Textural Characteristics of Coastal Sediments Between Bhavanapadu and Baruva Villages in Srikakulam District, East Coast of India

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Abstract: The texture of a rock or sediment is the size, shape, and arrangement of the grains. The microgeometry of sediments deals with intergranular relationship of grains, their size and shape. In the present study, a total of sixty surficial sediment samples were collected from the study area (foreshore-20, berm-7, backshore-13, and dunes-20) with an interval of 1 km. The geology, geomorphology, drainage pattern, climate, waves, and currents are discussed. The grain size parameters viz., mean grain size, standard deviation, skewness, and kurtosis are discussed extensively. Sand is the predominant component in all the sediment samples (99.82–99.93%) whereas silt and clay contents are less than 1% from the four environments. The mean grain size of the sediment samples shows that medium grained sands are followed by fine grained sands indicating a low energy environment of deposition. The standard deviation values reveal that the sediments are well to moderately sorted. The average values of skewness indicate that all the sediment samples are negatively skewed to positively skewed representing an environment of deposition of low to moderate energy conditions. Most of the kurtosis values indicate that the sediments are of platykurtic to leptokurtic in nature. The platykurtic nature of sediments indicates the sorting of tail portions of sediment populations.

Keywords: Texture, microgeometry, mean grain size, standard deviation, skewness, kurtosis, platykurtic, and leptokurtic.

1. INTRODUCTION

The texture of a rock or sediment is the size, shape, and arrangement of the grains. The microgeometry of sediments deals with intergranular relationship of grains, their size and shape. For the past several decades, granulometric studies of unconsolidated sediments have been taken up by many researchers as they are fundamentally related to the mechanism of transportation and deposition of ancient as well as the Recent sediments. These studies have proved that the study of textural parameters serves as effective tools to understand the mode of transportation and the nature of the depositional environment of sediments. In the present study, the grain size characteristics of sediments from the foreshore, berm, backshore, and dune environments between Bhavanapadu and Baruva villages the in Srikakulam district, Andhra Pradesh, East coast of India, were investigated.

Location of the Study Area

The present study area is the coastal area with a length of about 44 km between Bhavanapadu and Baruva villages in the Srikakulam district. Bhavanapadu is a village in the Santha Bommali mandal and Baruva is also a village in the Sompeta mandal in Srikakulam district. The geographical coordinates of the study area lie between 18º 32′ & 18º 53′ North Latitudes, and 84º 14′ & 84º 35′ East Longitudes (Figure 1).

Geology of the Source Area

The source material for the beach sands is the sediment carried out by the various rivers and streams originating and flowing through the hinterlands, and remote landforms. The hinterlands expose a variety of litho-units ranging in age from the Archean to Quaternary period which form a part of the Eastern Ghats Granulite Belt (EGGB) fringing the eastern part of the Indian Peninsular Shield. The studies on the regional geology by several researchers and employees from the Geological Survey of India (GSI) have given a generalized stratigraphic sequence (Table 1) for the Srikakulam and Vizianagaram districts (Varaprasada Rao, 1963; Sharma, et. al., 1974; Venkata Subba et al., 1978). Geologically, the hinterland is constituted of an assemblage of khondalites, charnockites, high grade granulites, and gneissic rocks belonging to the Eastern Ghats Supergroup (Figure 2). The coastal stretch is characterized by the presence of extensive alluvial plains.

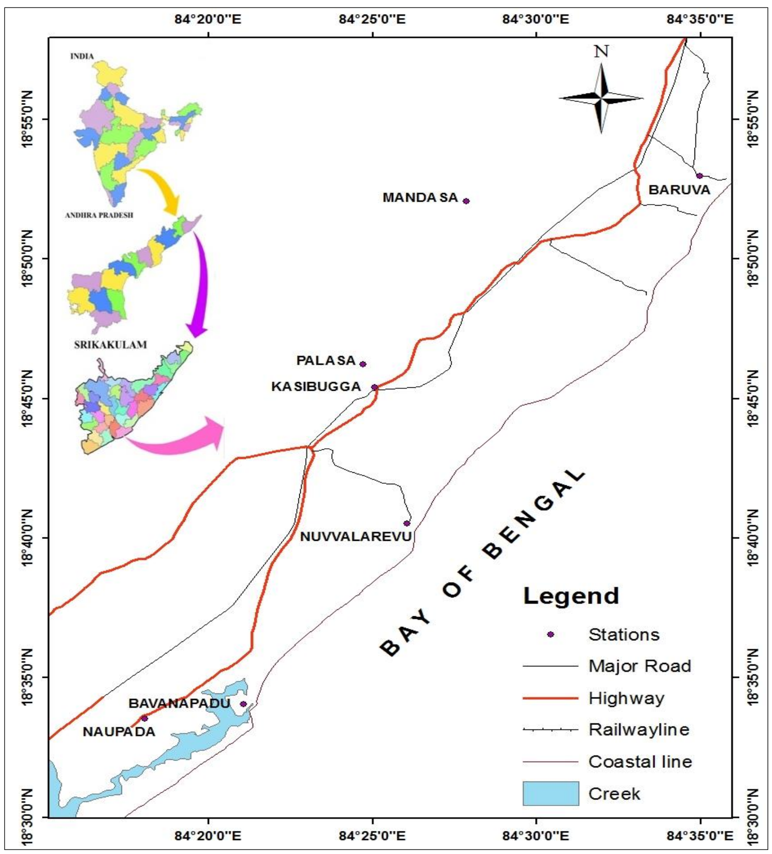


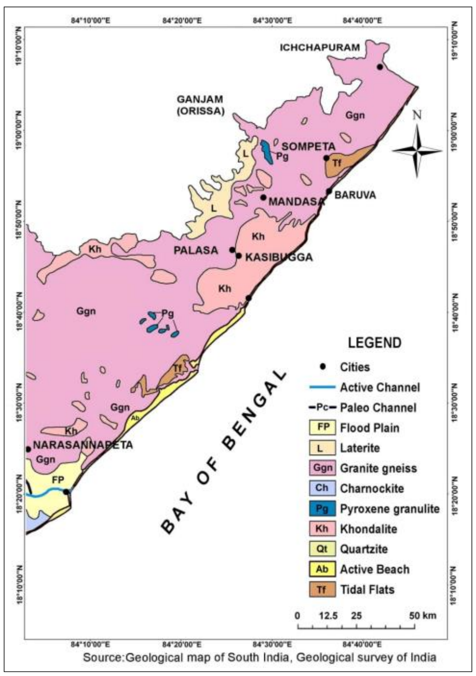
Figure 1. Location of the study area

Geomorphology of the Study Area

Varied and geologically significant geomorphological features are observed in the study area. Geomorphologically, the Srikakulam and Vizianagaram districts can be broadly divided into four distinct units i.e., structural hills, pediplains, alluvial and coastal plains (Figure 3). The study area has straight coastline and some geomorphological features such as estuaries, rock protrusions, mudflats, dune complexes, ridges, hills, and bays are recorded. The average height for the coastal dunes ranges from 7.7 to 14.0 m above mean sea level. Dune complexes are very well identified with the development of frontal dunes, inter-dunes, and rear-dunes in the study area. The beach segments between Bhavanapadu and Baruva have a symmetrical or asymmetrical ripple

Table 1. Geological succession of rock formations in the Eastern Ghats of Visakhapatnam and Vizianagaram Districts

Geologic Age of Formations	*Type of Rocks/ Formations*		*Mineral Assemblages*
Recent	Coastal alluvium and River alluvium		Sand, silt, and clay
Sub – Recent	Laterite and Lateritic wash		Mostly altered gneisses
Archaeans	Igneous formations	Charnokite series	Hypersthene-quartz-feldspar-granites
		Granite gneisses	Garnet-quartz-feldspar biotite-granite
	Metasedimentary rocks	Khondalite series of rocks	Garnet-sillamanite-quarz-feldspar-gneisses; Garnet-sillimanite-biotite-gneisses; Quartzites, garnetiferous quartzites and cac- granulites



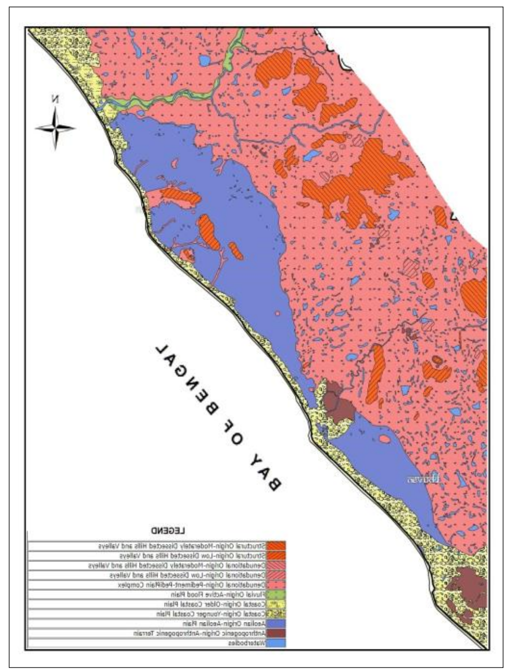


Figure 2. Geological map of the study area. **Figure 3.** Geomorphological map of the study area.

formation, and heavy mineral concentrations are noted in the troughs. Rock protrusions into the sea are observed at some places. Hills are elevated in and around the study area.

Drainage Pattern in the Study Area

The Mahendratanaya which is a tributary to the Vamsadhara River provides the major drainage system to contribute terrigenous sediments to the study area. The total catchment area of the Vamsadhara River basin is about 10,832 sq. km. Many streams originate in the hinterlands which are parts of the Eastern Ghats and drain the study area and deposit some sediments in the beach between Bhavanapadu and Baruva. All these drainage systems carry huge sediments during the rainy season. Mahanadi and Vamsadhara rivers join the Bay of Bengal in the north, and Godavari and Krishna rivers join the Bay of Bengal in the south of the study area. Thus, the study area lies between four major rivers which deposit huge sediments in the east coast of India. These sediments may be reworked by the waves and currents of the sea and some sediments may be transported longer distances along the seacoast. Hence, some of these sediments, especially sand, might be transported to the study area.

Physiography of the Hinterland

The hinterland of the study area is a part of the Eastern Ghats and the hilly terrain representing the high topographic relief is characterized by hills, and forming extension of the Eastern Ghats, exhibits a NE–SW trend. Many valleys exist in the hinterland and serve as conduits for the transport of sediments into the study area. Several plains consisting of river alluvium are also observed in the Eastern Ghats bordering the study area.

CARTOSA-I satellite data is used to prepare the Digital Elevation Model (DEM) which is availed in the present study using GIS. In the study area, digital topography varies from mean sea level (0 m) to an elevation of 543 m. Here the low elevation shows river basin, and flood plain areas. The hilly regions exhibit higher elevation with dissected and structurally controlled Eastern Ghats which serve as source rocks of the present study area.

Winds, Waves and Currents

Waves and currents are the two transporting agents which rework the sediments deposited earlier in the sea. During the southwest monsoon (June to September) and pre-monsoon, the direction of the waves is predominantly from southwest, south, and west, and the heights of the waves range from 1 m to 3.72 m whereas northeast monsoon (December–February) waves approach from north, northeast, east-northeast, and east and the heights of the waves vary from 0 m to 2.25 m. The seasonal wind systems drive the surface circulation and include corresponding seasonal currents in the Bay. During the northeast monsoon season, the prevailing winds produce a westerly drift in the deep sea which accumulates along western boundary of the Bay (i.e., the east coast of India) and results in north to south currents down the coast. In the east coast shelf, the currents have strength of 1-1.5 m/sec^{-1} in the southwest monsoon and 0.5-1.0 m sec^{-1} in the northeast monsoon season. Wave turbulence puts the sediment in suspension while the current carries it away from the source.

