Granulometric Analysis and Depositional Environment of Beach Sediments along Tuticorin Coast, Tamil Nadu

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Abstract

Granulometric analysis of beach sediments from Mullakadu Beach, located on the East Coast of India, provides insights into coastal sediment dynamics and depositional environments. The study area, affected by factors such as terrigenous, calcareous, and siliceous materials, as well as human activity, is notable for its distinct environmental conditions. Fifteen sediment samples were collected along a 30 km stretch of the Tuticorin coast and analyzed for texture and statistics. The sediments were primarily sandy (85.2% to 93.1%), with moderate silt (4.1% to 12.2%) and low clay content (0% to 2.9%), suggesting deposition under moderate to high-energy conditions and occasional low-energy phases. The mean grain size ranged from 1.94 to 2.78 ϕ, representing fine sand to coarse silt. Sorting values (0.46ϕ to 0.72ϕ) showed that the sediments ranged from moderately well-sorted to moderately sorted. Skewness (-0.10 to 0.38) and kurtosis (0.71 to 1.25) indicated symmetrical and slightly skewed distributions, with grain size curves that are platykurtic to mesokurtic. Linear discriminant function analysis revealed mixed signatures of wind reworking, river input, and shallow marine wave influence, typical of nearshore to backshore depositional systems. The energy process diagram further supported the interpretation of a dynamic coastal environment, characterized by fluvial, beach, and inner shelf processes. These findings improve our understanding of coastal sediment dynamics and depositional settings along India's East Coast, highlighting the complex interactions of natural and human factors shaping Mullakadu Beach's sediment features.

1. Introduction

Granulometric analysis of beach sediments offers extensive information on the inherent properties of sediments and their depositional settings. It also helps explore the nature and energy flux of the various agents that transport sediments. Coastal sediment dynamics are vital for understanding how sediment transport and deposition interact within coastal environments. These areas are influenced by a complex mixture of physical, chemical, and biological factors that shape sediment features and distribution. Such dynamics involve wave action, tidal currents, river inputs, and human impacts. Grain size analysis of beach sediments provides key insights into these processes, indicating sediment properties, transport mechanisms, and depositional environments (Folk and Ward, 1975; Medina et al., 1994; Lepesqueur et al., 2019; Woodruff et al., 2021; Nugroho and Putra, 2018; Le Roux and Rojas, 2007). Mullakadu Beach, situated on India's East Coast, offers a unique opportunity to study coastal sediment dynamics due to its specific environmental and human-related conditions. Systematic granulometric research has uncovered the complex coastal processes affecting sediment properties along both India's east and west coasts (Rajamanikam and Gujar, 1984, 1985, 1993; Chaudhri et al., 1981; Angusamy and Rajamanickam, 2006, 2007; Suresh Gandhi et al., 2008; Anithamary et al., 2013). These studies demonstrate how historical and current coastal processes influence sediment characteristics, offering insight into sedimentation history. The goal of this research is to analyze the texture of the beach sediments in the study area, infer their textural properties, identify potential sediment sources, and understand the hydrodynamic conditions under which the sediments were deposited. The analysis involves examining the grain size distribution of Mullakadu Beach sediments through statistical and graphical methods. Additionally, it aims to assess sediment textural features, such as mean grain size, sorting, skewness, and kurtosis.

2. Study area

The study region, Thoothukudi, also known as Tuticorin in the state, is located at 8°19'00" north latitude and 78°40'00" east longitude in southeastern Tamil Nadu. Thoothukudi district is one of the coastal districts of Tamil Nadu (Fig.1). The area has hilly terrain with a general eastward slope. The Vaippar and Karamaniyar rivers are well-developed estuarine systems with chemical processing industries, including heavy water plants, alkali chemical factories, thermal power stations, and petrochemical industries (Magesh et al., 2011). The Tamiraparani River is the most significant perennial river in the district, characterized by a mature stage of development. East Coast districts experience a typical climate characterized by high humidity and moderate to low temperatures throughout the year. The region has a hot tropical climate. The average annual temperature ranges from 23°C to 29°C, with an average yearly rainfall of around 570 to 740 mm. The district receives rainfall influenced by both the southwest and northeast monsoons (Singaraja, 2015). The current study focuses on the Tuticorin area, situated on Tamil Nadu's eastern coast. The location was chosen based on its proximity to industrial activities, land use, oceanographic conditions, and geology. Its physiographic features include an elevated beach with a sandbar running parallel to the coastline north of Tiruchendur. The observed geomorphologic features encompass beaches, coastal ridges, bluffs, dunes, beach terraces, spits, salt marshes, and terraced lands. Sediments surrounding the Tuticorin coast in the Gulf of Mannar consist of calcareous sand and gravel derived from coral and algal reefs, benthic macrofauna, and other terrigenous detritus, depending on local sources. The sediments in the study area are a heterogeneous mix mainly composed of quartz sand, biogenic carbonate, and shell fragments (Karikalan, 2014).

3. Materials Methods

A total of 15 beach sediment samples were collected along the Tuticorin coast, covering a distance of 30 km between Mullakadu and Tuticorin Harbor, using the interval determination method. The sediment samples were dried in an oven at 60°C. One hundred grams of each dried sample were then taken by repeated coning and quartering to ensure uniformity and prevent errors during analysis. After soaking in water overnight, the samples were agitated with a mechanical stirrer to disaggregate them and remove clay fractions (Carver 1971). The stirred samples were decanted repeatedly with distilled water until a clear, turbidity-free column of water was achieved. Concentrated HNO_3 was added to samples with a ferruginous coating. To entirely remove the coating, a pinch of $SnCl_2$ was added to the concentrated HNO_3, and the mixture was slightly warmed (Krumbein and Pettijohn, 1938). Sieving was performed using ASTM sieves at 1/2-φ intervals. The sieves, stacked in descending order of size, were shaken continuously with a Ro-tap sieve shaker for approximately 20 minutes. During sieving, care was taken to minimize sand loss from the sieves. The sieved materials were collected separately for weighing, and their weights were recorded for granulometric analysis. For this study, the GRADISTAT version 4.0 program, developed by Blott and Pye (2001), was used. It is available in Microsoft Excel format, providing both spreadsheet and graphical outputs. The program is well-suited for analyzing data from sieve or laser granulometer analysis. Users need to input the mass or percentage of sediment retained on sieves at any interval or the rate of sediment detected in each bin of a laser granulometer. To interpret the transport modes and depositional environments of sediments, a granulometric study was conducted using both the graphic method (Folk and Ward, 1957) and moment methods (Friedman, 1961, 1967).

