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Textural Analysis of Coastal Sediments along East Coast of India

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ABSTRACT

The study investigates textural characteristics of sediment at selected tourist beaches extending from Rameswaram to Paradip along east coast of India. Samples were taken from backshore and foreshore at nine selected locations to evaluate sediment grain size distribution and its seasonality. Analysis of grain size distribution carried out to identify textural characteristics (mean size, standard deviation, skewness and kurtosis) and its variability in two different seasons (southwest and northeast monsoon). Results show that sediments lying in backshore regions are mostly medium sand, while its changes are relatively invariant against seasons. The percentage of fine sand is higher during January compared to September due to prevalence of calm wave conditions. The mean grain size trend decreases at backshore region while it increases at foreshore region from south to north along the coast indicating dominance of aeolian transport. Sediments are mostly moderately sorted at backshore and moderately well sorted at foreshore region. Mostly symmetrical and mesokurtic sediments are dominated along the coast indicating sediments are well sorted at central portion of sediment distribution. The CM diagram depicts sediment source are from beach environment during both the seasons and some of them transported by tractive current in September and transporting during September is by rolling, bottom suspension and rolling; and graded suspension no rolling.

INTRODUCTION

Sedimentology which includes characteristics and dynamics of sediments is an important area of research often provides valuable information on coastal environment. Many researchers in the field, work on coastal sediments on a seasonal scale to understand behavior of the coast viz. erosion, accretion and evolution of sand dune systems. Besides, sediment texture acts as instrument for fundamental analysis of origin of coastal sediments, prevalence of oceanographic conditions and sediment transport processes (Komar, 1998; Pentney and Dickson, 2012). The beach sediment moves both in cross-shore and alongshore direction under the action of wind, wave, tide, and extreme events such as storm, cyclone, tsunami and coastal/terrestrial flooding. In general, beach sediment transport occurs by wind at upper part of beach while oceanographic conditions such as tide, current and waves are accountable for uninterrupted transport of sediments at swash zone and nearshore region up to continental shelf. Textural analysis of sediments has fascinated coastal researchers around the globe and also these studies are made available worldwide to investigate the potential information about transport behavior and size-sorting processes of sediments in several environments (Folk and Ward, 1957; Friedman, 1961; Tairaand Scholle, 1979; Clark, 1981; Slyetal., 1982). The study has been carried out along the east coast of India whose sedimentology and transport mechanisms are essential for coastal management.

Sediment along east coast of India is influenced by reversal wind and current pattern (Shetye et al.,1993; Schott and McCreary, 2001), which resulted in northerly sediment movement during southwest monsoon and southerly during northeast monsoon (Chandramohan and Nayak, 1991; Mishra et al., 2001). The aim of this work is to investigate the seasonality in textural characteristics of major selective sandy beaches along the east coast of India. The study explain the grain size characteristics and mode of transport at each location. Textural parameters for Tamil Nadu coast is studied by Chandrasekar (1992), for Andhra Pradesh (Karunakarudu et al., 2013; Bangaku Naidu et al., 2016; Suvarna et al., 2017) and for Odisha coast (Chauhan, 1986, 1992; Mohanty et al., 2012) have made significant contributions in differentiating the environments of beach and river sediments. However, information is lacking on the grain size characteristics of such sediments and on the processes operating along the east coast of India. The present study aims to fill this gap.

STUDY AREA

The study area lies along the east coast of India, which has an extensive coastline of about 3480km with diverse oceanographic conditions (Fig.1). The southern east coast of India (Tamil Nadu coast) is generally dominated by micro tidal pattern while the central east coast of India (Odisha coast) is dominated by the meso-tidal pattern. The east coast of India is characterized with various geomorphological features such as open beaches, rocky shores, sandy spits, estuaries, tidal inlets, bays, lagoons, marshy land & mangroves etc. The stations at which sediment samples were collected are experienced with reversal sediment transport as well as regional coastal processes which are influenced by a number of environmental drivers such as geological, meteorological and oceanographical factors. Besides, many river systems also discharge huge amount of sediments, which takes part in coastal evolution process. Therefore, east coast of India is much more dynamic compared to the Arabian coast due to huge propensity of sediment out flux to Bay of Bengal. The study sites along east coast of India is highly exposed to tropical cyclones (Dube et al., 1997; Singh et al., 2001; Monalisha and Panda, 2018; Baral et al., 2018) and tsunami like extreme catastrophic events are responsible to changes in the nearshore geomorphology drastically. On the other hand, anthropogenic activities like development of port, groyne field and breakwater along the coast acts as barrier for uninterrupted sediment transport along the Indian coast and noticed the changes in sediment distributions and budget (Rao et al., 2009; Mohanty et al., 2012). Study area has been fixed along east coast of India within four maritime states and one union territory.

