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Seasonal Variation in Textural Characteristics of Beach Sediments Along Sindhudurg Coast, Western Maharashtra, India: Implications on Depositional Environments

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Abstract

Seasonal variations in the textural parameters of 140 sediment samples with different environmental setup (foreshore, backshore, raised beach and dune) along Mithmumbri and Talashi coastal areas of the Sindhudurg District of Maharashtra state, India were studied. On the basis of geomorphological characteristics the study area has been divided into two sectors *i.e.* I (erosional) and II (depositional). During pre-monsoon season, the sediments are dominantly fine to medium-grained, very well sorted to moderately sorted, finely skewed to strongly coarse skewed and very platykurtic to very leptokurtic. During post-monsoon season, medium to fine sand was observed at foreshore, backshore, and raised beach regions signifying very high energy condition. During pre and post-monsoon seasons, Achra, Vayagani, Tondavali, and Talashi beaches reveal the presence of well-sorted to moderately well-sorted sediments resulting from very high wave energy conditions. During pre and post-monsoon seasons, the foreshore zone of sector I had totally negatively skewed samples indicating consistent beach erosion at Mithmumbri, Kunkeshwar, Mithbav, Katvan, and Munge coasts. Majority of samples belong to beach environment and few samples signify riverine/aeolian environment, whereas Linear Discriminant Function (LDF) indicates dominance of shallow marine environment of deposition for both the seasons. The *CM* diagram shows that sediment samples fall predominantly in the tractive current and beach environment of deposition. The pre-monsoon Sector-I samples are bottom suspended, rolling and come in category of suspension, whereas sector-II are predominantly arrived as suspended, graded suspended and without rolling. The present study also unraveled that the post-monsoon (Sector-I) samples are characterized by high energy conditions.

Keywords: Grain Size Study, Bivariate Plots, LDF, CM plots, Sindhudurg, Maharashtra, India

Introduction

Coastal sedimentology and morphodynamics are controlled by a variety of factors, including tides and waves, sea-level changes, rate of sediment supply, climatic and oceanographic settings and geology (Wang, 2012). Coastal environments are dynamic environments that vary in their topography, climate, and vegetation. Most of the coastal landforms were carved out during the Late Quaternary period. Tandale (1993) opines west coast of India was tectonically active during Mio-Pliocene times. Textural characteristics of diverse geomorphological units of nearshore sediments are used to primarily decipher sedimentary environments influenced by a number of erosional and/or depositional agents. The foreshore sediments are generally impacted by wave action and beach morphology in the form of beach-face slope and shoreline orientation. The backshore sediments are impacted by wind and slope, as also the shoreline orientation. The impact of wind is clear on the raised marine terraces and dunes. Thus, grain size characteristics of these different sub-environments of the beach can be quite distinct and variable. The spread of different grain sizes in different morphological sections of a nearshore zone is indicative of different forces acting on the sediments. The statistical analysis helps to identify sedimentary environments and sedimentary processes leading to their accumulation or erosion. Mean size, sorting and skewness are the most useful parameters to describe the sediments (Carranza-Edwards, 2001; Friedman, 1961). The grain size statistics can also be used to delineate high and moderate-energy environments (Nordstrom, 1977). The textural characteristics of beach sediment have been studied in the past by many researchers, especially along the east and west coast of India (Kumar, 1977; Chaudhri *et al.,* 1981; Hanamgond *et al.,* 1999; Gawali *et al.,* 2020; Herlekar *et al.,* 2017). Shetty and Jayappa (2021) studied proxies for sediment transport patterns and environmental changes along the Karnataka Coast. Waghmare *et al.* (2020) reported sediment movement along the Harwada Beach using remote sensing and GIS techniques. Herlekar and Sukhtankar (2009) reported medium to fine sand, well-sorted to poorly sorted, fine skewed to strongly coarse skewed and very platykurtic to very leptokurtic sediments from Dabhol to Jaigarh creek of the Ratnagiri District, Maharashtra. The percentage of fine sand is higher during January compared to September due to the prevalence of calm wave conditions along the east coast of India (Pradhan *et al.,* 2020). The textural study reveals that fine to very fine size, well to very well sorted, and mostly mesokurtic to platykurtic distribution at the Karwar Beach, India (Chavadi and Nayak, 1987). Herlekar *et al.* (2017) from the beach sediments along Kelshi to Anjarle creek, Ratnagiri district, revealed that the sediments are fine to very fine sand, moderately sorted to moderately well sorted, strongly coarse skewed, and very platykurtic to leptokurtic. The sedimentary environment at the Kundapura Beach has high wave action compared to the Padukare and the Pavinkurve Beaches along the Karnataka shoreline, which were under erosion with a strong winnowing process (Udhaba *et al.,* 2011). The coast of Vengurla, Maharashtra, reveals the presence of stabilized dunes, younger and older raised beaches apart from the present intertidal zone indicating a fall in sea level to the extent of 4 m and 1 m during the Holocene period (Sukhtankar, 1986). The textural analysis of surface sediments revealed inner shelf off Kalpakkam along SE Indian coast, are mostly very poorly sorted, positively skewed sediments with very leptokurtic, very platykurtic (Selvaraj and Mohan, 2003). Kulkarni *et al.* (2015) studied seasonal variation in textural characteristics and sedimentary environments of beach sediments along Karnataka coast. Longshore sediment transport along the west coast is generally towards the south from January to May and in October (Sanilkumar *et al.,* 2006). Gujar *et al.* (2008) reported ilmenite, magnetite, and chromite beach placers from Pirwadi to Talashil, west coast of India.

The depositional facies observed at Kalbadevi, Mirya, and Ratnagiri bay is aeolian, beach, and shallow marine respectively (Rajamanickam and Gujar, 1988). The Ratnagiri bay sands consist predominantly suspension material of surface creep and poorly sorted (Rajamanickam and Gujar, 1993). The medium to fine sand, moderately to well-sorted sediments, symmetrically skewed sediments are a result of the influence of palaeo-sediments deposited by rivers by offshore waves and currents (Angusamy and Rajamanickam, 2007). The objectives of this work are to investigate the seasonal variation in the textural parameters along the Mithmumbri to Talashi areas, west coast of Maharashtra, India by harnessing mean size, standard deviation, skewness, kurtosis, LDF, CM, and bivariate investigations. The textural study can also help in identifying past changes in current, wave, and wind conditions, as well as changes in the provenance.

StudyArea

The present study covers an area from Mithmumbri to Talashi regions of the Sindhudurg District, West Coast of Maharashtra, India (Latitude 16°, 21'38.01"N, Longitude 73°, 23'02.56"E in the North to Latitude 16°, 05' 23.36"N, Longitude 73°, 27' 44.18" E in the South). The area is covered in the Survey of India topographic sheet number 47H/7, 47H/8, and 47H/12 on a scale of 1: 50,000 (Fig.1). The Konkan Region experiences a humid tropical climate throughout the year with an average rainfall of 2500-3000 mm during monsoon *i.e.* June to September. The spring tide range (< 2.0 m), neap tide range (<1.5 m), and average humidity range between 60-90%). During the monsoon season, the waves exceed 5 m in height, wave period 3-6 s, tidal current velocity 70-90 cm/s along the South Konkan Coast (Karlekar and Thakurdesai, 2017). The area is characterized by tropical climatic conditions and it experiences more commonly three seasons in a year. The months from February to May are generally the summer season. The mean maximum temperature during the summer season ranges between 34°C to 37°C. The month from June to September is the rainy season, in which the area received heavy rainfall from the SW monsoon. October to January is the months of pleasant climatic conditions and regarded as a winter season.

The study area is divided into two sectors based on coastal geomorphological features, sector I (erosional) and sector II (depositional). There are 5 sandy beaches in Sector I (Mithmumbri to Munge) from where 10 locations were identified for sample collection (Fig. 2). Sector II, on the other hand, extends from Achra to Talashi comprising four beaches. Here, ten locations were identified for sample collection too

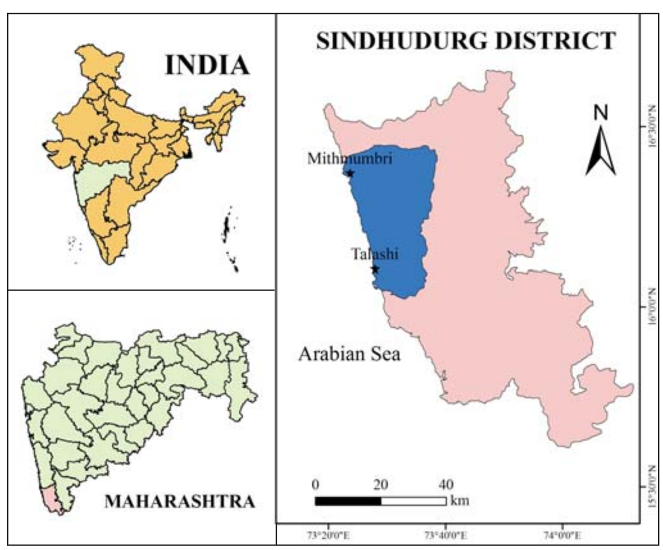


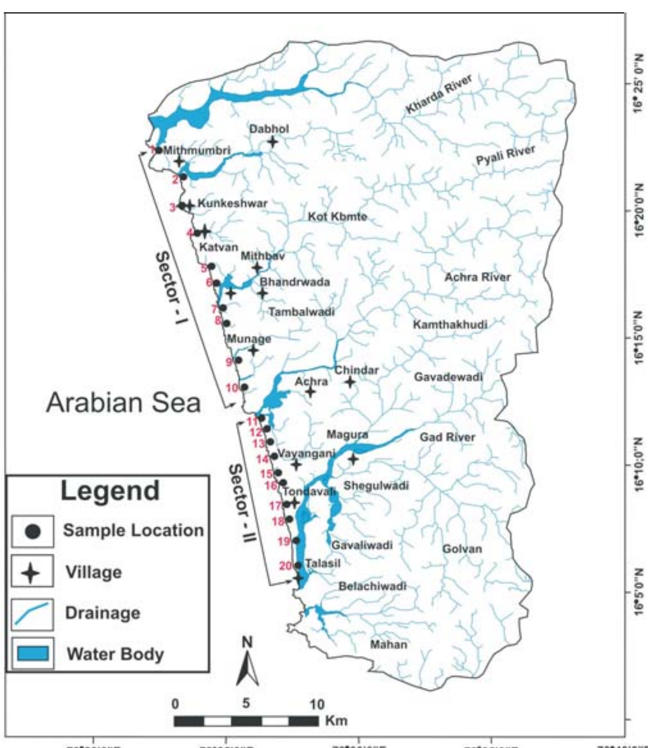
Fig. 1. Location map of the study area.