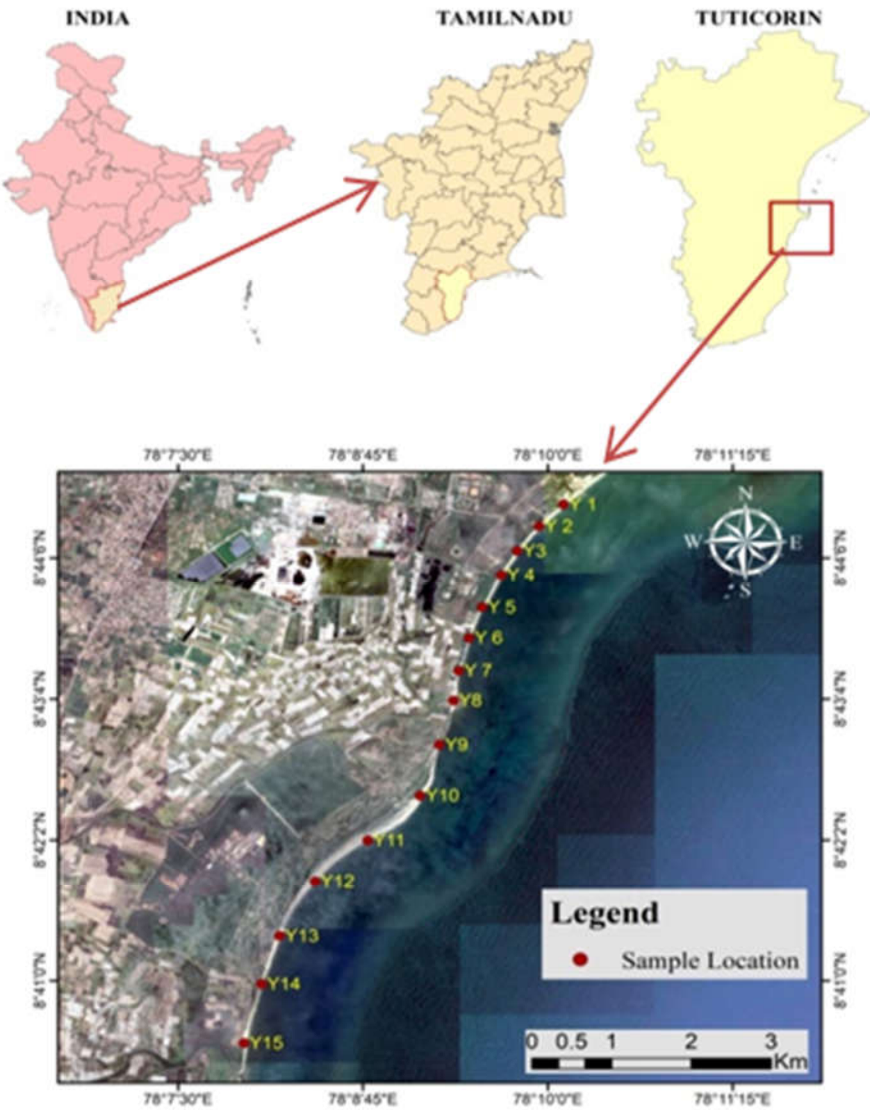

Fig 1 Map of the study area showing the sample locations

3.1 Textural distribution

The textural analysis of sediment samples (A1–A15) shows that the deposits are mainly sandy, with sand content ranging from 85.2% to 93.1% (average 89.63%), followed by silt between 4.1% and 12.2% (average 8.42%), and clay between 0% and 2.9% (average 1.93%) (Table.1,Fig.2). The dominance of sand indicates deposition in a moderate- to high-energy environment, such as a beach, river bar, or shallow fluvial channel, where coarse grains are actively transported and sorted. The moderate amount of silt suggests occasional, low-energy conditions that allowed finer particles to settle, while the minimal clay content indicates a limited suspension load and rapid sedimentation. Overall, the uniformity in composition and high sand content confirm that the sediments were deposited under stable hydrodynamic conditions with occasional input of finer materials during calmer depositional phases, suggesting a relatively high-energy environment controlled mainly by mechanical sorting rather than chemical processes.

Table 1 Textural classes based on sand-silt-clay ratios (Shepard, 1954)			
S. No	Sand	Silt	Clay
A1	93.1	4.1	2.8
A2	88.9	8.5	2.6
A3	90.2	6.9	2.9
A4	90.4	7.1	2.5
A5	92.9	5.3	1.8
A6	92.5	5.7	1.8
A7	88.6	9.5	1.9
A8	89.5	8.9	1.6
A9	86.6	11.8	1.6
A10	89.6	10.4	0
A11	90.2	9.8	0
A12	85.2	12.2	2.6
A13	87.9	9.5	2.6
A14	89.2	8.4	2.4
A15	89.7	8.2	1.9
Max	85.2	4.1	0
Min	93.1	12.2	2.9
Avg	89.63	8.42	1.93

