Sediment transport and sedimentation in a coastal ecosystem – a case study

Sedimentni transport in sedimentacija v priobalnem ekosistemu - zgled študije

B. K. Purandara[1], B. Venkatesh[1] & V. K. Choubey[2]

[1]Regional Center, National Institute of Hydrology, Hanuman Nagar, Belgaum – 590 001 Karnataka, India
[2]NIH, Roorkee - 2447667, Uttarakhand, India

*Corresponding author. E-mail: purandarabk@yahoo.com

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Abstract: The determination and interpretation of particle grain-size has a fundamental role in hydraulics, geomorphology and sedimentology. The study of textural parameters of the sediments is of paramount utility in differentiating various depositional environments. The present study is carried out along the Central Kerala coast. Grain-size data have been collected from various sources. Apart from collected data, few representative surface sediment samples from the downstream of important rivers like Pamba, Manimala, Muvattupuzha, Minachil and Periyar which debauches into Vembanad lake have been collected. Surface and suspended sediment samples were also collected from the Vembanad lake area where the rivers join the lake and the adjacent nearshore area. Beach sediments were also collected from the selected locations. The study revealed a systematic change in grain-size pattern from moving from one environment to another. Coastal waters showed significant quantities of suspended sediment which resulted in the formation of mud banks (wave dampening). It is also observed that the accumulation of finer sediments aid in protecting the coast during southwest monsoon season. A socio-economic survey has been conducted in the study area to know the importance and significance of the rare coastal phenomena known as mud banks. Mud banks acts as a treasure house for fishes.

Original scientific paper

Izvleček: Določanje in interpretacija zrnavosti ima bistveno vlogo v hidravliki, geomorfologiji in sedimentologiji. Preučevanje strukturnih značilnosti sedimentov je izjemno pomembno pri razločevanju različnih sedimentacijskih okolij. To študijo so opravili ob obali osrednje Kerale (Indija). Podatke o zrnavosti so zbrali iz različnih virov. Razen tega so vzeli nekaj značilnih površinskih vzorcev naplavin iz spodnjega teka pomembnejših rek, ki se izlivajo v jezero Vembanad, kot so Pamba, Manimala, Muvattupuzha, Minachil in Periyar. Površinski in suspendirani sediment so vzorčili pri izlivu rek na območju jezera Vembanad in v okolici. Nadalje so vzorčili tudi obalni sediment v izbranih točkah. Študija je razkrila sistematično spreminjanje zrnavosti na prehodih od enega okolja do drugega. Ugotovili so, da priobalne vode vsebujejo znatne količine suspendiranega sedimenta, kar vodi do nastanka blatnih usedlin ("wave dampening"). Opazili so tudi, da kopičenje zelo drobnozrnatih usedlin pripomore k varovanju obale v obdobjih jugozahodnega monsuna. Na preučevanem območju so opravili tudi družbeno-ekonomsko raziskavo za oceno pomembnosti redkega obalnega pojava, znanega kot blatni nasipi. Blatni nasipi so prava zakladnica za ribe.

Key words: grain-size, lake, suspended sediments, mud bank, nearshore, beach

Ključne besede: zrnavost, jezero, suspendirane usedline, blatni nasip, priobalno okolje, obala

INTRODUCTION

The various processes involved in the movement of water and its relationship to depositional patterns have attracted the scientists and engineers from various fields. Tides, freshwater outflow, and waves cause complicated water movement which transport, fractionate and modify the properties of particulate matter in coastal regions. These area differ geomorphologically, but have the common feature that suspended matter is carried back and forth, deposited, and eroded many times before it finally settles, either permanently or for a long period. Although the problem of the source of the sediments is often very complex, the process of sorting and grain size selection usually establishes an equilibrium between the bottom, suspended matter and the water.

Sediment granulometry have been studied using grain-size statistics. Review of this work has been given by

(Folk & Ward, 1957; Folk, 1966; Friedman, 1961, 1967; Veerayya et al. 1975; Rawlison,1984; Purandara, 1993; Pathani,1997; Kumar et al, 2000; Ganesan, 2004; Sanil et al., 2006; Purandara, 2008).

Kerala coast is one of the most dynamic and distinctive areas with variety of natural resources and facilities and there has always been a zone of hectic human activity. In the coastal areas, numerous problems such as devastation of natural habits due to erosion, pollution, siltation, over population, salt water intrusion, flooding etc are encountered. This part of the coastal area is known for highest density of population in the world.