(Fig. 2). Various coastal geomorphological features are observed like erosional features that include sea cliff, headland, wave-cut platform, and pocket beaches (Kunkeshwar), whereas the depositional features seen include sand bars, sand spits, raised beach (Achra, Tondvali, and Talashi beaches) and dunes, based on which the study area has been categorized into erosional and depositional. The four major rock units *viz.*, Gneissic rocks with granitic intrusions, Kaladgi Quartzite, and Shales, Deccan Traps Basalts, and laterites (Wilkinson, 1871). The Kaladgi Supergroup of rocks are scattered all over the study area and represented by quartzites, shales, sandstones, and conglomerates. The Deccan trap basalts are seen to overlay the Archaean and the Kaladgis, are exposed along with a few isolated patches at Achra and Gad Basins (Fig. 3). The Deccan traps and other formations, at all other places, are covered by thick beds of laterites. The Kaladgi quartzite is exposed at Mithbav, Achra, and Morve regions, which exhibit large fluctuations in dip intensity and direction. The present attempt is undertaken mainly to investigate textural aspects of beach sediments to understand the depositional environments.

Methodology

Samples were collected from the foreshore, backshore, raised beaches and dune sediments during pre-monsoon (February-2017) and post-monsoon (November-2017). A total of 140 (70 for each season) samples were collected along with the beach profile between two sectors.

Samples were collected with a plastic pipe (diameter 5 cm) from the foreshore, backshore, raised beach and dune. The dune was sampled to a depth of 25 cm. All the sediment samples were dried in hot air oven at 60°C and subsequently the size of the samples were reduced to 100 gm by coning and quartering. These representative samples were then washed with distilled water to remove salt content and were further treated with 1:10 HCl to remove carbonate shells. In order to eliminate organic content, the sediment samples were treated with 30% H_2O_2 (Ingram, 1970). Later, these samples were washed again with distilled water and dried in hot air oven at 65°C. After drying, the sediment samples were weighed again to measure loss of carbonate and organic content. The samples were then sieved on a Fritsch sieve shaker for 20 minutes using ASTM sieves at half phi intervals between mesh number 12 and number 270. The sieved samples were collected from all the sieves, weighed, and packed separately for further analysis. The grain size data obtained after sieving was processed using software packages such as Gradistat 8.0 (Boltt and Pye, 2001) to delineate statistical parameters such as mean, standard deviation, skewness and kurtosis by Folk and Ward (1957) graphic method. Linear discriminant function (Sahu, 1964) was used to interpret depositional facies of the



Sample Location-Mithmumbri-1-SM1, 2-SM2; Kunkeshwar-3-SKU1; Katvan-4-SKAT1; Mithbav-5 SMTB1, 6-SMTB2, 7-SMTB3, 8-SMTB4; Munge-9-SMUG1, 10-SMUG2; Achra-11-SACH1, 12-SACH2, 13-SACH3, 14-SACH4 ; Vayagani-15-SVAG1, 16-SVAG2; Tondovali-17- STOND1, 18-STOND2; Talasil-19-STALS1, 20-STALS2

Fig. 2. Sample Locations map of Mithmumbri to Talashi area.

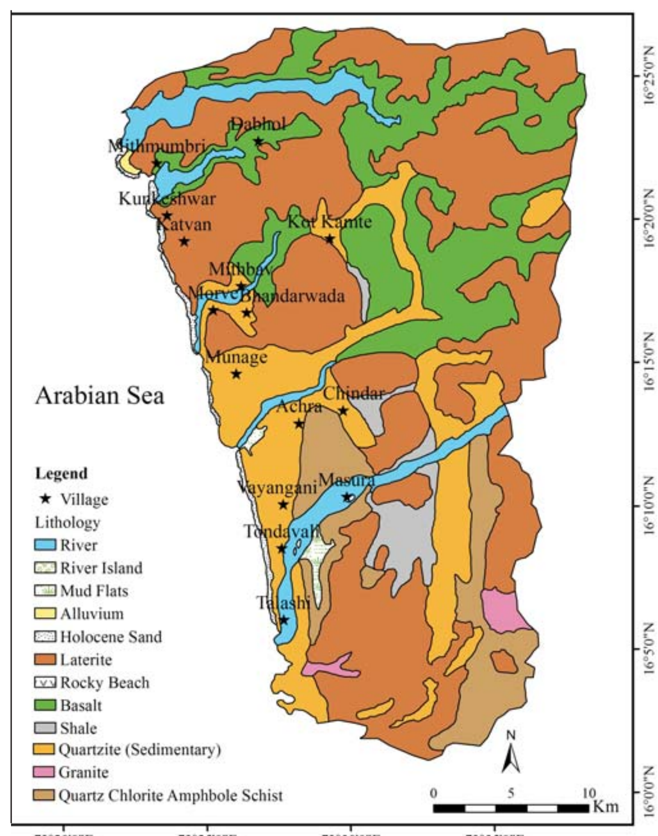


Fig. 3. Geological map of Mithmumbri to Talashi area.

sediments. Seasonal variations have been depicted through bivariate plots (Friedman, 1967; Moiola and Weiser, 1968; Visher, 1969; Rajamanickam and Gujar, 1984). GStat was used to plot C-M diagram developed by Dinesh (2008) which is based on the hypothesis formulated by Passega (1957, 1964).

Results and Discussion

Frequency Distribution

The frequency distribution curves, for the pre-monsoon season, show unimodal to polymodal class. In the foreshore zone, within sector I and II, the sediments are bimodal to unimodal with the primary mode between 2.5 to 3.5 phi size, which show weak secondary mode between 1 to 2 phi size (Fig. 4a-b). The backshore zone (Sector-I and II) sediments are polymodal with the primary mode between 2.5 to 3.5 phi size, secondary mode between 2 to 3 phi size and third mode between 1 to 2 phi size (Fig. 4c-d). The sediments of raised beach and beach dunes of sector I are bimodal with the primary mode between 2 to 3 phi size and secondary mode between 1 to 2 phi size. However, sector II sediments are unimodal with the primary mode between 2 to 3 phi size (Fig. 4e-h).

The frequency distribution curves for the post-monsoon season, show unimodal to the polymodal character. The

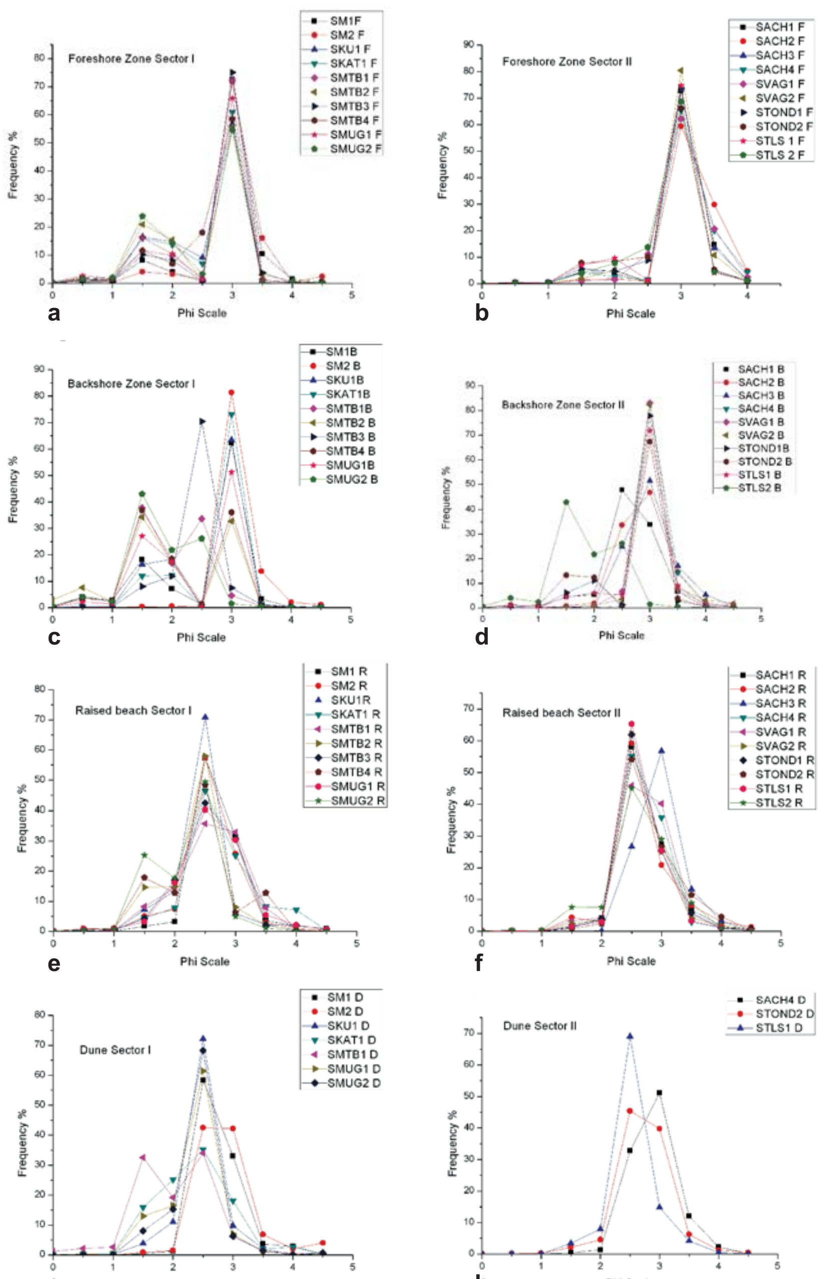


Fig. 4. Frequency Curves of Sector-I and Sector-II from Pre-Monsoon season.