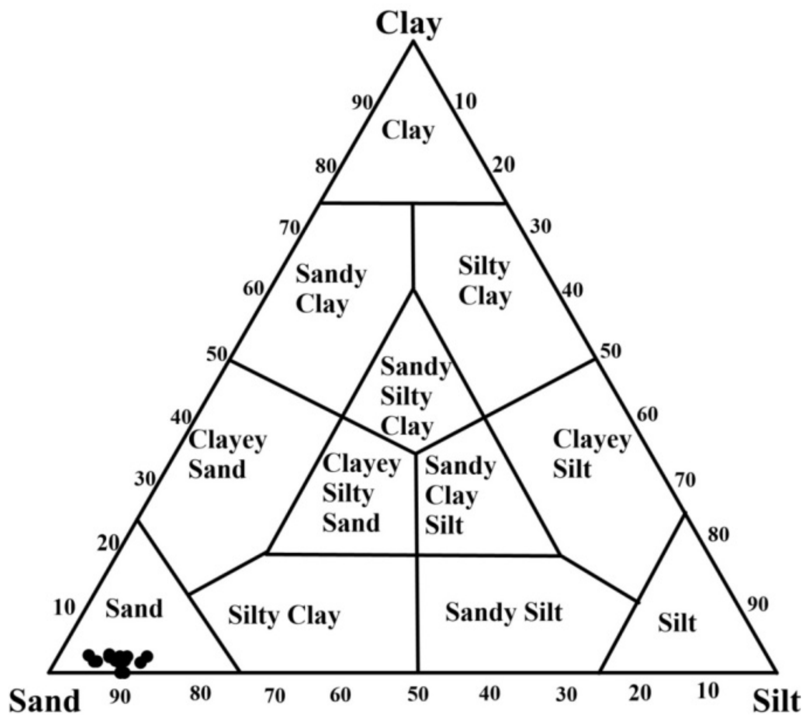

Fig 2 Ternary plot showing the relative percentage of sand, silt, and clay fraction of the Beach sediments

4. Result and discussions

4.1 Mean Grain Size

Statistical parameters such as the mean (Mz), standard deviation (Std), skewness (Ski), and kurtosis (Kg) provide insights into the origin of the sediment and the depositional conditions of the beach environment (Folk & Ward, 1957; Friedman, 1961; Rajganapathi et al., 2013). The average grain size is the arithmetic mean of sediment sizes and is affected by the source, transport, and depositional environment (Edwards, 2001; Komar, 1998). The mean grain size of the samples ranges from 1.94ϕ (A10) to 2.78ϕ (A1), indicating that the sediments range from coarse silt to fine sand. The highest mean value (A1, 2.78ϕ) suggests a dominance of finer materials. Conversely, the lowest value (A10, 1.94ϕ) indicates relatively coarser grains (Table.2, Fig.3). Overall, most samples fall between 2.2ϕ and 2.7ϕ, showing a predominantly fine sand texture. The consistency of mean values suggests relatively uniform depositional conditions with minor fluctuations in energy, likely due to variations in current velocity or sediment supply.

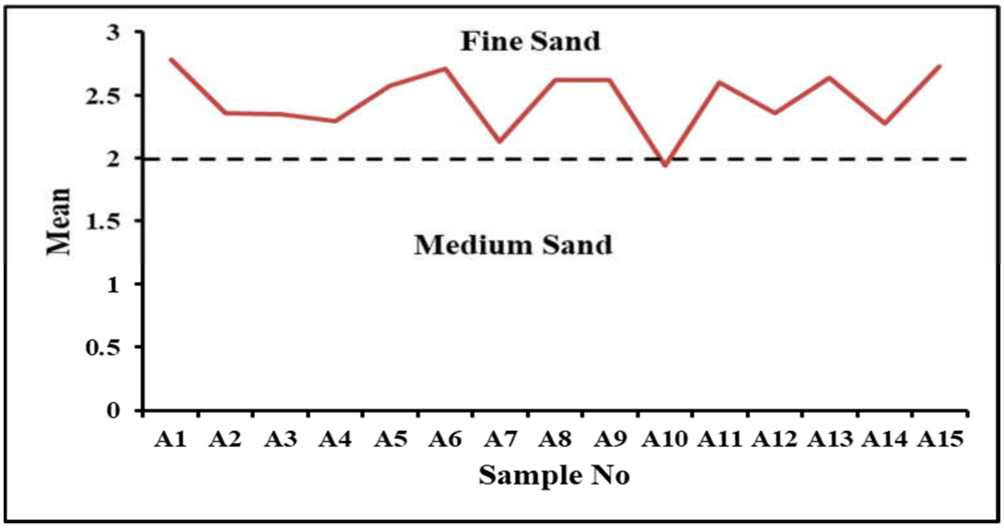

Fig 3 Mean size variations of the beach sediments

4.1.1 Sorting (Standard Deviation)

This is expressed using the graphical standard deviation method of Folk and Ward (1957), as it includes both tails of the distribution. The standard deviation is a complex measure influenced by the amount of sediment available, the sorting method, and the time needed for sorting. Table 2 shows the standard deviation results for each of the seven stations. Sorting values range from 0.46ϕ (A4) to 0.72ϕ (A6, A7). According to Folk and Ward's (1957) classification, all samples fall within the moderately well-sorted to moderately sorted category. The best sorting is in sample A4 (0.46ϕ), indicating deposition under more uniform hydraulic conditions. Meanwhile, A6 and A7 (0.72ϕ and 0.70ϕ) exhibit relatively fluctuating energy conditions, resulting in poorer sorting (Fig.4). This variation suggests periodic changes in depositional energy, possibly due to differences in flow regimes or local turbulence.

