

Patterns of seasonal variability in granulometric characteristics of Bhitarkanika Mangrove – estuarine complex, East coast of India

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Textural attributes of recent sediments measured in terms of mean (M_z), Standard deviation (σ_1), Skewness (Sk_1) and Kurtosis (K_g) are widely used to reconstruct the depositional environments of sediments. Sediments were collected in three seasons from different areas of Bhitarkanika mangrove estuary to investigate the spatial and seasonal variability and influence of sediment transport on grain size characteristics. A marked variation in granulometric parameters was observed with respect to its geomorphic location in different seasons. Most of sediments were dominated by fine to very fine grain size, which are poorly sorted throughout the year. These poorly sorted, positively skewed fine grained sand indicate depositional process in a low energy environment. Linear discriminant function (LDF) showed aeolian process for mixed up sediment causing poor sorting of the sediments during all seasons.

[**Keywords:** Mangrove, Bhitarkanika, Grain size, Mean, Standard deviation, Skewness, Kurtosis]

Introduction

Mangroves and estuarine areas are ecotonal habitat that often deposit sediment, which are generally in form of loose sand, silt, clay, and other small particles that settle at the bottom of water body. Sediment texture refers to the proportions of sand, silt and clay below 2000 micrometers (2 mm) in diameter in a mass of sediment¹. Distribution pattern of grain size are highly influenced by sediment transportation mechanisms, which are energy dependent process and comprise long shore current transport, swash and backwash motion, wind deflation, and tidal currents. Mangrove directly affects the sediment flux by influencing hydrodynamic condition through their physical configuration. Process of rolling, suspension and saltation often control grain size distribution². Analysis of sediment texture is based on information recognizing sub-populations within individual grain size distributions. Each sub-population may be related

to a different mode of sediment transport and deposition, thus providing a measure of their importance in the genesis of a sand unit. Textural attributes of sediments and sedimentary rocks viz. Mean (M_z), Standard deviation (σ_1), Skewness (Sk_1) and Kurtosis (K_g) are widely used to reconstruct the depositional environments of sediments and sedimentary rocks³. These statistics may be used individually or plotted against one another to discriminate sedimentary environments.

Several granulometric studies have been conducted over east and west coasts of India to understand various aspects of coastal sedimentology. Some of these include Maharashtra coast⁴ Beach sediments; continental shelf, Andaman Sea⁵, Tamil Nadu coast⁶; Sunderban mangrove, West Bengal⁷; Gulf of Kutch⁸, Coleroon estuary, Tamil Nadu⁹, Thiruchendur coast, Tamil Nadu¹⁰. Till date no systemic granulometric studies have been reported

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from Bhitarkanika mangrove estuary, Odisha, East Coast of India. Also, very few studies have been reported in literature to assess the seasonal variation of textural attributes in sedimentary environment¹¹. Hence, an attempt has been made to understand the seasonal variation of distribution pattern of sediment grain size and to evaluate processes governing its deposition in Bhitarkanika mangrove estuary, Odisha, East Coast of India.

Material and Methods

Bhitarkanika mangroves are rich, lush green vibrant ecosystem lying in the estuarine region of Brahmani Dharma and Baitarani rivers in the northeastern corner of Kendrapada District Odisha East Coast of India. It covers an area of 672 sq. km extending between 86°48'–87°03'E longitude and 20°33'N–20°47'N latitude. The total mangrove area is a conglomeration of 13 protected reserve forests (PRF), 12 protected forests (PF) and one newly formed island. This area experiences tropical warm and humid climate. The maximum temperature recorded is 41°C and the minimum is 9°C during May and January respectively. Mean relative humidity ranges from 70 to 85% throughout the year.

Surface sediments samples at 0-5 cm depth were

collected from intertidal regions of seven sampling locations (S1, S3, S4, S6, S7, S9, S10) covering the entire Bhitarkanika mangrove and adjoining estuarine complex during low tide in three seasons viz. Pre-monsoon, Monsoon and Post monsoon (Fig.1). Based on geomorphic characteristics of sampling locations, the entire region was demarcated in three zones-riverine (S6), mangrove (S₁, S₃, S₄) and Bay (S7, S9, S10) region. Sediments collected from each sampling station were stored in a labelled polythene bags, and kept in an ice-chest box before transferring to the laboratory. Sediment samples were air dried in laboratory condition and gently pounded. Sediment samples were pretreated with hydrogen peroxide to remove organic matter, so that possibilities of flocculation of clay minerals could be minimized.