The present study is an attempt to understand the distribution pattern of sediments in rivers, lake, beach and adjoining shelf. The study has been conducted along the central Kerala coast, between Azhikode in the north to Purakkad in the south (south of Alleppey). This stretch of coastal land is important for their unique formation of `Mud banks'. Mud banks are natural smooth water anchorages formed at particular locations along the Kerala coast during the southwest monsoon season. It extends outwards up to a distance of 3–4 km from the shore. These are semicircular in shape, with their northern and southern edges defined by two crescentic lines of breakers running outwards to the sea. The formation of mud banks play a major role in moulding the socio-economic set up of the coastal people by providing a stable fishing ground during the monsoon season. Mud banks affect the coastal processes by damping the waves in the following ways:

- traps the littoral material transported from the updrift side thereby preventing its downcoast movement,
- causes refraction of waves on its sides, (iii) protects the beach in particular from erosion.

Study area

Geologically, the study area is covered by the Tertiary and Recent sediments which rests directly upon the Archaean crystalline complex consisting of khondalites, leptynites, charnockites and mica hornblende gneisses. The entire wetland ecosystem comprises of four major rivers that debouches into the Vembanad lake which fringes the coastal tract with an outlet to sea. The sediments brought by the rivers first settles in the lake and then it filters out to the sea through the estuary. The estuarine region presents a stable marine condition for major part of the year. During the monsoon period temporary halocline formed with fresh to brackish wa-

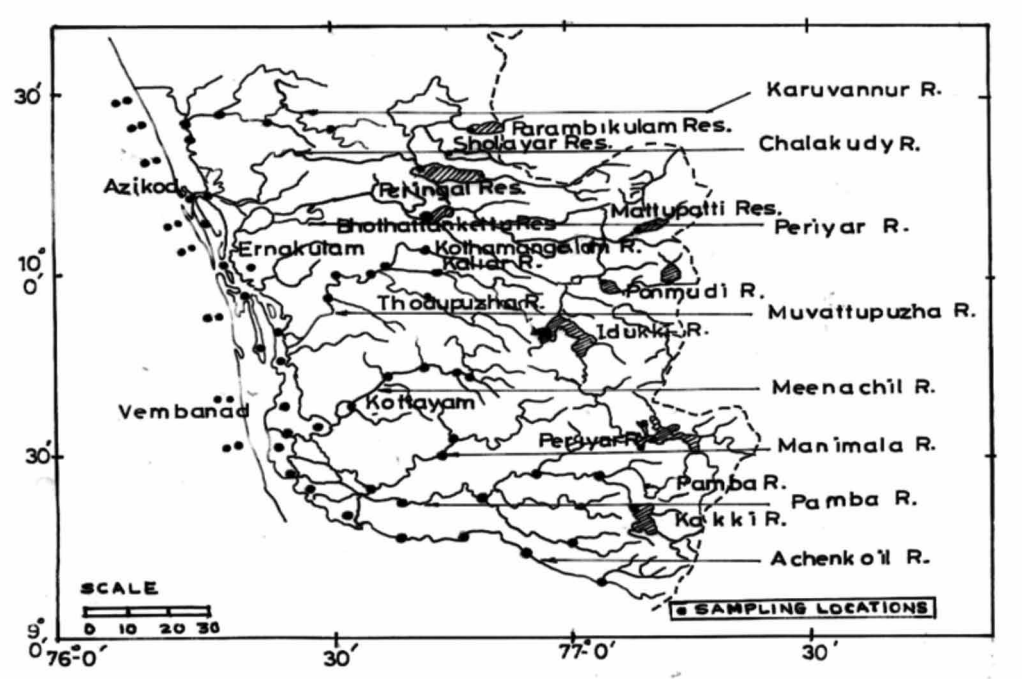

Figure 1. Study Area map with sediment sampling locations

ter condition exists at the surface, and marine condition continues to prevail at the bottom. The estuarine region is highly productive and the underlying sediments are correspondingly rich in organic matter content. The coastal sedimentary basins of the Kerala form the eastern margin of a bigger basin extending westward over the continental shelf. In the nearshore, gradients are 20 m/km to 80 m/km. The sediments present in the Kerala coastal basin include primarily Miocene sediments overlain by a thin section of Quarternary sediments. Present study has been carried out along the Central Kerala coast (Figure 1) to understand the distribution pattern of sediments. Surficial sediments from the rivers (downstream areas of Pamba, Manimala, Minachil, Muvattupuzha and Periyar) Vemband lake, mud banks and shelf were collected and sedimentological analysis were carried out.