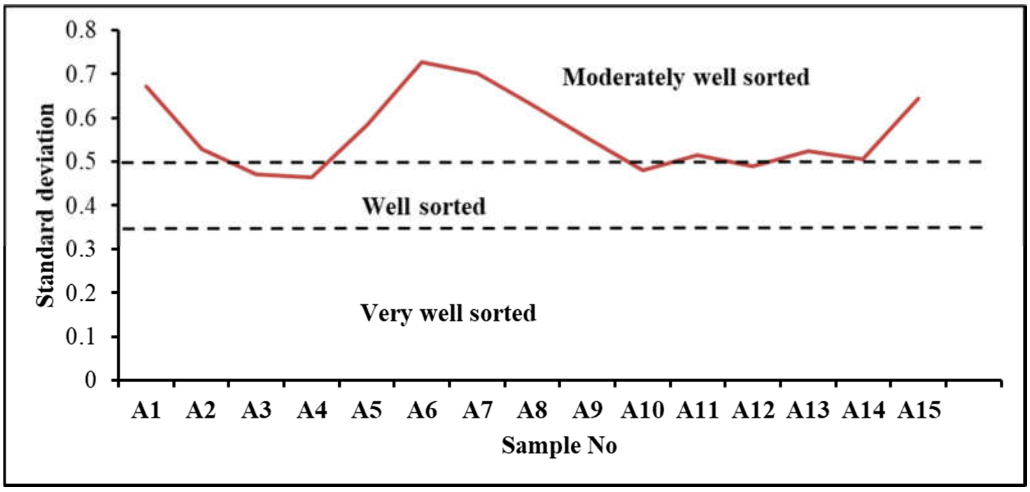

Fig 4 standard deviation variations of the beach sediments

4.1.2 Skewness

The skewness measures the symmetry of the grain size distribution. According to the classification of Folk and Ward (1957), the skewness values for these sands generally range from negatively skewed to very positively skewed. Dune (1964) found that negative skewness is associated with a high-energy environment, while positive skewness is linked to a low-energy environment. Skewness values range from -0.10 (A6) to 0.38 (A2), indicating both symmetrical and slightly skewed distributions. Negative skewness, seen in A5, A6, A8, and A9, suggests a dominance of coarser particles in the tail of the distribution, pointing to selective deposition under moderate to high energy conditions (Fig.5). Positive skewness, observed in samples like A2, A3, and A4, indicates an excess of finer particles, likely caused by low-energy depositional settings like slack-water zones. Most samples have low overall skewness values, reflecting an approximately symmetrical grain size distribution.

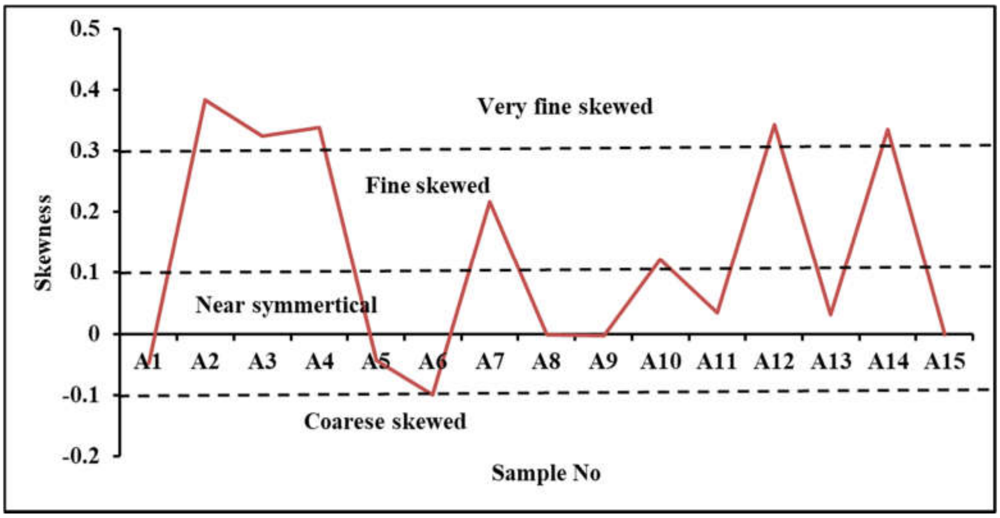

Fig 5 Skewness variations of the beach sediments

4.1.3 Kurtosis

Kurtosis measures the ratio of the tails to the median in the grain size distribution. Folk and Ward (1957) explained skewness and kurtosis as a mixture of two normal grain size distributions. Graph kurtosis is a qualitative measure indicating the proportion of sediment that has been sorted in one high-energy environment and then transported and changed in another environment (Folk & Ward, 1957). Kurtosis values range from 0.71 (A3) to 1.25 (A10). Most samples display platykurtic to mesokurtic distributions, meaning a relatively flat-topped particle-size frequency curve. Sample A10 shows the highest kurtosis (1.25), suggesting a leptokurtic distribution where most grains cluster near the mean size (Fig.6). This pattern can occur due to well-controlled sediment transport with limited mixing of particle sizes. Overall, the kurtosis patterns suggest consistent sediment transport and deposition, with minor local differences influenced by hydrodynamic stability.