DATA AND METHODOLOGY

Sediment sample from nine locations along east coast of India were collected during the month of September and January 2016 representing southwest and northeast monsoon at study locations.

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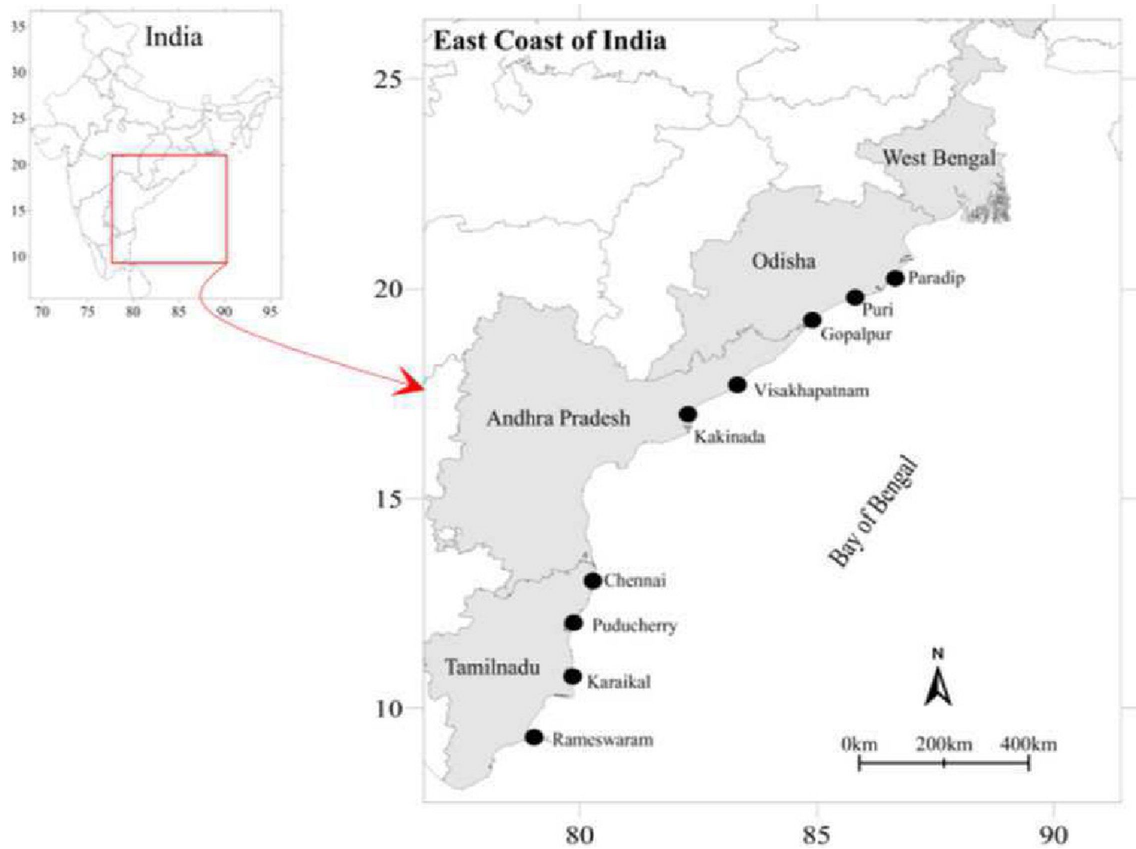

Fig.1. Study area shows the sampling locations along east coast of India.

