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Sediment Properties and Provenance Study of Heavy Minerals Along Chinnavilai and Erayumanthurai Beach, South West Coast of India

M. Suresh Gandhi*, G. S. Gayathri, Maya.V. Panicker and Selvin Shyam Paul

Department of Geology, University of Madras, Chennai- 600 025 (TN), India
*(*Corresponding author, E-mail: msureshgandhi@gmail.com)*

Abstract

The Chinnavilai and Erayumanthurai beach sediments of the Kanyakumari District consist of medium-grained, moderately well-sorted, unimodal, occasionally bimodal, mesokurtic, leptokurtic and platykurtic. The fine skewed and symmetrical nature of sediments implies the prevalence of high and low energy, entailing a mixed distribution of coarse and fine sediments. The washing and backwashing of waves cause the coarser sediments to retainment and entrapped amidst finer sediments. The heavy minerals distribution reflects that the less content in Erayumanthurai samples, whereas the Manavalakurichi, Enayam, Kurumpanai sediments comprise >60%. The oval shape zircon is devoid of inclusions, whereas, the euhedral zircons comprise subhedral inclusions. Distinct fractures in zircons are caused due to transportation by waves and currents. The garnet and zircon grains are well-rounded, implying the source for these sediments are an admixture of medium to high-grade metamorphic rocks, reworked sediments, charnockite, and granite gneisses.

Keywords : Sediment Texture, Provenance, Heavy Minerals, Kanyakumari,South West Coast of India

Introduction

The heavy minerals are resistant to chemical breakdown and have high density and durability. These are grouped based on specific gravity between 6.8 and 21 (native gold, cassiterite), light-heavy minerals specific gravity 4.2 and 5.3 (Ilmenite, rutile, monazite, zircon) and those with densities (2.9 - 4.1); garnet, sillimanite, hypersthene. Besides, constructed on their physical and chemical nature as opaques, micas, ultra-stables and meta-stables (Folk,1966). The research references are on the texture and mineralogy of Kerala and Tamil Nadu coastal sediments. Badesab *et al.,* (2017) have been investigated the heavy mineral dynamics using magnetic fingerprinting techniques along the North Maharashtra coast. Gurjar *et al.,* (2020) have studied the muti-mineral potential of littoral placers along the Vijaydurg and Redi Point of Maharashtra coast and littoral heavy mineral placers from selected beaches of Goa, the central west coast. Similarly, Sharath *et al.,* (2022) studied the provenance based on textural and heavy mineral characteristics of sediments from the Chaliyar River and adjoining Beypur Beach, Kerala. Sedimentology and geochemistry of heavy minerals along Kerala and Tamil Nadu coast with special reference to Raman Spectroscopy was also done during the recent times (Gayathri *et al.*, 2022). Based on the above information, an attempt has been made to address the heavy distribution and its provenance along the Chinavilai and the Erayumanthurai Beach Sediments.

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Study Area

The study area lies between Chinnavillai and Eruyamanthurai areas of the Kanyakumari District, Tamil Nadu, India (Fig.1). Kanyakumari to Colachel area is underlain by the peninsular gneissic terrain of Indian. A Sub-recent of Calcareous limeshell is noticed near Kanyakumari (Bhavathi Perumal *et al.*, 2010). All along the west coast from Kanyakumari, the Colachel area is covered by thick lateritic soil dotted with a scanty outcrop (Kaliraj *et al.*, 2017). The major river in the district is Thamiraparani (popularly as Kuzhithuraiar). The marine landforms along the Kanyakumari district are restricted to < 1km width due to high relief of inland areas which represented the slope of the Western Ghats when compared to the Eastern Coast (Kaliraj *et al.*, 2017).

