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RESEARCH ARTICLE

GRAIN SIZE ANALYSIS AND CHARACTERIZATION OF SEDIMENTARY ENVIRONMENT ALONG MANAKUDY ESTUARY, TAMIL NADU, INDIA

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ABSTRACT

Grain size analysis of Manakudy estuary around mangrove forest , Tamil Nadu, India has been studied and textural parameters namely mean, sorting, skewness and kurtosis. Textural pattern shows complicated profile as a result of the fluctuation in the physicochemical conditions due to the sediments and the marine interactions. Abundance of the medium sand to fine sand shows the prevalence of comparatively moderate- to low-energy condition in the Mankudy mangrove area. In monsoon the abundance of fine sand shows high energy condition. LDF results show the dominance of shallow marine deposits in the Aeolian beach and the influence of turbidity. The granulometric and CM pattern indicates most of the grains from by bottom suspension rolling to graded suspension condition. The comparison with the tractive current diagram, all the season fall in tractive current environment, that is by interaction with wave actions.

INTRODUCTION

The complex coastal processes operated in the past and operating today have left their imprints in the sediments. In this regard, the sedimentology of beach sediments plays a vital role in documenting the depositional history of a region (Angusamy and Rajamanickam 2007). The difference in size distribution is mainly due to variation in wave energy reaching the point of sampling and extent of turbulence affecting the environment. Tidal flats are defined as "sandy to muddy or marshy flats emerging during low tide and submerging during high tide (Reineck, 1972). The particle size analysis is one of the most powerful tools available for the interpretation of any population of sedimentary particles and is a prerequisite to understand their roles in a set of sedimentary processes (Swift *et al.,* 1972). Tubbs (1977) found that the organic and nutrient contents in intertidal sediments got negative correlation to particle size. The contaminant concentration is related to the spatial variation of sediment grain size. Wall *et al.* (1978) found that the sediment samples not pre treated before particle size analysis, the percentage of total clay found in the silt and sand size aggregates can range from 15 to 60%. Unconsolidated sedimemts were mapped by grain size and percent calcium carbonate and the sand was classified according to biogenic constituents. Sediment play an important role in controlling the water chemistry of rivers and it often dominates the flux of many contaminants through river systems. In particular fine grained suspended particulate material (<0.63 mm) is an important transport vector of phosphorus in rivers. Compared to larger grain size fractions, sediment <0.63 mm is generally more active geochemically (Ongley *et al.,*1982) and can remain suspended for longer periods of time (Lick, 1982) thus promoting the transport of surface bound P. Macrophytes have the ability to accumulate nitrogen and phosphorus thereby accelerating the nutrient turnover in the aquatic ecosystems (Brock *et al.,* 1983).

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More over the quantum of transported toxic substances such as heavy metals, radionuclides, nutrients etc. are controlled to a large extent by the grain size of the riverine sediments (Salomons and Forstner, 1984). There are also vast amounts of colloids and clay aggregates circulating in the basin, which is characteristics of the wash load (Konta, 1985). Stone and Mudroch (1989) reported the sorption data for individual grain size fractions of summer sediment with the results obtained for sediment grain size fractions collected during autumn. They also noted that the shaking of the composite sediment samples may have resulted in the further breakdown of water stable aggregates into constituent smaller grain size fractions. The increased mass of smaller size fractions in solution would potentially result in an increased release of phosphate into solution. Mud (silt and clay) in the marine environment is easily dispersed by currents and waves and may serve as good tracers for their sources. Inorganic and organic chemicals from different sources tend to concentrate in the mud fraction as particulate matter or be absorbed onto particulate mineralogical particles. The composition of the mud fraction in the sea may be of environmentalsignificance (Behiary *et al.,* 1991). The smaller the size of the sediment fraction, the higher the content of contaminant accumulates in sediments (Whitney, 1975; Martincic *et al.,* 1990). Studying grain size distribution of sediment is needed due to particular benefit to environmental management of estuarine area which is sensitive to natural processes and human activities. The grain size of the sediments in the basin is determinate by silt and clay sizes (Orfeo, 1999).

The grain size distribution is an important property to understand the hydrodynamic condition, biogeochemical cycle and contaminated process. Deposition is generally associated with low energy environments where fine grained material tends to accumulate. Whereas, where erosion dominates, sediment is over- consolidated (Dyer *et al.,* 2000). The grain size properties can suggest sources and hydrodynamic conditions of marine sediments (Carranza – Edwards *et al.,* 2005). Based on a number of environmental variables the grain size distribution of suspended sediment in fluvial systems can vary both on an event basis (Horowitz *et al*., 1989) or on a seasonal basis (Walling and Moorehead, 1989; Stone and Saunderson, 1992). Intertidal area exhibits heterogeneous sediments in regard to grain size distribution from land to the sea ward, which resulted from environment of sediment transportation and deposition and hydrodynamic conditions (tidal energy, wave and tidal current) in the estuarine area.

Erema *et al*. (2013) reported, grain size analysis show that sediments from the Azuabie creek were generally sandy mud in nature with textural characteristics being fairly constant over the study period. Sediments with fine particles provide better surface areas for pollutants to adsorb than those with coarse particles. The nature of the sediment and the organic matter composition also determine the benthic community structure found in particular sediments.

MATERIALS AND METHODS

Study location

Kanyakumari District is located on the Southern extremity of the Indian Peninsula between lat $8^0 2'$ and $8^0 4'$N and between long $77^0 26'$ and. $77^0 30'$E The district receives heavy rains during the South West (June to August) and North East monsoons (October to December). Pazhayar is one of the main river systems in the District and this river takes its origin at the Western ghats. From the place of its origin it traverses 23.1km before entering the Arabian Sea through the Manakudy estuary. The Manakudy estuary is the confluence of river Pazhayar and has an area of about 150ha. It is a sand built estuary connected to the sea during the rainy season. During the period of total occlusion of the river mouth, the estuarine water swells due to heavy inflow of water from the head of the estuary and also by the land drainage. During heavy inflow into the estuary the sand bar opens up under the force of gravity. Compared to the expanse of the estuarine area, the bar mouth is relatively small and even during summer months the local people cut open the bar mouth and the estuary has open access to the sea. Manakudy estuary abounds with fishery resources and has neighbouring fishing helmets. There are no major industries, however three small-scale industries, viz coconut husk retting, lime shell dredging and salt works are well established on the banks of the estuary. Further there is large scale sand mining at the head of the estuary.