METHODOLOGY

Field Investigations

Sediment samples were collected from the downstream region of the rivers Pamba, Manimala, Minachil, Muvattupuzha and Periyar (up to 30 km) were collected from the mid-stream channel at an interval of about 2 km to 10 km to

the point of origin of the rivers. Sediment samples were collected during pre-monsoon and post-monsoon season. Samples were collected from the beach, mud bank and non-mud bank areas of the continental shelf. Surficial sediments were collected by using van Veen grab and water sampling for suspended sediments and salinity determinations were carried out by using Hi-Tech water bottles at different depths.

Laboratory Investigations

Textural analysis

Textural analysis include both sieve and pipette analysis. Samples collected from the Vembanad lake and mud bank region was subjected to combined sieve and pipette analysis. For pipette analysis known quantities of dried sediments were dispersed overnight in a solution of sodium hexametaphosphate. The silt and clay fractions were separated by sieving the dispersed sediments through 230 μm mesh sieve. The coarse fractions remained in the sieve were dried and analysed. Statistical parameters like mean, standard deviation, skewness and kurtosis were determined by the method suggested by Folk & Ward (1957).

Results and discussion

The size analysis of the sediments collected from various rivers, namely, Pamba, Minachil, Muvattupuzha and Periyar reveal that the downstream sediments are very fine in size and the upstream sediments are medium to coarse grained. This is clear from the polymodal nature of the sediments in the upstream. The decreasing tendency of grain-size with distance has been attributed to various hydraulic processes associated with the sediment movement which mainly depends on the travel distance.

However, the present investigations reveal that the distribution of sediment varies widely, particularly in the downstream regions as shown in figures 2a, 2b & 2c. The variation is more pronounced in the river Pamba where there is a sudden change of grain size at a distance of 22 km from the river mouth. This is attributed to the change in river pattern and also due to the confluence of Puthan ar which supplies comparatively finer sediments to the main stream by depositing the coarser sediments in the meandering course. It can also be explained on the basis of irregular mixing up of the estuarine and nearshore sediments. The mixing up process is influenced by the tidal currents, waves and coastal currents which push the sediment towards the estuarine region and from there it reaches the river mouth and vice versa.

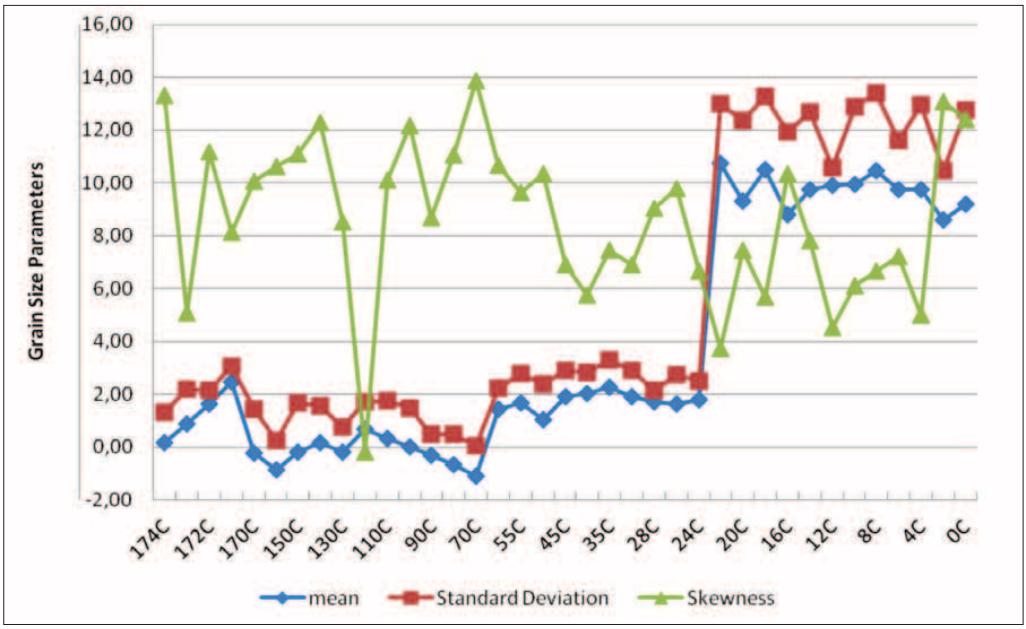

Figure 2a. Plots showing variation of Grain size parameters (Phi mean size, Standard deviation and Skewness) with Distance (upstream to downstream) along the river Pamba