foreshore zone sediments of sector I and II are bimodal to polymodal with the primary mode between 2 to 3 phi size, secondary mode between 1 to 2 phi size and weak third mode between 0.5 to 1 phi size (Fig. 5a-b). Within the backshore zone, sector I sediments are strongly polymodal in character, with the primary mode between 2 to 3 phi size, secondary mode between 1 to 2 phi size and weak third mode between 0 to 1 phi size (Fig. 5c). The backshore sediments of sector II and of raised beach sector I, the sediments are bimodal, with the primary mode between 2 to 3 phi size and secondary mode 1 to 2 phi size (Fig. 5d-e). The raised beach sector II sediments are bimodal, the primary mode is between 2 to 3 phi size and secondary mode 3.5 phi size (Fig. 5f). The dune sediments are unimodal to bimodal with the primary mode between 2 to 3 phi size and weak secondary mode between 1 to 1.5 size (Fig. 5g-h). The frequency curves are seen to vary from unimodal to polymodal class at places of river discharge found along Mithmumbri, Mithbav, Munge, Achra, Todavali and Talashi, as a result of which an additional sub-population is seen to be deposited.

Mean Size

Mean size represents the average of the total distribution of sediments. It is the function of the total amount of sediments available, the amount of energy imparted to the sediments and

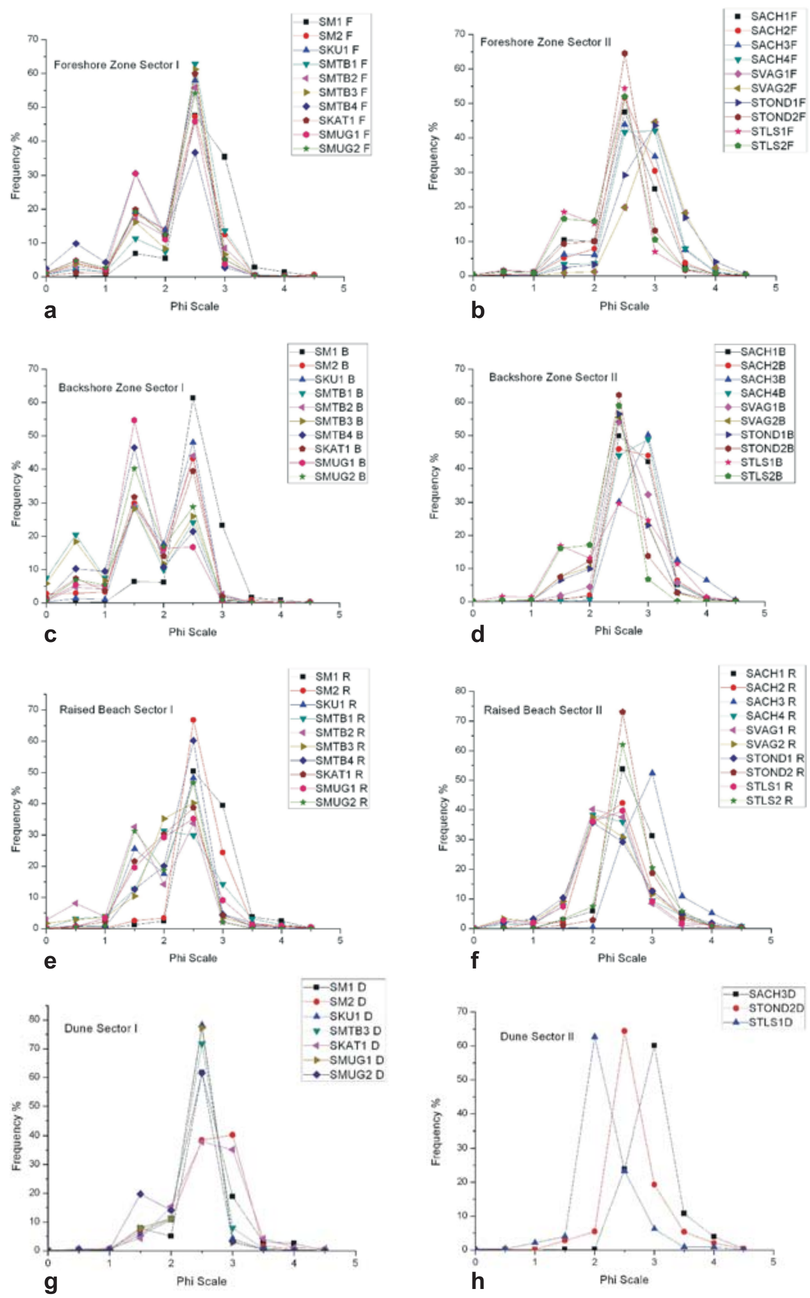


Fig. 5. Frequency Curves of Sector-I and Sector-II from Post-Monsoon season.

the nature of transporting agent (Folk, 1966). The energy of transporting agent includes the degree of turbulence and the role played by currents and waves.

Sector I

During the pre-monsoon season, the foreshore zone shows fine sand, whereas backshore, raised beach, and beach dune shows medium to fine sand. The average value of mean sizes from foreshore (2.38phi), backshore (2.19phi), raised beach (2.14phi), and dune (2.17phi) are observed. During the pre-monsoon season, most of the sands were found to be fine sand with low amount of medium sand. The higher wave heights and longer wave periods in flatter foreshore results in finer sediments (Nordstrom, 1977). During the post-monsoon season, foreshore, backshore, raised beach, and dune show sand mean size in the range of medium to fine. The observed average values of mean sizes from foreshore are 1.91phi, backshore 1.68phi, raised beach 1.84phi, and dune are 2.24phi (Table 1- 4). The occurrence of medium sand indicates very high energy condition resulting from SW monsoon winds.

Sector II

During the pre-monsoon season, foreshore, raised beach, and beach dune have fine mean size, whereas backshore zone shows medium to fine sand. The average values of mean size from foreshore are 2.69phi, backshore (2.49phi), raised beach (2.55 phi), and dune is 2.46 phi. During post-monsoon season, foreshore, backshore, raised beach shows medium to fine sand, whereas beach dune shows fine sand. The average values of mean size from foreshore (2.33phi), backshore (2.32phi), raised beach (2.34phi), and dune (2.47phi) are observed (Table 1- 4).

In the pre-monsoon season, the foreshore zone contains almost 100% fine sand, backshore zone contains 75% fine sand, and medium sand 25%. Raised beach and beach dune contains 90% fine sand and 10%, medium sand. Foreshore zone (pre-monsoon) has 100% fine sand, due to the prevalence of calm wave conditions. The backshore, raised beach and beach dune sediments are fine sized, indicating the influence of aeolian activity in transporting fine sediments in saltation and suspension. In the post-monsoon, foreshore and raised beach shows fine sand is 60% and medium sand 40%; backshore zone shows fine sand to be 50%, medium sand 50%; whereas beach dunes contain 90% fine sand and 10% medium sand.

Standard Deviation

Sector I

During the pre-monsoon season, foreshore zone shows moderately well sorted to well sorted and the backshore zone

Table 1: Graphic Measures from the grain size analysis of the Foreshore zone Sediments of Pre-Monsoon (PRM) and Post-Monsoon (POM) Seasons

Sample No.	Mean		Standard Deviation		Skewness		Kurtosis		Inference	
	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM
SM1	2.73	2.41	0.45	0.45	-0.22	-0.05	2.45	1.19	FS,WS,CS,VL	FS,WS,S, L
SM2	2.79	1.60	0.43	0.40	-0.11	-0.24	2.11	2.35	FS,WS,CS,VL	MS,WS,CS,VL
SKU1	2.28	1.91	0.64	0.49	-0.56	-0.49	0.73	0.78	FS,MWS,SCS,P	FS,WS,SCS, P
SMTB1	2.30	2.06	0.63	0.50	-0.58	-0.37	0.75	1.96	FS,MWS,SCS,P	FS,MWS,SCS,VL
SMTB2	2.37	1.94	0.62	0.58	-0.64	-0.44	1.19	1.08	FS,MWS,SCS, L	MS,MWS,SCS,M
SMTB3	2.25	1.93	0.69	0.61	-0.58	-0.54	0.62	1.19	FS,MWS,SCS,VP	MS,MWS,SCS,L
SMTB4	2.45	1.59	0.57	0.71	-0.63	-0.13	2.15	0.90	FS,MWS,SCS,VL	MS,MS,CS,M
SKAT1	2.32	1.95	0.62	0.49	-0.56	-0.44	1.09	0.86	FS,MWS,SCS,M	FS,WS,SCS,P
SMUG1	2.28	1.82	0.68	0.62	-0.64	-0.48	0.72	0.87	FS,MWS,SCS, P	MS,MWS,SCS,P
SMUG2	2.21	1.88	0.69	0.62	-0.57	-0.54	0.59	0.99	FS,MWS,SCS,VP	MS,MWS,SCS,M
SACH1	2.78	2.20	0.43	0.56	-0.13	-0.19	2.21	1.43	FS,WS,CS,VL	FS,MWS,CS,L
SACH2	2.92	2.38	0.35	0.43	0.23	0.07	0.88	1.21	FS,WS,FS, P	FS,WS,S,L
SACH3	2.75	2.44	0.41	0.49	-0.17	0.01	2.18	1.24	FS,WS,CS,VL	FS,WS,S,L
SACH4	2.85	2.50	0.48	0.43	-0.06	0.01	2.05	1.06	FS,WS,S,VL	FS,MS,S,M
SVAG1	2.82	2.73	0.38	0.43	0.08	0.08	1.29	1.08	FS,WS,S,L	FS,WS,S,M
SVAG2	2.75	2.43	0.34	0.58	-0.13	-0.11	1.90	1.54	FS,VWS,CS,VL	FS,WS,S,L
STOND1	2.63	2.65	0.43	0.48	-0.38	0.09	2.02	1.01	FS,WS,SCS,VL	FS,WS,S,M
STOND2	2.51	2.16	0.53	0.42	-0.46	-0.22	1.62	1.85	FS,MWS,SCS,VL	FS,WS,CS,VL
STLS1	2.52	1.95	0.54	0.52	-0.52	-0.34	2.17	0.96	FS,MWS,SCS,VL	MS,MWS,SCS,M
STLS2	2.58	1.99	0.43	0.53	-0.39	-0.28	1.57	1.09	FS,WS,SCS,VL	MS,MWS,CS,M