Methodology

A total of 30 samples were collected one is beach and another one is intertidal zone at 15 locations from Chinnavilai to Erayumanthurai area for textural and heavy mineral studies. Granulometric study is an essential part to understand the mode of transportation and depositional environment of sediments. Using graphic (Folk and Ward, 1957) and moment methods (Friedman, 1961, 1967, 1979) the weight percentage data of 12 samples were processed in personal computer by using the modified programme of Schlee and Websters (1967) procedure. From the statistical parameters, frequency curves, mean, standard deviation, skewness, kurtosis, CM diagram, bivariant plots was drawn for the analysis

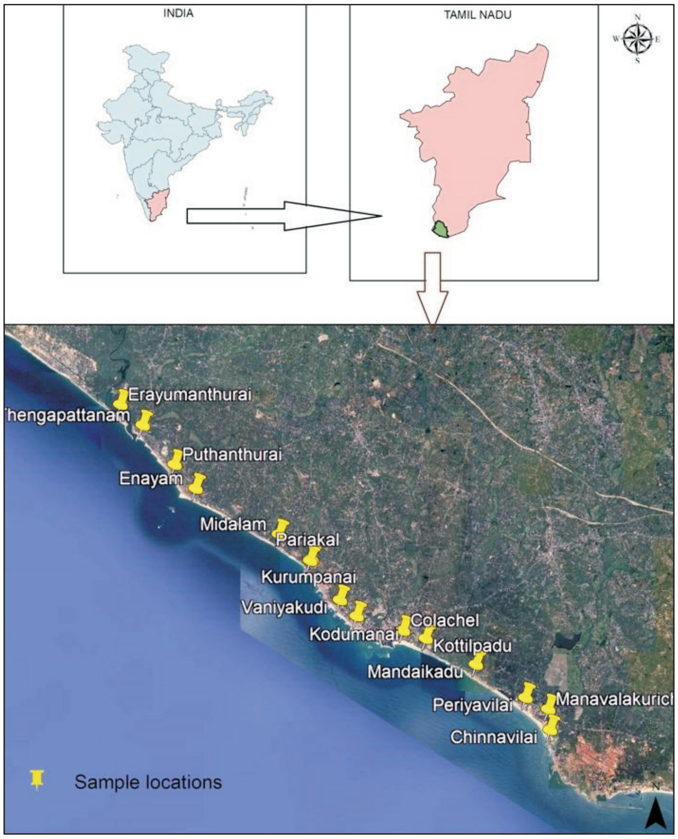

Fig. 1. Location Map of Study Area

proceedings. The sieved fractions of sediments have been made into light and heavy mineral fractions. The individual fractions have been grouped into seven different fraction 0.25 φ - 0.75 φ, 0.75 φ, 1.25 φ, 1.25 φ - 2.0 φ, 2.0 φ - 2.75 φ, 2.75 φ - 3.25 φ, 3.25 φ - 3.75 φ, 3.75 φ - 4.25 φ for heavy mineral separation.

Results and Discussion

Sediment Properties

The study area is divided as South of Colachel and North of Colachel. The grain size studies are used for delineating the subtle difference in depositional environments (Folk and Ward,1957). The statistical method has been applied in diagnosing the finer differences that may exist within a particular environment (Mohan and Rajamanickam, 1998, 2000). This study endeavours the grain size characteristics of sediments investigated in the part of the environment that is subjected to a diversified degree of erosion, transportation and deposition process. Various textural parameters are derived from the graphic and moment methods (Table 1).

Statistical Parameters

The different combination of sub-population has been identified to address the statistical results of the sediments. A network of perennial rivers traverses between Chinnavailai and Eraymanthurai, and these rivers transported sediments are debouched into the ocean. The compactness of beach sediments, resulting in the onshore and offshore drifting of sediments. The frequency plot pattern point towards the presence of unimodal and bimodal distribution having peaked at 1 φ, 2.5 φ and 3 φ. The first population constitutes 30 to 40% of the sand. The excessive coarser population of sediments is suggestive of the influence of open sea conditions and strong winnowing action that in turn results in the removal of fines, which is supplemented by the gentle beaches around the region. The mean value ranges from 1.03 φ to 2.18 φ (Table 1) indicating a medium to fine sand distribution in this area. The distribution of finer sediments might have accrued from the displacing of coarser lighter sediments by the panning action of high-velocity waves. The medium sand along the beaches is attributed to the high waver energy conditions, causing the finer sediments to be winnowed away, leading to the accumulation of heavy minerals of a finer size grade. The sorting of sediments demonstrates that the nature and mode of transportation of sediment. The sorting values range from 0.50 φ to 0.87 φ (Table 1), specify moderately sorted to moderately well-sorted nature. The moderately well sorting nature is owing to the prevailing high energy environment.