The Manakudy estuary has a luxuriant growth of mangrove forests on the mudflats. However due to pollution from industrial effluents and domestic sewage from the fishermen settlements, there is a threat to this ecosystem. The increase and spred of salt pans have also adversely affects the mangroves.

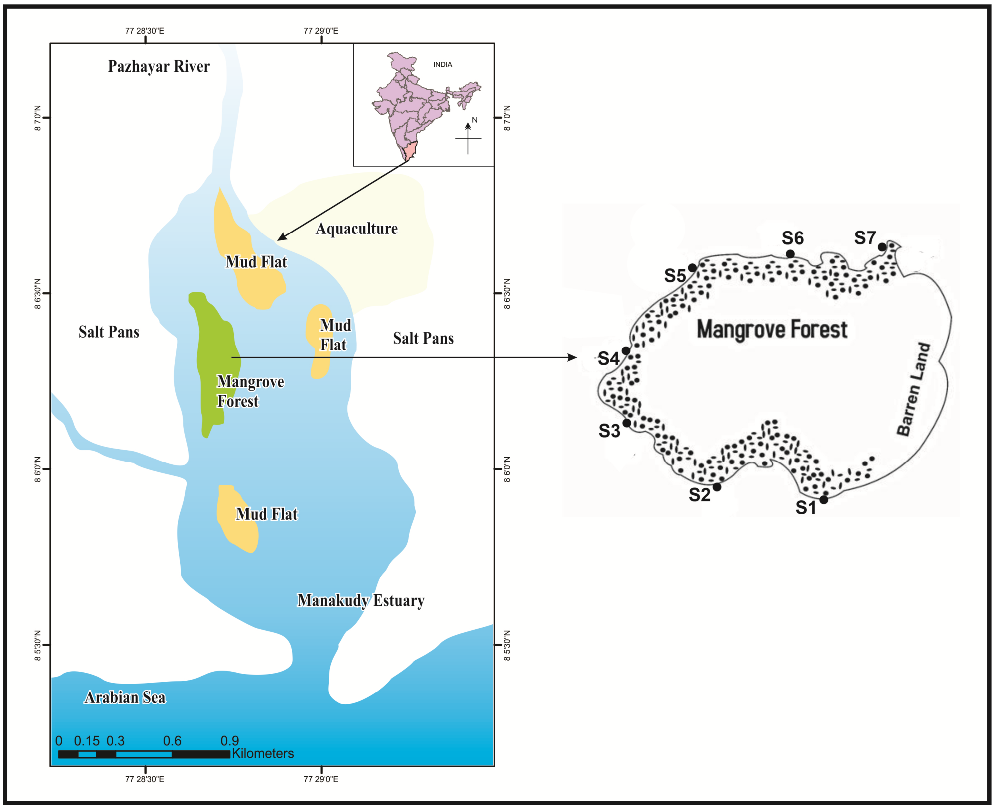


Fig 1. Location map of study area in water

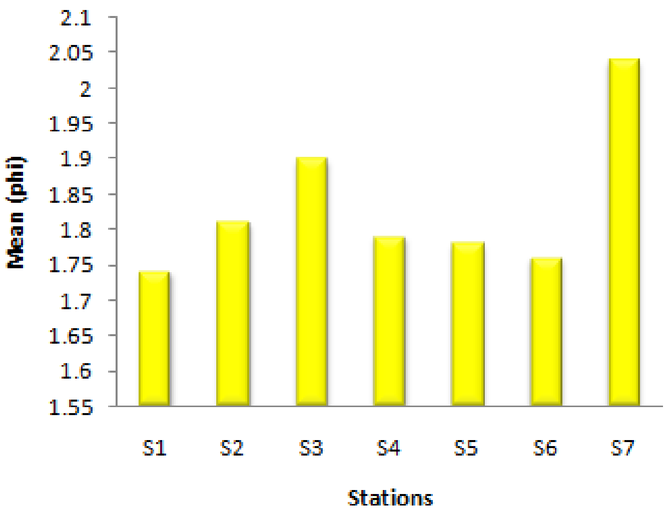
This Manakudy mangrove was also devastated by the Indian Ocean Tsunami. The baseline information on the nutrients and trace metal concentrations, the patterns as well as on linkages and interrelationship between the ecosystem is still lacking. The present investigation is proposed to understand and assess the nutrients, trace metals in sediments and water and primary productivity of the Manakudy mangrove ecosystem.

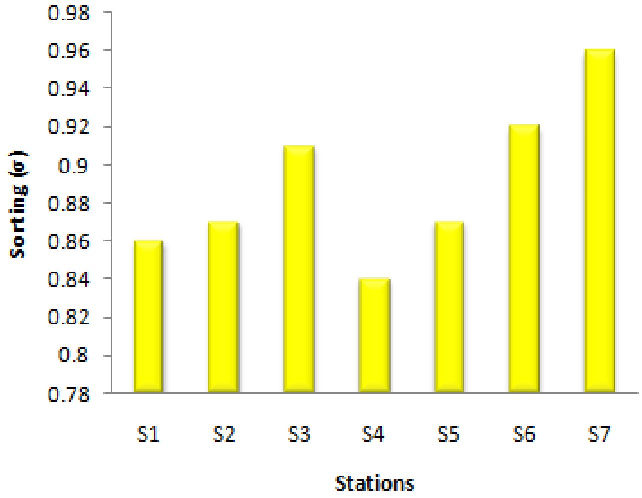
In order to study the state of health of the Manakudy estuary seven stations were selected around the mangrove forest of the estuary. The results of the present investigation are based on the analyses of month (February 2013, May 2013 and October 2013) collections of sediments from seven stations.

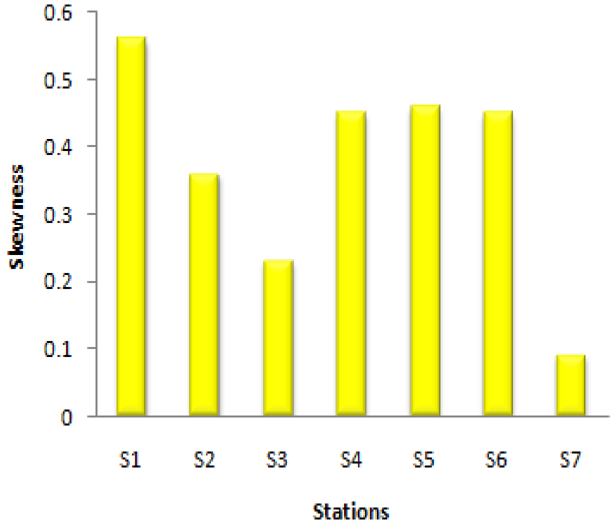
Seasonal study: Based on the duration of the monsoon three seasons are recognized and the data are grouped into three categories viz. Pre monsoon season , monsoon season and post monsoon season.