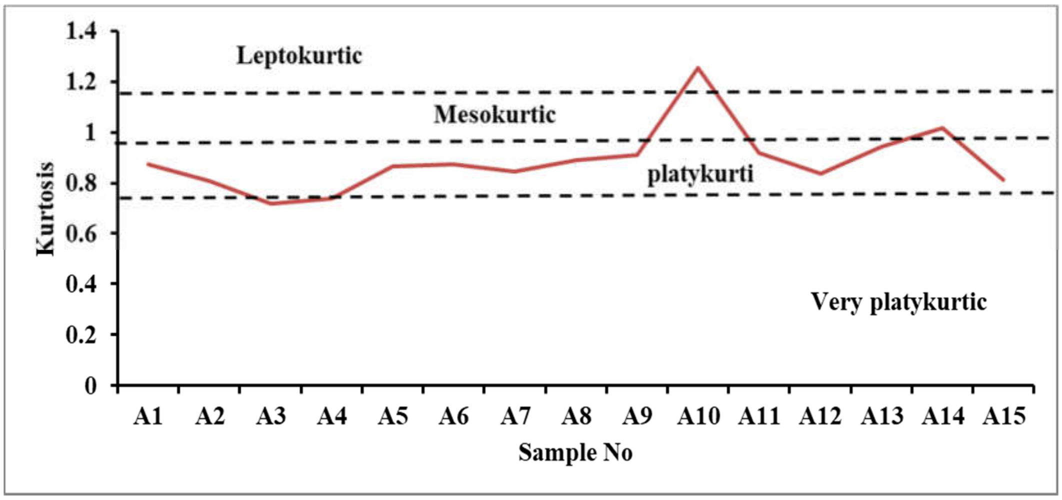

Fig 6 Kurtosis variations of the beach sediments

Table 2 Statistical Analysis of Grain Size Distribution of Post-monsoon Tuticorin Beach Sediments								
S. No	**Mean**	**Standard deviation**	**Skewness**	**Kurtosis**	**Mean**	**Standard deviation**	**Skewness**	**Kurtosis**
A1	2.785	0.671	-0.049	0.872	Fine Sand	Moderately well sorted	symmetrical	Platykurtic
A2	2.357	0.528	0.384	0.81	Very Fine Sand	Well Sorted	Very Fine skewed	Platykurtic
A3	2.35	0.472	0.325	0.719	Fine Sand	Well Sorted	Very Fine skewed	Platykurtic
A4	2.296	0.465	0.338	0.737	Fine Sand	Well Sorted	Very Fine skewed	Platykurtic
A5	2.576	0.583	-0.044	0.867	Fine Sand	Moderately well sorted	symmetrical	Platykurtic
A6	2.707	0.727	-0.1	0.875	Fine Sand	Moderately sorted	Coarse skewed	Platykurtic
A7	2.131	0.701	0.217	0.844	Fine Sand	Moderately sorted	Fine Skewed	Platykurtic
A8	2.62	0.63	-0.001	0.889	Fine Sand	Moderately well sorted	symmetrical	Platykurtic
A9	2.619	0.555	-0.003	0.911	Fine Sand	Moderately well sorted	symmetrical	Mesokurtic
A10	1.942	0.481	0.122	1.253	Fine Sand	Moderately well sorted	Fine Skewed	Leptokurtic
A11	2.603	0.516	0.035	0.917	Fine Sand	Moderately well sorted	symmetrical	Mesokurtic
A12	2.356	0.49	0.343	0.838	Fine Sand	Moderately well sorted	Very Fine skewed	Platykurtic
A13	2.637	0.523	0.031	0.943	Fine Sand	Moderately well sorted	symmetrical	Mesokurtic
A14	2.274	0.506	0.335	1.015	Very Fine Sand	Moderately well sorted	Very Fine skewed	Mesokurtic
A15	2.728	0.645	-0.002	0.812	Very Fine Sand	Moderately well sorted	symmetrical	Mesokurtic

4.2 Bivariate scatter graphs of grain size parameters

Scatter plots of specific parameters are also helpful in distinguishing different sedimentation environments, interpreting energy conditions and transport media, and thus identifying environments (Folk 1980). Scatter plots between the mean and kurtosis were created to understand the relationship between various parameters and to determine the type of depositional environment. Fig.9 illustrates the relationship between mean grain size and sorting at Mullakadu Beach. It appears that most samples consist of fine sand that is moderately well sorted (Fig. 8). Rajganapath (2013) explained that both mean grain size and sorting are hydraulically controlled, so in all sedimentary environments, the best-sorted sediments have a mean size in the fine sand range. Figure 4 shows the correlation between mean size and skewness. Most sediments along the Mullakadu coast are primarily symmetrical to very fine skewed.

4.3 Linear Discriminant Functions

The statistical analysis method for interpreting variations in energy and fluidity factors in sediments appears to have a strong correlation with different processes and the depositional environment (Kulkarni, Deshbhandari, and Jayappa 2015; Rajganapathi et al., 2013; Sahu 1964). In our analysis, several selective functions were used, following Sahu (1964). The following equation (Mz, the mean value of particle size) was employed to develop a linear discriminant function analysis of the sediments to describe the depositional environment. SK represents skewness, KG indicates kurtosis, and σ1 denotes the graphical standard deviation (sorting).

1. Differentiating between the beach and aeolian environments (Y1)

$$Y1= -3.5688Mz+3.716\ \sigma i2\ -2.766SK+3.1135KG$$

If Y1 is less than -2.7411, it indicates aeolian deposition, and if it's greater than -2.7411, it suggests a beach environment. Half of the samples have Y1 values both above and below -2.7411, indicating the presence of both aeolian and near-beach deposition in moving water.

2. Distinction between beach and shallow, agitated marine environment (Y2)

$$Y2 = 15.6534\ Mz+65.791\ \sigma i2+18.171SK+18.543KG$$

If Y2 is less than 65.365, it indicates a beach deposit. If it is greater than 65.365, it suggests a shallow-moving marine environment. The Y2 measurements in the sediments show that most sediments come from a shallow, agitated marine environment if the Y2 value exceeds 63.365. However, the discriminator only identifies some of the samples as originating from the beach environment.

3. Discrimination between shallow agitated marine and fluvial environments (Y3)

$$Y3 = 0.2852\ Mz - 8.7604\ \sigma i2\ -4.8932\ SK1 + 0.0482\ KG$$

If Y >–7.4190, the environment is ‘Shallow Sea’, but if Y <–7.4190, the environment is ‘Fluvial’

4. Fluvial/turbidity

$$Y4 = 0.7215 \, Mz + 0.403 \, \sigma i2 + 6.7322 \, SK + 5.2927 \, KG$$

If Y >10,000, the environment is 'Turidity but if Y <10,000, the environment is 'Fluvial'.