Climate:

Temperature and Humidity

Temperature in the study area rises from the middle of February to May, and maximum temperature recorded is about 42^{o} C in May. With the onset of southwest monsoon, the temperature decreases by 2-3^{o} C, in the winter season. Humidity in this region is more (nearly 80%) in the early hours of the day and by evenings, it decreases relatively low up to 70%. Humidity is more during rainy season and less in winter season.

2. MATERIALS AND METHODS

Sampling Method

A total of sixty surficial beach sand samples have been collected from the study area (foreshore-20, berm-7, backshore-13, and dunes-20) with an interval of 1 km as shown in the sample location map (Figure 4). Samples have been collected by penetrating PVC pipes of 10 cm diameter and 30 cm length into the sediments at the sampling stations. All the samples have been carefully transferred to the labelled polythene bags for laboratory investigations.

In addition, rock samples from different litho-units *viz*. charnockites, khondalites, pyroxene granulites and leptynites of Central Eastern Ghat Granulite Belt forming the hinterland of the study area were collected.

Treatment of the Collected Samples

A representative portion of 100 gm of bulk sample collected from the study area has been taken by coning and quartering method and treated with 10–20 ml of 6% hydrogen peroxide (H_2O_2) and 10–20 ml of dilute hydrochloric acid (HCl) to dissolve the organic matter and carbonate shell material respectively. After washing and drying, the samples were ready for textural analysis.

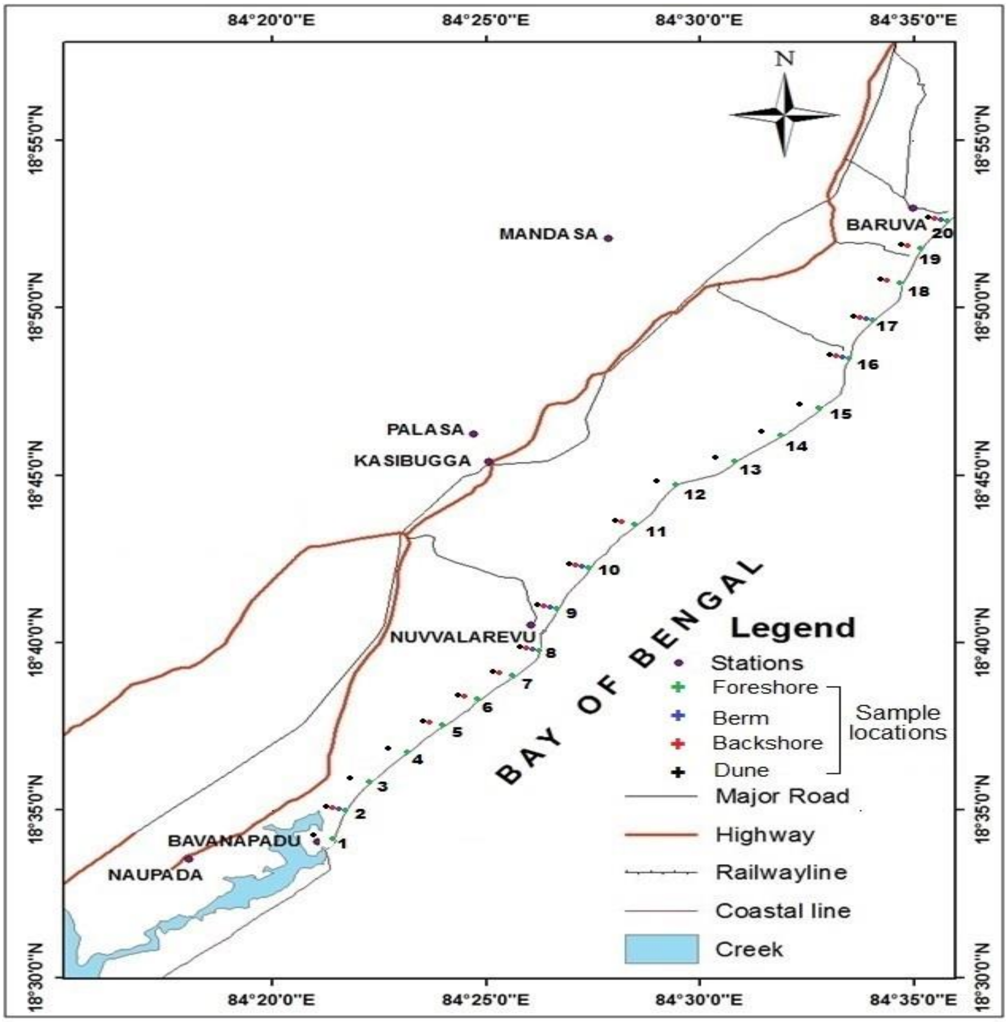


Figure 4. Sample location map of the study area.

Sieving Analysis Method

The stack of sieves is in such an order that the coarsest sieve is at the top and the finer ones are below the upper one with a pan at the bottom to catch any sediment that passes through the lowest and finest sieve. The dried sediment samples have been placed in the uppermost sieve as suggested by Lewis (1984). The sieve set (18, 25, 35, 45, 60, 80, 120, 170, +230 and -230 mesh) was placed on Ro-Tap sieve shaking machine. Sieving of sand is carried out in the ASTM (American Society for Testing Materials) sieving sets at ½ φ interval using Ro-Tap sieve shaker continuously for about 15 minutes. During sieve, care should be taken to minimize the sand loss from the sieve sets. The sieved material from each sieve was collected separately for weighing. Weights of the individual fractions have been tabulated for granulometric studies. The sieved sands were kept separately for light and heavy mineral separation.

3. RESULTS AND DISCUSSION:

Sand, Silt and Clay Contents of the Sediments

Sand, silt, and clay contents in sediments of the foreshore (FS), berm (B), backshore (BS), and dune (D) environments of the study area, are given in Tables 2, 3, 4, and 5 respectively. Weight percentages of sand, silt, and clay were plotted in triangular diagram (Shepard, 1954) & (Figure 5) to know the type of texture of the sediments.

It has been observed that sand is the predominant component in all the sediment samples. It varies from 99.44% at 9D to 99.99% at 18FS with an average from 77.71% in the berm environment to 90.84% in the foreshore environment. Silt varies from 0.01% at 20FS to 0.07 at 10B and 20B with an average ranging from 0.07 in berm and backshore environments to 0.12% in the dune environment. Clay is absent in all the four environments (Tables 2-5).

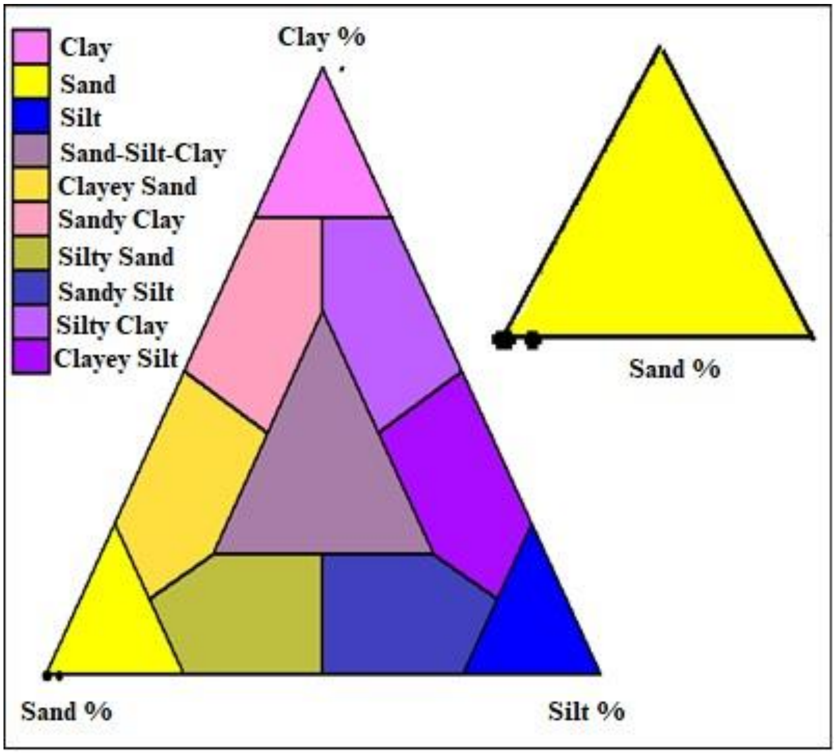


Figure 5. Textural nomenclatures of coastal sediments between Bhavanapadu and Baruva (After Shepard, 1954)

Table 2. Distribution of Sand, Silt and Clay (wt.%) in the sediments from Foreshore environment between Bhavanapadu and Baruva

Traverse No	Sample No.	Sand	Silt	Clay	Textural type
1	**1FS**	99.91	0.06	0.00	Sand
2	**2FS**	99.90	0.08	0.00	Sand
3	**3FS**	99.93	0.07	0.00	Sand
4	**4FS**	99.82	0.16	0.00	Sand
5	**5FS**	99.93	0.08	0.00	Sand
6	**6FS**	99.95	0.05	0.00	Sand
7	**7FS**	99.92	0.07	0.00	Sand
8	**8FS**	99.90	0.07	0.00	Sand
9	**9FS**	99.85	0.18	0.00	Sand
10	**10FS**	99.86	0.19	0.00	Sand
11	**11FS**	99.88	0.12	0.00	Sand
12	**12FS**	99.88	0.11	0.00	Sand
13	**13FS**	99.96	0.07	0.00	Sand

14	**14FS**	99.98	0.02	0.00	Sand
15	**15FS**	99.97	0.03	0.00	Sand
16	**16FS**	99.97	0.05	0.00	Sand
17	**17FS**	99.96	0.04	0.00	Sand
18	**18FS**	99.99	0.02	0.00	Sand
19	**19FS**	99.95	0.04	0.00	Sand
20	**20FS**	99.97	0.01	0.00	Sand
Minimum		**99.82**	**0.01**	**0.00**	**-**
Maximum		**99.99**	**0.19**	**0.00**	**-**
Average		**90.84**	**0.07**	**0.00**	**-**

Table 3. Distribution of Sand, Silt and Clay (wt.%) in the sediments from Berm environment between Bhavanapadu and Baruva

Travers No.	Sample No.	Sand	Silt	Clay	Textural type
2	**2B**	99.92	0.08	0.00	Sand
8	**8B**	99.91	0.09	0.00	Sand
9	**9B**	99.91	0.09	0.00	Sand
10	**10B**	99.93	0.07	0.00	Sand
16	**16B**	99.91	0.09	0.00	Sand
17	**17B**	99.92	0.08	0.00	Sand
20	**20B**	99.93	0.07	0.00	Sand
Minimum		**99.91**	**0.07**	**0.00**	**-**
Maximum		**99.93**	**0.09**	**0.00**	**-**
Average		**77.71**	**0.06**	**0.00**	**-**

Table 4. Distribution of Sand, Silt and Clay (wt.%) in the sediments from Backshore environment between Bhavanapadu and Baruva

Travers No.	Sample No.	Sand	Silt	Clay	Textural type
2	**2BS**	99.92	0.08	0.00	Sand
5	**5BS**	99.91	0.09	0.00	Sand
6	**6BS**	99.87	0.14	0.00	Sand
7	**7BS**	99.92	0.08	0.00	Sand
8	**8BS**	99.98	0.02	0.00	Sand
9	**9BS**	99.90	0.10	0.00	Sand
10	**10BS**	99.96	0.04	0.00	Sand
11	**11BS**	99.93	0.07	0.00	Sand
16	**16BS**	99.91	0.09	0.00	Sand

17	**17BS**	99.92	0.08	0.00	Sand
18	**18BS**	99.97	0.03	0.00	Sand
19	**19BS**	99.95	0.05	0.00	Sand
20	**20BS**	99.96	0.04	0.00	Sand
Minimum		**99.87**	**0.02**	**0.00**	-
Maximum		**99.98**	**0.14**	**0.00**	-
Average		**86.61**	**0.06**	**0.00**	-