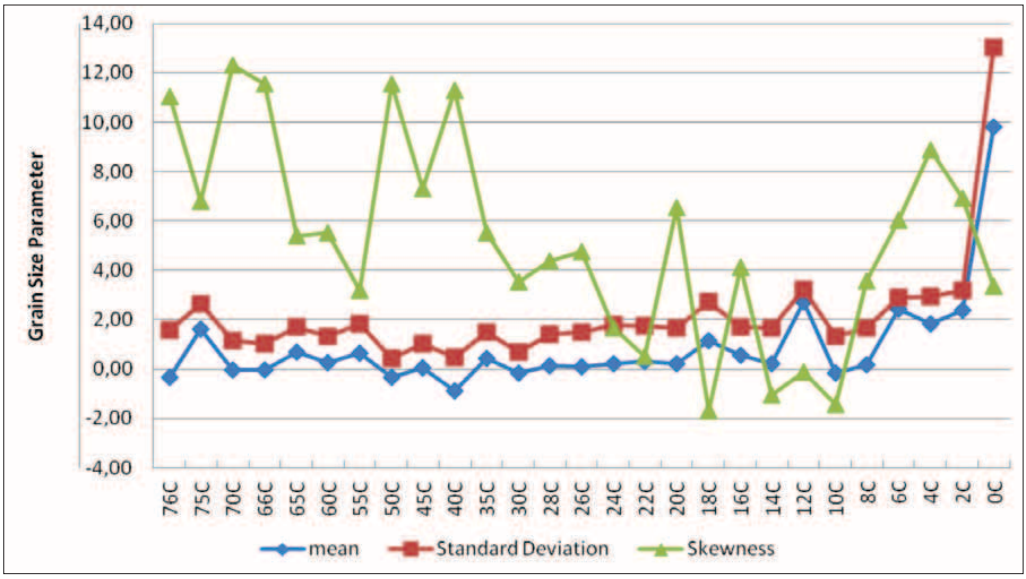

Figure 2b. Plot showing variation of Grain size parameters (Phi mean size, Standard deviation and Skewness) with Distance (upstream to downstream) along the river Minachil

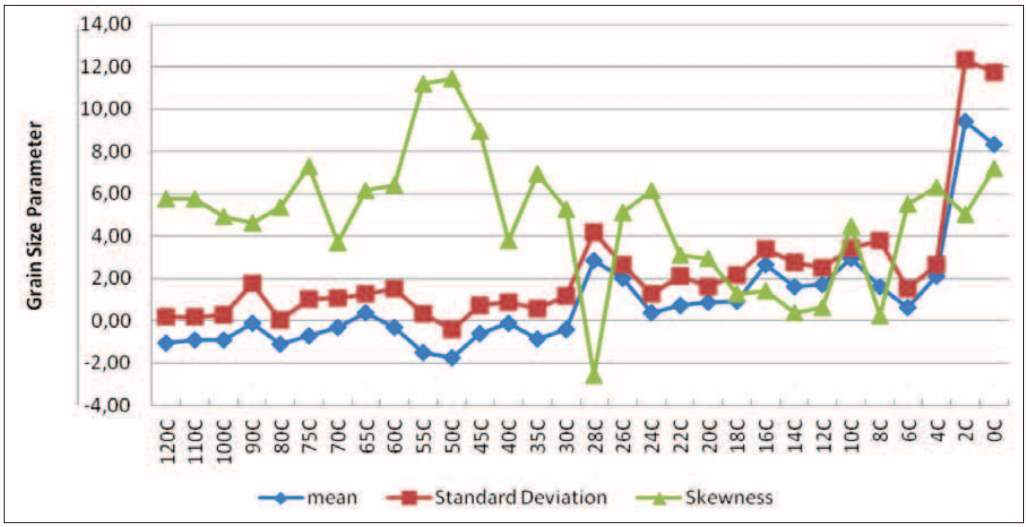

Figure 2c. Plot showing variation of Grain size parameters (Phi mean size, Standard deviation