Sediment samples were collected from foreshore and backshore reason at each location to evaluate the textural characteristics of beach sediments as well as to understand the depositional/erosional environment during occurrence of two reversal wind and current pattern along the east coast of India. Soon after the collection of sediments, it was treated with 1:10 of HCl to remove $CaCO_3$ shells and 30% of H_2O_2 to remove the organic matter and impurities (Ingram, 1970). Further, the samples were washed with freshwater and oven dried at 70-80 °C following the method suggested by Folk and Ward (1957). Then, 100gm of purified dried sample was subjected to sieving for the grain size analysis using AS 200 Retsch Sieve shaker, where sediments were sieved for ten minutes with sieve size ranging from 63µm to 1000µm. The sediment retained in each sieve were collected and individually weighted with help of electronic weight machine with a precision of 0.5 gm. To understand the grain size statistics, GRADISTAT Software package was used to obtain the statistical parameters such as mean (Mz), sorting (σ_1), skewness (Sk) and Kurtosis (K_G) (Folk and Ward, 1957; Blott and Pye, 2001). Besides to assess the mode of sediment transport as well as source of sediments at each location, C-M digram was adopted through GSTA software developed by Dinesh (2008), which is based on the hypothesis formulated by Passega (1964; 1957). In C-M diagram coarsest one percentile of grain size diameter and median of sediment grain size is considered.

RESULTS AND DISCUSSION

Sediment grain size statistics such as mean (Mz), sorting (σ_1), skewness (S_k) and kurtosis (K_G) are determined and analyzed for understanding backshore and foreshore sediment characteristics and its seasonality at different tourist beaches forced with different environmental conditions. Results on sediment texture and seasonality in its grain size distribution are vividly discussed in relation to scientific and engineering importance, interest of various coastal infrastructure projects and ephemeral changes in beach geomorphology along east coast of India.

Textural Distribution (Sand-Silt-Clay Ratio)

The distribution of sediment grain size is presented by cumulative weight percentage diagram to understand occurrence of different categories of sediments i.e. sand, silt and clay in the sediment sample. It is observed that seasonal variability in grain size distribution is quite significant during month of September compared to January representing monsoon and fair weather period respectively (Fig.2). The variability of wave energy and local morphological conditions at sampling locations are prime causes of differences in grain size distribution. Besides it is noted that during monsoon cumulative weight of sediments is limited to 80% between mean grain size of 0-4 ϕ scale while similar percentage of sediments are within mean grain size of 0-3 ϕ scale. During September cumulative weight of sediments varies from 1 to 60% at most of the locations with mean grain size of 0-1 ϕ scale while it varies from 1 to 45% during January with mean grain size ranging from 0-1 ϕ. Less percentage of cumulative weight of sediments during January within mean grain size 0-1 ϕ depicts amount of coarse sediments are less in beach environment compared to September. Lower amount of coarse sediments during January could be a cause of prevalence of low energy ocean waves along east coast of India and higher rate of suspension mode of sediment transport rather than bed load transport. During September, wide range of mean grain size above 80% of cumulative weight of sediment reveals different types of sediments (very fine to coarse sediment) are available and transported along the backshore and foreshore region while range of mean grain size limited between 1.5-4 ϕ. The mean grain size ranging between 1.5-4 ϕ represents medium to very fine sediments are only available in beach environment and take part in sediment transport processes.