Dried sediment samples are passed through a stack of progressively smaller sieves varying in size classes > 125 µm, 125-250 µm, 63-125µm, <63 µm using sieve shaker¹². Further separation of <63µm samples into 50, 30, 20, 10, 5, < 5µm were carried by Atterberg sedimentation cylinders, which segregate sediment based on Stokes's law. Statistical parameters of grain size compositions were calculated using the logarithmic method of moments of GRADISTAT software: mode (abundant grain-size class), mean (weighted average grain-size class), sorting (the spread of sizes around the average), skewness (symmetry or preferential spread to one side of the average), and kurtosis (Peakness with relation to normal distribution)^{13,14}. Various graphic and moment measures were calculated with the logarithmic (original) formulae¹⁵.

Results and Discussion

Bhitarkanika mangrove dominated estuary showed wide variability in grain size distribution across various sampling locations for entire region. Gravel-Sand-Mud ratio diagram showed the majority of the samples fall under muddy sand fraction, which is typical characteristic of the estuarine environment. A triangular plot of Sand-Silt-Clay ratio diagram showed the preponderance of the silty-sand fraction, which is essentially due to strong currents by tidal action (Fig 2)¹⁶. Average value of weight percentage



Fig. 1–Location map of Bhitarkanika mangrove estuary showing sampling locations.

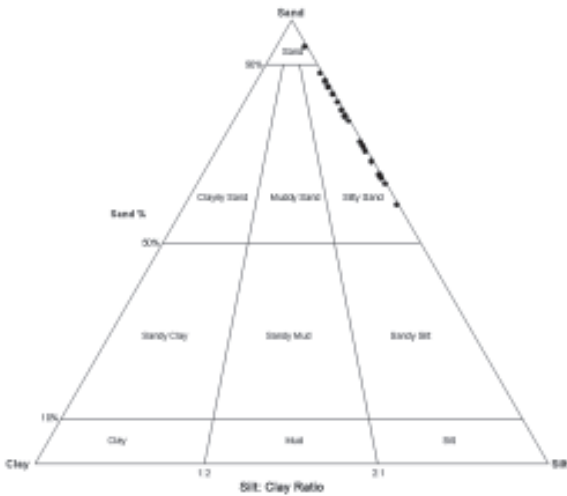


Fig. 2 –Triangular Plot for the Sand –Silt- Clay Diagram

of sand and silt- clay exemplified marked variation between sampling locations, which is in agreement with geomorphic location. Sample S6 near entry point of Brahmani river to mangroves showed higher percentage of sand than other sampling locations. These sand were generally deposited by fluvial process along course of Brahmani River. S3 and S4 samples located in dense mangrove tend to bind clayey fraction and thus accumulate more silt and clay than loose sand fraction. Sample S9 being located near Bay of Bengal are mainly dominated (more than 90%) by sand fraction, which indicates preponderance of coarse sand that are deposited by river process. During pre-monsoon season, nearly all samples showed high fraction of fine grained sands, which is due to high tidal influences, which increase the capacity of carrying fine sand¹⁷.

Samples from mangrove and bay region showed progressive increase in silt- clay fraction from pre-monsoon to monsoon to post monsoon. Although the extent of increase in silt- clay fraction was much higher (3-4 times) in bay region from 8.1 to 31.2% than those of mangrove sediments, which showed a meager increase (two fold) from 18.3 to 35.8%, which corroborates with the fact that mangrove region on whole have sheltered habitat, which have relatively lower capacity of carrying coarse sand and thus favouring settling of finer grain size. On contrary, S6 sample showed highest fraction of silt and clay (35%)

during monsoon season followed by post-monsoon and pre-monsoon. This could be evident during monsoon on sediment transported from upstream and catchment to the river mouth through surface runoff and strong river flow¹¹.