Description of study area

The bulk sample was reduced by coning and quartering, and a 100-g portion of the sample was selected for laboratory analysis. Organic matter and ferruginous coatings were removed from the samples by treatment with 30 % by volume H_2O_2 and $SnCl_2$. After this pre treatment, the samples were sifted at 0.50 ø intervals through ASTM sieve (from +18 to +230 mesh sizes)sets using a Ro-Tap sieve shaker for 15 min. The sieved materials were collected and weighed. The carbonates present in the sediments were estimated after sieving by treatment with 1:10 HCl. Weight percentage frequencies and cumulative weight percentage frequencies were computed (Folk and Ward 1957). The sieved materials were weighed separately. Then the fractions were properly tabulated and the sands of the respective fractions were kept for further studies. The grain size parameters like graphic mean (Mz), inclusive graphic standard deviation (SD), inclusive graphic skewness (Sk1) and graphic kurtosis (KG) were determined using the software package (Fig. 2). The various graphic and moment measures were calculated with the formulae of Folk and Ward (1957).







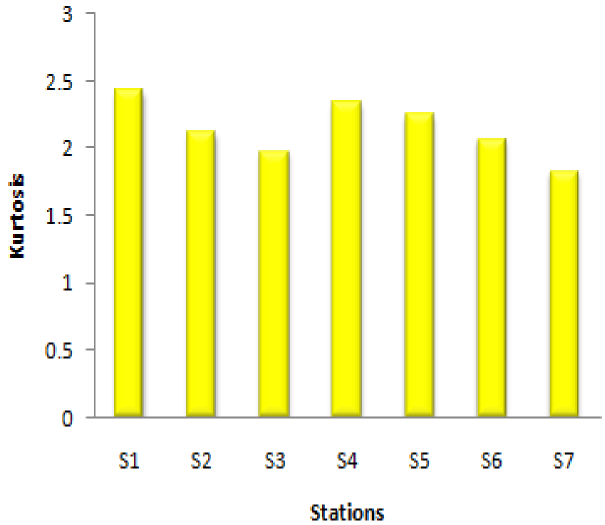


Fig. 2. Average values of grain size statistical parameters, Manakudy estuary: a mean vs sorting; b sorting vs skewness; c skewness and kurtosis

RESULTS AND DISCUSSION

Textural attributes of sediments, viz. mean (Mz), sorting (SD), skewness (Ski) and kurtosis (KG) are widely used to reconstruct the depositional environment of sediments

(Angusamy and Rajamanickam 2006). Correlation between size parameters and transport processes/depositional mechanisms of sediments has been established by exhaustive studies from many modern and ancient sedimentary environments (Folk and Ward 1957; Mason and Folk 1958; Friedman 1967; Visher 1969; Valia and Cameron 1977; Wang *et al*., 1998; Asselman 1999; Malvarez *et al*., 2001; Ramamohanarao *et al*., 2003; Suresh Gandhi *et al*., 2008; Ramanathan *et al*. 2009; Anithamary *et al*., 2011).

Table 1 shows the descriptive statistics of the different grain size parameters. Table 2 summarises parameters for the different sampling sectors.

the dominance of finer size of platykurtic nature of sediments reflects the maturity of the sand. This may be due to the aggregation of sediment particle size by compaction, and the variation in the sorting values are likely due to continuous addition of finer/coarser materials in varying proportions (Ramanathan *et al.,* 2009).

CS coarse sand, MS medium sand, FS fine sand, WS well sorted, MWS moderately well sorted, MS moderately sorted, PS poorly sorted, VFS very fine skew, FS fine skew, NS near symmetry, CS coarse skewed, VPK very platykurtic, PK platykurtic, MK mesokurtic, LK leptokurtic, VLK very leptokurtic

Table 1. Descriptive statistical analysis for the grain size parameters

		Grain size parameters			
Seasons		Mean (Φ)	Sorting (σ)	Skewness (Ski)	Kurtosis (KG)
Pre monsoon	Min	1.56	0.84	0.24	1.81
	Max	2.01	0.98	0.82	2.43
	Average ±	1.76 ± 0.14	0.90 ± 0.04	0.46 ± 0.19	2.09 ± 0.20
monsoon	Min	1.84	0.78	-0.14	1.66
	Max	2.18	1.02	0.39	2.59
	Average ±	2.01 ± 0.13	0.89 ± 0.09	0.13 ± 0.21	2.06 ± 0.31
Post monsoon	Min	1.52	0.81	0.17	1.93
	Max	1.94	0.92	0.86	2.99
	Average ±	1.72 ± 0.12	0.87 ± 0.05	0.51 ± 0.21	2.29 ± 0.37

Table 2. Descriptive statistic sediment remarks - Pre monsoon

Stations	Mean (phi)	Remarks	Sorting (σ)	Remarks	Skewness (Ski)	Remarks	Kurtosis (KG)	Remarks
S1	1.65	Medium sand	0.92	Moderately sorted	0.59	Very fine skewed	2.08	Very leptokurtic
S2	1.76	Medium sand	0.84	Moderately sorted	0.35	Very fine skewed	2.09	Very leptokurtic
S3	1.81	Medium sand	0.90	Moderately sorted	0.32	Very fine skewed	1.94	Very leptokurtic
S4	1.80	Medium sand	0.90	Moderately sorted	0.51	Very fine skewed	2.26	Very leptokurtic
S5	1.75	Medium sand	0.92	Moderately sorted	0.45	Very fine skewed	2.04	Very leptokurtic
S6	1.56	Medium sand	0.89	Moderately sorted	0.82	Very fine skewed	2.43	Very leptokurtic
S7	2.01	Fine sand	0.98	Moderately sorted	0.24	Fine skewed	1.81	Very leptokurtic