Table .5. Distribution of Sand, Silt, and Clay (wt.%) in the sediments from Dune environment between Bhavanapadu and Baruva

Travers No.	Sample No.	Sand	Silt	Clay	Textural type
1	**1D**	99.90	0.10	0.00	Sand
2	**2D**	99.86	0.14	0.00	Sand
3	**3D**	99.91	0.09	0.00	Sand
4	**4D**	99.90	0.10	0.00	Sand
5	**5D**	99.89	0.11	0.00	Sand
6	**6D**	99.87	0.13	0.00	Sand
7	**7D**	99.84	0.17	0.00	Sand
8	**8D**	99.84	0.16	0.00	Sand
9	**9D**	99.44	0.56	0.00	Sand
10	**10D**	99.87	0.13	0.00	Sand
11	**11D**	99.90	0.10	0.00	Sand
12	**12D**	99.92	0.08	0.00	Sand
13	**13D**	99.64	0.36	0.00	Sand
14	**14D**	99.95	0.05	0.00	Sand
15	**15D**	99.97	0.04	0.00	Sand
16	**16D**	99.93	0.07	0.00	Sand
17	**17D**	99.91	0.09	0.00	Sand
18	**18D**	99.92	0.08	0.00	Sand
19	**19D**	99.91	0.09	0.00	Sand
20	**20D**	99.95	0.05	0.00	Sand
Minimum		**99.44**	**0.05**	**0.00**	**-**
Maximum		**99.97**	**0.56**	**0.00**	**-**
Average		**90.79**	**0.12**	**0.00**	**-**

In the foreshore environment, sand varies from 99.82% (station 4FS) to 99.99 % (station FS) with an average of 90.84%, in the berm environment from 99.91 % (stations 8B, 9B & 16B) to 99.93 (stations 10B & 20B) with an average of 77.71%, in the backshore environment, from 99.87% (station 6BS) to 99,98% (station 8BS) with an average of 86.61 %, and in the dunes, from 99.44% (station 9D) to 99.97 % (station 15D) with an average of 90.79 %. The sand is fine-grained at 2 stations (stations 1FS & 2FS) and medium-grained at the remaining 18 stations in the foreshore environment. In the berm environment, sand is medium grained at all the 7 stations. In the backshore environment also, the sand is medium grained at all the 13 stations. In the dunes, fine-grained sand occurs at 8 stations (1D,3 2D, 3D, 4D, 6D, 8D, 11D, & 12D) and medium grained at the remaining 12 stations.

4. GRAIN SIZE PARAMETERS

Mean Grain Size

Grain size is the average size of the grains in a sediment sample and is also known as the particle size. Sand consists of grains of particle size varying from 0.063 to 2 mm. Silt consists of grains of particle size varying between 0.009 and 0.063 mm. and is intermediate between sand and clay. Clay consists of grains of particle size between silt and colloidal particles. These particles include any of the various hydrous aluminum silicate minerals which consist of plasticity and are expanding having ion-exchange capacities. The Mean Grain Size (M_z) can be obtained from the formula of Folk and Ward (1957). It represents the average size of the total distribution of sediments. The Mean Grain Size of the sediments depends on the energy and the time taken by the depositing medium, and composition and durability of the grains. The availability of grains of various sizes is also another important controlling factor. According to Folk and Ward (1957), the Mean Grain Size values have been grouped as coarse sand (0 to 1Ø), medium sand (1 to 2Ø), fine sand (2 to 3Ø), and very fine sand (3 to 4Ø).

The average mean grain size values of all the four environments vary from 1.16 (foreshore environment) to 2.33Φ (dune environment) indicating that all the sediments samples are medium to fine grained in nature (Tables 6-9). The mean grain size values of sediments of the foreshore ranges from 1.16 to 2.38Φ with an average of 1.50Φ. The average value denotes that the major sediment class is medium grained in size. Two sediment samples having the value >2Φ (1FS & 2FS) have comparatively fine-grained sands. In berm sediments, mean grain size ranges from 1.75 to 1.77Φ with an average 1.37Φ which indicates that all the sediments are of medium sand. In backshore sediments, mean grain size values range from 1.55 to 1.89Φ with an average value of 1.47Φ. All the sediment samples in backshore environment having the value less than 2Φ are medium grained, and in the dune sands the mean grain size values range from 1.61 to 2.33Φ with an average value of 1.76Φ. The value indicates that most sediments are medium to fine grained in size.

Table 6. Statistical Parameters of sediments (Φ) from Foreshore environment between Bhavanapadu and Baruva

Traverse No.	Sample No.	Mean Size (Mz)		Standard Deviation (σ1)		Skewness (SK_1)		Kurtosis (K_G)	
1	**FS 1**	2.38	Fine Sand	0.46	Well Sorted	-0.06	Nearly Symmetrical	0.85	Platykurtic
2	**FS 2**	2.37	Fine Sand	0.48	Well Sorted	-0.02	Nearly Symmetrical	0.88	Platykurtic
3	**FS 3**	1.68	Medium Sand	0.70	Moderately sorted	-0.20	Nearly Symmetrical	1.29	Leptokurtic
4	**FS 4**	1.65	Medium Sand	0.71	Moderately sorted	-0.22	Negatively Skewed	1.24	Leptokurtic
5	**FS 5**	1.55	Medium Sand	0.62	Moderately sorted	-0.12	Negatively Skewed	1.21	Leptokurtic
6	**FS 6**	1.75	Medium Sand	0.55	Moderately sorted	0.07	Nearly Symmetrical	1.23	Leptokurtic
7	**FS 7**	1.54	Medium Sand	0.61	Moderately sorted	-0.16	Negatively Skewed	1.17	Leptokurtic
8	**FS 8**	1.55	Medium Sand	0.61	Moderately sorted	-0.13	Negatively Skewed	1.18	Leptokurtic
9	**FS 9**	1.55	Medium Sand	0.71	Moderatly sorted	-0.21	Negatively Skewed	1.13	Leptokurtic
10	**FS 10**	1.57	Medium Sand	0.72	Moderatly sorted	-0.21	Negatively Skewed	1.16	Leptokurtic

11	**FS 11**	1.74	Medium Sand	0.70	Moderatly sorted	-0.18	Negatively Skewed	1.44	Leptokurtic
12	**FS 12**	1.75	Medium Sand	0.68	Moderatly sorted	-0.19	Negatively Skewed	1.39	Leptokurtic
13	**FS 13**	1.64	Medium Sand	0.45	Well Sorted	0.38	very positive skewed	0.97	Mesokurtic
14	**FS 14**	1.68	Medium Sand	0.53	Moderatly sorted	0.08	Nearly symmetrical	0.97	Mesokurtic
15	**FS 15**	1.50	Medium Sand	0.38	Well Sorted	0.32	very positive skewed	1.14	Leptokurtic
16	**FS 16**	1.33	Medium Sand	0.48	Well sorted	0.19	Positively Skewed	1.64	Very Leptokurtic
17	**FS 17**	1.58	Medium Sand	0.42	Well Sorted	0.44	Very Positive Skewed	0.99	Mesokurtic
18	**FS 18**	1.45	Medium Sand	0.46	Well Sorted	0.27	Positively Skewed	1.23	Leptokurtic
19	**FS 19**	1.58	Medium Sand	0.43	Well Sorted	0.37	Very Positive Skewed	0.97	Mesokurtic
20	**FS 20**	1.16	Medium Sand	0.57	Moderatly sorted	0.01	Nearly Symmetrical	1.34	Leptokurtic
Minimum		**1.16**	-	**0.38**	-	**-0.22**	**-**	**0.85**	-
Maximum		**2.38**	**-**	**0.72**	-	**0.44**	**-**	**1.64**	-
Average		**1.5**	-	**0.51**	-	**0.02**	**-**	**1.06**	-

Table 7. Statistical Parameters of sediments (Φ) from Berm environment between Bhavanapadu and Baruva

Traverse No.	**Sample No.**	**Mean Size (Mz)**		**Standard Deviation (σ1)**		**Skewness (SK1)**		**Kurtosis (K_G)**	
2	**2B**	1.77	Medium Sand	0.58	Moderately Sorted	0.09	Nearly Symmetrical	1.29	Leptokurtic
8	**8B**	1.76	Medium Sand	0.57	Moderately Sorted	0.08	Nearly Symmetrical	1.28	Leptokurtic
9	**9B**	1.76	Medium Sand	0.54	Moderately Sorted	0.04	Nearly Symmetrical	1.36	Leptokurtic
10	**10B**	1.76	Medium Sand	0.51	Moderately Sorted	0.03	Nearly Symmetrical	1.30	Leptokurtic
16	**16B**	1.75	Medium Sand	0.52	Moderately Sorted	0.02	Nearly Symmetrical	1.29	Leptokurtic
17	**17B**	1.77	Medium Sand	0.53	Moderately Sorted	0.04	Nearly Symmetrical	1.31	Leptokurtic
20	**20B**	1.76	Medium Sand	0.57	Moderately Sorted	0.05	Nearly Symmetrical	1.32	Leptokurtic
Minimum		**1.75**	**-**	**0.51**	**-**	**0.02**	**-**	**1.28**	**-**
Maximum		**1.77**	**-**	**0.58**	**-**	**0.09**	**-**	**1.36**	**-**
Average		**1.37**	**-**	**0.42**	**-**	**0.04**	**-**	**1.02**	**-**

Table 8. Statistical Parameters of sediments (Φ) from Backshore environment between Bhavanapadu and Baruva

Traverse No.	**Sample No.**	**Mean Size (Mz)**		**Standard Deviation (σ1)**		**Skewness (SK1)**		**Kurtosis (K_G)**	
2	**2BS**	1.64	Medium sand	0.51	Well Sorted	0.06	Nearly Symmetrical	1.21	Leptokurtic
5	**5BS**	1.75	Medium sand	0.56	Moderately Sorted	0.06	Nearly Symmetrical	1.28	Leptokurtic
6	**6BS**	1.62	Medium sand	0.51	Well Sorted	0.06	Nearly Symmetrical	1.27	Leptokurtic
7	**7BS**	1.65	Medium sand	0.51	Well Sorted	0.06	Nearly Symmetrical	1.24	Leptokurtic
8	**8BS**	1.81	Medium sand	0.63	Moderately Sorted	0.07	Nearly Symmetrical	1.22	Leptokurtic
9	**9BS**	1.89	Medium sand	0.70	Moderately Sorted	0.16	Positively Skewed	1.02	Mesokurtic
10	**10BS**	1.82	Medium sand	0.65	Moderately Sorted	0.12	Positively Skewed	1.18	Leptokurtic
11	**11BS**	1.64	Medium sand	0.64	Moderately Sorted	0.02	Nearly Symmetrical	1.16	Leptokurtic

16	**16BS**	1.68	Medium sand	0.58	Moderately Sorted	0.07	Nearly Symmetrical	1.25	Leptokurtic
17	**17BS**	1.68	Medium sand	0.59	Moderately Sorted	0.12	Positively Skewed	1.23	Leptokurtic
18	**18BS**	1.55	Medium sand	0.54	Moderately Sorted	-0.04	Nearly Symmetrical	1.28	Leptokurtic
19	**19BS**	1.56	Medium sand	0.49	Well Sorted	-0.02	Nearly Symmetrical	1.22	Leptokurtic
20	**20BS**	1.80	Medium sand	0.44	Well Sorted	0.29	Positively Skewed	0.87	Platykurtic
Minimum		**1.55**	**-**	**0.44**	**-**	**-0.04**	**-**	**0.87**	**-**
Maximum		**1.89**	**-**	**0.70**	**-**	**0.29**	**-**	**1.28**	**-**
Average		**1.47**	**-**	**0.49**	**-**	**0.07**	**-**	**1.03**	**-**

Table 9. Statistical Parameters of sediments (Φ) from Dune environment between Bhavanapadu and Baruva