The range of skewness is -0.18 to 0.26 (Table 1). The negative skewness is along the north of Colachel is indicative of the higher energy conditions entailing a mixed distribution of coarse and fine sediments. Due to the washing and backwashing of waves, coarser sediments are retained and get entrapped amidst finer sediments. The graphic kurtosis ranges from 0.732 to 1.581 and classifies under Mesokurtic, Platykurtic and Leptokurtic (Table 1) which are inferring the diversified environment. The movement of longshore currents and the fluvial discharge of sediments have been responsible for these two populations mixing. This is also attributable to the widely varying nature of sediments and the change in gradients of the coastline. The kurtosis value is probably due to the transport and mixing of sediments of different energy environments (Gujar *et al.*, 2021).

Depositional Environment

The sediments are beach and the mixing of riverine and aeolian environments. The bivariant plot of mean vs. standard deviation, skewness vs. mean, skewness vs. standard deviation, skewness vs. kurtosis, interprets that the dominant influence of beach environment. The scatter plot of skewness vs inclusive graphic standard deviation shows that the samples concentrate in the beach environment and there is a spread of plots in the river environment (Fig. 2). The mean against skewness confirms as beach environment (Fig. 3). The cumulative curve pattern for the sediments of Chinavilai to Erayumanthurai is expressing similar to that of Passega (1957) pattern of beach sands. Most of these samples are closer and parallel to the limit C=M, indicating their rolling transport.

Heavy Mineral Distribution

The common heavy mineral assemblages of Chinnavilai to Erayumanthurai beaches consist of opaque minerals (Ilmenite and Magnetite), garnet, zircon, rutile, sillimanite, monazite, kyanite etc., however opaque concentration dominates the entire assemblage. The abundant among opaque minerals are magnetite and ilmenite and in non-opaques; garnet followed by zircon, garnet, rutile, and sillimanite. Ilmenite is an opaque mineral that is low compared to magnetite. Monazite is a non-opaque mineral that is high compared to other non-opaque minerals. Heavy mineral

Table 1: Result of Textural analysis in the study area (1- Chinnavilai; 2- Manavalakurichi , 3- Periyavilai, 4- Mandaikadu,5- Kottilpadu, 6-Colachel, 7- Kodimunai,8-Vaniyakudi,9-Kurumpanai,10-Pariyakal,11-Midalam,12-Enayam,13-Puthenthurai,14-Thengapattinam,15-Erayumanthurai)