Backshore regions which is mainly controlled by prevalence of

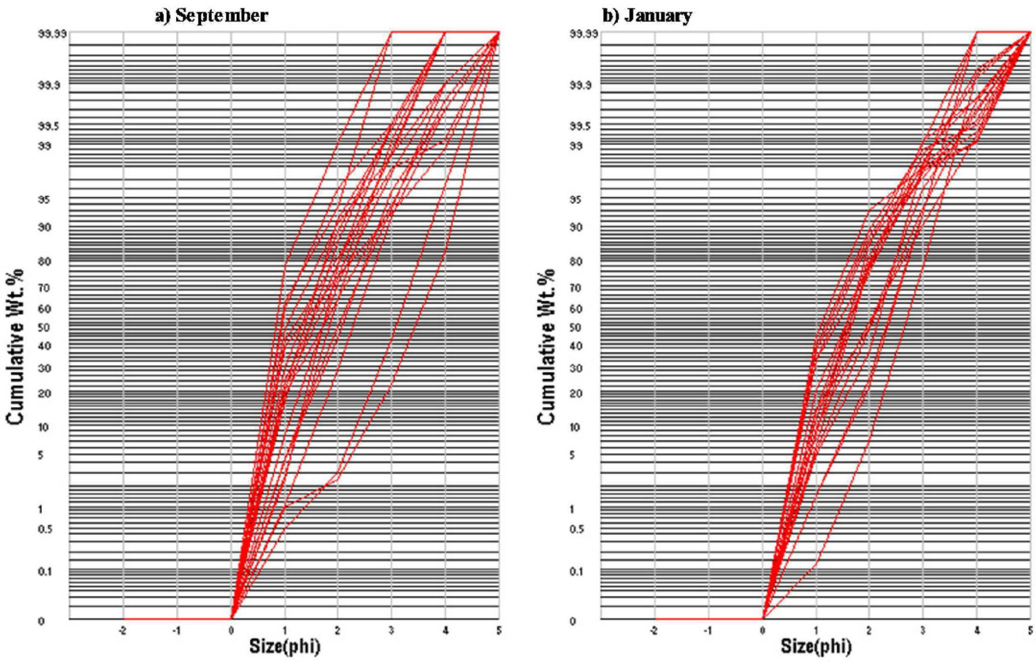

Fig.2. Beach sediment distributions (phi) along east coast of India.

wind, play a key role in changing geomorphology of coastal landforms. The sediment composition at backshore region mainly comprises of medium sand followed by fine and very fine sand during the September (monsoon) and January (northeast monsoon) respectively (Table 1). The medium sand percentage is higher at all locations on spatio-temporal scale except at Rameswaram during the September. During September, medium sand percentage at backshore region varies between 28-96% with mean value of 72.5%. Higher percentage of medium sand is observed at Puri (96%) at Puri while lower value is observed at Rameswaram (28%). During January medium sand percentage varies between 49.1-89% with mean value of 74% at backshore region. Medium sand percent is observed higher at Chennai (89%) and lower at Kakinada (49%). Fine sand percent varies between 3.5-63.5% with mean value of 24% during September. Higher and lower percent of fine sand is observed at Rameswaram (63.4%) and Puri (3%). During January, fine sand percent varies between 9-47% with mean value of 22% with higher and lower percent of fine sand at Chennai and Kakinada respectively. Very fine sand percent is higher at Rameswaram (8%) during September and 9% at Karaikal beach in January. Very fine sand percent varies between 0.5-7.9% with mean value of 2% during September while it varies between 0.7-9 with mean value of 2.6% during January. The percentage of mud type of sediment is very negligible, 1% is maximum at Chennai and Visakhapatnam during September and January respectively. Spatial analysis of medium, fine and very fine sand during September and January in backshore region shows stations located north of central east coast of India accommodate with higher (lower) percentage of medium (fine & fine sand) compared to their respective mean values. The lower percentage of fine and very fine sand above central east coast of India represents aeolian transport is relatively higher compared to southern east coast of India. However, seasonal variation shows that mean value of medium, fine and very fine sand percentage during September is higher than January. Foreshore region is primarily controlled by oceanographic drivers such as tide, current and ocean waves. Among these currents caused by ocean tide significantly alters the sediment characteristics along the foreshore region and also helps in transporting sediments from one location other depending on the strength of natural drivers and sediment composition and grain size diameter. Analysis of foreshore sediments at all locations along the east coast depicts medium sand is predominant at all the locations during September and January followed by fine and very fine sand (Table 1). The medium sand percentage during the September varies between 42.9-93.5% with mean value of 73.6%. The higher value of medium sand percent is observed at Puri (93.5%) and lower at Visakhapatnam (42.9%). During January, percent of medium sand varies between 7-92.9% with mean value of 52.4%. Higher and lower percent of medium sand is observed at Visakhapatnam (93%) and Gopalpur (7%) respectively. Fine sand percent varies between 6.5-52.9% with mean value of 23.9% during September while it varies between 5-71% with mean value of 41.5% during January. Higher percentage of fine sand are observed at Visakhapatnam (53%) and Paradip (71%) while lower percentage of fine sand is observed at Puri (6.5%) and Visakhapatnam (5%) during September and January respectively. Very fine sand percentage varies between 0-6.8% with mean value of 2.3 % during September while it varies between 0.7-22.3% with mean value of 5.7%