Grain-size analysis (phi mean size, standard deviation and skewness) of the sediments carried out for all the four rivers in the downstream region are poorly sorted to very poorly sorted. The upstream sediments of Pamba, Minachil and Muvattupuzha show almost a constant value and are poorly sorted. The coarseness and poor sorting of the sediments may be due to its high energy conditions, relative proximity of the source area and the influx of the sediments from the tributaries. The poor sorting of the sediments towards Pamba from Muvattupuzha are noted both in the downstream and upstream region. Generally, river sands display better sorting towards downstream due to progressive sorting based on size. Here, instead, in the downstream area, a complex distribution pattern is observed. This may be due to its sharp decrease in the competency of the transporting agent, intensive mixing of sediments in the river mouth and an increase in depth which is observed during the field investigations. The decrease in velocity is responsible for the sudden deposition of coarser sediments which mixes with the finer sediments. The skewness of the sediments vary between positive to very negative values both in the upstream and downstream region. In general, most of the downstream sediments show a negative skewness or nearly symmetrical distribution. The negative skewness of sediments could be attributed to the addition of material to the coarser terminal, or subtraction of fines from the normal population. This is evident from the observation that the finer sedi-

ments are added through bank erosion and the tidal currents carry finer sediments during the flood tides.

The CM pattern (Figure 3) of the rivers of Central Kerala, closely resembles the pattern of river Mississippi. From the diagram, it is clear that the majority of the samples fall in region IV of PASSEGA & BYRAMJEE (1969) showing graded suspension with high turbulence. A small percentage of the samples fall in region I showing rolling with high energy environment. This shows that the river sediments are mainly transported either as graded suspension or bottom suspension with minor rolling and uniform suspension (PURANDARA, 1990). It is also assumed that particles of graded suspension are lifted by bottom turbulence and the sorting of the deposit is due to settling out of a bottom current (PASSEGA & BYRAMJEE, 1969). It is also important to note that the diameter of the coarsest grain of a graded suspension deposit indicates slow bottom currents. Sediments in the deposits having median values lower than 15 μm never