(Note: FS-Fine sand, MS-medium sand, CS-coarse sand, VFS-very fine sand, WS-well sorted, MWS-moderately well sorted, MS-moderately sorted, PS-poorly sorted, SFS-strongly fine skewed, FS-fine skewed, NS-near symmetrical, CS-coarse skewed, SCS-strongly coarse skewed, VP-very platykurtic, P-platykurtic, M-mesokurtic, L-leptokurtic, VL-very leptokurtic, EL-extremely leptokurtic)

Table 2: Graphic Measures from the grain size analysis of the Backshore zone Sediments of Pre-Monsoon (PRM) and Post-Monsoon (POM) Seasons

Sample No.	Mean		Standard Deviation		Skewness		Kurtosis		Inference	
	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM
SM1	2.25	2.3	0.77	0.40	-0.67	0.02	0.72	1.63	FS,MS,SCS,P	FS,WS,S,VL
SM2	2.79	1.56	0.25	0.35	0.21	-0.31	1.16	1.58	FS,VWS,FS,L	MS,VPS,SCS,VL
SKU1	2.31	1.85	0.63	0.49	-0.60	-0.38	0.69	0.66	FS,MWS,SCS,P	MS,WS,SCS,VP
SMTB1	2.39	1.20	0.59	0.89	-0.63	-0.08	0.89	0.66	FS,MWS,SCS,P	MS,MS,S,VP
SMTB2	1.71	1.77	0.58	0.60	0.01	-0.35	0.79	0.84	MS,MWS,SCS,P	MS,MWS,SCS,P
SMTB3	1.77	1.26	0.88	0.88	0.19	-0.11	0.82	0.67	MS,MS, FS,P	MS,MS,CS,P
SMTB4	2.14	1.39	0.38	0.68	-0.26	0.07	1.81	1.10	FS,WS,CS,VL	MS,MWS,S,M
SKAT1	1.86	1.68	0.75	0.64	0.24	-0.17	0.64	0.90	MS,MS,FS,VP	MS,MWS,CS,M
SMUG1	2.19	1.46	0.69	0.55	-0.55	0.18	0.58	1.30	FS,MWS,SCS,VP	MS,MWS,FS,L
SMUG2	1.60	1.57	0.57	0.61	0.14	0.10	0.91	0.92	MS,MWS,FS, M	MS,MWS,FS,M
SACH1	2.44	2.48	0.47	0.34	0.04	0.15	1.21	0.78	FS,WS,S,L	FS,VWS,FS,P
SACH2	2.61	2.50	0.41	0.36	0.04	0.13	0.93	0.84	FS,WS,S,M	FS,WS,FS,P
SACH3	2.74	2.68	0.45	0.45	0.10	0.12	1.20	1.15	FS,WS,S,L	FS,WS,FS,L
SACH4	2.79	2.53	0.24	0.34	0.19	0.05	1.13	0.82	FS,VWS,FS,L	FS,VWS,S,P
SVAG1	2.74	2.44	0.26	0.39	0.04	0.21	1.29	1.00	FS,VWS,S,L	FS,WS,FS,M
SVAG2	2.76	2.28	0.26	0.45	0.21	-0.05	1.27	1.52	FS,VWS,FS,L	FS,WS,S,VL
STOND1	2.51	2.36	0.49	0.36	-0.58	0.15	1.94	1.17	FS,WS,SCS,VL	FS, WS,FS,L
STOND2	2.36	2.19	0.64	0.42	-0.62	-0.12	0.81	1.77	FS,MWS,SCS,P	FS,WS,CS,VL
STLS1	2.68	2.19	0.44	0.73	-0.2	-0.10	2.16	0.88	FS,WS, CS,VL	FS,MS,CS,P
STLS2	1.60	1.99	0.57	0.46	0.14	-0.38	0.91	1.02	MS,MWS,FS,M	MS,WS,SCS,M

Table 3: Graphic Measures from the grain size analysis of the Raised Beach zone Sediments of Pre-Monsoon (PRM) and Post-Monsoon (POM) Seasons

Sample No.	Mean		Standard Deviation		Skewness		Kurtosis		Inference	
	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM
SM1	2.43	2.47	0.36	0.35	0.30	0.19	0.92	0.83	FS,WS,VFS,M	FS,WS,FS,P
SM2	2.37	2.36	0.41	0.33	0.07	0.18	1.30	1.21	FS,WS,S,L	FS,VWS,FS,L
SKU1	2.15	1.90	0.37	0.52	-0.21	-0.31	1.78	0.78	FS,WS,CS,VL	MS,MWS,SCS,P
SMTB1	2.19	1.60	0.26	0.80	-0.25	-0.19	1.36	0.87	FS,VWS,CS,L	MS,MS,CS,P
SMTB2	2.00	1.57	0.51	0.71	-0.32	-0.06	1.18	0.96	FS,MWS,SCS,L	MS,MS,S,M
SMTB3	2.02	1.37	0.50	0.60	-0.31	-0.49	1.25	1.32	FS,MWS,SCS,L	MS,MWS,SCS,L
SMTB4	2.05	2.01	0.48	0.42	-0.31	-0.39	1.36	1.03	FS,WS,SCS,L	FS,WS,SCS,M
SKAT1	2.11	1.52	0.67	0.54	-0.06	-0.25	1.28	1.89	FS,MWS,S,L	MS,MWS,CS,VL
SMUG1	1.94	1.70	0.65	0.38	-0.64	-0.45	1.80	0.81	MS,MWS,SCS,VL	MS,WS,SCS,P
SMUG2	1.91	1.84	0.51	0.48	-0.34	-0.31	0.76	0.65	MS,MWS,SCS,P	MS,WS,SCS,VP
SACH1	2.44	2.42	0.40	0.41	0.31	0.12	1.05	1.09	FS,WS,VFS, M	FS,WS,FS,M
SACH2	2.63	1.85	0.39	0.60	-0.10	0.26	0.99	0.90	FS,WS,S,M	MS,MWS,VFS,P
SACH3	2.67	2.64	0.38	0.41	-0.10	0.05	1.13	1.12	FS,WS, S,L	FS,WS,S,L
SACH4	2.66	2.20	0.42	0.42	0.06	0.50	0.93	0.72	FS,WS,S,M	FS,WS,FS,P
SVAG1	2.65	2.30	0.47	0.64	0.16	0.51	1.08	0.80	FS,WS,FS,M	FS,MWS,FS,P
SVAG2	2.59	2.75	0.40	0.74	0.09	0.37	0.96	0.46	FS,WS,S,M	FS,MS,FS,VP
STOND1	2.53	2.25	0.43	0.23	0.32	0.41	0.97	1.14	FS,WS,VFS,M	FS,VWS,VFS,L
STOND2	2.5	2.35	0.44	0.29	0.39	0.33	0.94	1.23	FS,WS,VFS,M	FS,VWS,VFS,L
STLS1	2.50	2.14	0.46	0.39	0.33	0.63	0.95	1.42	FS,WS,VFS,M	FS,WS,VFS,L
STLS2	2.42	2.36	0.53	0.41	0.05	0.19	1.29	1.49	FS,MWS,S,L	FS,WS,FS,L

shows moderately sorted to very well sorted sand. The raised beach and beach dune show detrital material to be moderately well sorted to very well sorted. The average values of standard deviation from foreshore are 0.61 phi, backshore (0.60 phi), raised beach (0.43 phi), and dune is 0.41phi. Kunkeshwar, Mithbav, Katvan, and Munge beaches of sector I are identified to have moderately well-sorted sediments formed under the influence of high wave energy conditions.