The Y1 parameter suggests that most of the samples represent aeolian deposition, except for sample A10, which indicates a beach-origin component. Meanwhile, Y2 values confirm that these sediments essentially correspond to a shallow, agitated marine environment (Fig.7). The Y3 values show that all samples are associated with shallow marine conditions, whereas Y4 strongly supports a fluvial influence with no evidence of turbidity currents. These combined results indicate that the sediments were likely deposited in a dynamic coastal environment, influenced by aeolian reworking, fluvial input, and shallow marine wave activity. Such mixed signatures are typical of nearshore to backshore depositional systems, possibly representing episodic reworking of dune and beach sands by marine processes

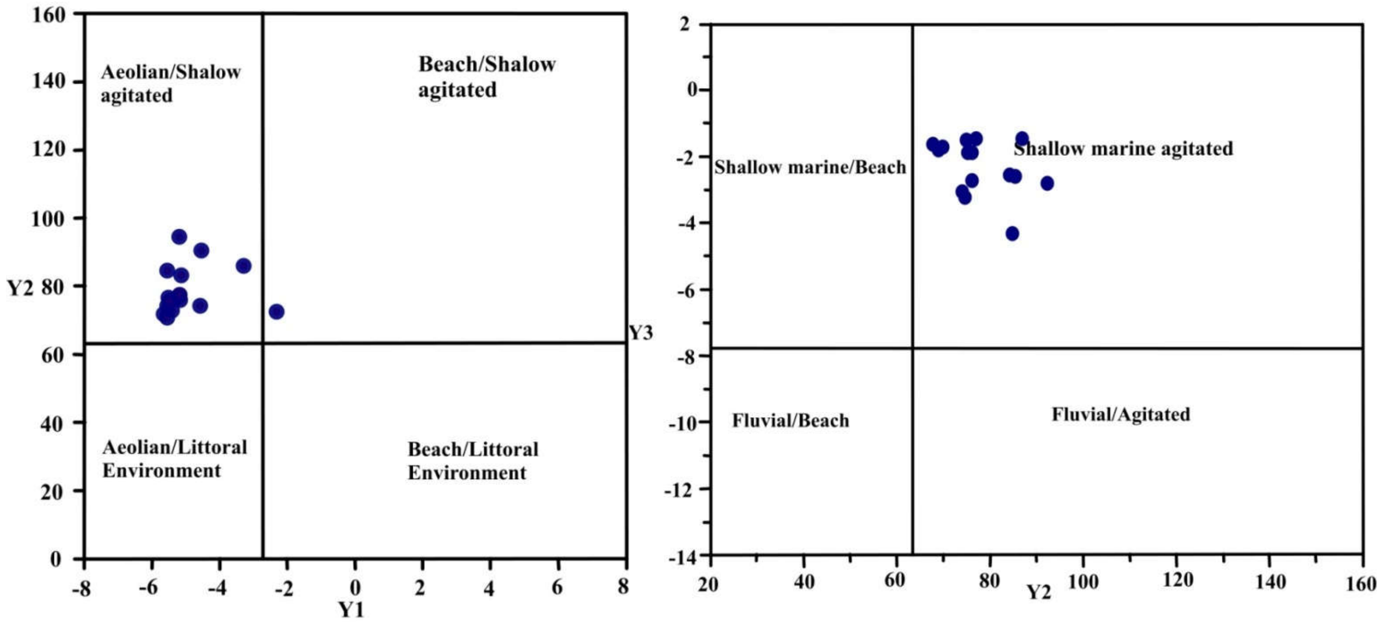

Fig 7 Linear discrimant function plots. Relationship between discriminant function a)Y2 and Y1: and B) Y3 and Y2 according to Sahu (1964)

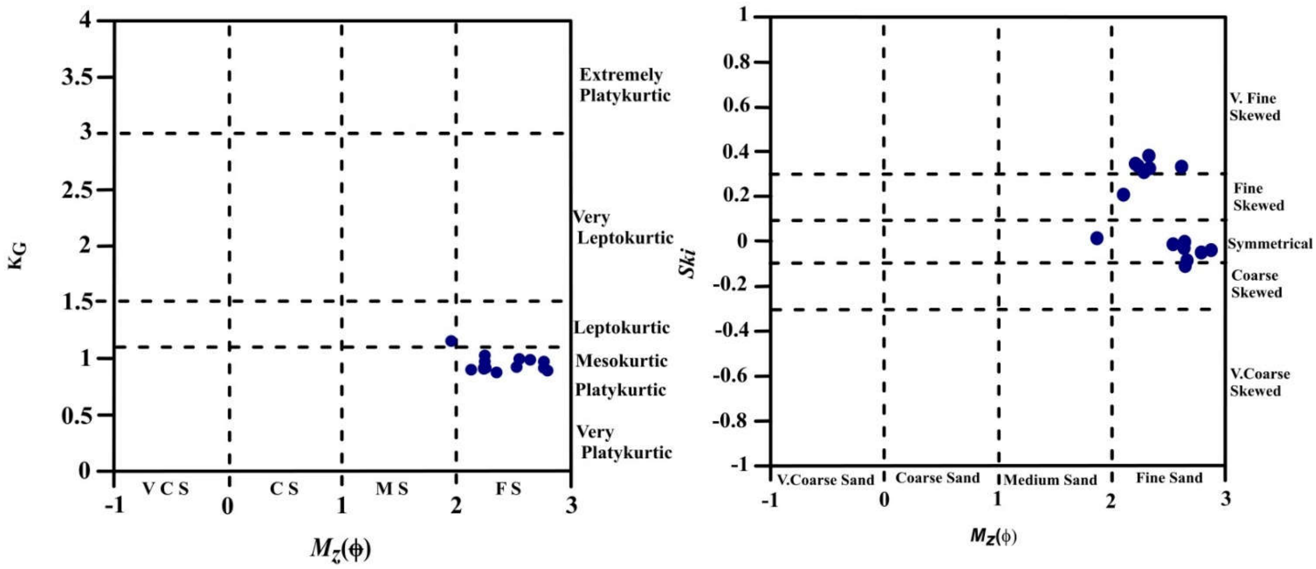

Fig 8 Plots showing the textural patterns of sediments in terms of statistical parameters, a) mean Vs Skewness b) Mean Vs Kurtosis

Table 3 Statistical Analysis of Grain Size Distribution of Tuticorin Beach Sediments