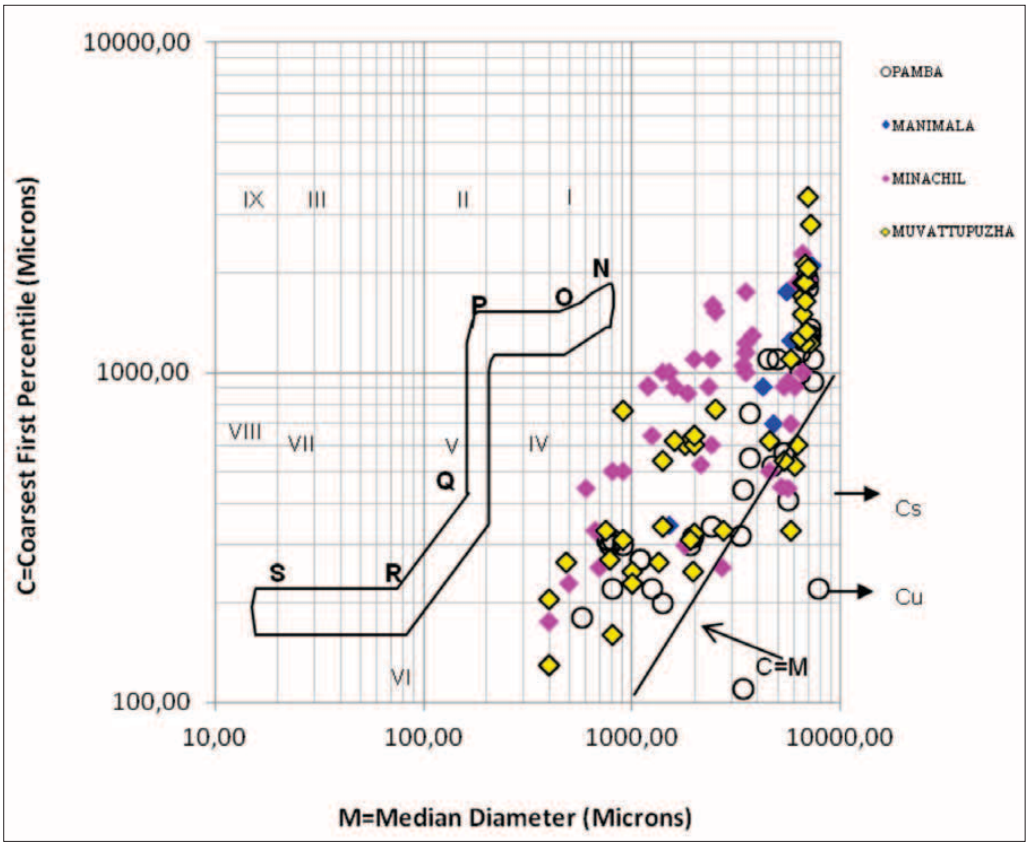

Figure 3. CM pattern diagram of selected rivers of central Kerala

show proportionality between C and M. They are too fine to be sorted by bottom currents. Hence, the uniform suspension is shown by fine particles of the downstream region where the competency of the river decreases and depth of water increases.

The phi mean size of the Vembanad lake sediments varies between 2.5 and 10.55. The average phi mean is 8.21 in the pre-monsoon and 6.4 for the post-monsoon sediments. The standard deviation varies from 1.39 phi to 4.54 phi (pre-monsoon) and 1.95 phi to 3.85 phi (post monsoon). The skewness varies between 0.38 and 0.48 phi during both the seasons. Lake sediments are platykurtic in nature. The kurtosis value ranges from 0.55 to 0.98 during Pre-monsoon and 0.31 to 0.98 during post-monsoon. Sorting of the sediments is poorer during post-monsoon and comparatively better sorted during pre-monsoon season. The kurtosis value shows decrease from pre-monsoon to post-monsoon season.

The CM pattern drawn for the pre-monsoon and post-monsoon sediments of Vembanad lake (Figure 4) show that the segment PM is missing during the pre-monsoon and post-monsoon seasons. In the case of pre-monsoon sediments, it contains QR and RS segments. Cluster of very fine sediments are noted due to its constant mean size and percentile values. In the pre-monsoon season, majority of the sediments are grouped below the coarsest percen-

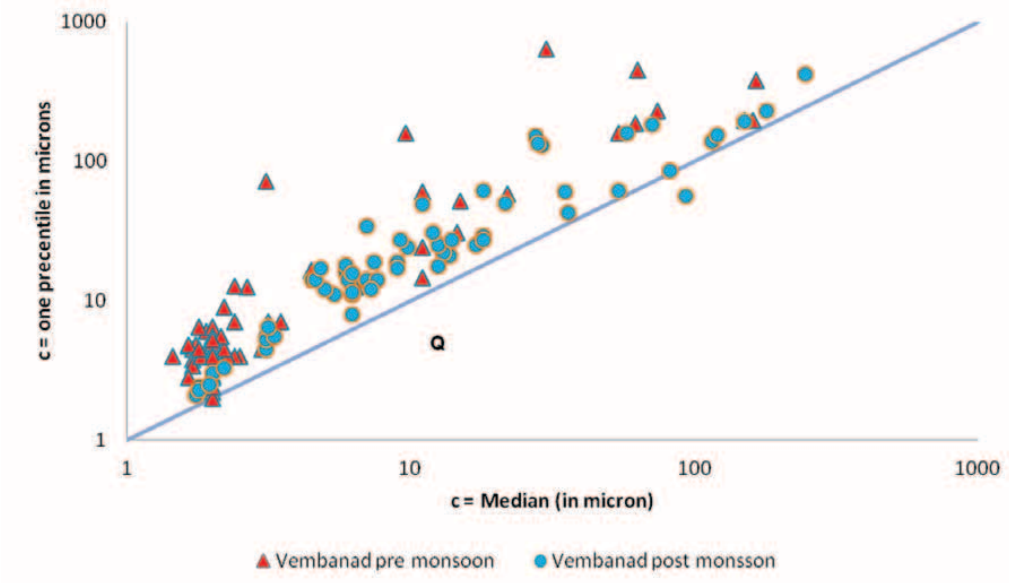

Figure 4. CM pattern diagram of Vembanad lake sediments (a) pre-monsoon; (b) post-monsoon