Table 1. Composition of beach sediments (%)

	Mud		Medium Sand		Fine Sand		Very Fine Sand	
	Sept.	Jan.	Sept.	Jan.	Sept.	Jan.	Sept.	Jan.
Backshore								
Rameswaram	0.3	0.2	28.3	78.1	63.5	20.5	7.9	1.2
Karaikal	0.1	0.7	70.4	52.1	27.1	38.2	2.4	9.0
Puducherry	0.0	0.1	73.3	81.2	25.4	16.9	1.3	1.9
Chennai	1.2	0.5	73.8	89.0	18.7	9.8	6.4	0.7
Kakinada	0.0	0.3	91.2	49.1	8.2	47.0	0.6	3.7
Visakhapatnam	0.0	0.9	63.6	87.5	35.5	10.2	0.9	1.4
Gopalpur	0.1	0.1	65.7	74.6	32.2	23.5	2.0	1.8
Puri	0.0	0.0	96.0	85.0	3.5	14.0	0.5	1.0
Paradip	0.0	0.0	90.5	77.0	8.0	20.5	1.5	2.5
Foreshore								
Rameswaram	0.0	0.9	88.7	79.3	10.7	18.3	0.6	1.5
Karaikal	0.1	0.2	49.8	48.1	43.3	45.3	6.8	6.4
Pondy Puducherry	0.1	0.3	78.2	86.2	20.4	10.8	1.3	2.7
Chennai	0.8	0.2	80.8	76.7	17.0	22.4	1.4	0.7
Kakinada	0.2	0.4	64.3	35.7	29.6	62.4	5.9	1.5
Visakhapatnam	0.3	0.6	42.9	92.9	52.9	5.0	3.9	1.5
Gopalpur	0.0	0.1	78.0	7.0	21.5	70.6	0.5	22.3
Puri	0.0	0.0	93.5	24.5	6.5	68.0	0.0	7.5
Paradip	0.0	0.0	86.0	21.5	13.5	71.0	0.5	7.5

during January. Higher percentage of fine sand is observed at Karaikal (6.8%) and Gopalpur (22%) while lower percentage of fine sand is observed at Puri (0%) and Chennai (0.7%) during September and January respectively. Spatial analysis of sediment percentage in foreshore environment shows region located north of central east coast of India occupied with higher (lower) percentage of medium (fine) sand than its mean value during September while occupied with lower (higher) percentage of medium (fine) sand during January than its mean values respectively. Similarly, very fine sand percentage at north of central east coast of India during September is less compared to their mean value while higher during January. Both spatial and temporal analysis of backshore and foreshore sediment conclude that backshore sediments percentage are almost equal during September and January while it does not hold tight for the foreshore sediments due to nonlinear oceanographic conditions. Temporal analysis of foreshore sediments suggests during the monsoon period (September) medium sand is predominant source of bed-load transport while it is both medium and fine sand during north-east monsoon (January). The higher mean of fine sand percentage during January compared to September translates prevalence of suspended mode of transport.