S. No	Mean	Sorting	Skewness	Kurtosis	Y1	Y2	Y3	Y4
A1	2.78	0.67	-0.04	0.87	-5.45	88.42	-2.86	6.47
A2	2.35	0.52	0.38	0.81	-5.65	77.15	-3.60	8.68
A3	2.35	0.47	0.32	0.71	-5.99	70.61	-2.83	7.77
A4	2.29	0.46	0.33	0.73	-5.80	69.90	-2.85	7.91
A5	2.57	0.58	-0.04	0.86	-5.14	77.90	-1.98	6.28
A6	2.70	0.72	-0.1	0.87	-4.77	91.48	-3.32	6.12
A7	2.13	0.70	0.21	0.84	-3.60	85.19	-4.71	7.66
A8	2.62	0.63	-0.001	0.88	-5.11	83.52	-2.68	6.74
A9	2.61	0.55	-0.003	0.91	-5.36	78.03	-1.89	6.81
A10	1.94	0.48	0.12	1.25	-2.42	70.99	-2.00	8.94
A11	2.60	0.51	0.03	0.91	-5.52	75.84	-1.71	7.07
A12	2.35	0.49	0.34	0.83	-5.62	74.37	-3.06	8.54
A13	2.63	0.52	0.03	0.94	-5.52	77.26	-1.75	7.21
A14	2.27	0.50	0.33	1.01	-4.70	77.26	-3.18	9.37
A15	2.72	0.64	-0.002	0.81	-5.66	85.02	-2.81	6.42

4.4 Energy Process diagram

Significant plots, which are essential for interpreting depositional environments (Friedman, 1961, 1967; Moiola and Weiser, 1968), have been analyzed. A plot of the mean versus the standard deviation is an effective method for distinguishing between different processes, including those found in beach, river, and inner shelf environments. Stewart's (1958) energy process diagram was developed with mean values on the X-axis and standard deviation on the Y-axis. This energy process diagram identifies the depositional environments of sediments, covering fluvial (river and beach processes), inner shelf, and river process settings. (Fig.9).

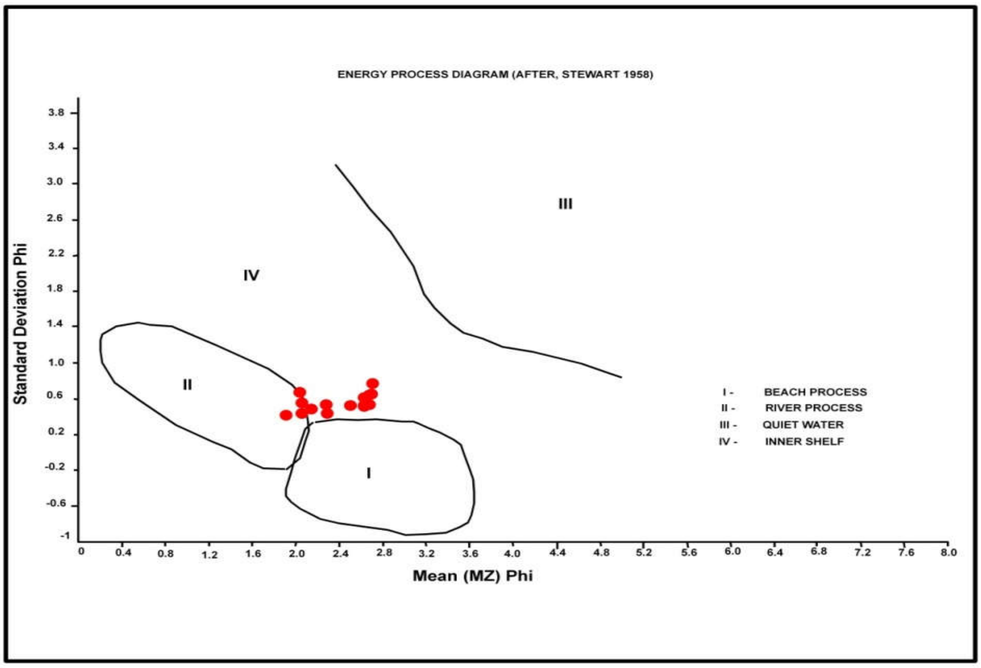

Fig 9 Energy process of Tuticorin beach sediments

5. Conclusion

The granulometric analysis of beach sediments along the Tuticorin coast shows that the sediments are mainly fine sand, moderately well sorted to well sorted, with symmetrical to slightly skewed grain size distributions and platykurtic to mesokurtic frequency curves. The textural features suggest deposition in a dynamic coastal environment influenced by moderate to high-energy conditions with occasional low-energy phases. Statistical discriminant function analyses indicate a mixed depositional setting shaped by aeolian reworking, fluvial input, and shallow marine wave activity, typical of nearshore to backshore zones. The energy process diagram further supports the complex interaction of fluvial, beach, and inner shelf processes that govern sediment deposition. These results emphasize the intricate interplay of natural and human factors affecting sediment dynamics and depositional environments at Mullakadu Beach, enhancing our understanding of coastal sedimentary processes along the East Coast of India.

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References

Angusamy, Nimalanathan, and G. Victor Rajamanickam. "Coastal processes of Central Tamil Nadu, India: clues from grain size studies." *Oceanologia* 49, no. 1 (2007).

Angusamy, Nimalanathan, and G. Victor Rajamanickam. "Depositional environment of sediments along the southern coast of Tamil Nadu, India." *Oceanologia* 48, no. 1 (2006).

Blott, Simon J., and Kenneth Pye. "GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments." *Earth surface processes and Landforms* 26, no. 11 (2001): 1237-1248.

Carver, Robert E. "Procedures in sedimentary petrology." (1971).

Chaudhri, R. S., Humayun MM Khan, and S. Kaur. "Sedimentology of beach sediments of the west coast of India." *Sedimentary Geology* 30, no. 1-2 (1981): 79-94.

Edwards, Jeffrey R. "Multidimensional constructs in organizational behavior research: An integrative analytical framework." *Organizational research methods* 4, no. 2 (2001): 144-192.

Folk, R. L., & Ward, W. C. (1957). Brazos River bar [Texas]; a study in the significance of grain size parameters. *Journal of sedimentary research*, *27*(1), 3-26.