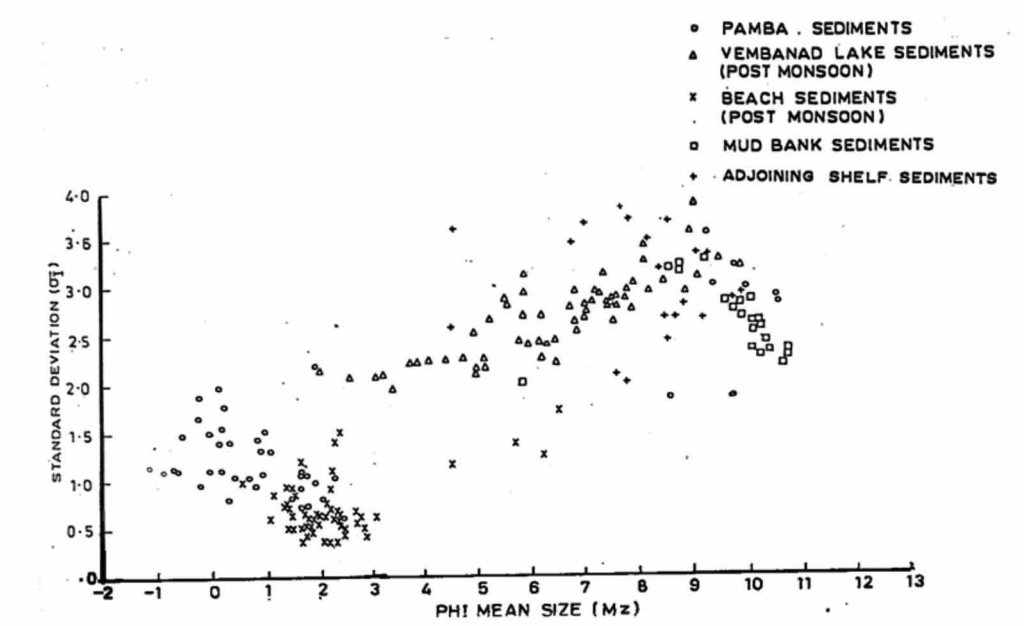

Figure 5. Scatter plot - Phi mean versus Standard deviation

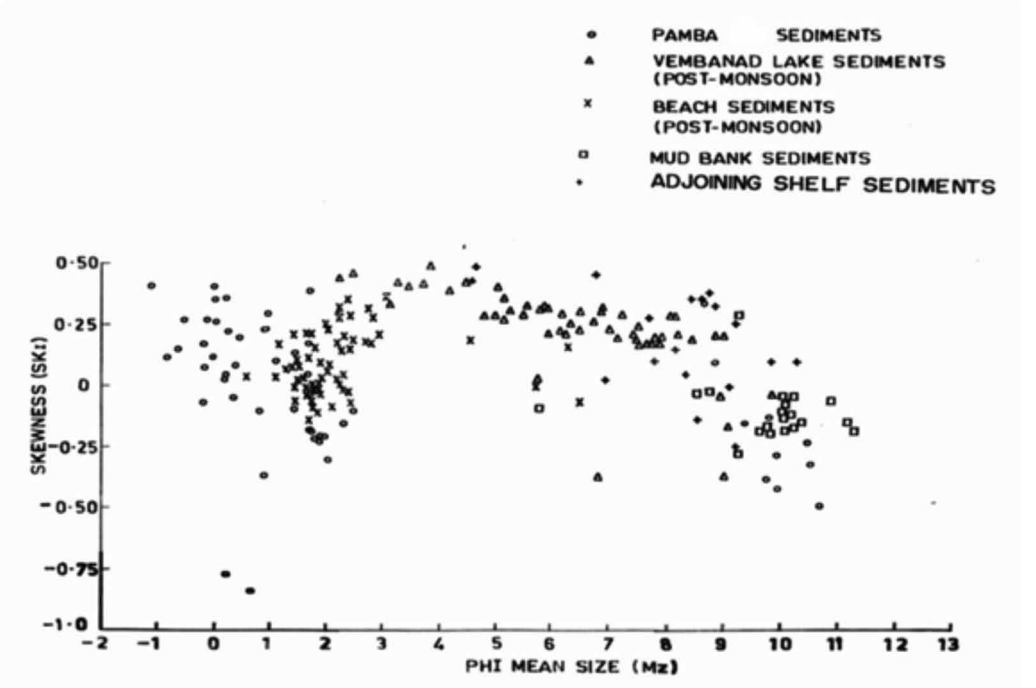

Figure 6. Scatter plot- Phi mean versus Skewness

tile of 31 μm and the median less than 3 μm. The total sediments in uniform suspension and graded suspension are less. The plot drawn for post-monsoon sediments indicates that the sediments are transported mostly by uniform suspension and graded suspension. The maximum size of the grains transported is 650 μm in size during pre-monsoon and it is 420 μm during post-monsoon.