Traverse No.	**Sample No.**	**Mean Size (Mz)**		**Standard Deviation (σ1)**		**Skewness (SK1)**		**Kurtosis (K_G)**	
1	**1D**	2.17	Fine Sand	0.57	Moderately Sorted	0.27	Positively Skewed	0.92	Mesokurtic
2	**2D**	2.18	Fine Sand	0.56	Moderately Sorted	0.28	Positively Skewed	0.91	Mesokurtic
3	**3D**	2.18	Fine Sand	0.56	Moderately Sorted	0.28	Positively Skewed	0.93	Mesokurtic
4	**4D**	2.17	Fine Sand	0.56	Moderately Sorted	0.21	Positively Skewed	0.93	Mesokurtic
5	**5D**	1.75	Medium Sand	0.71	Moderately Sorted	0.15	Positively Skewed	1.10	Mesokurtic
6	**6D**	2.11	Fine Sand	0.51	Moderately Sorted	0.29	Positively Skewed	0.96	Mesokurtic
7	**7D**	1.61	Medium Sand	0.67	Moderately Sorted	0.03	Nearly Symmetrical	1.18	Leptokurtic
8	**8D**	2.33	Fine Sand	0.65	Moderately Sorted	-0.10	Negatively Skewed	0.92	Mesokurtic
9	**9D**	1.87	Medium Sand	0.70	Moderately Sorted	0.22	Positively Skewed	1.15	Leptokurtic
10	**10D**	1.80	Medium Sand	0.73	Moderately Sorted	0.14	Positively Skewed	1.17	Leptokurtic
11	**11D**	2.15	Fine Sand	0.59	Moderately Sorted	0.34	Very Positive Skewed	0.97	Mesokurtic
12	**12D**	2.15	Fine Sand	0.59	Moderately Sorted	0.36	Very Positive Skewed	0.97	Mesokurtic
13	**13D**	1.65	Medium Sand	0.59	Moderately Sorted	0.16	Positively Skewed	1.28	Leptokurtic
14	**14D**	1.91	Medium Sand	0.49	well sorted	0.11	Positively Skewed	0.92	Mesokurtic
15	**15D**	1.81	Medium Sand	0.48	well sorted	0.25	Positively Skewed	0.94	Mesokurtic
16	**16D**	1.66	Medium Sand	0.48	well sorted	0.31	Very Positive Skewed	0.74	Platykurtic
17	**17D**	1.71	Medium Sand	0.44	well sorted	0.40	Very Positive Skewed	0.97	Mesokurtic
18	**18D**	1.81	Medium Sand	0.45	well sorted	0.26	Positively Skewed	0.86	Platykurtic
19	**19D**	1.92	Medium Sand	0.51	Moderately sorted	0.05	Nearly Symmetrical	0.87	Platykurtic
20	**20D**	1.79	Medium Sand	0.43	well sorted	0.29	Positively Skewed	0.88	Platykurtic
Minimum		**1.61**	**-**	**0.43**	**-**	**0.03**	**-**	**0.74**	**-**
Maximum		**2.33**	**-**	**0.73**	**-**	**0.40**	**-**	**1.28**	**-**
Average		**1.76**	**-**	**0.51**	**-**	**0.20**	**-**	**0.89**	**-**

Standard Deviation

Standard deviation is a measure of uniformity or sorting characteristics of sediments. According to Mc Kinney and Friedman (1970), standard deviation is a measure of the dispersion of the grain size distribution. It is also the resultant characteristic of sediments controlled by size, shape, and specific gravity of the sediments, and energy, velocity, time, degree of turbulence and viscosity of the transporting medium. Sorting is A useful property because it reflects the energy of the depositional environment and the presence or absence of course- and fine-grained fractions (Frank and Friedman, 1973). The sediments as per the classification of Folk and Ward (1957) can be grouped as follows; very well sorted (<0.35Ø), well sorted (0.35 to 0.5Ø), moderately sorted (0.5 to 1Ø), poorly sorted (1 to 2Ø), very poorly sorted (2 to 4Ø) and extremely poorly sorted(>4Ø).

The average standard deviation values of sediments of the study area ranges from 0.38Ø (in the foreshore environment) to 0.73Ø (in the dune environments) which indicates all the sediment samples are moderately to well sorted in nature (Tables 6-9). The standard deviation values of the foreshore vary from 0.38Ø at station FS15 to 0.Φ 72 at station 10FS with an average value of 0.51Ø. The average value indicates that these sediments are moderately sorted to well sorted in nature. In berm environment, the standard deviation values range from 0.51Ø at station 10B to 0.58Φ at station 2B with an average value of 0.42Φ. The average value indicates that the sediment samples are moderately to well sorted. The standard deviation values of backshore sediments vary from 0.44Ø at station 20BS to 0.70Φ at station 9BS with an average value of 0.49Φ. Most of the sediment samples are showing moderately to well sorted. The standard deviation values of dune sediments vary from 0.43Ø at station 20D to 0.73Φ at station 10D with an average value of 0.51Φ which indicates that these sediments are also moderately sorted.

Skewness

Skewness is a measure of symmetry of grain size distribution. In other words, it is the degree of symmetry or asymmetry of the grain size distribution which is in turn a function of the coincidence or non-coincidence of mean, median, and mode (Veera Krishna, 2020). It is a significant parameter in delineating environments because it is sensitive to sub-population mixing. The importance of skewness has been discussed in detail by Duane (1964). Negative skewness is correlated with high energy while positive skewness is correlated with low energy conditions Ganapathi Rao, 2016.

Based on the verbal classification of Folk and Ward (1957) skewness values can be grouped into very negatively skewed (-1.00 to -0.30 Ø), negatively skewed (-0.30 to -0.10 Ø), near symmetrical (-0.10 to 0.10 Ø), positively skewed (0.10 to 0.30 Ø), and very positively skewed (0.30 to 1.00 Ø).

The average Skewness value of the sediments of the four environments ranges from -0.22Ø to 0.44 Ø in the foreshore environment. The average values indicate that all sediment samples are negatively skewed to very positively skewed (Tables 6-9). The skewness values of foreshore environment range from -0.22Ø at station FS4 to 0.44Φ at stations FS17 and the average value is 0.02Ø. These values represent that the sediments are negatively skewed to very positively skewed. The skewness values of sediments from berm environment range from 0.02Ø at station 16B to 0.09Φ at station 2B and the average value is 0.04Φ. The skewness values of backshore environment range from -0.04 at station 18BS to 0.29Φ at station 20BS and the average value is 0.07Φ) and these sediments are nearly symmetrical to very positively skewed. The skewness values of dune sediments range from 0.03Ø at station 7D to 0.40Φ at station 17D and the average value is 0.20Φ. These values indicate that these sediments are near symmetrical to very positively skewed.

Kurtosis

Kurtosis is a measure of ratio of the sorting in the tails of the cumulative curves of sediments and the sorting in the central portion. Based on the verbal class limits of Folk and Ward (1957), the kurtosis values are grouped into very platykurtic (<0.67Ø), platykurtic (0.67 to 0.9Ø), mesokurtic (0.9 to 1.11Ø), leptokurtic (1.11 to 1.5Ø), very leptokurtic (1.5 to 3Ø) and extremely leptokurtic (>3 Ø).

The average kurtosis values of sediments of the study area ranges from 0.74Ø in the dune environment to 1.64Φ in the foreshore environment (Tables 6-9). The kurtosis values of sediments from foreshore environment ranges from 0.85Ø at station FS1 to 1.64Ø at station FS16 and the average value is 1.06Ø. These values represent that the sediments are platykurtic to very leptokurtic in nature. The kurtosis values of sediments from berm environment ranges from 0.1.28Ø at station 8B to 1.36Ø at station 9B and the average value is 1.02Ø. These values indicate that the sediments are leptokurtic in nature. The kurtosis values of sediments from backshore environment ranges from

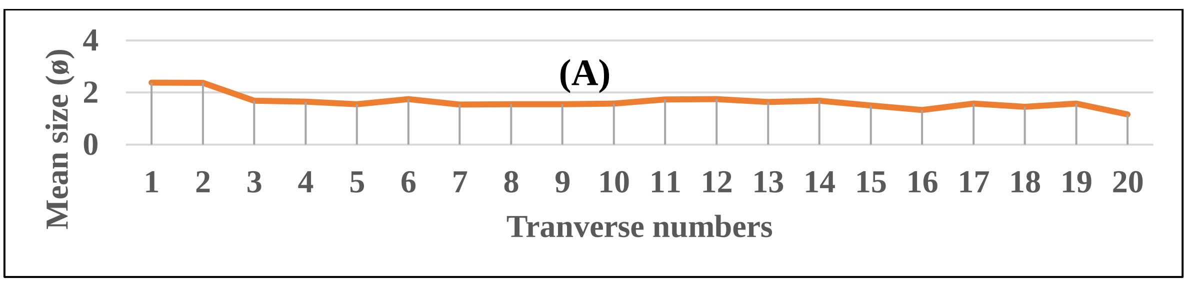
0.87Ø at station 20BS to 1.28Ø at stations 5BS & 18BS and the average value is 1.03Ø). These values represent that the sediments are platykurtic to leptokurtic in nature. The kurtosis values of sediment samples of dune environment ranges from 0.74Ø at station 16D to 1.28Ø at station 13D and the average value is 1.89Ø). These values represent that the sediments are platykurtic to leptokurtic in nature.

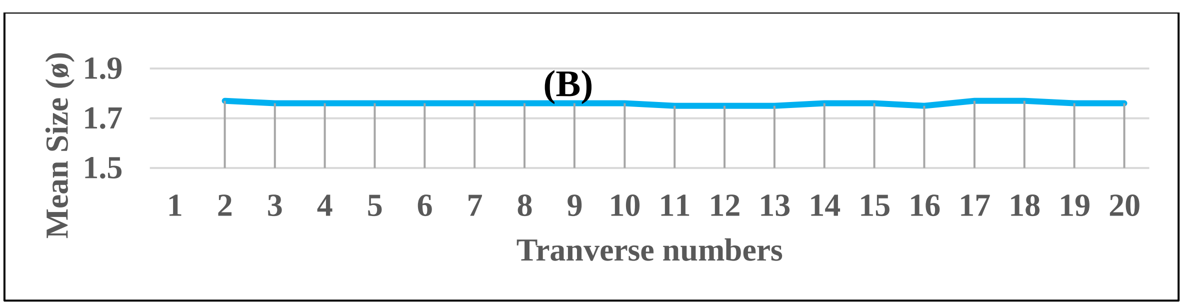
5. SPATIAL VARIATION OF TEXTURAL PARAMETERS

Spatial variation of the mean grain size of the foreshore, berm, backshore, and dune environments of the study area have been presented (Figure 6). Alongshore variation of mean grain size (phi) decreases away from seashore in the foreshore, berm, backshore, and dune environments. There is no systematic variation in mean grain size. The standard deviation of the sediments from foreshore, berm, backshore, and dune environments is plotted against the traverse numbers (Figure 7) and the standard deviation values of sediments from foreshore environment decreases away from the seashore which indicates poorly sorted sediments towards the berm and dune environments and moderately sorted sediments between the berms and the seashore. There is no systematic alongshore variation in standard deviation values in the berm, backshore, and dune environments. The skewness values of sediments from different microenvironments of the study area are plotted against traverse numbers (Figure 8). The negatively skewed sediments occur in foreshore, berm, and backshore environments and in other areas away from the seashore positively skewed sediments were distributed. There is no systematic alongshore variation of skewness in dune environment. At some traverses, negatively skewed sediments occur, and other areas were covered with positively skewed sediments. The kurtosis values of sediments from different microenvironments of the study area plotted against traverse numbers (Figure 9) and there is no systematic variation in kurtosis values of sediments in all microenvironments except foreshore, in which the values increase away from the seashore and with respect to kurtosis values, majority of the sediment samples show platykurtic to leptokurtic in nature. The variation in textural parameters of coastal sediments from environment to environment is prominent. Under the influence of the different wave energy conditions, the textural parameters exhibit differences in the distribution pattern.