During the post-monsoon, the foreshore zones are seen to have moderately sorted to well sorted sands, while

Table 4: Graphic Measures from the grain size analysis of the Dune zone Sediments of Pre-Monsoon (PRM) and Post-Monsoon (POM) Seasons

Sample No.	Mean		Standard Deviation		Skewness		Kurtosis		Inference	
	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM
SM1	2.74	2.33	0.161	0.45	0.23	0.07	0.74	1.97	FS,VWS,S,P	FS,WS,S,VL
SM2	2.55	2.29	0.462	0.40	0.23	-0.09	1.18	1.80	FS,WS,FS,L	FS,WS,S,VL
SKU1	2.23	2.18	0.317	0.28	-0.01	-0.29	1.69	1.48	FS,VWS,S,VL	FS,VWS,CS,L
SKAT1	2.14	2.15	0.421	0.36	-0.21	-0.24	1.63	1.58	FS,WS,CS,VL	FS,WS,CS,VL
SMTB1	1.77	2.54	0.597	0.58	-0.04	-0.87	0.83	1.58	MS,MWS,S,P	FS,MWS,SCS,VL
SMUG1	2.05	2.14	0.450	0.31	-0.32	-0.38	1.28	1.56	FS,WS,SCS,L	FS,VWS,SCS,VL
SMUG2	2.12	1.96	0.387	0.45	-0.26	-0.48	1.71	0.85	FS,WS,CS,VL	MS,WS,SCS,P
SACH1	2.61	2.66	0.395	0.38	0.18	-0.02	0.98	1.27	FS,WS,S,M	FS,WS,S,L
STOND2	2.47	2.37	0.14	0.42	-0.23	0.24	1.65	1.58	FS,VWS,CS,VL	FS,WS,FS,VL
STLS1	2.29	2.39	0.355	0.39	0.11	0.23	1.67	1.26	FS,WS,FS,VL	FS,WS,FS,L

backshore zone contains moderately sorted to very poorly sorted sands. The raised beach shows moderately sorted to very well sorted sands, whereas the beach dune are moderately well sorted to very well sorted. The average values of standard deviation from foreshore (0.52 phi), backshore (0.57phi), raised beach (0.49phi), and dune (0.41phi) are observed to be quite moderate. Mithmumbri, Kunkeshwar, and Katvan beaches have well-sorted sediments (Table 1- 4).

Sector II

During the pre-monsoon season, the foreshore and backshore zone shows moderately well sorted to very well sorted, whereas raised beach shows moderately well sorted to well sorted sands. In beach dune the sediments are very well sorted to well sorted. The moderately well sorted to well sorted sediments are obtained due to the sudden winnowing action of the sediments by the depositing agent (Singarasubramanian *et al.,* 2009). The average values of standard deviation from foreshore (0.44 phi), backshore (0.43phi), raised beach (0.44phi), and dune (0.297phi) are observed to be low to moderate. During the post-monsoon season, foreshore and beach dune sediments are well-sorted whereas, the backshore and raised beach sediments are moderately sorted to very well sorted. The average values of standard deviation from foreshore are 0.49phi, backshore (0.44phi), raised beach (0.45phi), and dune (0.39phi). During the pre- and post-monsoon seasons, Achra, Vayagani, Tondavali, and Talashi beaches are having well-sorted to moderately well-sorted sediments, which may have been formed under the influence of very high wave energy conditions. The moderately well sorted to very well-sorted sediments are found in high-energy conditions (Friedman, 1962).

In the pre-monsoon season, the foreshore zone shows well sorted sands are 45%, moderately well sorted 50%, very well sorted 5%; backshore zone shows well sorted 30%, moderately well sorted 35%, very well sorted 20%, moderately sorted 15%. Raised beach contains well sorted 65%, moderately well sorted 30%, very well sorted 5%; while beach dune shows well sorted are 60%, moderately well sorted 10% and very well sorted 30%. The moderately well sorted nature of the sediment could be due to partial winnowing action as well as the addition or influx of previously sorted sediments in a marine environment (Angusamy and Rajamanickam, 2006).

In the post-monsoon season, the foreshore zone shows well-sorted sediments are 50%, moderately well sorted 40%, moderately sorted 10%; whereas backshore zone shows well-sorted 45%, moderately well sorted 25%, very well sorted 10%, moderately sorted 15%, and very poorly sorted 5%. Raised beach contains well sorted 45%, moderately well sorted 25%, very well sorted 15% and moderately sorted 15% sand; while beach dune contains well sorted 70%, very well sorted 20% and moderately well sorted 10% sediments.

Skewness

Sector I

During the pre-monsoon season, the foreshore zone shows strongly coarse skewed to coarse skewed, backshore and beach dune are strongly coarse skewed to fine skewed, whereas raised beach shows strongly coarse skewed to very fine skewed sands. The average values of skewness changes for foreshore (-0.50), backshore (-0.32), raised beach (-0.204) and dune (-0.64) (Table 1- 4).

During the post-monsoon season, the foreshore zone sediments show strongly coarse skewed to coarse skewed, while the backshore zone are strongly coarse skewed to fine skewed. The raised beach region shows strongly coarse skewed to very fine skewed, whereas beach dune shows strongly coarse skewed to symmetrical. The average values of skewness also varies for foreshore (-0.39), backshore (0.17), raised beach (-0.21), and dune (1.58). Majority of sector-I sediments are strongly coarse skewed compared to sector-II in the foreshore zone. During the pre and post-monsoon seasons at foreshore of sector-I, the percentage of negative skewed samples were found to be 100%, indicating beach erosion at Mithmumbri, Kunkeshwar, Mithbav, Katvan, and Munge as compared to sector-II. The backshore samples are inclined towards being positively skewed due to the influence of aeolian activity (Angusamy and Rajamanickam, 2007).

Sector II

During the pre-monsoon season, the foreshore and backshore zone shows strongly coarse skewed to fine skewed sands. Raised beach has very fine skewed to symmetrical, whereas beach dune contains coarse skewed to fine skewed sands. The average values of skewness varies for foreshore (-0.24), backshore (-0.11), raised beach (0.18), and dune (0.19). During the post- monsoon season, the foreshore zone shows strongly coarse skewed to near symmetrical sands, whereas the backshore zone has strongly coarse skewed to fine skewed sands. Raised beach shows fine skewed to very fine skewed, and beach dune shows symmetrical to fine skewed sands. The sediments are nearly symmetrical to positively skewed, suggesting the presence of fine sands is influenced by the discharge of rivers like Pyali, Achra, and Gad. The average values of skewness are different for foreshore (-0.15), backshore (-0.10), raised beach (0.36) and dune (1.37). According to Folk (1966) the beach sands are negatively skewed. In the study area, more than 90% of the beach sands are negatively skewed (Table 1- 4).

In the pre-monsoon season, the foreshore zone contains sands that are 60% strongly coarse skewed, 25% coarse skewed, 5% fine skewed and 10% very fine skewed; whereas backshore zone is 10% coarse skewed , 35% strongly coarse skewed and fine skewed and 20% very fine skewed. Raised beach region is 10% coarse skewed, 25% strongly coarse skewed, 35% symmetrical and 25% very fine skewed; whereas beach dunes are 30% coarse skewed, 10% strongly coarse skewed, 40% symmetrical and 20% finely skewed.

In the post-monsoon season, the foreshore zone shows 25% coarse skewness, 40% strongly coarse skewness and 35% symmetrical; while backshore zone is 20% coarse skewed, 20% strongly coarse skewed, 35% fine skewed and 25% symmetrical. The raised beach region is 10% coarse skewed, 25% strongly coarse skewed, 35% finely skewed, 10% symmetrical and 20% very finely skewed; while beach dune is 20% coarse skewed, 30% strongly coarse skewed, 20% fine skewed and 30% symmetrical.

Kurtosis

Sector I

During the pre-monsoon season, the foreshore and backshore zones show very platykurtic to very leptokurtic sands, while raised beaches and beach dunes are platykurtic to very leptokurtic. The average values of kurtosis are different for foreshore (1.14), backshore (0.85), raised beach (1.359) and beach dune (1.32). The leptokurtic to platykurtic nature indicates multiple source of depositional environment along the coast *i.e.* one derived from the riverine/ aeolian environment and the other derived from the marine environment (Godson *et al.,* 2014).

During the post-monsoon season, foreshore and dune sediments show platykurtic to very leptokurtic characteristics, while backshore and raised beach sediments are very platykurtic to very leptokurtic. The extreme high or low values of kurtosis imply that part of the sediment achieved its sorting elsewhere in a high-energy environment (Friedman, 1962). The average values of kurtosis are varied for foreshore (1.12), backshore (1.19), raised beach (1.94) and dune (1.58) (Table 1-4). The variability in kurtosis values appears to be strongly related to the variability and energy of the wave regimes (Nordstrom, 1977).

Sector II

During the pre-monsoon season, foreshore and backshore zones demonstrate values ranging from platykurtic to very leptokurtic, while raised beach region is leptokurtic to mesokurtic. The beach dune shows sands to be very leptokurtic to mesokurtic. The platykurtic nature of the sediments prevails under the high energy conditions, while leptokurtic nature reveals the energy fluctuations of the depositing medium (Singarasubramanian, 2009). The average values of kurtosis are fluctuating for foreshore (1.77), backshore (1.32), raised beach (1.32), and dune (1.43). During the post-monsoon season, the foreshore zone shows mesokurtic to very leptokurtic, while the backshore zone has very leptokurtic to platykurtic sands. Raised beach region shows leptokurtic to very platykurtic, whereas the beach dune shows leptokurtic to very leptokurtic. The average values of kurtosis are 1.25, 1.14, 1.06 and 1.37 for foreshore, backshore, raised beach and dune, respectively.

During the pre-monsoon season, foreshore zone shows 55% of very leptokurtic sediments because of the strong mixing of the fluvial sediments mainly by Pyali, Achra and Gad Rivers, and also has leptokurtic (10%), platykurtic (20%), very platykurtic (10%) and mesokurtic (5%) sands; while backshore zone is very 15% very leptokurtic, 30% very leptokurtic, 30% platykurtic, 10% very platykurtic and 15% mesokurtic. The raised beach region is 40% leptokurtic, 5% platykurtic, 10% very platykurtic, 45% mesokurtic; whereas dune sediments are 50% very leptokurtic, 20% leptokurtic, 20% platykurtic, and 10% mesokurtic.

In the post-monsoon season, the foreshore zone shows sediments to be very leptokurtic (15%), leptokurtic (30%), platykurtic (15%), and mesokurtic (40%). The backshore zone sediments are 20% very leptokurtic, 15% leptokurtic, 30% platykurtic, 10% very platykurtic, and 25% mesokurtic. The raised beach region is 5% very leptokurtic, 35% leptokurtic, 35% platykurtic, 10% very platykurtic, 15% mesokurtic and beach dune is 60% very leptokurtic, 30% leptokurtic, and 10% platykurtic.