The textural analysis of the beach sands showed that generally, sediments are finer during May and also immediately after the offset of monsoon. The finer size of the sediments may be due to the action of sediments by waves and currents along the beaches at certain places. The formation of mud bank is also significant in depositing the sediments along the coast. Most of the beach sediments are moderately sorted (Figure 5). The range of standard deviation is from moderately sorted to well sorted. Generally, the better sorting of the sediments could be due to the constant action by waves and currents. The skewness value of the pre-and post monsoon sediments varies widely. However, majority of the sands are nearly symmetrical in nature. In general, some of the beach sands are positively skewed. The positive skewness in beach sands as in the case of river sands may be because of the infiltration of fines.

The micro-environmental delineation of granulometric characteristics of the beach sediments are attempted. The size varies from coarse to very fine sand (Figure 5, 6). It is observed that beach sands relatively finer during May and immediately after the offset of monsoon. Most of the beach sands are moderately sorted and nearly symmetrical. Sediment movement in a coastal environment indicates that the various transport mechanisms remain active and it tend to retain the sediments as far as possible in the nearshore environment. In fact, very limited quantity of sediments brought by rivers and other geological agents passes to offshore. In the first stage, the sediments are filtered through estuary and escape into the nearshore and are mostly accumulated as suspended matter due to settling, scour lag effect and salinity variation. Only coarser denser materials are transported further offshore. This kind of accumulation of fine sediments in the nearshore region lead to the formation of mud banks. Mud banks are smooth water tracts along the study area formed during southwest monsoon season. This zone is relatively calm due to the dampening of the waves. The sediment characteristics of this region shown that the percentage of clay increase from May to August and there is a considerable decrease after September. The sediment with grain size less than 1 μm exceeds more than 50 %. During the south-west monsoon, the overflowing rivers of central Kerala are the major contributors of the

sediments through the lake and estuary. These overloaded sediments brought by rivers as suspension and bed load may be filtered through the estuarine mouth and will be transported to the nearshore zone. The transportation of sediments through such a long distance will bring very finer sediments and may remain in suspension due to lower salinity. Due to high concentration of suspended sediments (100 mg/L to 900 mg/L in the surface layer and 120 mg/L to 3600 mg/L in the bottom waters), waves are unable to reach the coast and are dampened completely. This process is very clear from the results which showed that there is a considerable increase in the concentration of suspended sediments from May to August and then a gradual decrease as observed by (KURUP, 1977; RAMACHANDRAN & MALLIK, 1985; PURANDARA & DORA, 1991). Furthermore, it explains that the accumulation of sediments take place in the low energy environment as the waves cannot reach the shore. This clearly indicates the gradual decrease of grain-size when transported to the sea through rivers and estuary. The confinement of suspended matter within a certain region, combined with movement by tidal and density currents, has an important selective effects on the sediment distribution on the continental shelf. In many areas distributional patterns are closely related to water movements including that of waves. Deeper portions on the shelf are often sufficiently quiet for mud deposition, but the deposits are coarse since no fine grained suspended matter is available. Conversely, muddy deposits may form in rough water if sufficient fine grained materials are supplied.

CONCLUSIONS

In summary, the movement of sediments in coastal sedimentary environments shows that various transport mechanisms are responsible for holding the material within these regions. The study reveal that the accumulation of fine grained sediments and suspension are mainly due to settling, tidal movements and scour lag effects. The size of the particles mainly depends on local conditions and also on the accumulation process but the retention is usually most effective for fine grained matter. Further, it is important to note that the confinement of suspended matter within a certain region, combined with movement by tidal and density currents, has an important selective effect on the grain-size distribution of the deposit. (POSTMA, 1967) explained similar condition while dealing with estuarine sedimentation.

A socio-economic survey was conducted by contacting the farmers in the region and they expressed the view that the formation of mud banks is a boon to them because, the waters in

the region is enriched with nutrients and therefore, fishes come closer to the coast during this particular season. Since, offshore movement is restricted during the monsoon season, the availability of fishes in the nearshore region helps them to fetch their livelihood. However, they also opined that, in the recent years the Vembanad lake is facing threat of pollution due to various industries located in and around the lake. The pollutants entering the lake will finally reach to the open sea and may harm the production fishes due to their pollutant. Therefore, it is essential to take control measures while discharging the industrial wastes to lake.

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