6. THE INTER–RELATIONSHIP OF TEXTURAL PARAMETERS

The inter-relationship of four textural parameters can be understood only when they are plotted against each other as scatter diagrams. Keller (1945), Inman (1952), Folk and Ward (1957), Friedman (1961, 1967), Visher (1969), Valia and Cameron (1977), Suresh Gandhi et al. (2008), Ramanathan et al. (2009), Anithamary et al. 2011), and many other researchers have successfully used the scatter plots to understand the geological significance of the four size parameters and an attempt has been made to bring out the mode of deposition and environmental conditions.





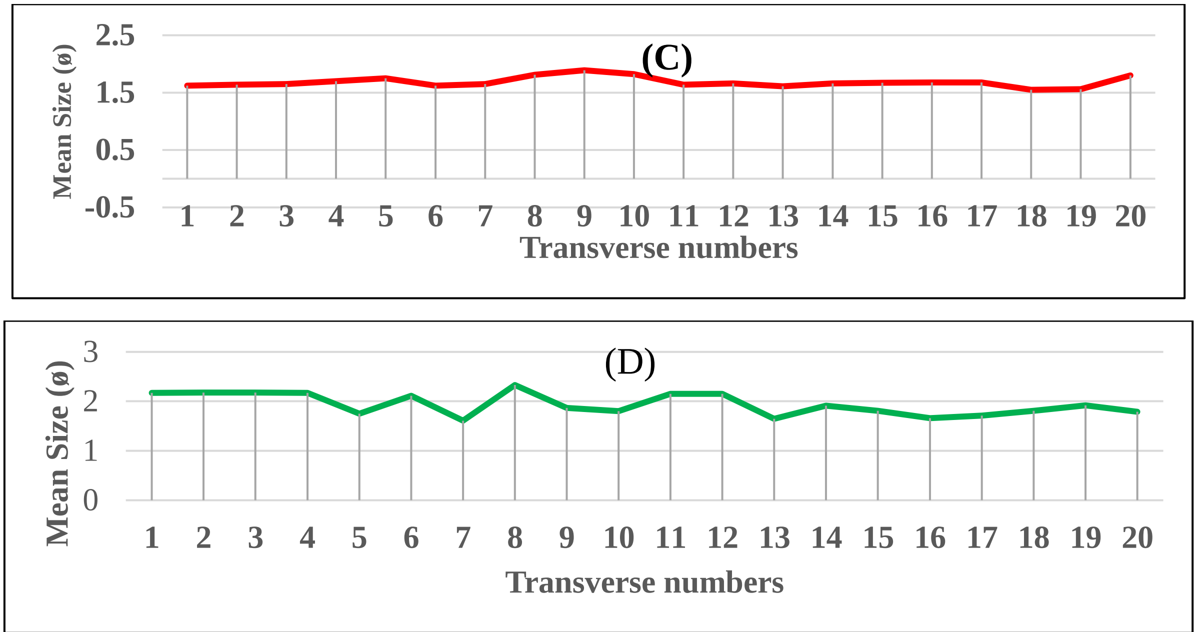
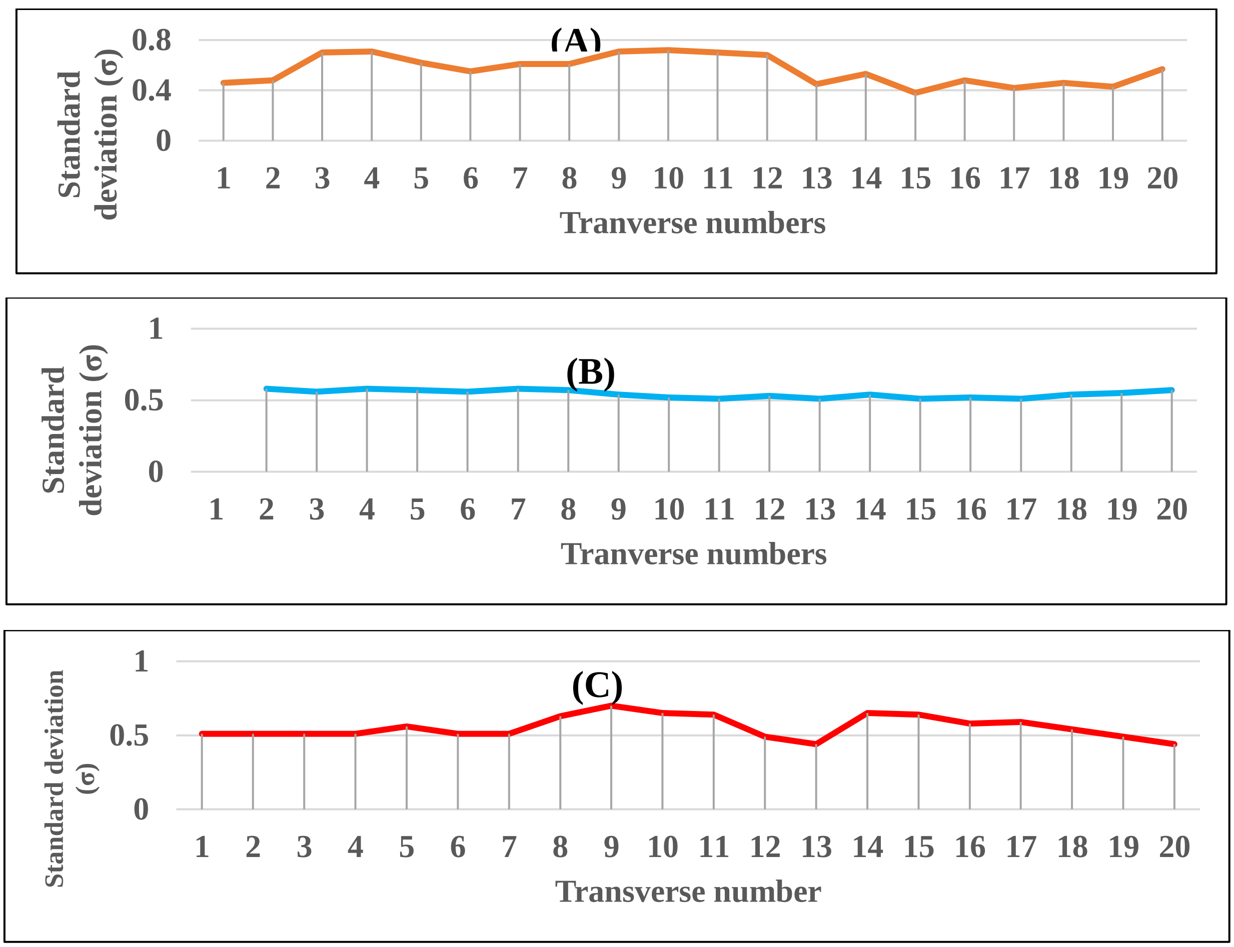


Figure 6. Spatial variation of mean Size (Φ) of coastal sediments from A) Foreshore, B) Berm, C) Backshore and D) Dune sands between Bhavanapadu and Barava



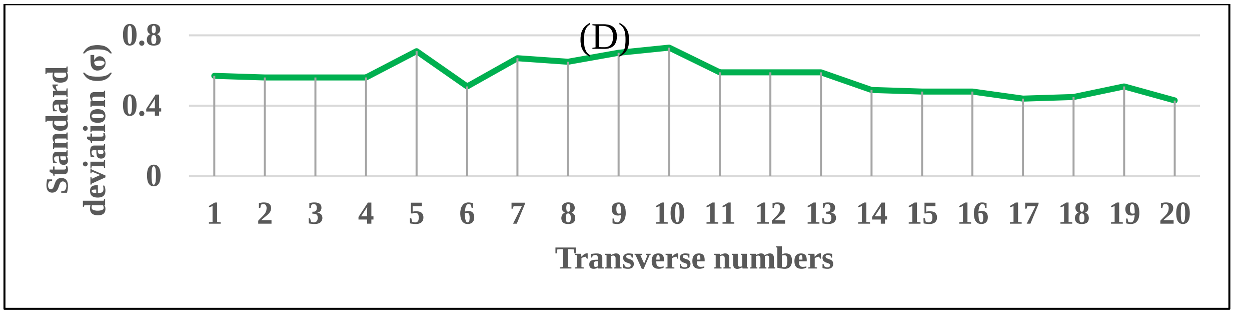


Figure 7. Spatial variation of standard deviation (Φ) of coastal sediments from A) Foreshore, B. Berm, C) Backshore and D) Dune sands between Bhavanapadu and Baruva

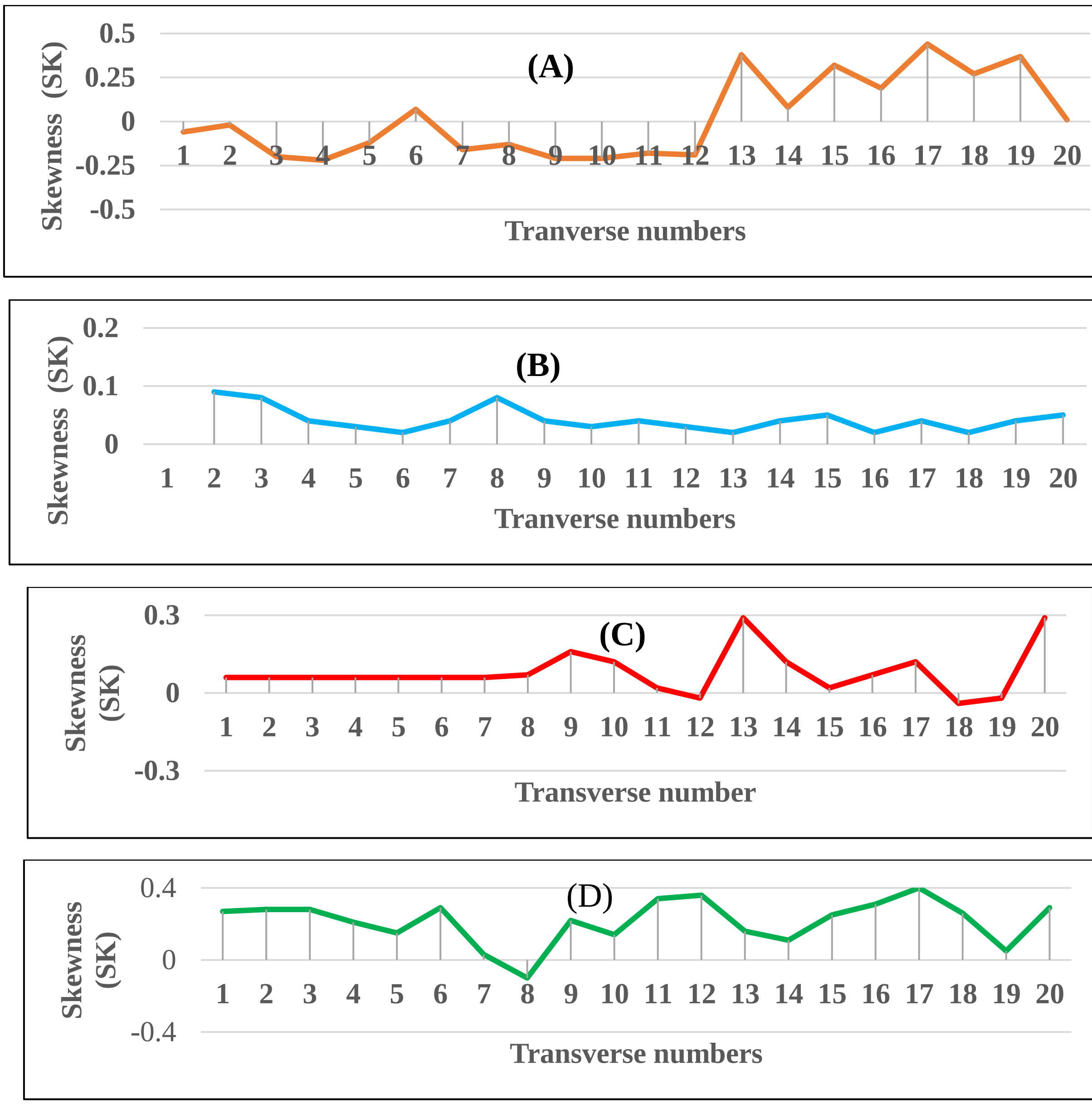


Figure 8. Spatial variation of skewness (Φ) of coastal sediments from A) Foreshore, B) Berm, C. Backshore and D) Dune sands between Bhavanapadu and Baruva