In pre-monsoon season, mean size of sediment grain varied from 2.5 Φ (at S9) to 3.2 Φ at S1, with an average mean size of 2.8 Φ (Fig 3). Nearly all the sediment samples during pre-monsoon season showed the presence of fine sand except for one sample (S1), which was dominated by very fine sand. The fine grain

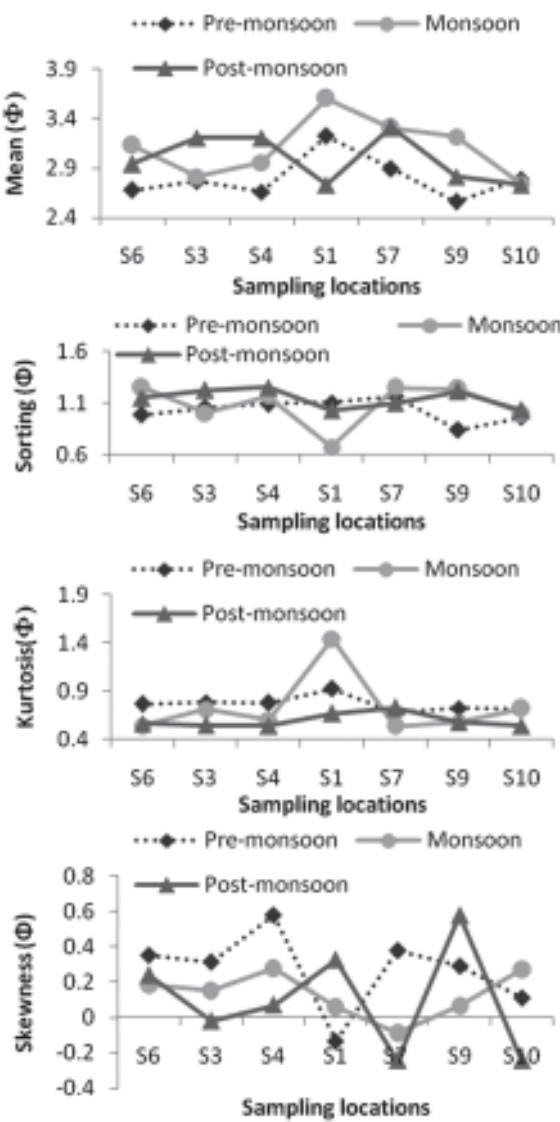


Fig. 3–Seasonal variation of Geo-statistical granulometric parameters of sediment

nature of sediment indicates the moderately low energy condition during deposition. In monsoon season, mean size ranged between 2.7Φ (S10) to 3.6Φ (S1), with average mean size was 3.2Φ . About 57% of the samples were very fine sand than rest 43% were dominated by fine sand. During post monsoon, mean size ranged between 2.7Φ (S10) to 3.3Φ (S7), with 3.0Φ as average mean size of sediment. About 57% of the samples were fine sand than rest 43% were dominated by very fine sand. Overall dominance of fine grained sediments in the region demonstrates that they were deposited by inner shelf processes. On an average basis, the mean size of sediment grain was relatively higher in monsoon (3.2Φ) than those of post monsoon (3.0Φ) and pre-monsoon (2.8Φ) season. Figure 3 describes the seasonal variation mean size with respect to sampling location. Except for S1, nearly all samples have smaller mean size of sediment grain, which is attributed to low energy condition during pre-monsoon. At S1, which is mixing area of riverine water with mangrove region, highest value of mean size was reported. Overall, the fraction of very fine sand were higher in monsoon and post monsoon season, which indicate that these very fine grained sediment might be transported through fluvial processes. The predominance of very fine sediment during monsoon and post monsoon also indicate the influence of aeolian activities in transporting fine sediments in suspension and of saltation from the adjoining coastal landforms⁶.