Bivariate Plots

The bivariate plots are helpful to understand various depositional environments. The relationship between the graphic mean size, graphic standard deviation, graphic skewness, and graphic kurtosis parameters can be well understood by plotting them against each other as scatter diagrams. The scatter diagrams for understanding the geological significance of these four size parameters have been successfully used by various workers (Friedman, 1967; Moiola and Weiser, 1968).

Graphic Mean Size vs. Graphic Standard Deviation

In the bivariate plots of graphic mean size vs. graphic standard deviation, variations of grain size parameters are inferred. The superimposed bivariate plots (Friedman, 1967), indicate that majority of the samples fall within the beach environment and few samples fall mainly in the riverine environment (Fig. 6a). In the post-monsoon season, most of the samples are well sorted to moderately well sorted and fall within the area of the beach environment. Few samples mark the prevalence of river environment probably associated mainly with Mithmumbri (SM1), Mithbav (SMTB4), Munge (SMUG1), Achra (SACH1), and Talashi (STLS2) locations (Fig. 7a). The sediments discharged by the rivers through the estuary in Pyali, Achra and Gad are carried away and deposited in the respective area during the post-monsoon season. According to Griffths (1967), both mean grain size and sorting are hydraulically controlled so that in all sedimentary environments the best-sorted sediments have a mean size in the fine sand size range. The study area reveals the presence of dominant beach and the mixing of riverine environments.

Mean Size vs. Standard Deviation

The superimposed bivariate plots of mean size vs. standard deviation (Rajamanickam and Gujar, 1984) indicate that most of the samples fall within the area of the beach and few samples fall in the dune environments (Fig.6b, 7b).

Graphic Mean vs. Graphic Skewness

The bivariate plots of graphic mean vs graphic skewness has been used for differentiating between dune and beach environment (Moiola and Weiser, 1968). In this bivariate plot, most of the samples fall in beach and dune depositional environments in pre and post-monsoon seasons (Fig. 6c, 7c).

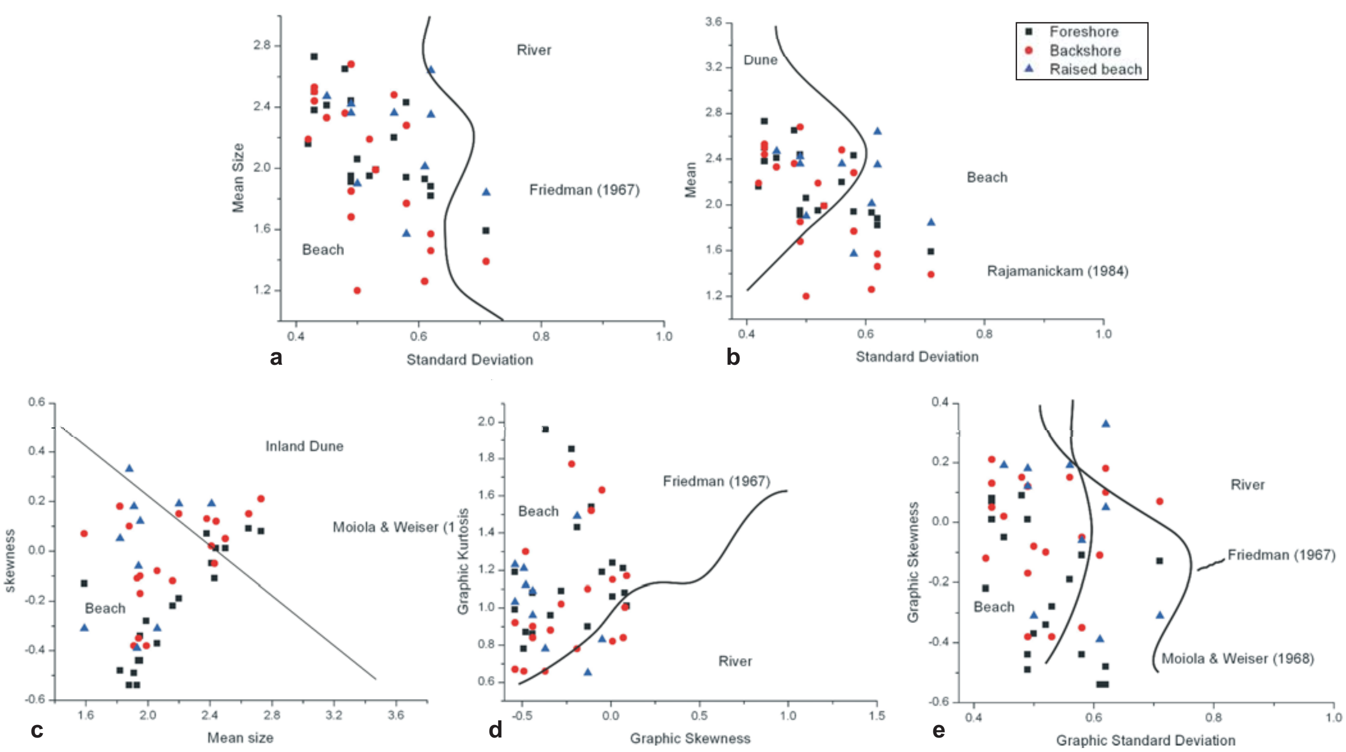


Fig. 6. Bivariate plots showing the textural patterns of sediments in terms of statistical parameters, *i.e.* (a) Mean size *vs*. Standard deviation, (Friedman, 1967), (b) Mean size *vs.* Standard deviation, (Rajamanickam and Gujar, 1984), (c) Mean size *vs.* skewness (Moiola and Weiser, 1968), (d) Graphic Skewness *vs.* Graphic Kurtosis (Friedman, 1967), (e) Graphic Standard *vs.* Graphic Skewness (Friedman, 1967; Moiola and Weiser, 1968) of Pre

Graphic Skewness vs. Graphic Kurtosis

In the superimposed bivariate plots of Friedman (1967), for the pre-monsoon season, the majority of the samples fall within the beach environment and few samples fall in the riverine environment (Fig. 6d). Most of the samples of the post-monsoon season fall in riverine environment, which is indicative of predominant sediment contribution from the rivers like Pyali, Achra, and Gad. The beach environment is also represented by some samples (Fig. 7d).

Graphic Standard Deviation vs Graphic Skewness

The superimposed bivariate plots of Friedman (1967) and Moiola and Weiser, (1968) show that most of the samples fall within the beach environment and few samples in the riverine environment that were collected at Mithmumbri (SM2), Mithbav, Achra (SACH1), and Talashi during the pre-monsoon season (Fig. 6e). The majority of the samples collected during the post-monsoon season, fall within the beach environment and few backshore samples fall within the riverine environment (Fig. 7e).

CM-Diagram

The plot of *CM* diagrams considers the coarsest one percentile of grain size (C) against the median grain size (M) of sediment that is plotted on a double log paper (Passega 1957). *CM* diagram has been prepared following the procedures of Passega (1957, 1964), which depicts various modes of sediment transport as well as provides information on the source of sediment origin.

The *CM* diagram has been sub-divided into five segments depending upon the mode of transport and deposition (Passega, 1964; where, NO - deposit of rolled grains, OP - mixtures of rolled grains and suspension sediments, PQ - suspension, QR - Graded suspension no rolling, and RS-uniform suspension). During the pre- and post-monsoon seasons, within sector I and II, CM diagram shows sediment samples fall predominantly in the tractive current and beach environment of deposition (Fig. 8a-b; 9a-b). The tractive current diagram of pre-monsoon (Sector-I) season shows majority samples fall in suspension, while few samples fall in bottom suspension and rolling condition. The sector-II samples predominantly fall in suspension and graded suspension and no rolling (Fig. 8c-d). The tractive current diagram of the post-monsoon (Sector-I) season shows that samples fall in mixtures of rolled grains and suspension indicating high energy condition, while few samples of Sector-II fall in suspension and graded suspension no rolling (Fig. 9c- d).

Linear Discriminant Analysis (LDA)

The linear discriminant function of Sahu (1964) has been used for multivariate analysis of beach sediments. This