Sample No.	MEAN	Mz	STANDARD DEVIATION	σ1	SKEWNESS	SK1	KURTOSIS	KG
1A	1.799	Medium Sand	0.668	Moderatly well sorted	0.229	Fine Skewed	0.89	Platykurtic
1B	1.736	Medium Sand	0.66	Moderatly well sorted	0.057	Symmetrical	1.033	Mesokurtic
2A	1.464	Medium Sand	0.60	Moderatly well sorted	0.094	Symmetrical	1.365	Leptokurtic
2B	1.85	Medium Sand	0.583	Moderatly well sorted	0.142	Fine Skewed	0.997	Mesokurtic
3A	1.073	Medium Sand	0.689	Moderatly well sorted	0.169	Fine Skewed	1.157	Leptokurtic
3B	1.451	Medium Sand	0.534	Moderatly well sorted	0.095	Symmetrical	1.271	Leptokurtic
4A	1.594	Medium Sand	0.64	Moderatly well sorted	0.268	Fine Skewed	1.218	Leptokurtic
4B	1.738	Medium Sand	0.78	Moderatly sorted	0.178	Fine Skewed	1.059	Mesokurtic
5A	1.906	Medium Sand	0.66	Moderatly well sorted	0.139	Fine Skewed	0.82	Platykurtic
5B	1.842	Medium Sand	0.503	Moderatly well sorted	0.108	Fine Skewed	1.007	Mesokurtic
6A	1.853	Medium Sand	0.629	Moderatly well sorted	0.143	Fine Skewed	0.839	Platykurtic
6B	1.828	Medium Sand	0.567	Moderatly well sorted	0.066	Symmetrical	0.942	Mesokurtic
7A	2.188	Fine Sand	0.622	Moderatly well sorted	0.008	Symmetrical	0.888	Platykurtic
7B	2.142	Fine Sand	0.644	Moderatly well sorted	-0.04	Symmetrical	0.824	Platykurtic
8A	1.7	Medium Sand	0.578	Moderatly well sorted	0.063	Symmetrical	1.134	Leptokurtic
8B	1.03	Medium Sand	0.874	Moderatly sorted	-0.18	Coarse Skewed	0.923	Mesokurtic
9A	1.203	Medium Sand	0.66	Moderatly well sorted	-0.058	Symmetrical	1.372	Leptokurtic
9B	1.447	Medium Sand	0.507	Moderatly well sorted	0.084	Symmetrical	1.214	Leptokurtic
10A	1.797	Medium Sand	0.687	Moderatly well sorted	0.184	Fine Skewed	0.939	Mesokurtic
10B	2.032	Fine Sand	0.656	Moderatly well sorted	-0.012	Symmetrical	0.743	Platykurtic
11A	1.559	Medium Sand	0.818	Moderatly sorted	0.211	Fine Skewed	1.074	Mesokurtic
11B	1.42	Medium Sand	0.508	Moderatly well sorted	0.219	Fine Skewed	1.235	Leptokurtic
12A	1.844	Medium Sand	0.749	Moderatly sorted	0.204	Fine Skewed	0.732	Platykurtic
12B	2.005	Fine Sand	0.638	Moderatly well sorted	0.135	Fine Skewed	0.762	Platykurtic
13A	1.191	Medium Sand	0.569	Moderatly well sorted	-0.033	Symmetrical	1.354	Leptokurtic
13B	1.446	Medium Sand	0.55	Moderatly well sorted	0.105	Fine Skewed	1.258	Leptokurtic
14A	1.504	Medium Sand	0.677	Moderatly well sorted	0.194	Fine Skewed	1.239	Leptokurtic
14B	1.457	Medium Sand	0.553	Moderatly well sorted	0.112	Fine Skewed	1.26	Leptokurtic
15A	1.277	Medium Sand	0.643	Moderatly well sorted	0.059	Symmetrical	1.581	Very Leptokurtic
15B	2.062	Fine Sand	0.678	Moderatly well sorted	0.093	Symmetrical	0.856	Platykurtic
Max	2.188		0.874		0.268		1.581	
Min	1.03		0.503		-0.18		0.732	
Avg	1.648		0.637		0.101		1.066	

percentage distribution in Manavalakurichi is 27%, Kurumpanai (82%), Periyavilai (35 %), Enayam (54 %). In all the sampling stations, zircon, garnet, sillimanite, monazite and kyanite and opaques are predominant (Fig. 4; Table 2).

The mineralogical assemblages in beaches depend on parent rocks in the province, climate conditions agents and mechanism of transport and hydraulic condition during deposition. The longshore sediment transport rates are estimated based on the observed data. The estimated annual gross longshore sediment transport rate is higher due to recent anthropogenic structures and the net transport is towards the west. The southwesterly waves move the sediment northwards, whereas the NE waves transport the sediment southwards. The beach level has been low in July and high in April months, ranging is 75m. The total volume of sand transported is 1,810 m^3 only. The range of wave heights is between 0.5 to 2.5m during 2007 and 0.5 to 2.2 m during 2008, whereas the wave period is from 8-15.5' and 9.2' to 12.8' for 2007 and 2008, respectively. During SW monsoon, the southerly movement of the net littoral drift at all stations is from south to north except for the Kanyakumari station, where the net drift is southwards. This occurs because the northerly littoral drift during SW monsoon is small (maximum of $41.31x10^3 m^3$/month), and a net annual southerly drift is recorded