Table 3. Descriptive statistic sediment remarks - Monsoon

Stations	Mean (phi)	Remarks	Sorting (σ)	Remarks	Skewness (Ski)	Remarks	Kurtosis (KG)	Remarks
S1	2.05	Fine sand	0.86	Moderately sorted	0.23	Fine skewed	2.23	Very leptokurtic
S2	1.90	Medium sand	0.88	Moderately sorted	0.28	Fine skewed	2.09	Very leptokurtic
S3	2.16	Fine sand	0.92	Moderately sorted	-0.14	Coarse skewed	1.93	Very leptokurtic
S4	1.93	Medium sand	0.82	Moderately sorted	0.24	Fine skewed	2.16	Very leptokurtic
S5	1.84	Medium sand	0.78	Moderately sorted	0.39	Very fine skewed	2.59	Very leptokurtic
S6	2.02	Fine sand	1.02	Poorly sorted	0.07	Near symmetry	1.66	Very leptokurtic
S7	2.18	Fine sand	0.99	Moderately sorted	-0.14	Coarse skewed	1.77	Very leptokurtic

Table 4. Descriptive statistic sediment remarks - Post monsoon

Stations	Mean (phi)	Remarks	Sorting (σ)	Remarks	Skewness (Ski)	Remarks	Kurtosis (KG)	Remarks
S1	1.52	Medium sand	0.81	Moderately sorted	0.86	Very fine skewed	2.99	Very leptokurtic
S2	1.77	Medium sand	0.88	Moderately sorted	0.45	Very fine skewed	2.19	Very leptokurtic
S3	1.74	Medium sand	0.9	Moderately sorted	0.51	Very fine skewed	2.09	Very leptokurtic
S4	1.64	Medium sand	0.81	Moderately sorted	0.6	Very fine skewed	2.62	Very leptokurtic
S5	1.75	Medium sand	0.92	Moderately sorted	0.55	Very fine skewed	2.12	Very leptokurtic
S6	1.71	Medium sand	0.86	Moderately sorted	0.45	Very fine skewed	2.12	Very leptokurtic
S7	1.94	Medium sand	0.91	Moderately sorted	0.17	Fine skewed	1.93	Very leptokurtic

Friedman (1962) suggested that the extreme high or low values of kurtosis imply that part of sediment achieved its sorting elsewhere in high-energy environment. Variation in the kurtosis values is a reflection of the flow characteristic of the depositing medium (Baruah *et al*., 1997; Ray *et al*., 2006), and

Bivariate scatter graphs of grain size parameters

Sedimentalogists have attempted to use scatter graphs of grain size parameters to distinguish between different depositional settings, via bivariate plots, which are based on the assumption

Table 5. Summery of grain size statistical parameters (in percentage of the total number at each sector)

Summary of grain size statistical parameters							
Mean (Φ)	S1	S2	S3	S4	S5	S6	S7
CS	0	0	0	0	0	0	0
MS	66.67	100	66.67	100	100	66.67	33.33
FS	33.33	0	33.33	0	0	33.33	67.67
Sorting (σ)							
WS	0	0	0	0	0	0	0
MWS	0	0	0	0	0	0	0
MS	100	100	100	100	100	66.67	100
PS	0	0	0	0	0	33.33	0
Skewness (Ski)							
VFS	66.67	66.67	66.67	66.67	100	66.67	33.33
FS	33.33	33.33	0	33.33	0	0	33.33
NS	0	0	0	0	0	33.33	0
CS	0	0	33.33	0	0	0	33.33
Kurtosis(KG)							
VPK	0	0	0	0	0	0	0
PK	0	0	0	0	0	0	0
MK	0	0	0	0	0	0	0
LK	0	0	0	0	0	0	0
VLK	100	100	100	100	100	100	100

that these statistical parameters reliability reflect differences in the fluid-flow mechanisms of sediment transportation and deposition (Sutherland and Lee 1994). Figure 3a shows the relationship between mean grain size and sorting for the Manakudy estuary. There is a clustering in coarse and moderately well sorted. Griffths (1967) explained that both mean grain size and sorting are hydraulically controlled, so that in all sedimentary environments the best-sorted sediments have mean size in the fine sand size range. Figure 3b shows the relationship between sorting and skewness for the Manakudy estuary. Sediments are well sorted and fine skew towards very fine skew fractions. By contrast, well sorted sediments are mainly clustered around the very fine skew range and have positive skewness values. Plotting of skewness against kurtosis is a powerful tool for interpreting the genesis of sediment, by quantifying the degree of normality of its size distribution (Folk 1966) Fig. 3c shows that the sediments from Manakudy estuary lie within the positively skewed/ leptokurtic range. This suggests that the dominance of medium grain size population and the subordinate of coarse and fine grain size which gives positive skewness. However, most of the sediments from the Manakudy estuary show mixing of different size-range sediment populations, with one predominant population and a very subordinate population.

Generally, most beach sediments are slightly negative skewed because of a small proportion of coarse grains (Folk 1966). Friedman (1962) showed that most sands are leptokurtic and are either positively or negatively skewed. This could be explained by the fact that most sands consist of two populations: one predominant population and one very subordinate, coarse (leading to negative skewness) to fine (leading to positive skewness). In Manakudy estuary, both pre and post monsoon all stations had positively skewed but in monsoon S3 and S7 had negatively skewed other stations had positively skewed (Table 2-4).

Linear discriminate function

According to Sahu (1964), the statistical method of analysis of the sediments to interpret the variations in the energy and fluidity factors seems to have excellent correlation with the different processes and the environment of deposition. Linear discriminate function (LDF) analysis of the sediment samples was carried out using the following equations:

1. Aeolian/beach

$$Y_{1(A:B)} = -3.5688\ M + 3.7016\ r^2 - 2.0766\ SK + 3.1135\ KG$$

If Y is >−2.7411, the environment is ‘Beach’ but if Y is <−2.7411, the environment is ‘Aeolian’.

2. Beach/shallow agitated water

$$Y_{2(B:SM)} = 15.6534\ M + 65.7091\ r^2 + 18.1071\ SK + 18.5043\ KG$$

If Y is <63.3650, the environment is ‘Beach’ but if Y is >63.3650, the environment is ‘Shallow marine’.