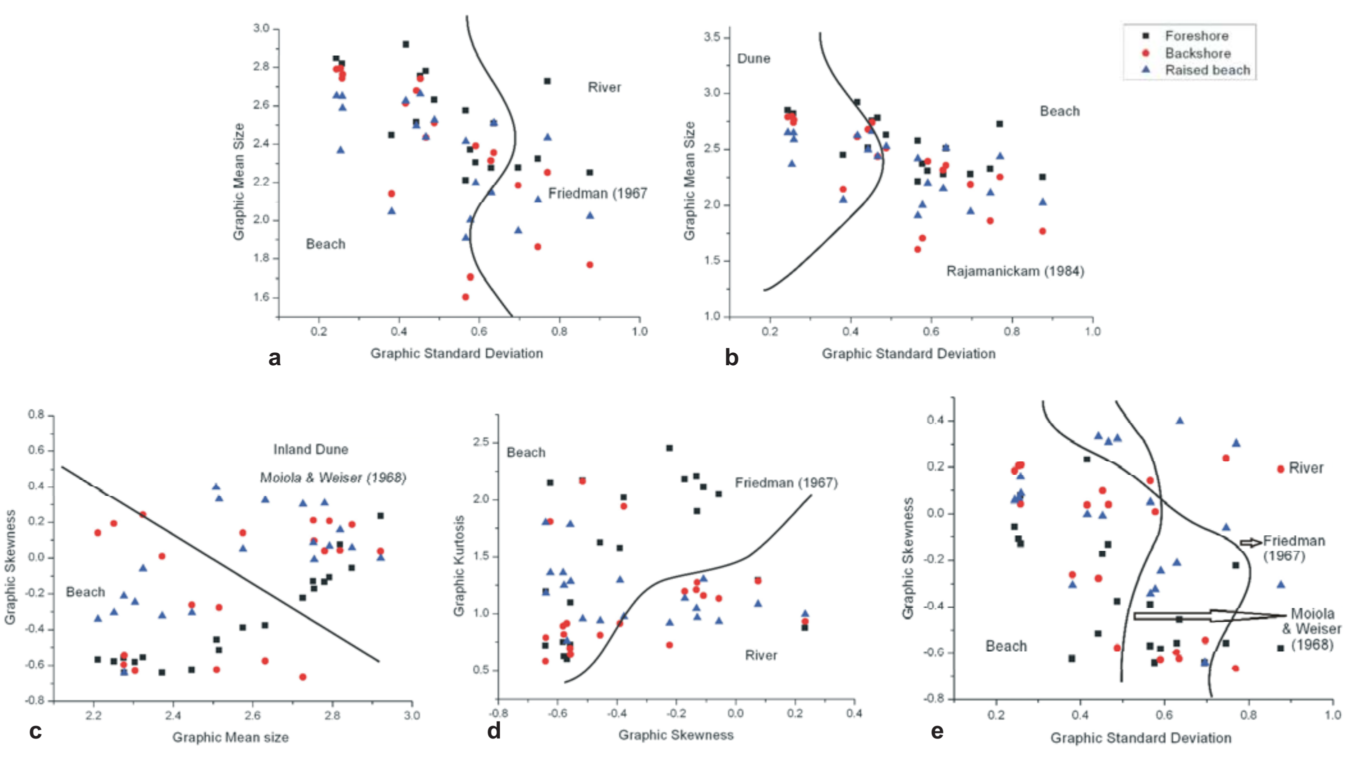
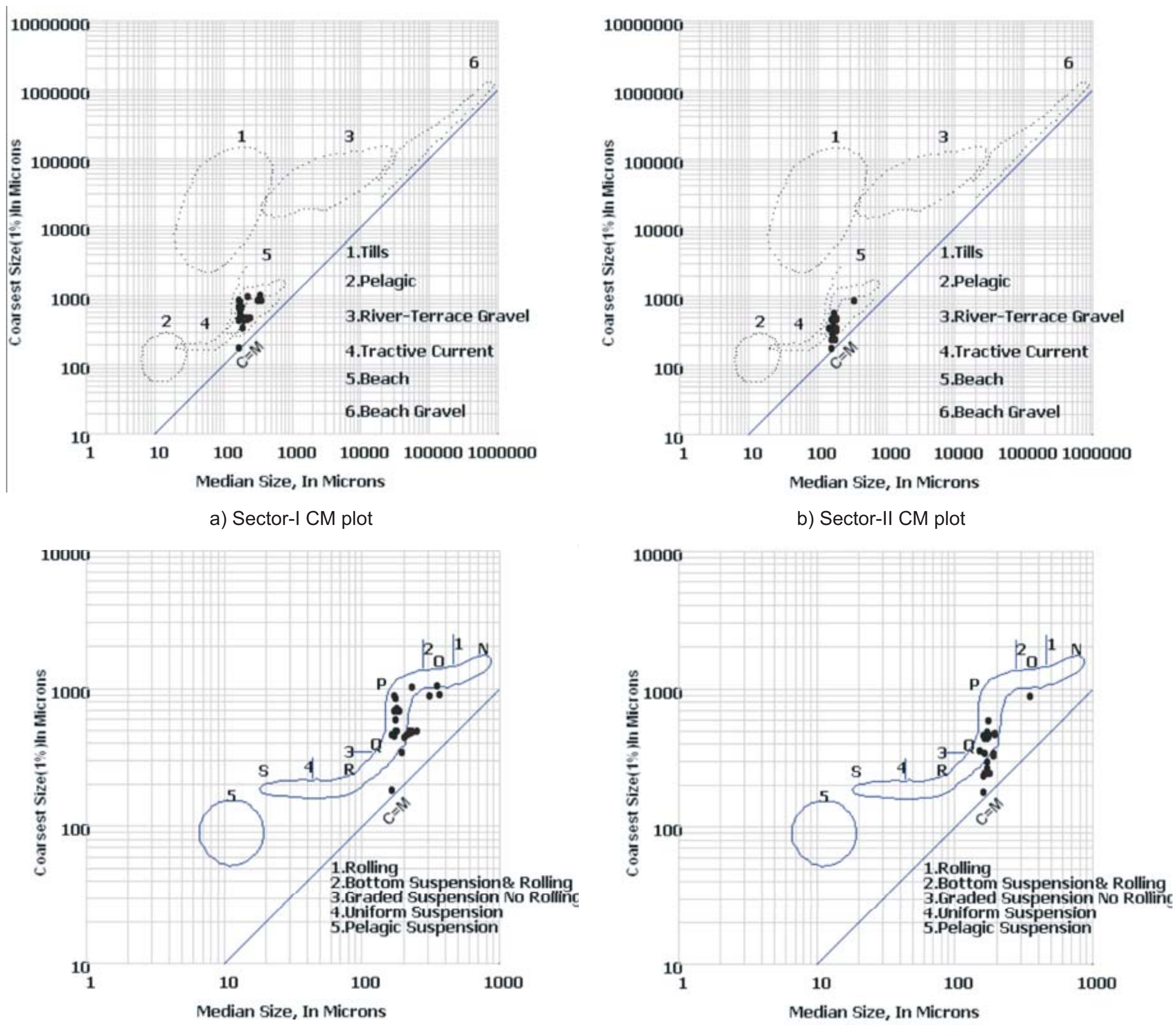


Fig.7. Bivariate Plots showing the textural patterns of sediments in terms of statistical parameters, *i.e.* (a) Mean size *vs.* Standard deviation, (Friedman, 1967), (b) Mean size *vs.* Standard deviation, (Rajamanickam and Gujar, 1984), (c) Mean size *vs.* Skewness (Moiola and Weiser, 1968), (d) Graphic Skewness *vs.* Graphic Kurtosis (Friedman, 1967), (e) Graphic Standard *vs.* Graphic Skewness (Friedman, 1967; Moiola and Weiser, 1968) of Post



a) Sector-I CM plot b) Sector-II CM plot

c) Sector-I Tractive current d) Sector-II Tractive current

Fig.8. *CM* Plots and Tractive Current diagram of Pre-Monsoon Season

helps to correlate different processes and environments of deposition. The following formulae and their association to a particular environment were utilized to interpret the environment of deposition, aeolian or beach, of sediments.

Y1 Aeolian: Beach =

$$-3.5688\ M + 3.7016\ r^2 - 2.0766\ SK + 3.1135\ KG \quad (1)$$

Where if Y is ≥ -2.7411 then the environment of deposition is beach, and if Y is ≤ -2.7411 the environment of deposition is considered aeolian.

Further, to delineate and to confirm the environment of deposition between beach and shallow marine, the following equation has been applied:

Y2 Beach: Shallow marine =

$$15.6534M + 65.7091r^2 + 18.1071SK + 18.5043KG \quad (2)$$

Where if Y is ≥ 63.3650, environment of deposition is shallow marine, and if Y is ≤ 63.3650, environment of deposition is beach.

To distinguish environment of deposition between shallow marine and fluvial, the following equation has been applied:

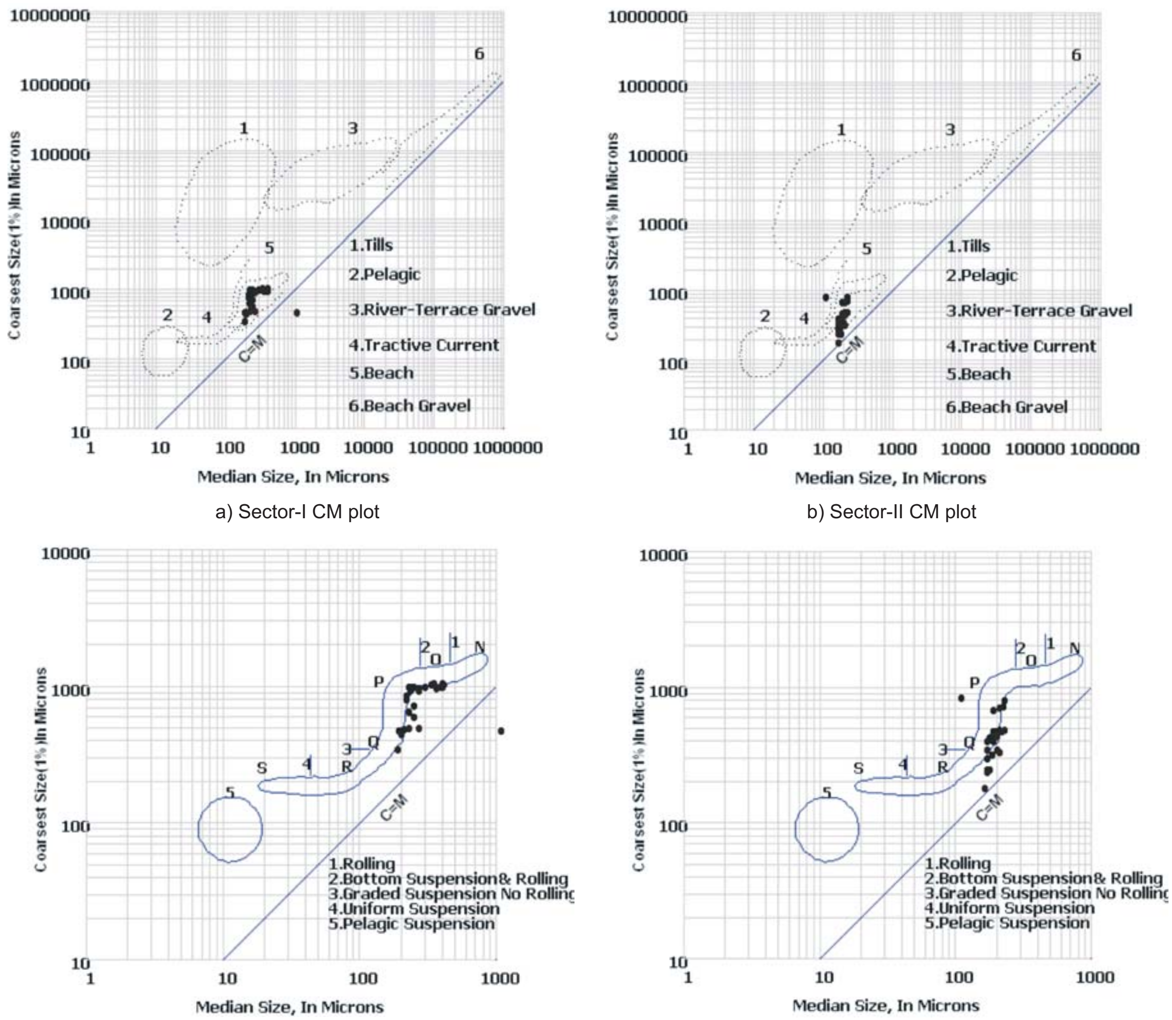
Y3 Shallow marine: Fluvial =

$$0.2852M - 8.7604\ r^2 - 4.8932SK + 0.0428KG \quad (3)$$

Where if Y is ≥ -7.4190 environment of deposition is shallow marine, and if Y is ≤ -7.4190, environment of deposition is fluvial.

