South Eravipuram in Quilon, where, it is southerly.

Table 2 Derived offshore wave data at 20m water depth for representative locations in the four Sediment Cells

| | Mean significant wave height (m) | | | | Mean Wave Direction (deg) | | | |
|---|---|---|---|---|---|---|---|---|
| Month | SC – I (Trivandrum) | SC – II (Aleppey) | SC- III (Nattika) | SC – IV (Kasargod) | SC – I (Trivandrum) | SC – II (Aleppey) | SC- III (Nattika) | SC – IV (Kasargod) |
| Jan. | 0.78 | 0.75 | 0.73 | 0.75 | 214 | 221 | 222 | 219 |
| Feb. | 0.71 | 0.68 | 0.67 | 0.69 | 216 | 225 | 226 | 223 |
| Mar. | 0.91 | 0.86 | 0.84 | 0.87 | 213 | 222 | 223 | 220 |
| April | 1.51 | 1.41 | 1.38 | 1.43 | 215 | 226 | 226 | 223 |
| May | 1.30 | 1.22 | 1.20 | 1.24 | 215 | 225 | 226 | 223 |
| June | 2.59 | 2.51 | 2.45 | 2.51 | 235 | 246 | 246 | 242 |
| July | 2.54 | 2.52 | 2.44 | 2.49 | 240 | 250 | 250 | 247 |
| Aug. | 2.34 | 2.25 | 2.19 | 2.26 | 230 | 240 | 240 | 237 |
| Sep. | 1.59 | 1.49 | 1.46 | 1.51 | 216 | 226 | 227 | 224 |
| Oct. | 1.30 | 1.23 | 1.20 | 1.24 | 216 | 224 | 225 | 222 |
| Nov. | 0.94 | 0.89 | 0.87 | 0.90 | 213 | 221 | 222 | 219 |
| Dec. | 0.97 | 0.92 | 0.90 | 0.93 | 215 | 224 | 225 | 222 |

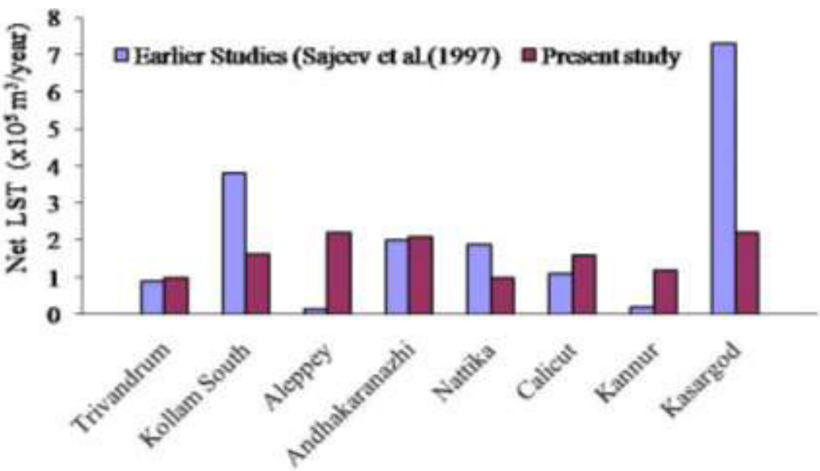


Fig. 2 Comparison of magnitude of the net LST for the eight locations along the Kerala coast

Table 3(a) Monthly LST (x $10^5$ $m^3$) at the eight locations along the Kerala coast computed using one year offshore wave data

| Month | 1 | 2A (South) | 2B (North) | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Jan. | 0.39 | 0.06 | 0.13 | 0.07 | 0.06 | 0.07 | 0.07 | 0.06 | 0.09 |
| Feb. | 0.29 | 0.04 | 0.10 | 0.06 | 0.05 | 0.06 | 0.06 | 0.05 | 0.07 |
| Mar. | 0.55 | 0.10 | 0.19 | 0.10 | 0.08 | 0.09 | 0.10 | 0.08 | 0.12 |
| April | 1.40 | 0.21 | 0.49 | 0.25 | 0.21 | 0.22 | 0.24 | 0.21 | 0.31 |
| May | 1.02 | 0.15 | 0.34 | 0.20 | 0.17 | 0.17 | 0.18 | 0.15 | 0.23 |
| June | -2.31 | -0.90 | -0.82 | 0.36 | 0.39 | -0.10 | 0.20 | -0.13 | 0.30 |
| July | -2.66 | -1.03 | -0.80 | 0.25 | 0.32 | -0.22 | -0.08 | -0.23 | -0.07 |
| Aug. | -0.96 | -0.70 | -0.43 | 0.37 | 0.37 | 0.17 | 0.26 | 0.11 | 0.37 |
| Sep. | 1.31 | 0.16 | 0.44 | 0.26 | 0.21 | 0.22 | 0.23 | 0.20 | 0.31 |
| Oct. | 0.82 | 0.10 | 0.29 | 0.17 | 0.11 | 0.15 | 0.15 | 0.13 | 0.20 |
| Nov. | 0.52 | 0.09 | 0.18 | 0.10 | 0.07 | 0.09 | 0.10 | 0.08 | 0.12 |
| Dec. | 0.61 | 0.08 | 0.21 | 0.11 | 0.08 | 0.11 | 0.11 | 0.09 | 0.14 |

Table 3(b) Computed annual gross and net LST (x $10^5$ $m^3$) for the 8 locations

| LST | 1 | 2A (South) | 2B (North) | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Gross | 12.85 | 3.62 | 4.42 | 2.29 | 2.12 | 1.69 | 1.76 | 1.53 | 2.34 |
| Net | 0.99 | 1.64 | 0.32 | 2.30 | 2.12 | 1.04 | 1.60 | 0.82 | 2.19 |

Note: Negative sign indicates southerly transport and vice versa

The net transport direction is very sensitive to the shoreline orientation and this can be explained by taking Quilon in south Kerala as a typical example. The net LST computed for a location south of Eravipuram in Quilon is southerly, whereas, it is northerly towards north of Eravipuram. The results are presented in Table 3(b). The magnitude of the net northerly transport increases towards the Thangassery headland and this can be easily validated by comparing with the fairly wide Quilon beach seen to the south of Thangassery harbour as shown in Fig. 3(a) (the headland forms the northern boundary of the harbour). The high rate of erosion along the Eravipuram-Thanni sector as seen in Fig. 3(b) can be easily attributed to the divergence in the LST between the above two locations (south and north).