3. Shallow marine/fluvial environment

$$Y_{3(SM:F)} = 0.2852\ M - 8.7604\ r2 - 4.8932SK + 0.0482KG$$

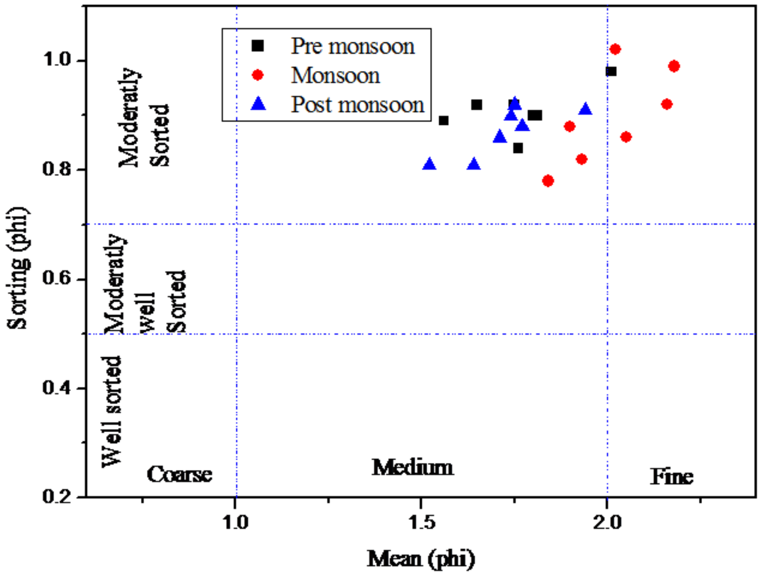
If Y is >−7.4190, the environment is ‘Shallow marine’ but if Y is <−7.4190, the environment is ‘Fluvial’.

4. Fluvial/turbidity

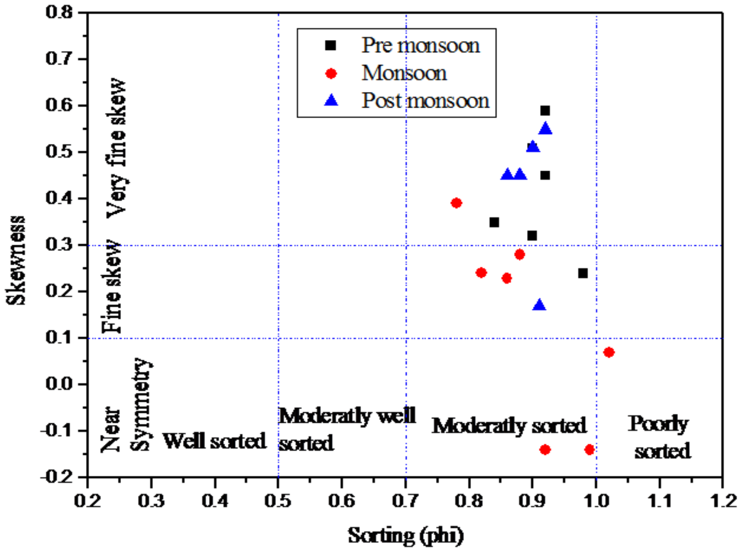
$$Y_{4(F:Turb)} = 0.7215M + 0.403r2 + 6.7322SK + 5.2927KG$$

If Y is >10.000, the environment is ‘Turbidity’ but if Y is <10.000, the environment is ‘Fluvial’.

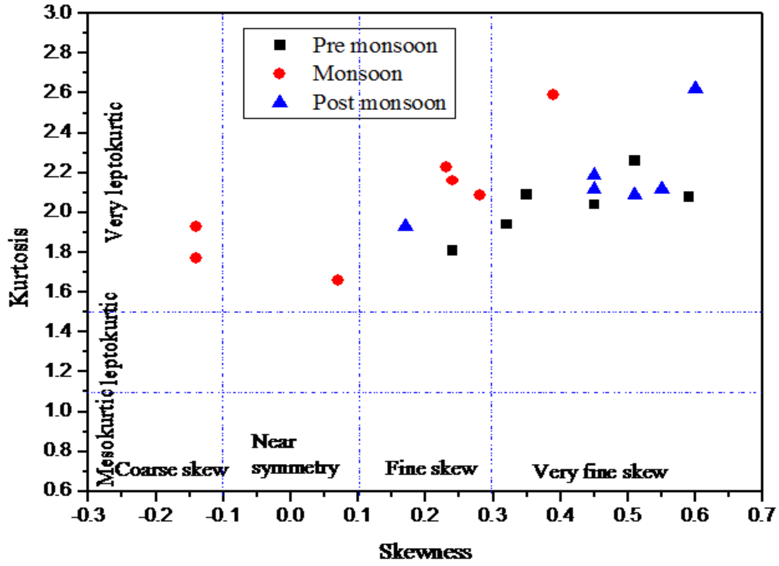
(Y1 = aeolian/beach, Y2 = beach/shallow marine, Y3 = shallow marine/fluvial, Y4 = fluvial/turbidity)



(a) Mean Vs Sorting



(b) Sorting Vs Skewness



(c)Skewness Vs Kurtosis

Fig. 3 Sector plot showing the bivariate relationship between (a) the grain size (phi) and sorting (b) sorting and skewness, (c) skewness and kurtosis