(M= mean, r = standard deviation, SK= skewness and KG= kurtosis)

Linear discriminant functions calculated for the samples using the equations given above, concerning the Y1 value during the premonsoon season, 70% of the samples fall in the beach environment and 30% of the samples fall in the aeolian environment. As far as Y2 is concerned, 100% of the samples belong to shallow marine environment. Y3 values indicate 90% of the samples fall in shallow marine and the remaining 10% of the samples fall in the fluvial environment (Fig. 10).



a) Sector-I CM plot
b) Sector-II CM plot
c) Sector-I Tractive current
d) Sector-II Tractive current

Fig.9. *CM* Plots and Tractive Current diagram of Post-Monsoon Season

During the post-monsoon season, Y1 values indicate 75% of the samples fall in the beach, remaining 25% of samples fall in the aeolian environment. As far as Y2 values are concerned 84% of samples fall in shallow marine environment, while remaining 16% of the samples fall in beach environment. Based on Y3 values 80% of the samples are seen to fall in shallow marine, and the remaining 20% of the samples fall in fluvial environment (Fig. 10). Thus, it can be inferred that the sediments in the present-day beaches have been deposited in shallow marine environment, and in due course of time, marine regression must have led to the development of present-day coastlines. In sector-I, Mithmumbri and Munge beach ridges are parallel to the shoreline, with dunes, indicating marine transgressions and differential sea-level changes during the Late Quaternary. The energy condition is inferred to change from beach littoral to beach shallow environment of deposition. The sediments discharged by the river Achra and Gad have been redeposited in the backshore regions during the monsoon period, when larger waves erode the backshore, thereby depositing the river-borne sediments.

As can be seen from the textural parameters derived from different microenvironments of coastal stretch of Sindhudurg from Mithmumbari to Talashi the occurrence of various forms of detrital material is influenced by a range of energy conditions that seem to differ with time and space. The sediment samples collected from foreshore, backshore, raised beach and dune coastal environment to understand the depositional dynamics and the energy conditions that they represent. The samples have been collected in two different seasons and the locations from where the samples were collected have been divided into erosional and depositional depending upon the geomorphology of the area. The present study revealed all the microenvironments during premonsoon are dominated by fine to medium-grains that are very well to moderately sorted, fine to strongly coarse skewed, which are very platykurtic to very leptokurtic. During the post-monsoon the sediments are seen to be medium to fine, well to moderately well sorted. This signifies the change in the energy condition that occurred between the two seasons. The dynamics seem to have changed in the post-monsoon with the

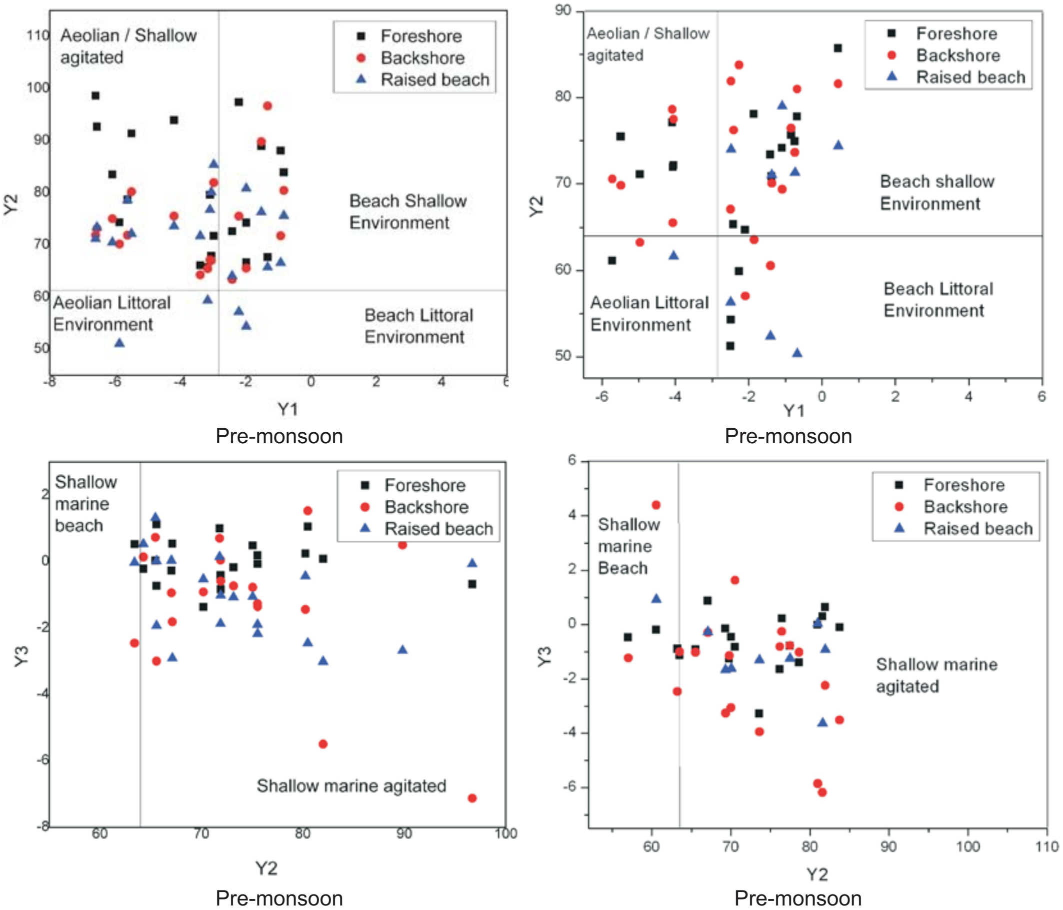


Fig.10. Linear Discriminant Analysis (LDA) plots of Pre and Post monsoon seasons

advent of monsoon in the intervening period. The monsoon changes the energy condition in the area and leading to more addition of material to the environment. Also, the winnowing and panning of the detrital material was more during the pre-monsoon season than the post-monsoon. The increase in erosion due to seasonal rains in this area and the hinterland led to less winnowing and panning leading to accumulation of coarse grains during the post-monsoon season. The monsoon has also affected and led to asymmetrical distribution reflected by the skewness of the sediments. The presence of platykurtic to leptokurtic nature indicates the maturity and immaturity of the sediments that are found in the different depositional environments studied. The beaches at Achara, Vayagani, Tondavali and Talashi contain more coarse sediments in both the seasons which can be related to presence of high energy conditions in general. The presence of negatively skewed sediments at Mithmumbri, Kunkeshwar, Mithbhav, Katvan and Munge beaches at sector I indicate that these beaches are undergoing erosion. Almost all the detrital material was inferred to belong to beach environment, though few could be considered to be of riverine or aeolian origin. However, the dominance of shallow marine environment could also be inferred from LDF analysis irrespective of the season present. The detrital material at these beaches has arrived through tractive current as revealed by the *CM* plot. The sector I samples arrived through suspension and by rolling, whereas sector II samples reached through suspension and without rolling. The manner in which the detrital material arrived at these microenvironments has a bearing on the mode of travel and the energy conditions of the medium of their travel.

Conclusions

The study reveals that most of the sediments are present as fine sand during the pre-monsoon season, due to the prevalence of calm wave conditions. During the post-monsoon season, the occurrence of medium sand indicates a very high energy condition from SW monsoon winds. Kunkeshwar, Mithbav, Katvan, Munge, Achra, Vayagani, Tondavali, and Talashi beaches are identified as moderately well-sorted sediments with the influence of high wave energy condition. During the pre and post-monsoon seasons, the percentage of negative skewed samples in (sector-I) the foreshore zone were 100% indicating presence of beach erosion at Mithmumbri, Kunkeshwar, Mithbav, Katvan, and Munge. In sector-II, depositional processes are dominant and development of sandbars at Achra, Vayagani, and Tondavali beaches and sand spit formed at Talashi mouth of the Gad River. The bivariate plots indicate that most of the samples fall within the beach environment and few samples fall in the riverine/aeolian environment. The *CM* plots indicate sediments mostly originated in the tractive current and beach environment in both the seasons. LDF analysis indicated sediments in the present-day beaches have been deposited in shallow marine environment and in due course of time marine regression must have led to the development of present-day coastlines.

Authors' Contributions

M.A. Herlekar: Investigation, Conceptualization, Supervision, Writing Original Draft, Visualization. **P.B. Kamble:** Writing, Formal Analysis, Data Curation, Methodology, Software, Validation. **Arijit Chakraborty:** Formal Analysis, Software. **P.B. Gawali:** Visualization, Supervision, Reviewing and Editing.

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