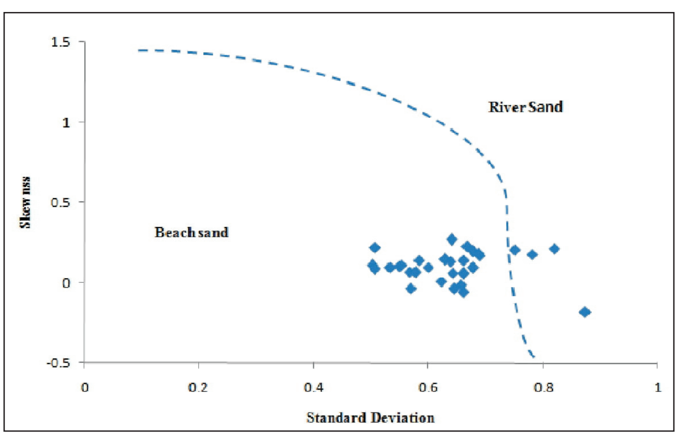

Fig. 2. Plots of sorting *vs.* skewness of grain - size distribution for discrimination of the river and beach sand (*after* Friedman 1961)

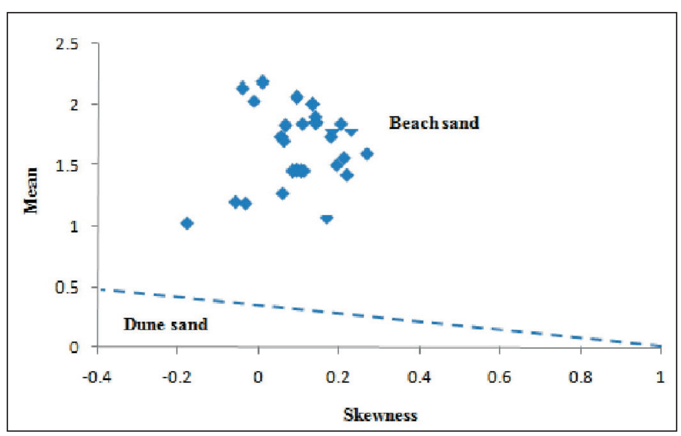

Fig. 3. Plots of skewness *vs.* mean grain-size for discrimination of beach and dune sand (*after* Friedman 1961)

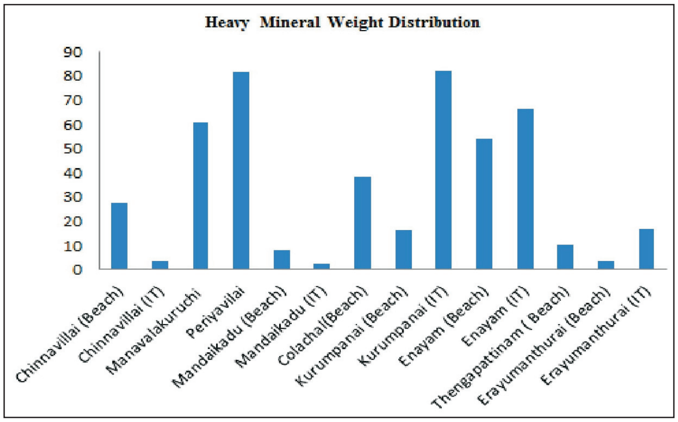

Fig. 4. Heavy mineral weight percentage in the Study Area

Table 2: Count Percentages of Heavy Minerals of Different Fractions in the study area (in %)