The accuracy of the LST rate estimated using the present method is certainly more than the earlier methods as the wave data used for the estimation of LST is the site specific nearshore wave data at 20m water depth derived from numerical model studies. The nearshore bed slope and the grain size used for the study are again site specific data which have been compiled from various sources. This also includes the shallow water depth data obtained from the nearshore bathymetric survey conducted for selected locations and sediment analysis data of beach samples collected during the period 2012-14.

From the results, it can be seen that the magnitude of monthly transport is comparatively more for the southern stations of Trivandrum and Quilon. This can be attributed to the high energy conditions and steep nearshore slope along this sector of the coast. At Aleppey and Andhakaranazhi stations located further north, the transport is northerly throughout the year and the magnitude of the transport computed for the Aleppey station is on the higher side compared to the values reported in literature (Sajeev et al., 1997). This is because the earlier studies were based on visually observed data and the occurrence of mud banks was also reported during the monsoon season (June-August) of the period of study. Since for the present computation, simulated site specific offshore wave data extracted at 20 m water depth from numerical model results were used, the effect of mud banks on the nearshore wave climate was not accounted. Hameed (1988) based on field observations had reported that that the wave heights can be as low as 0.4 m during the occurrence of mud banks. This usually happens after a period of rigorous wave activity during the initial stages of monsoon (June). As a result of the high wave activity, the fine grained sediments (combination of silt and clay) which are normally present in the shallow water region of the mud bank areas are brought into suspension.  A corresponding increase in the turbidity and viscosity of the surrounding water are also observed due to the increase in the suspended sediment concentration. Mud banks used to occur regularly during the monsoon season along the coastal sector extending from north of Kayamkulam inlet to Calicut (Thomas et al. 2013). But in recent years there has been a reduction in the occurrence of mud banks along the central and north Kerala coast. The influence of mud banks can be easily accounted in the LST computation using the Kamphuis formula by reducing the wave height to 40-50 % of the present value. The longshore transport rates when computed with this reduction in wave height compares well with the earlier values reported for mud bank areas.

The annual net and gross longshore transport direction computed using the formula of Kamphuis (2002) is northerly at all the selected stations except Quilon. Even though, the gross annual transport near the southernmost station of Trivandrum is maximum (12.8 x $10^5$ $m^3$), the net transport (0.99 x $10^5$ $m^3$) is less and comparable with other stations. The net annual longshore sediment transport is predominantly towards north along the Kerala coast, even though, during the monsoon months of June-July the sediment transport is consistently towards the south at almost all the locations.  The net annual longshore transport varies between 0.32 x $10^5$ $m^3$ and 2.30 x $10^5$ $m^3$ along the Kerala coast. The variation in monthly LST magnitude is considerable when the monthly transport rates for the 8 locations are compared. The results show that for a high energy location the variation can be 8-11 times more than that for a location with moderate to low wave conditions during the monsoon season while it is 3 - 5 times during the non-monsoon periods. The breaker angles with respect to the shore normal are also higher for the northern region which can be attributed to the decrease in bed slope in the nearshore region.


Fig. 3 (a) Wide beach to the south of Thangassery harbour and (b) Erosion along the Eravipuram-Thanni coastal sector located a few km to the south of the Thangassery harbour

## 5. Summary and Conclusions

The three commonly used formulae for the estimation of LST viz. CERC (SPM 1984), Van Rijn (1991) and Kamphuis (2002) were reviewed for their application along the Kerala coast and the Kamphuis formula was found to be the most appropriate one. The LST estimates for eight locations along the Kerala coast were computed using the Kamphuis (2002) formula and the results were compared with the earlier estimations available in literature. It was observed that even though the net magnitude was of the same range, there were deviations in the direction. The results of the present study compared well with the field observations (where morphological indicators were used) and a reasonable agreement could be established for the directions also. The net annual longshore sediment transport was found to vary between 0.32 x $10^5$ $m^3$ and 2.3 x $10^5$ $m^3$ along the Kerala coast and the net transport direction was pre-dominantly northerly for almost all the locations selected for the study. The maximum gross sediment transport of 12.85 x $10^5$ $m^3$ was obtained for Trivandrum but the net transport for this station was much less (0.99 x $10^5$ $m^3$).

The study revealed that there can be a distinct variation in the sediment transport both in terms of magnitude and direction within a major Sediment Cell. This was demonstrated for the southernmost sector of the Kerala coast taking the Eravipuram – Thangassery coastal stretch as a typical example. The study further emphasizes the need to have a micro-level approach to understand the shoreline dynamics when site specific coastal management measures are adopted. Such studies are particularly important for locations having a distinct variation in shoreline orientation and also for coastal areas affected by anthropogenic activities like extensive beach sand mining, construction of hard structures, etc., as these activities can have a direct impact on the short-term as well as long-term shoreline changes.

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