Table 6. LDF sediment remarks - Pre monsoon

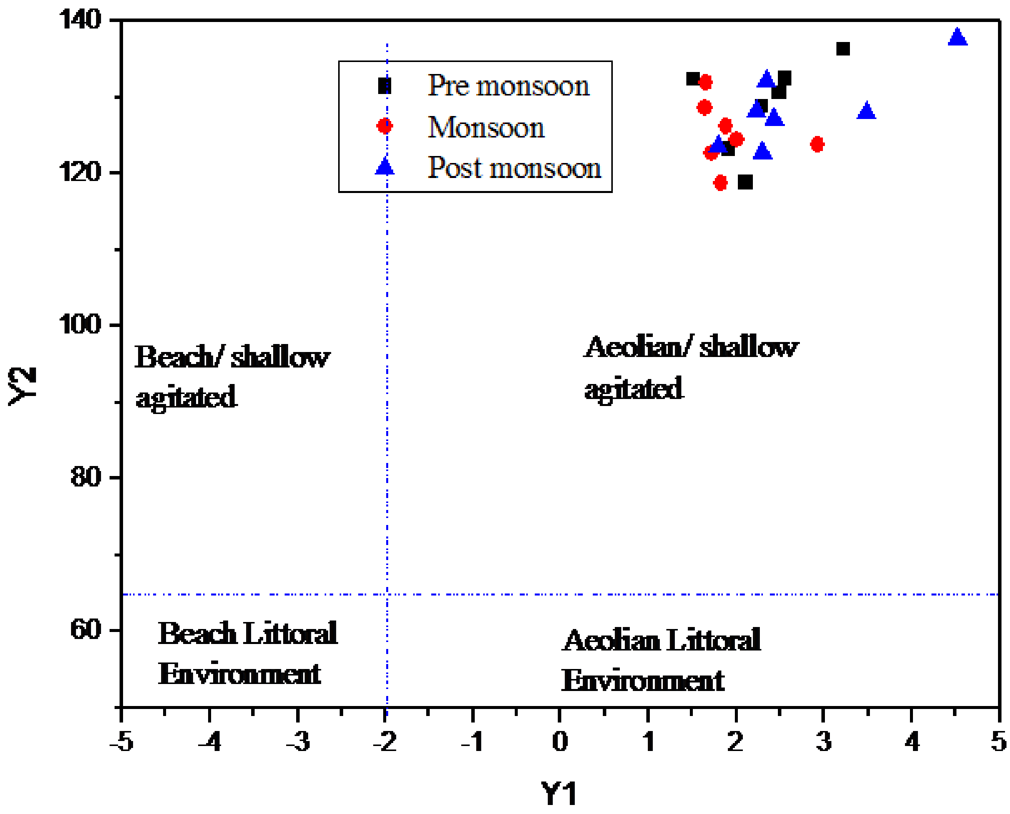
Stations	Y1	Remarks	Y2	Remarks	Y3	Remarks	Y4	Remarks
S1	2.49	Aeolian	130.61	Shallow Marine	5.09	Fluvial	16.51	Turbidity
S2	2.11	Aeolian	118.92	Shallow Marine	5.07	Fluvial	14.97	Turbidity
S3	1.91	Aeolian	123.24	Shallow Marine	6.13	Fluvial	14.05	Turbidity
S4	2.55	Aeolian	132.45	Shallow Marine	5.22	Fluvial	17.02	Turbidity
S5	2.30	Aeolian	128.90	Shallow Marine	5.81	Fluvial	15.43	Turbidity
S6	3.22	Aeolian	136.28	Shallow Marine	3.48	Fluvial	19.82	Turbidity
S7	1.51	Aeolian	132.40	Shallow Marine	7.89	Fluvial	13.03	Turbidity

Table 7. LDF sediment remarks - Monsoon

Stations	Y1	Remarks	Y2	Remarks	Y3	Remarks	Y4	Remarks
S1	1.88	Aeolian	126.11	Shallow Marine	6.04	Fluvial	15.12	Turbidity
S2	2.01	Aeolian	124.37	Shallow Marine	6.05	Fluvial	14.62	Turbidity
S3	1.72	Aeolian	122.60	Shallow Marine	8.81	Fluvial	11.17	Turbidity
S4	1.82	Aeolian	118.70	Shallow Marine	5.37	Fluvial	14.71	Turbidity
S5	2.93	Aeolian	123.76	Shallow Marine	4.07	Fluvial	17.90	Turbidity
S6	1.66	Aeolian	131.96	Shallow Marine	9.42	Fluvial	11.13	Turbidity
S7	1.64	Aeolian	128.74	Shallow Marine	9.97	Fluvial	10.39	Turbidity

Table 8. LDF sediment remarks - Post monsoon

Stations	Y1	Remarks	Y2	Remarks	Y3	Remarks	Y4	Remarks
S1	4.52	Aeolian	137.80	Shallow Marine	2.11	Fluvial	22.97	Turbidity
S2	2.43	Aeolian	127.26	Shallow Marine	5.19	Fluvial	16.21	Turbidity
S3	2.23	Aeolian	128.36	Shallow Marine	5.19	Fluvial	16.07	Turbidity
S4	3.48	Aeolian	128.12	Shallow Marine	3.41	Fluvial	19.35	Turbidity
S5	2.34	Aeolian	132.19	Shallow Marine	5.32	Fluvial	16.52	Turbidity
S6	2.30	Aeolian	122.74	Shallow Marine	4.86	Fluvial	15.78	Turbidity
S7	1.79	Aeolian	123.57	Shallow Marine	7.06	Fluvial	13.09	Turbidity