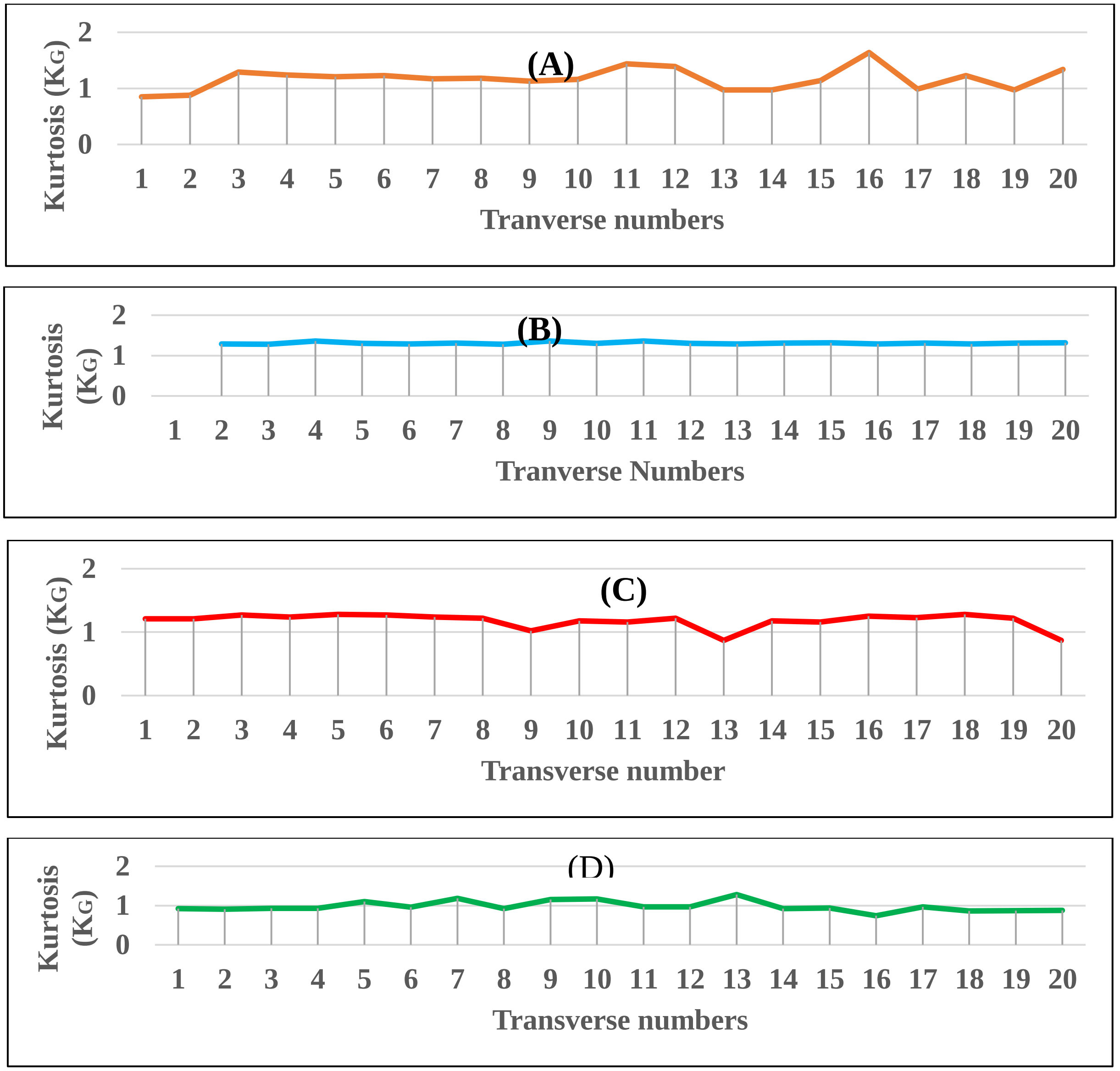


Figure 9. Spatial variation of kurtosis (Φ) of coastal sediments from A) Foreshore, B) Berm, C) Backshore and D) Dune sands between Bhavanapadu and Baruva

In the present study, scatter plots using statistical parameters obtained from graphic method are constructed to understand the relationship between them.

Mean Size vs Standard Deviation

The mean grain size versus standard deviation gives a great amount of information about the depositional environment (Figure 10). The sediment samples of foreshore and dune environments clearly show insignificant negative correlation. Sediment samples from the backshore environment, shows positive correlation (r= 0.32), i.e., mean grain size (Φ) values increase with increase of standard deviation values, and sediments from berm environment show negative correlation (r = - 0.37) i.e., mean grain size decreases with increase of standard deviation values, which indicates that fine sands are better sorted than coarse sands.

Mean Size vs Skewness

The scatter plot between mean grain size and skewness shows foreshore (r = -0.20) and berm (r = -0.37) sediments have insignificant negative correlation and backshore (r = -0.59) and dune (r = -0.44) sediments have significant negative correlation which indicates that the grain size in phi decreases with increase of skewness that implies coarse grained sediments are very positively skewed too positively skewed (Figure 11).

Mean size vs Kurtosis

The relation between mean grain size and kurtosis of coastal sediments from different microenvironments of study region i.e., foreshore (r = -0.50), backshore (r = -0.24), berm (r = -0.39) sediments shows negative correlation and dune sediments shows insignificant positive correlation (r = 0.08). From the scatter diagram (Figure 12), the grain size in phi increases, kurtosis values decrease from leptokurtic to platykurtic. There is no significant relation between mean size and kurtosis of sediment samples of dune environment.

Standard Deviation vs Skewness

The relationship between standard deviation (sorting) and skewness in sediments from foreshore (r = -.0.82), berm (r = -0.64) and backshore (r = -0.57) except dune (r = -0.02) environment which shows insignificant negative correlation i.e., standard deviation values increase with decrease of skewness values which indicates that very well sorted sediments have very positively skewed in nature (Figure 13).

Standard Deviation vs Kurtosis

Scatter plot of standard deviation vs kurtosis exhibits, foreshore (r = 0.45), berm (r = 0.27) and dune (r = 0.37) sediments show positive correlation which indicates increase the standard deviation values, kurtosis also increases which implies well sorted sediments have leptokurtic in nature and sediments from backshore (r = -0.07) environment shows insignificant negative correlation figure 14).

Skewness vs Kurtosis

The scatter diagram shows significant negative correlation for foreshore (r = -0.34), berm (r = -0.28) and dune (r = -0.32) sediments indicates decrease of skewness values kurtosis values decreases which implies negatively skewed sediments have platykurtic in nature. Sediments from backshore (r = -0.10) environment shows insignificant negative correlation (Figure 15).

Grain size parameters of sediment samples of the foreshore, berm, backshore, and dune environments of the study area illustrate that the sediments are medium to fine grained sands, well to moderately sorted, nearly symmetrical to very positively skewed and platykurtic to very leptokurtic in nature.

The mean grain size of surface sediments of different microenvironments ranges from 1.16 Φ (medium sand) to 2.67 Φ (fine sand) among the individual stations. Mean grain size of the beach sediments influenced by nature of source sediments, wave energy level and offshore slope (Komar, 1976).

The sediments transported along straight shoreline tend to become fine grain in the direction of transportation (Li and Komar, 1992; Frihy and Dewidar, 1993; and Ergin et al.2007). The study area is almost straight coastline and medium sands have been noticed in the mouths of rivers indicate that the sediments are transported from drainage network and mixing to the existing sediments in the foreshore, which will cause for local variation of mean grain size of the sediments. In the other microenvironments i.e., berm, backshore, and dune there is no systematic variation in mean grain size indicates that intensity of beach processes like wave energy, aeolian action and a continuous addition of finer materials in the backshore region by marine processes and onshore winds also remove the material from backshore environment and deposit in the dune environment, these processes will cause for the local variation of the mean grain size.

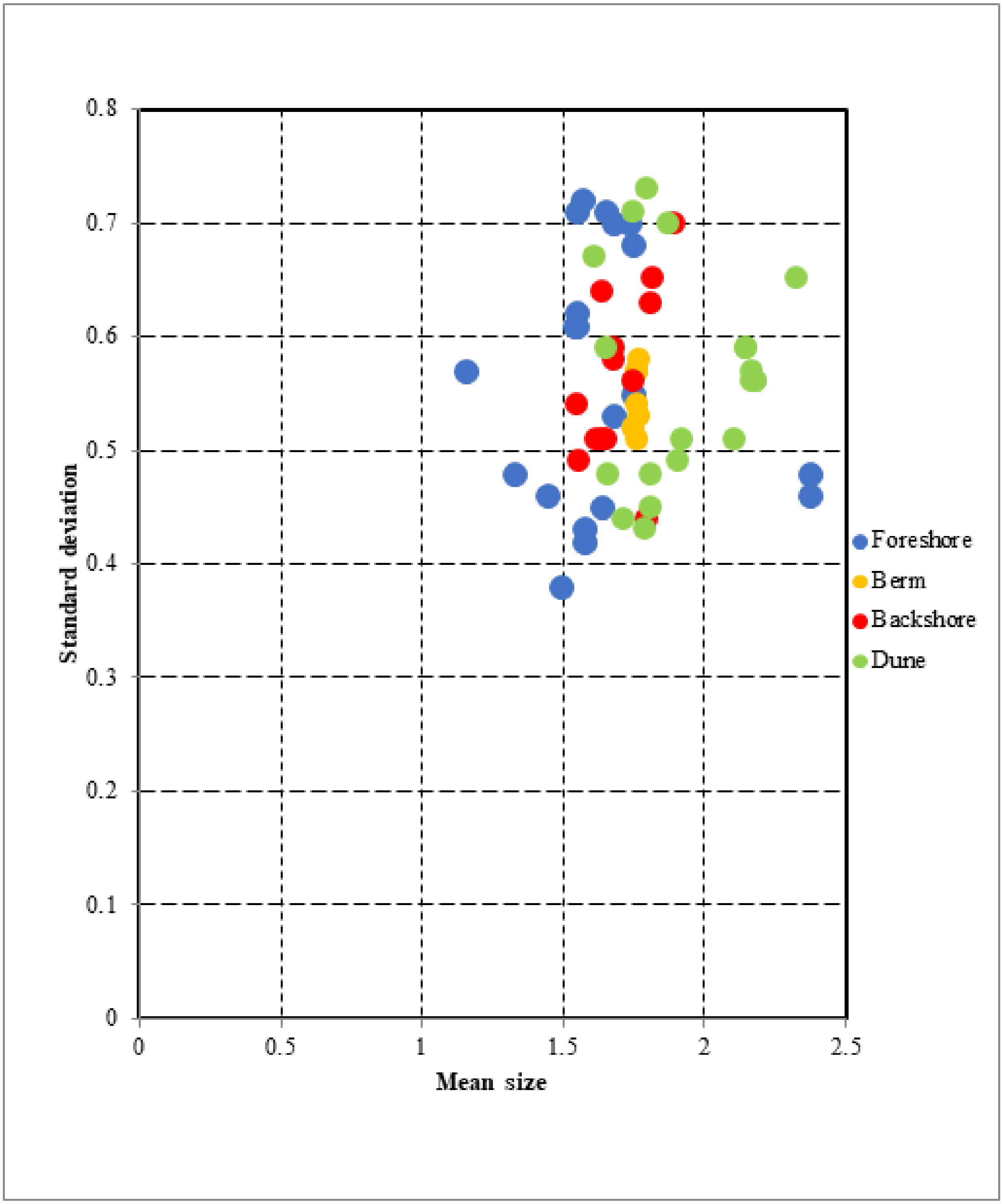


Figure 10. Scatter plots for mean size vs standard deviation of coastal sediments between Bhavanapadu and Baruva