Grain Size Statistics

Mean Grain Size

Mean grain size is representative diameter of coastal sediments that describes various environmental information such as physical and geomorphological processes near the coastal environment. The mean grain size is computed using formula $M = (\phi_{16} + \phi_{50} + \phi_{84})/3$ as suggested by Folk and Ward (1957). Coastal sedimentologists use mean grain size for understanding of origin of sediment, accretion and erosion processes within a coastal environment. The analysis of backshore sediment shows dominance of medium sand while rare occurrence of coarse and fine sand at some stations along east coast of India (Fig. 3a). The mean grain size along the coast varies between 0.67-2.36 ϕ and 1.14-1.96 ϕ with mean value of 1.40 ϕ and 1.56 ϕ during September and January respectively. Higher mean value of mean grain size depicts sediments are relatively finer during January compared to September. The spreading of mean grain size during September is higher than January representing participation of different diameters of sediments in aeolian processes. The higher and lower mean grain size (ϕ) at southern (Rameswaram) and northern region (Gopalpur and Puri) during September represents zone of accretion and erosion at backshore due to aeolian processes. Besides, mean grain size (ϕ) starts decreasing trend from south to north during the September while no trend is visible during the January indicating month of September is favorable for winnowing of fine sand from backshore region. The absence of fine and medium sand in backshore of Gopalpur and Puri could be a potential cause for development of sand dune system back to the backshore region. Analysis of foreshore sediment shows dominance of medium and fine sand during the month of September and January respectively (Fig. 3b). The mean grain size along the foreshore environment varies between 0.84-2.16 ϕ and 1.03-2.66 ϕ with mean value of 1.54 ϕ and 1.85 ϕ during the month of September and January respectively. Higher mean of mean grain size represents sediments are finer relatively during January compared sediment prevalence during September at foreshore region. The spreading of mean grain size is observed higher during January indicating different diameter of sediments are transported in foreshore environment compared to September. Foreshore sediments showed an increasing trend in mean grain size (ϕ) from south to north during January while no trend during September indicating accretion of fine sand due to low energy environment during January at northern region of east coast of India. Seasonal variations along the coast are different at Visakhapatnam compared to rest of the stations due to presence of seawall and port development activity.

Sediment Sorting

Sediment sorting which describes how sediment diameter are associated with mean grain size of sediment sample and computed mathematically by $SD = (\phi_{84} - \phi_{16})/4 + (\phi_{95} - \phi_5)/6.6$. Lower the magnitude of sorting indicates uniformity in sediment diameter while higher magnitude depicts assemblage of various types of sediments. Sahu (1964) revealed that sediment sorting act as an environmental cue to determine characteristics (kinetic energy and velocity) of environmental driver that cause accretion or erosion. Besides, some researchers revealed that better the sediment sorting are representation of either fine or coarse sediment than poor sorting sediments (Griffith, 1951; Inman and Chamberlain, 1955). During period of observation at backshore and foreshore region, it is observed that sediment sorting varies between 0.46-0.98 (ϕ) and 0.51-0.80 (ϕ) with mean sorting values of 0.68 (ϕ) and 0.66 (ϕ) during month of September and January respectively (Fig. 4a). Sediments are mostly moderately sorted to well sorted during September and moderately sorted to moderately well sorted nature during January at backshore region. The spreading of

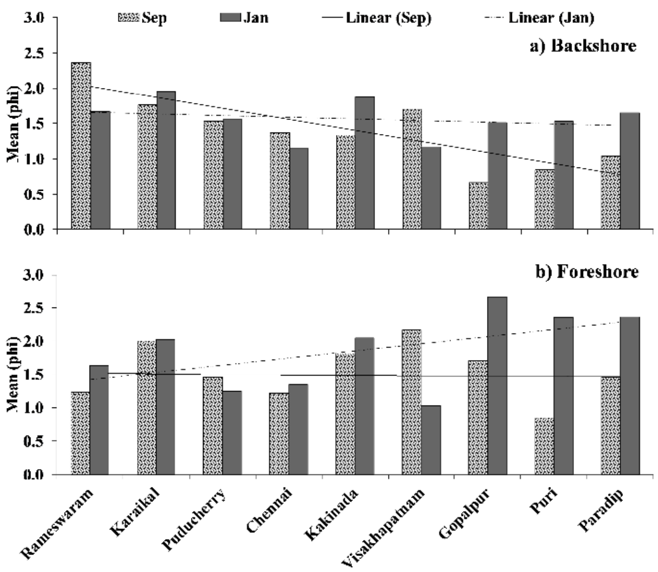

Fig.3. Beach sediment mean size distribution (phi) along east coast of India **(a)** Backshore, **(b)** Foreshore.