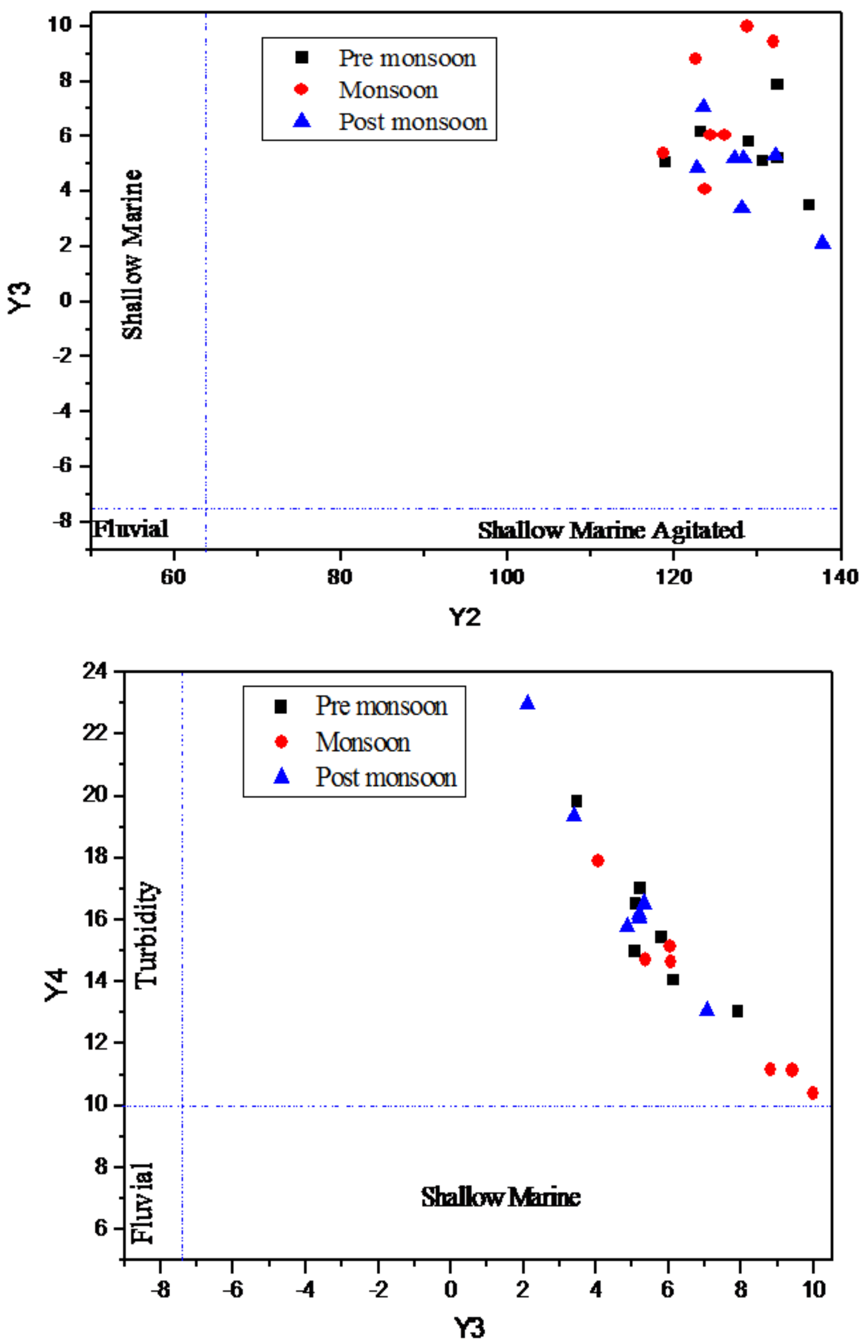


Fig. 4. LDF values plot for Manakudy estuary samples

The process and environment of deposition were deciphered by Sahu's linear discriminate functions of Y1 (aeolian, beach), Y2 (beach, shallow agitated water), Y3 (shallow marine, fluvial) and Y4 (turbidity, fluvial). With reference to the Y1 and Y2 values, all the samples fall (100 %) in an aeolian process (Y1) and all the samples (100 %) fall in shallow marine waters (Y2) respectively. Further, all the samples (100 %) fall in the (Y3) fluvial, Y4 values show that about 100 % of the samples were deposited by turbidity action (Fig. 4).

CM pattern

Grain size parameters and the plots of CM patterns help to distinguish between the sediments of different environments of fluvial and deltaic deposits (Passega 1964; Visher 1969) .In the present study, an attempt has been made to identify the modes of deposition of sediments of the Manakudy estuary by CM pattern. Parameter C (one percentile of the grain size distribution) and M (the median) were plotted with phi values of the C and M obtained from cumulative curves in microns (Fig. 5-7). The relation between C and M is the effect of sorting by bottom turbulence. CM pattern is subdivided into three segments namely, NO (rolling), OPQ (bottom suspension and rolling), QR (graded suspension no rolling), RS (uniform suspension), S (pelagic suspension). The plotted results of Manakudy estuary sediments (pre monsoon, monsoon and post monsoon) shows that all the samples fall in bottom suspension rolling to graded suspension condition. The comparison with the tractive current diagram, the samples fall in beach and tractive current environment, that is by interaction with wave actions (Fig. 5-7).

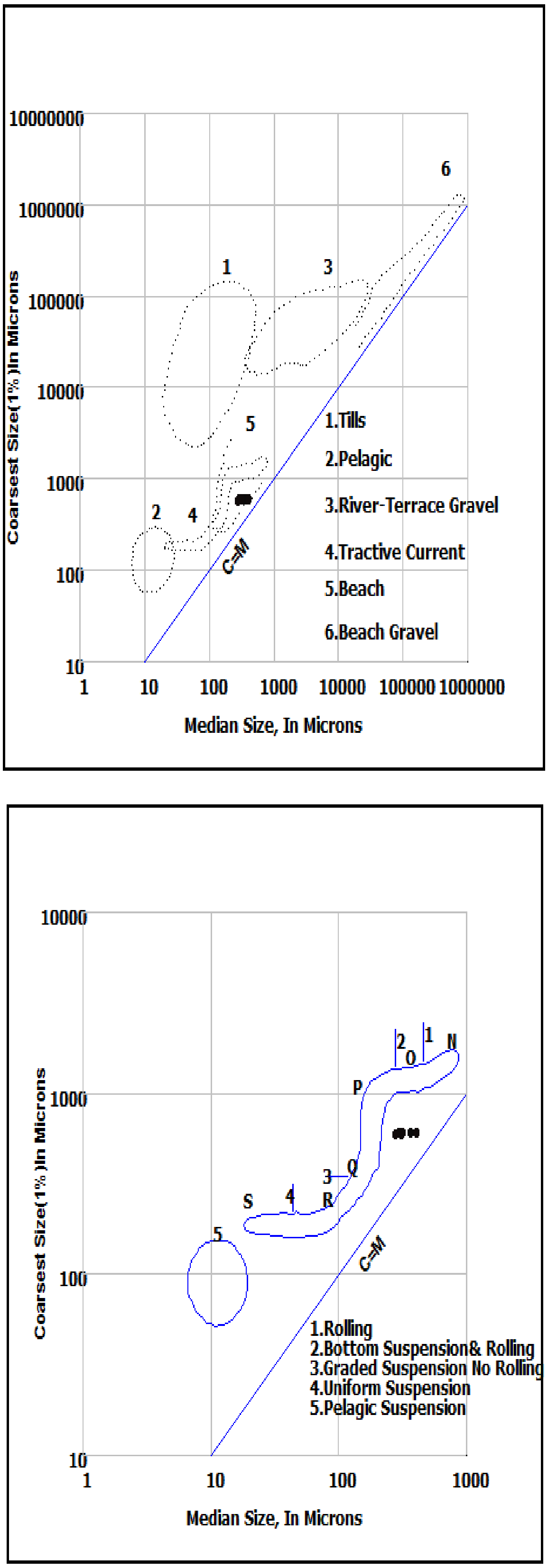


Fig. 5. CM diagram (Passega 1957, 1964) and tractive current deposit plot for Pre monsoon