Location	Opaque	Garnet	Silli manite	Zircon	Rutile	Monazite	Others
Chinnavilai	39.52	8.21	8.1	3.2	0.2	0.12	0.1
Manavalakurichi	81.36	8.93	8.2	1	0.7	0.16	0
Periyavilai	69.33	19.5	4.96	5.76	0.36	0.1	0
Mandaikadu	76.52	10.7	7.2	1.02	0.72	0.01	0.01
Colachel	54.93	15.7	6.23	1.8	1.03	0	0
Kurumpanai	69.62	8.52	5.41	1.4	0.1	0.01	0.1
Pariakal	49.23	6.24	4.12	1.2	0.01	0.01	0.1
Enayam	77.52	9.7	5.2	1.2	0.21	-	0.01
Thengapattinam	48.9	7.8	4.6	2.8	0.2	-	0.01
Erayumanthurai	46.4	8.4	4.2	2.3	0.4	0.01	0.05

(Sakthivel and Chandrasekar, 2015). The study indicates that the beach is essentially stable with seasonal fluctuations. Colachel, which is being subjected to erosion phase during Southwest monsoon season, regains the profiles by January or February. Longshore currents are stronger in June, July and August and steady during the rest of the year (Chandrasekar *et al.*, 2012). It is presumed at a few traversing streams originating from the nearby Western Ghats uphold the supply of heavies to the shoreface. These heavies are greater in number and varieties probably because of the proximity of the source region. Later, these dumped heavies are sorted out hydro dynamically based on their physical properties largely specific gravity by breakers, surf and swash zone processes supplemented by longshore currents. The formation and concentration of heavy minerals differ from place to place based on sea wave directions and dynamics, interstitial separation, underwater current, sorting factors influenced by the confluence of sea and river. This is corroborated by the variations in heavy mineral accumulation, which probably suggest that the beach morphology and sediment characters are influenced by energy domains along the coast (Gujar *et al.*, 2021). The wave characteristics and energy are governed by coastal configuration, outcrops and river discharge (Nayak, 1997). The distribution pattern of Zircon shows an abundance of rounded zircon and overgrown and outgrown zircons, the latter might be due to the longer stay of sediments in the depositional basin and derived primarily from Charnockite (Sidiquie, 1969). The placer deposits were inferred to have been accumulated due to the arcuate nature of the coastline, strong convergence of wave orthogonal and a down warped basinal structure (Angusamy *et al.*, 2004).

The zircon, rutile, illemanite and garnet from Kanyakumari to Colachel area is underlain by the peninsular gneiss and Calcareous lime shell is noticed near Kanyakumari. The estuary at Manavalakurichi shows the enrichment of minerals transported by rivers from the source rock. The assemblages of ilmenite, sillimanite, zircon, garnet, monazite, kyanite are strikingly uniform in Manavalakurichi, indicating a uniform provenance throughout the area. The heavy minerals associated with sediments indicate that they are derived from metamorphic terrain (Vinoth Kumar and Asaithambi, 2013). The Kanyakumari coastal erosional accretion was estimated as – 300.63 m, whereas the net rate of shoreline changes is – 157.92 m (Kaliraj *et al.*, 2014). Due to these erosional activities, the impact of high wave energy wave action on the coast caused the backwash sediments from the downslope to the coastal headlands, hence the heavies are dominant in this region

Conclusions

The sediments are unimodal and bimodal, medium to fine-grained sand moderately sorted to moderately well-sorted, positively skewed. The heavies are dominant in Manavalakurichi, Kurumpanai, Periyavilai and Enayam. The grains of garnet, zircon are well-rounded attributes to the source for these sediments are an admixture of medium to high-grade metamorphic rocks, reworked sediments, charnockite, and granite gneisses. The oval shape zircon is devoid of inclusions, whereas, the euhedral zircons comprise subhedral inclusions. Distinct fractures in zircons are causing due to transportation by waves and currents.

Authors' Contributions

M. Suresh Gandhi : Conceptualization, Methodology, Analysis, Writing Original Draft, Reviewing and Editing. **Gayathri G. S. :** Field investigation, Analysis, Heavy Mineral Identification. **Maya V. Panicker :** Reviewing and Editing. **Selvin Shyam Paul :** Software, Diagrams and Supervision.

Conflict of Interest

Authors declare no conflict of interest.

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