The standard deviation/sorting values of the sediments during pre-monsoon season ranged between 0.8Φ (at S9) to 1.2Φ (at S7) (Fig 3). About 57% of the sample showed moderately well sorted in nature while rest of 43% samples were poorly sorted. Moderately well sorted character of sediments specified the influence of stronger energy conditions of the depositing agent or prevalence of strong energy conditions in the basin. The deviation values of the monsoon season ranged between 0.7Φ (at S1) to 1.2Φ (at S6) with average value of 1.1Φ . Only 14 % of the samples were moderately well sorted while majority (86 %) were poorly sorted. Sorting variations observed could be attributed to the difference in water turbulence and

variability in the velocity of depositing current. During post monsoon season, the deviation values ranged between 1.0Φ (S1) to 1.2Φ (S4) with average standard deviation value of 1.1Φ . All samples (100%) were poorly sorted nature. A large standard deviation, or poor sorting, indicates that little selection of grains has taken place during transport or deposition. This might be the result of highly variable energy, turbulent conditions, and a lack of constant energy input in any one direction.

Pre-monsoon sediment samples showed the skewness values ranging between -0.1Φ (S1) to 0.6Φ (S4) with an average skewness value of 0.3Φ . The values revealed coarse to fine to very fine skewed nature of distribution. A positive skewness on the phi scale indicates a relative excess of fine grains, usually from the preferred transport and deposition of fine material. Sample S1 revealed coarse skewed, which may result from winnowing out of fine material, or a high energy storm deposit in mixing zone. In monsoon season, surface samples showed the skewness values ranged between -0.1Φ to 0.5Φ with an average skewness value of 0.1Φ . The values again showed symmetrical to fine skewed nature of the sediments. About 43% of samples showed symmetrical while 57 % of samples were fine skewed. These values indicate that monsoon has the positive deposition in this mangrove area. In post monsoon season, surface samples showed the skewness values ranging between -0.2Φ to 0.6Φ with an average skewness value of 0.2Φ . About 43% were very fine skewed, 28 % were symmetrical, 14 % coarse and rest 14 % are fine skewed. A marked variation of season was observed at all sampling locations (Fig 3). In most of sampling locations, skewness values for premonsoon was relatively higher than monsoon and post monsoon. These values indicate that after monsoon, the sediments had settled to reach the equilibrium, henceforth more symmetrical distribution. Except for S1 and S9, skewness was highest during post monsoon season followed by monsoon and then pre monsoon.

The kurtosis values for pre-monsoon season varied from 0.7 to 0.9 Φ with an average of 0.8 Φ (Fig 3). Nearly all samples (86%) were platykurtic

in nature of distribution except S1, which showed mesokurtic. Mesokurtic character of the sediments showed moderate winnowing action of the depositing agent. Mesokurtic nature of the sediments in the study area suggested that the sediments achieved good sorting in the high-energy environment. During the monsoon season, the kurtosis values varied from 0.5 to 1.4 Φ , with an average of 0.7 Φ . All the samples showed variation from Leptokurtic to platykurtic to very platykurtic in nature of distribution. About 57 % of the samples were very platykurtic, 28 % are platykurtic and rest 14 % were leptokurtic in nature of distribution. The leptokurtic nature of the sediments indicated the higher kurtosis values and the mixing of a predominant population with very minor amounts of coarser and finer materials¹⁸. The leptokurtic behavior of the sediments also indicated the variations of the energy conditions of the environmental setup of depositions of the sediments. Leptokurtic character reflected the extreme skewness values, either positive or negative, indicating concentration of coarser and finer grained materials finally showing the impact of fluctuation of energy condition in the deposition of the sediments from most of the formations¹⁹. Accumulation of finer materials show the influence of moderate to low energy conditions in the environmental setup showing the leptokurtic character of the sediments²⁰. In post monsoon season, the kurtosis values were 0.5 to 0.7 Φ with an average of 0.6 Φ . Nearly all samples are very platykurtic in nature of distribution, except for S7 sample. Platykurtic nature and very platykurtic showed extreme peakyness with respect to normal distribution, which could be attributed to poor winnowing without any sorting, i.e. all size fractions of grain size mixed up. Comparison of kurtosis values between seasons across all sampling showed a specific trend with pre monsoon showing highest values, followed by monsoon and post monsoon. As noted earlier, Sample S1 again diverge from usual trend with highest kurtosis value in monsoon season. It may be emphasized again, S1 was only region which showed mesokurtic in pre-monsoon and leptokurtic nature in monsoon season (Fig 3). This could be attributed to impact of extreme fluctuation

of energy condition in the deposition of the sediments at S1 from most of the formations during these seasons. Further, during monsoon and post-monsoon, most of samples were very platykurtic. These extreme variations in the kurtosis values are a reflection of the energy conditions of the depositing medium and the dominance of finer size of platykurtic nature of sediments reflects the maturity of the sand²¹.