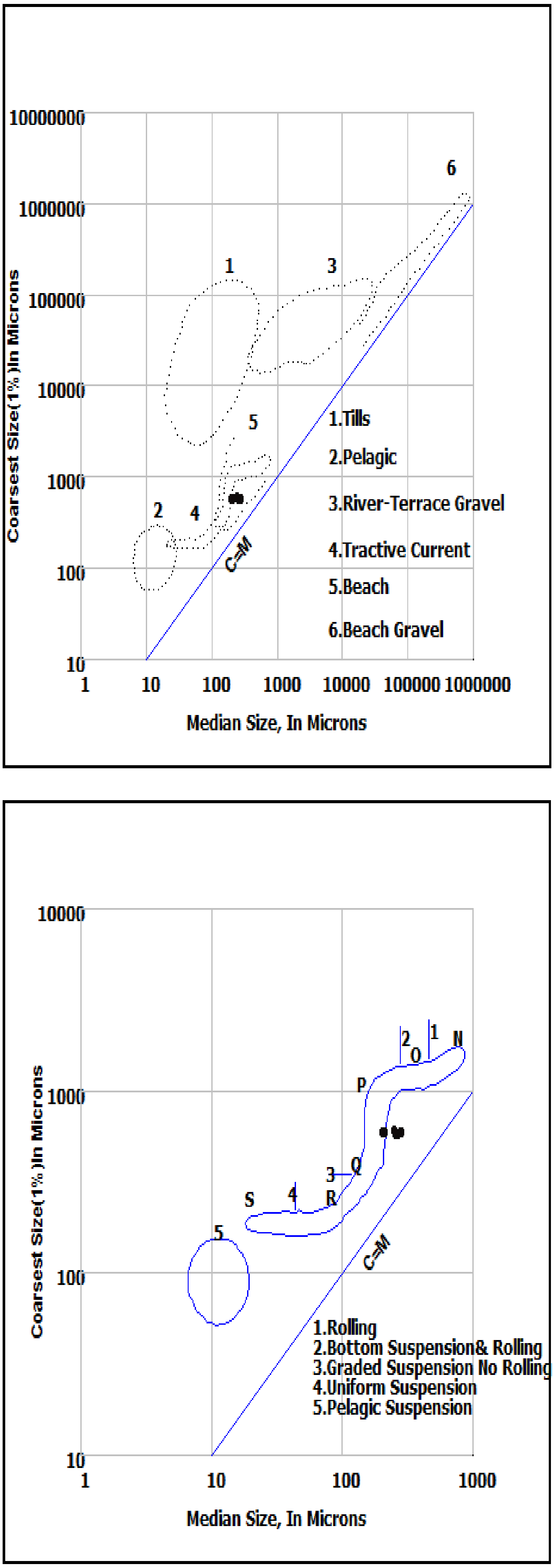
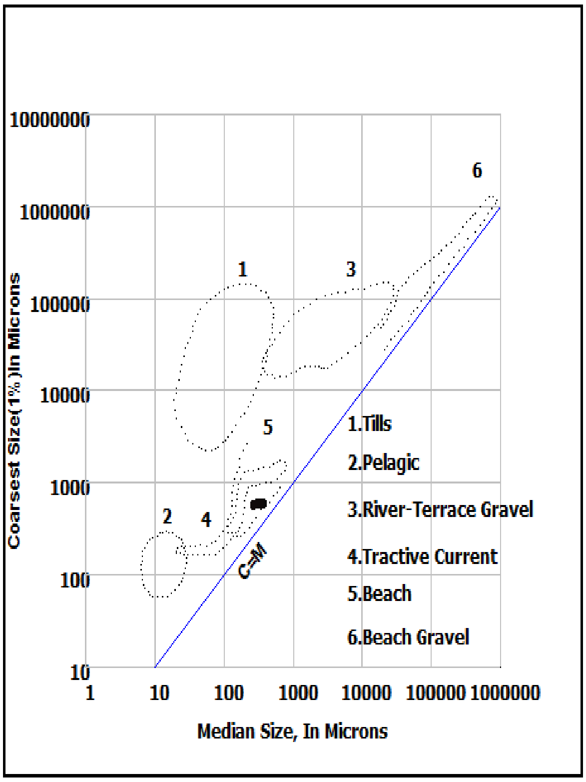


Fig. 6. CM diagram (Passega 1957, 1964) and tractive current deposit plot for Monsoon



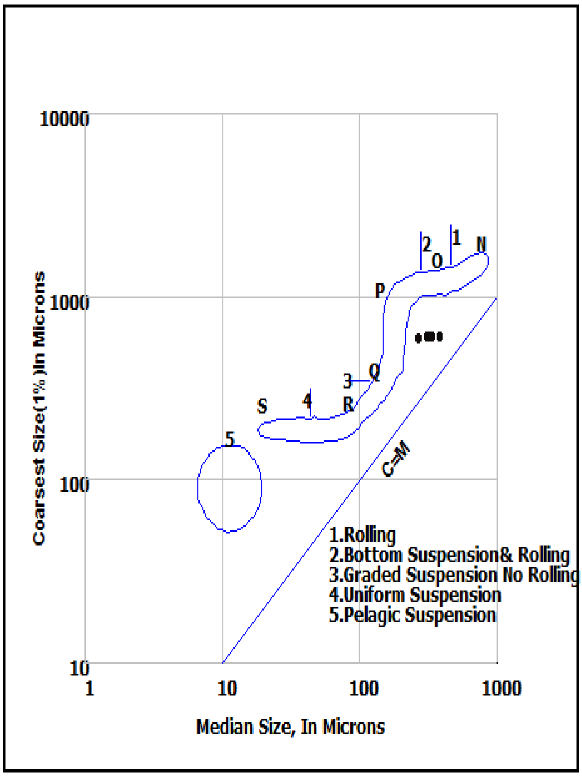


Fig. 7 CM diagram (Passega 1957, 1964) and tractive current deposit plot for Post monsoon

Conclusion

Textural analysis indicates the dominance of medium to fine grained in premonsoon samples. Fine to medium grained sediments dominant in monsoon samples. Medium sand in post monsoon samples due to high energy condition.LDF results show the dominance of shallow marine deposits in the Aeolian beach and the influence of turbidity. The granulometric and CM pattern indicates most of the grains from by bottom suspension rolling to graded suspension condition. The comparison with the tractive current diagram, all the season fall in tractive current environment, that is by interaction with wave actions.

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