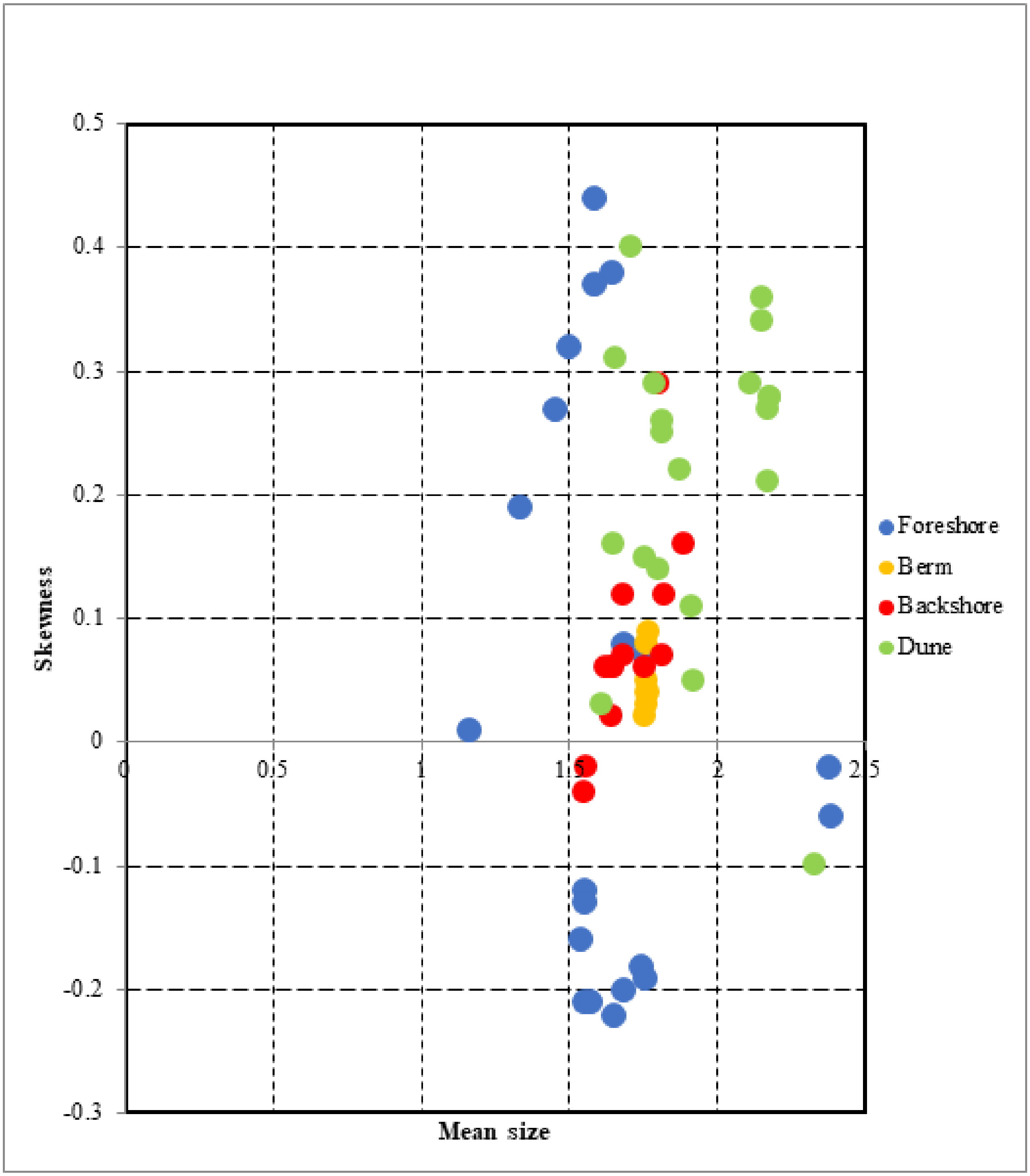


Figure 11. Scatter plots for mean size vs skewness of coastal sediments between Bhavanapadu and Baruva

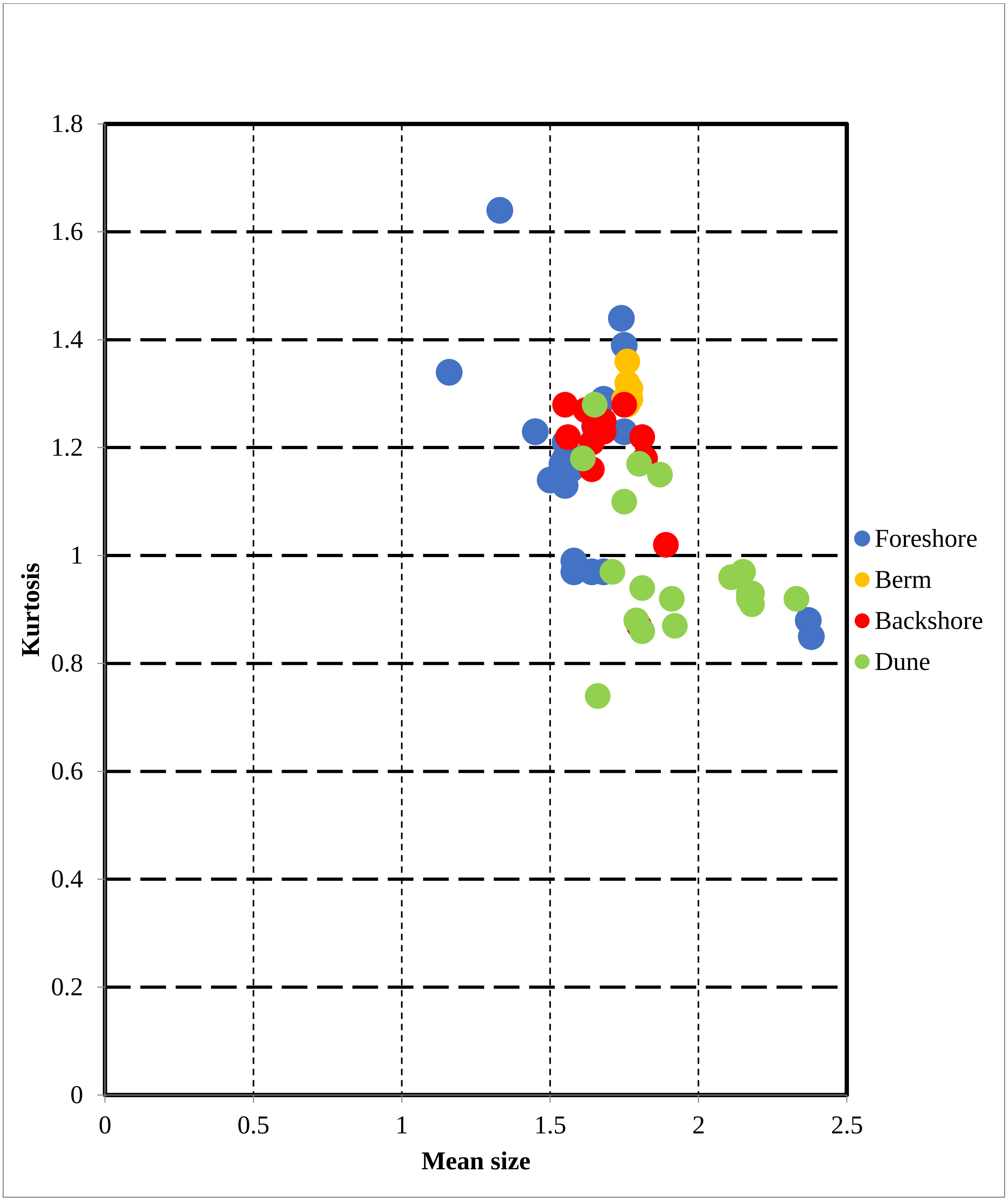


Figure 12. Scatter plots for mean size vs kurtosis of coastal sediments between Bhavanapadu and Baruva

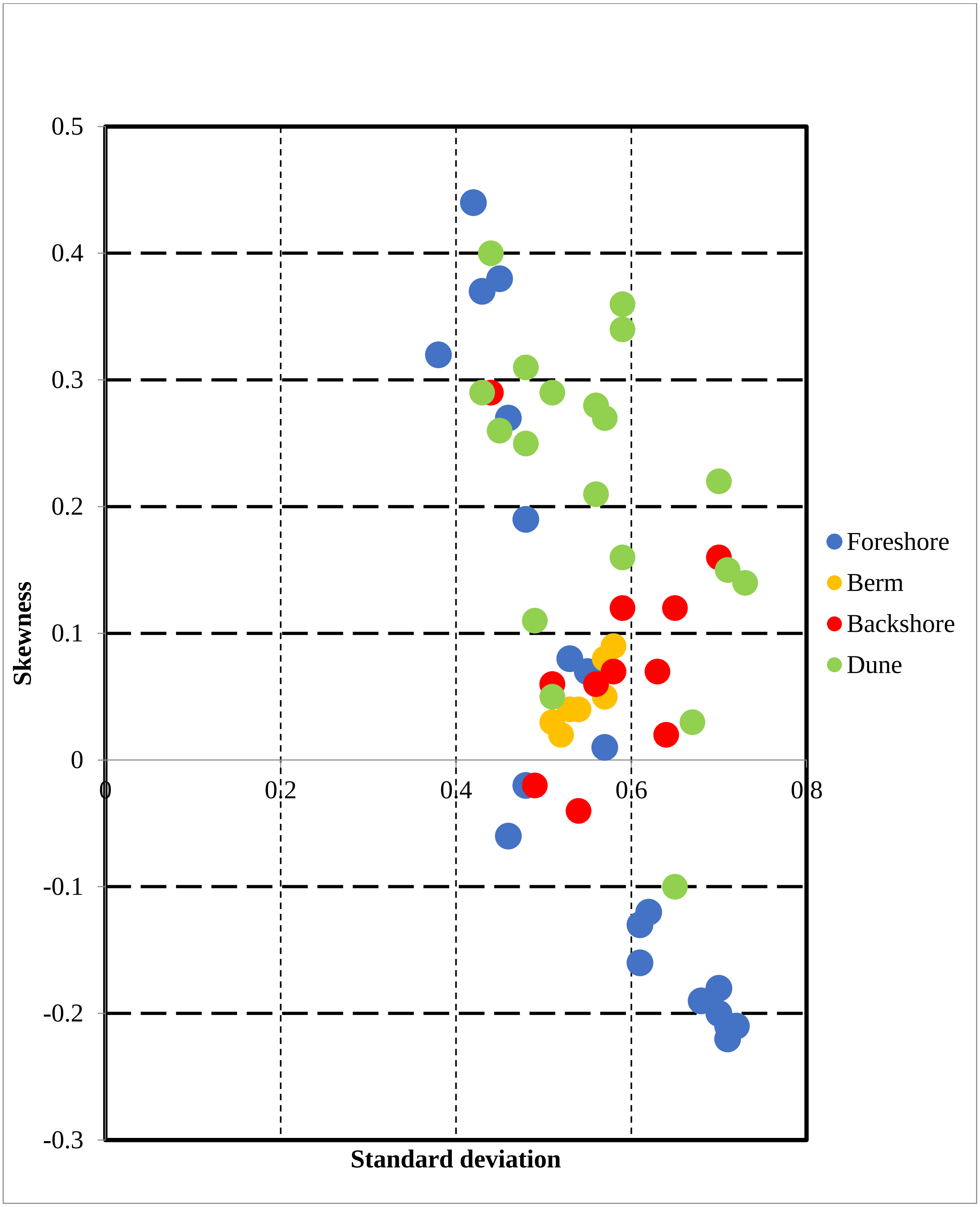


Figure 13. Scatter plots for standard deviation vs skewness of sediments of coastal sediments between Bhavanapadu and Baruva