The sedimentary depositional environment are characterized by a unique set of physical, biological and chemical processes operating at a specified rate and intensity, which determine the pattern of sediment deposition. Variations in the energy and fluidity factors have excellent correlation with the different processes and the environment of deposition. The linear discriminant functions of Y1 (Aeolian, beach), Y2 (Beach, Shallow agitated), Y3 (Shallow Marine, Fluvial) and Y4 (Turbidity, Fluvial) were used to decipher the process and environment of deposition²². Based on Y1 values, nearly all samples (100%) represent aeolian processes during all season. Influence of aeolian process during all seasons are clearly reflected in the poor sorting of the sediments, since aeolian processes mix up sediments⁶. Activity of wind carry fine sediments in suspension, thus causing poor sorted nature of sediments. Based on Y2 values, it can be showed nearly all samples (100%) showed shallow agitated deposition during all seasons. Except for only one S1 sample during monsoon, rest of all samples was influenced by shallow marine deposition and in due course of time, marine regression must have led to the development of the present-day shorelines. It can be explicitly specified here that sediments in S1 sample were derived through fluvial process by river borne sediments/debris discharged by River Maipura and/or transported by river runoff during monsoon season. This is again corroborated by Y4 values, which showed that only S1 sample which are deposited under fluvial condition during monsoon season, while other all samples are deposited under influence of turbidity current (Table 1).

Table 1—Seasonal variation of linear discriminant values of sediment

Pre- monsoon	Y1	Y2	Y3	Y4	Description			
S1	-4.5	129	-9.9	7.3	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S3	-5.2	141	-9.7	4.6	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S4	-5.3	144	-10.4	5.2	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S6	-5	136	-10.4	6.3	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S7	-5	133	-7.4	4.2	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S9	-5	145	-12.6	8.5	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S10	-4.8	141	-10.6	7.5	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
Monsoon								
S1	-6	128	-5.1	10.4	Aeolian	Shallow agitated	Fluvial	fluvial Deposit
S3	-4.4	126	-8.7	6.4	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S4	-4.9	139	-10.7	6.7	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S6	-5.2	145	-11	5.9	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S7	-5.4	142	-9.5	4.1	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S9	-5.3	144	-10.2	-14.3	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S10	-4.4	127	-9.3	7.2	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
Post monsoon								
S1	-4.3	138	-8.1	5.8	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S3	-4.2	133	-9.9	7.8	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S4	-4.2	138	-11.6	9.5	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S6	-4.2	127	-9.6	8	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S7	-4.7	141	-11.2	7.8	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S9	-4.4	114	-8	7.3	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition
S10	-4.4	122	-8.1	6.2	Aeolian	Shallow agitated	Shallow marine	Turbidity Current deposition

Depositional environment

Bivariate plots /scatter graphs of grain size parameters have been widely used to distinguish between different depositional settings, which are based on the assumption that these statistical parameters are reliable to reflect differences in the fluid-flow mechanisms of sediment transportation and deposition²³. Fig 4 depicts the relationship of mean

grain size with sorting, which clearly showed that fine and very fine sediments are mostly poorly sorted. Several studies have highlighted the influence of size on sorting that fine sand is better sorted¹⁵. It is explained that both mean grain size and sorting are hydraulically controlled, so that in all sedimentary environments the best-sorted sediments have mean size in the fine sand size range^{10,12}. However, our study