Friedman, Gerald M. "Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands." *Journal of Sedimentary Research* 37, no. 2 (1967): 327-354.

Friedman, Gerald Manfred. "Distinction between dune, beach, and river sands from their textural characteristics." *Journal of Sedimentary Research* 31, no. 4 (1961): 514-529.

Friedman, Gerald Manfred. "Distinction between dune, beach, and river sands from their textural characteristics." *Journal of Sedimentary Research* 31, no. 4 (1961): 514-529.

Gandhi, M. Suresh, A. Solai, K. Chandrasekaran, and V. Rammohan. "Sediment characteristics and heavy mineral distribution in Tamiraparani Estuary and off Tuticorin, Tamil Nadu-SEM studies." *Earth Science India* 1 (2008).

Goldbery, Ron. "Use of grain-size frequency data to interpret the depositional environment of the Pliocene Pleshet Formation, Beer Sheva, Israel." *Journal of Sedimentary Research* 50, no. 3 (1980): 843-856.

Goldsmith, Victor. "Coastal dunes." In *Coastal sedimentary environments*, pp. 171-235. New York, NY: Springer US, 1978.

Karikalan, K., S. P. Mohan, and S. Srinivasalu. "Studies on the surface sediment characteristics of Tuticorin, South East Coast of India." *Int. J. Modn. Res. Revs* 2, no. 11 (2014): 536-540.

Komar, Paul D. "Wave erosion of a massive artificial coastal landslide." *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Group* 23, no. 5 (1998): 415-428.

Krumbein, W. C., and F. J. Pettijohn. "Manual of sedimentary petrography. XIV+ 549 pp., 8: o, 265 fig. New York and London 1938,(1939). D. Appleton—Century company. 8 6.50 (30 s.)." *Geologiska Föreningen i Stockholm Förhandlingar* 61, no. 2 (1939): 225-227.

Kulkarni, Sarang J., Praveen G. Deshbhandari, and K. S. Jayappa. "Seasonal variation in textural characteristics and sedimentary environments of beach sediments, Karnataka Coast, India." *Aquatic Procedia* 4 (2015): 117-124.

Le Roux, J. P., & Rojas, E. M. (2007). Sediment transport patterns determined from grain size parameters: Overview and state of the art. *Sedimentary Geology*, *202*(3), 473-488.

Lepesqueur, J., Hostache, R., Martínez-Carreras, N., Montargès-Pelletier, E., & Hissler, C. (2019). Sediment transport modelling in riverine environments: on the importance of grain-size distribution, sediment density, and suspended sediment concentrations at the upstream boundary. *Hydrology and Earth System Sciences*, *23*(9), 3901-3915.

Magesh, N. S., Chandrasekar, N., & Roy, D. V. (2011). Spatial analysis of trace element contamination in sediments of Tamiraparani estuary, southeast coast of India. *Estuarine, Coastal and Shelf Science*, *92*(4), 618-628.

Moiola, R. J., and D. A. N. I. E. L. Weiser. "Textural parameters; an evaluation." *Journal of Sedimentary Research* 38, no. 1 (1968): 45-53.

Nugroho, S. H., Putra, P. S., Yulianto, E., & Noeradi, D. (2018). Multivariate statistical analysis for characterization of sedimentary facies of Tarakan sub-basin, North Kalimantan. *Marine Georesources & Geotechnology*, *36*(8), 907-917.

Rajamanickam, G. V., and A. R. Gujar. "Depositional processes inferred from the log probability distribution." (1993).

Rajamanickam, G. V., and A. R. Gujar. "Indications given by median distribution and CM patterns on clastic sedimentation in Kalbadevi, Mirya and Ratnagiri bays, Maharashtra, India." *Giornale di Geologia* 47, no. 1-2 (1985): 237-251.

Rajamanickam, G. V., and A. R. Gujar. "Sediment depositional environment in some bays in central west coast of India." *Indian J Mar Sci* (1984).

Rajganapathi, V. C., N. Jitheshkumar, M. Sundararajan, K. H. Bhat, and S. Velusamy. "Grain size analysis and characterization of sedimentary environment along Thiruchendur coast, Tamilnadu, India." *Arabian Journal of Geosciences* 6, no. 12 (2013): 4717-4728.

Rajganapathi, V. C., N. Jitheshkumar, M. Sundararajan, K. H. Bhat, and S. Velusamy. "Grain size analysis and characterization of sedimentary environment along Thiruchendur coast, Tamilnadu, India." *Arabian Journal of Geosciences* 6, no. 12 (2013): 4717-4728.

Rajganapathi, V. C., N. Jitheshkumar, M. Sundararajan, K. H. Bhat, and S. Velusamy. "Grain size analysis and characterization of sedimentary environment along Thiruchendur coast, Tamilnadu, India." *Arabian Journal of Geosciences* 6, no. 12 (2013): 4717-4728.

Ramkumar, Thirunavukkarasu, Senapathi Venkatramanan, Irudhayanathan Anithamary, and Sheik Mohamed Syed Ibrahim. "Evaluation of hydrogeochemical parameters and quality assessment of the groundwater in Kottur blocks, Tiruvarur district, Tamilnadu, India." *Arabian Journal of Geosciences* 6, no. 1 (2013): 101-108.

Sahu, Basanta K. "Depositional mechanisms from the size analysis of clastic sediments." *Journal of Sedimentary Research* 34, no. 1 (1964): 73-83.

Singaraja, C., S. Chidambaram, K. Srinivasamoorthy, P. Anandhan, and S. Selvam. "A study on assessment of credible sources of heavy metal pollution vulnerability in groundwater of Thoothukudi districts, Tamilnadu, India." *Water Quality, Exposure and Health* 7, no. 4 (2015): 459-467.

Stewart, John Q., and William Warntz. "Physics of population distribution." *Journal of regional science* 1, no. 1 (1958): 99-121.

Woodruff, A. G., & Choong, K. (2021). Long-term outcomes and the post-intensive care syndrome in critically ill children: a North American perspective. *Children*, *8*(4), 254.