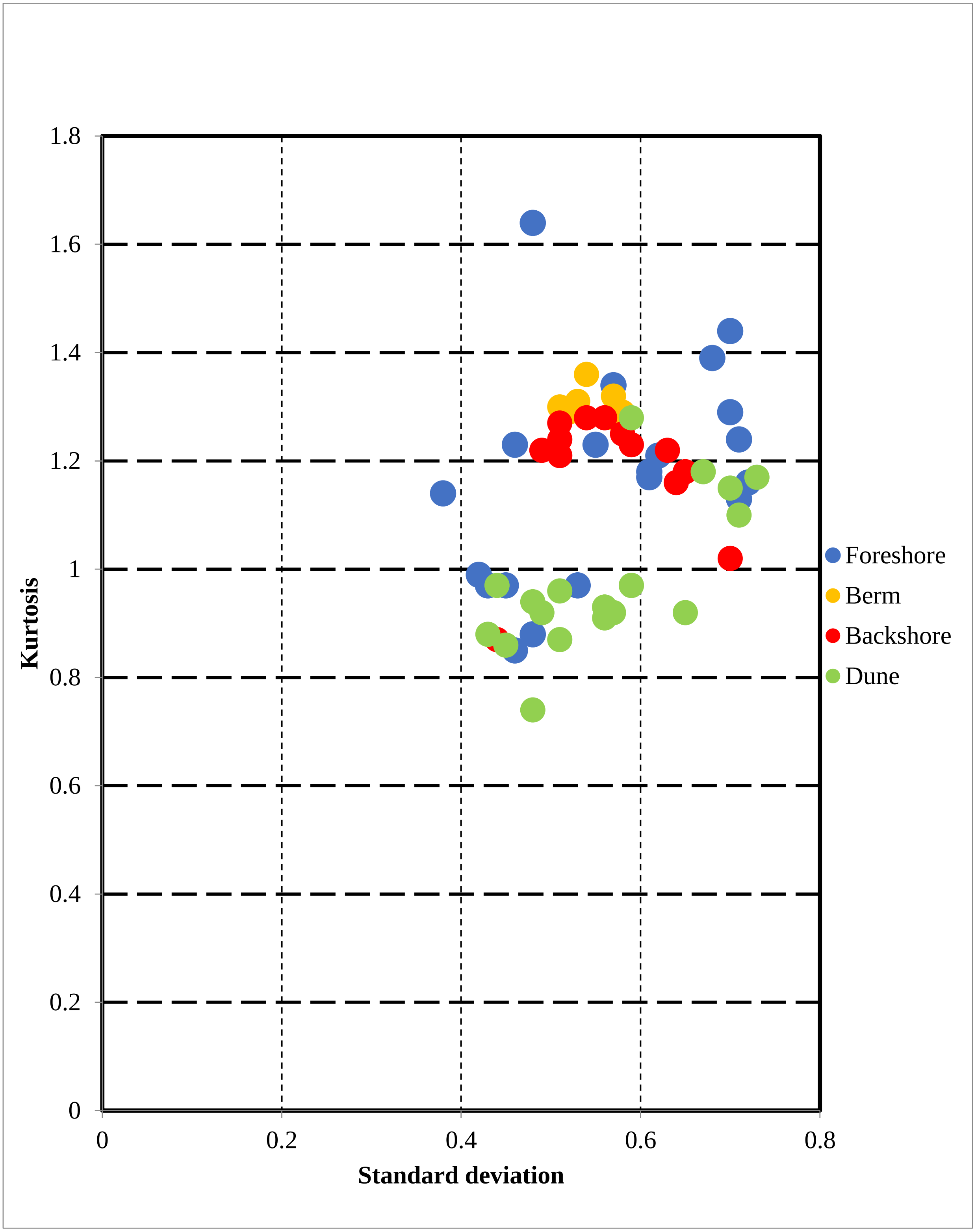


Figure 14. Scatter plots for standard deviation vs kurtosis of sediments of coastal sediments between Bhavanapadu and Baruva

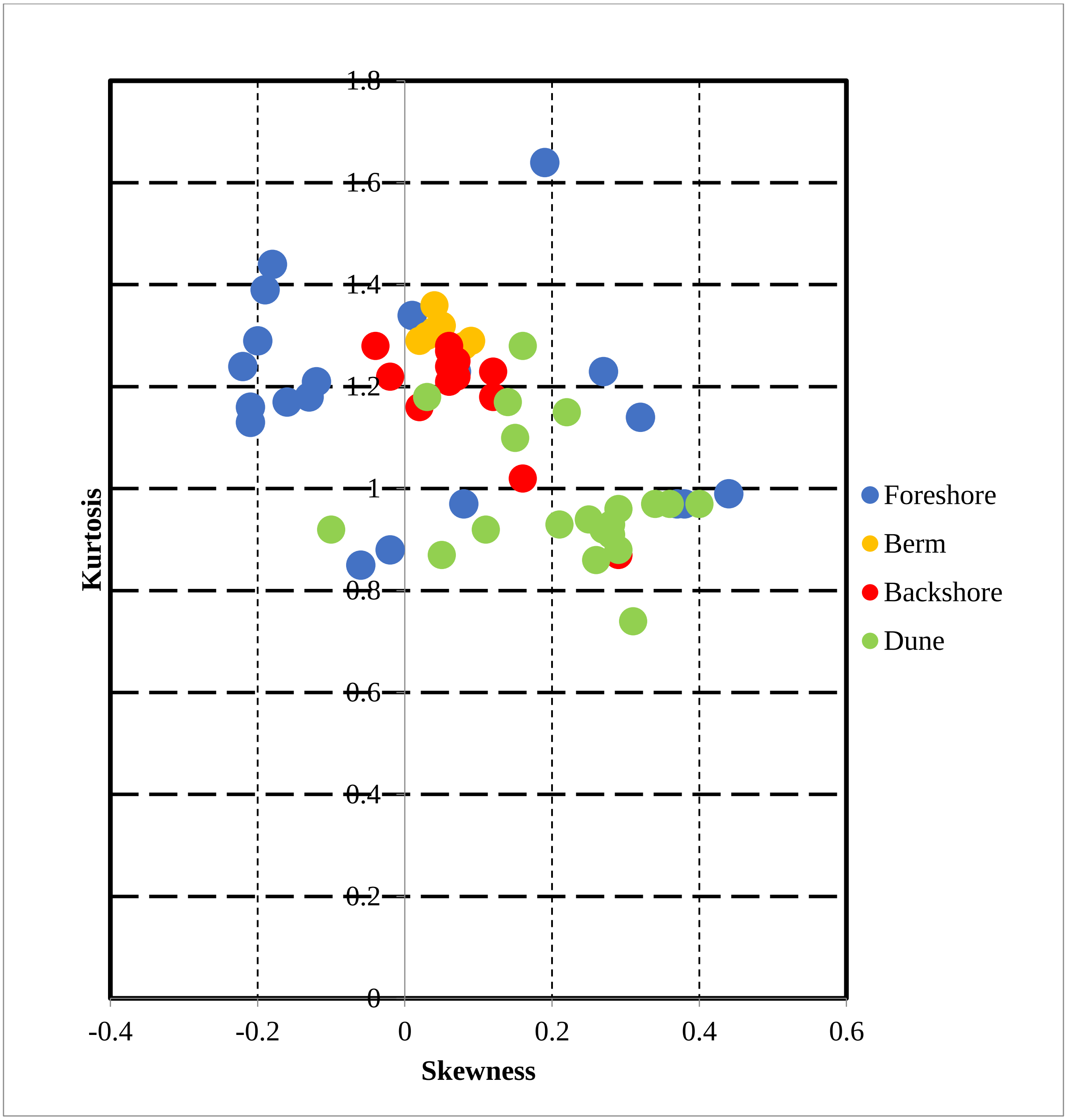


Figure 15. Scatter plots for skewness vs kurtosis of sediments of coastal sediments between Bhavanapadu and Baruva

The medium grained sands are poorly sorted and fine-grained sands are better sorted. The mean grain size and sorting are hydraulically controlled so that in the micro-environments, well sorted sediments are of fine-grained nature. The variation in the sorting values is likely due to the continuous addition of finer/coarser materials in varying proportions (Ramanathan et al., 2009) from the same or different environment.

Generally, the foreshore sediments are more negatively skewed than the adjacent backshore and dune environments because of continuous removal of material from foreshore by waves (Friedman, 1961). In the study region sediments in the traverses of foreshore environment and sediments in the traverses of berm and backshore environments are covered with negatively skewed sediments which indicate high energy conditions and more winnowing action than sediments from other traverses. The sediments from other microenvironments are positively skewed, indicating low energy depositional conditions. Sediments from the berm environment considerably different from other microenvironments and show positive skewness which support swash transport dominance over aeolian deflation (Trindade and Pereira, 2009).

There is no systematic variation of kurtosis values of sediments from different microenvironments of the study region but near the Mahendratanya River, the sediments show platykurtic to leptokurtic nature in the foreshore, berm, and backshore environments. Dune sediments show platykurtic to mesokurtic in nature with medium grained size. The platykurtic nature of sediments indicates the sorting of tail portions of sediment populations. Generally, the finer populations are deposited by tidal currents, and they show characteristic platykurtic nature (Rajesh et al., 2007). Variation in the kurtosis values reflects the flow characteristic of the depositing medium (Baruah et al., 1997) and the dominance of finer size of platykurtic nature of sediments reflect the maturity of the sand.

Skewness and kurtosis were referred to as indicators of selective action of the transporting agents (Krumbein and Pettijohn, 1938). Folk and Ward (1957) suggest that sands deposited near the source are characteristically leptokurtic and positively skewed. Berm and dune sands are near symmetrical to very positively skewed and average values indicate that the sediments are positively skewed, platykurtic to very leptokurtic and average values indicate these sediments are mesokurtic (Mason and Folk, 1958).

In the study area, berm zone is covered with medium sands and changes from place to place and time to time depending on the intensity of wave energy. The distribution and nature of berm sands will be controlled by the wave energy conditions prevailing at the time of deposition.

Most of the samples are leptokurtic and either positively or negatively skewed. This could be explained by the fact that most sands consist of two populations, one predominant population and one very subordinate, medium (leading to negative skewness) to fine (leading to positive skewness). Some sediment samples exhibit positive skewness even those are medium grained in nature.

7. CONCLUSIONS

Sand is the predominant component in all the sediment samples (99.82 – 99.93%), while silt + clay content is <1% from different microenvironments viz., foreshore, berm, backshore, and dunes of the study area. The mean grain size of sediment samples from different micro-environments between Bhavanapadu and Baruva shows that medium grained sands are followed by fine grained sands in nature, which indicates low energy environment of deposition. The standard deviation values reveal that the beach and dune sediments are well to moderately sorted. The average values of skewness indicate that all the sediment samples are negatively skewed to positively skewed in nature which indicates the depositional environment of low to moderate energy conditions. Mean size versus skewness has a poor to good relationship and the samples are nearly symmetrical to very fine skewed, in narrow range of mean size indicating fluctuation in energy condition of depositional medium. Most of the kurtosis values indicate that the sediments are of platykurtic to leptokurtic in nature. The platykurtic nature of sediments indicates the sorting of tail portions of sediment populations.

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