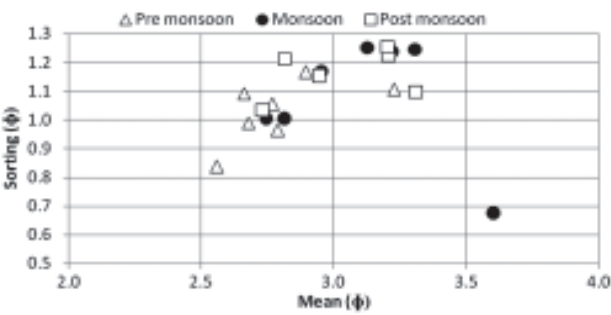


Fig. 4–Scatter plot of mean vs. standard deviation

showed opposite behaviour as fine sediments are poorly sorted. It may be argued that the combination of various modes of transport (creep, saltation and suspension) may lead to poorly sorted sediments⁶. Also, during monsoon and post-monsoon season, the eroded material as well as suspended sediment in river runoff/discharge along with aeolian process due to cyclonic storms might be responsible for poor sorting of sediments in region.

The bivariate scatter plot of mean vs. standard deviation showed that mostly fine grained sands were poorly sorted while very fine sands are moderately well sorted (Fig. 4). Both mean grain size and sorting are hydraulically controlled, so that degree of sorted sediments is high in fine grained sediments. Bivariate scatter plot of standard deviation(sorting) vs. skewness also showed that except of one sample during monsoon, the deposition of sediment were under the influence of shallow marine conditions (Fig 5). Most of poorly sorted samples were either near symmetry, finely skewed or very fine skewed. Bivariate scatter plot of skewness vs. kurtosis provide

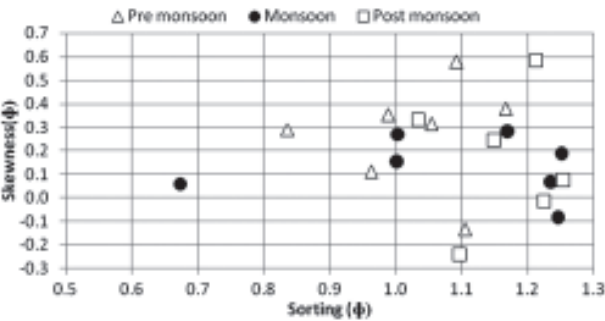


Fig. 5–Scatter plot of Standard deviation (Sorting) vs. Skewness

information about the genesis of sediment, by quantifying the degree of normality of its size distribution²⁴ Scatter plot of skewness vs. kurtosis showed that most of samples are positively skewed (Fig 6). From all the three seasons, positive skewed sediments exhibit platykurtic to very platykurtic nature. These findings emphasized on view that most

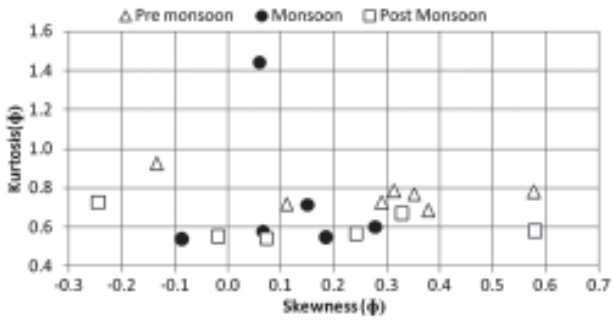


Fig. 6–Scatter plot of Skewness vs. Kurtosis

of fine grained sediments are transported alongwith fluvial system through river runoff/discharge or aeolian process as a result of strong winds/cyclonic storms during monsoon and post-monsoon season and deposited in low energy sheltered environment of mangrove ecosystem. Overall, it was observed that much more sediment organic matter was located at the high tide area with weak tide energy. Sediment characteristics had definite relationship with the community structure of mangroves, reflecting the complicated association between the hydrodynamic conditions and the mangroves.

Conclusion

Present study describes the sedimentary properties of Bhitarkanika mangrove dominated estuary with its seasonal variability in terms of major inputs and their main transport and depositional processes in various hydrodynamic conditions at different locations. Textural characteristics in sediments of Bhitarkanika mangrove dominated estuary indicate the dominance of fine grain sized sediment at all sampling locations in all three seasons. Most of these fine grained sediments are moderately well sorted to poorly sorted and wide range of skewness values indicate depositional process in a

low energy environment. LDF values indicate dominance of shallow marine deposits under aeolian process and/or turbidity currents by tidal actions.

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