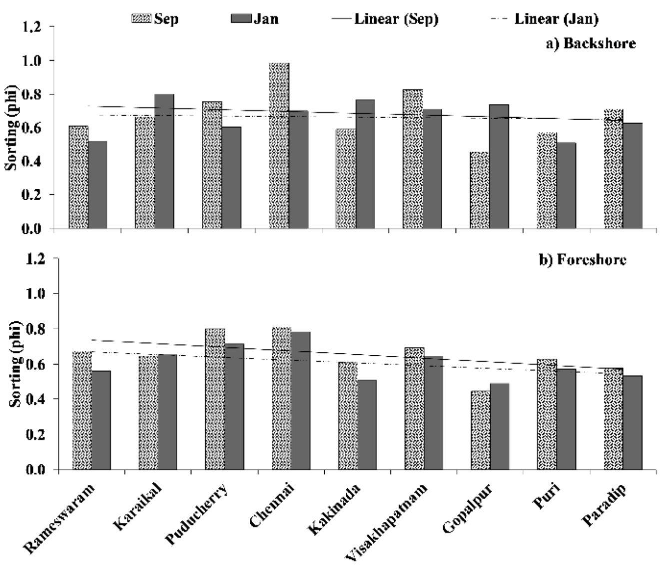

Fig.4. Beach sediment sorting distribution (phi) along east coast of India **(a)** Backshore **(b)** Foreshore

sediment sorting showed higher value during the September compared to January indicating backshore sediments are almost similar during January compared to September. The backshore sediment sorting during September and January showed no trend from south to north along east coast of India. The analysis of foreshore sediment sorting varies between 0.44-0.81 (ϕ) and 0.49-0.78 (ϕ) with mean value of 0.65 (ϕ) and 0.61 (ϕ) indicating either moderately sorted or well sorted by nature during September and January respectively (Fig. 4b). Spreading of foreshore sediment sorting observed almost similar during both the periods. Decreasing trend in sediment sorting from south to north along the coast during both seasons indicates dominance of well sorted sediments. The higher sorting value at Puducherry and Chennai could be a possible cause of sediment accretion either due to intervention of coastal structure or weakening of longshore currents. In sediment transport view point, higher amount of sediments getting transported during September compared to January since sorting value is higher during September at almost all locations.

Sediment Skewness

The sediment skewness is useful information for characterization of sediments and skewness measures the symmetry of grain size frequency distribution. The positive skewness indicates either of dominance of finer sediments or area of deposition while negatively skewed sediments indicates either the dominance of coarse sediments or erosional environments due to high energy environment (Duane, 1964). Skewness is computed as $SK = (\phi_{16} + \phi_{84} - 2\phi_{50})/2(\phi_{84} - \phi_{16}) + (\phi_5 + \phi_{95} - 2\phi_{50})/2(\phi_{95} - \phi_5)$. Sediments at most of the locations are symmetrically skewed. Magnitude of skewness is relatively higher during September compared to January. It is observed that sediment skewness at backshore varied between -0.32-0.23 and -0.29-0.04 with mean values of 0.03 and -0.03 during September and January respectively (Fig. 5a). Negative skewed sediments at Rameswaram and Kakinada beach during September and January indicates dominance of coarse sediments. The lower spreading value of skewness (0.10) during January indicates variability of sediment grain size distribution and is relatively less compared to September. Most of the station showed reversal pattern in skewness during course of time from southwest monsoon to northeast monsoon. Backshore sediments showed positive trend during September while no trend is visible during January from south to north along the coast.

In foreshore region, skewness of sediment distribution varied between -0.36-0.22 and -0.25-0.01 with mean values of 0.02 and -0.08 during September and January respectively (Fig. 5b). Magnitude of negative skewed sediments are higher during both periods compared to positive and symmetrical skewed sediments. Prevalence of symmetrical skewed sediments is higher during January compared to September indicating availability of equal proportion fine sand and coarse sand at foreshore environment. The trend of sediment skewness is slightly increased during September while decreased towards north direction along the east coast of India. The transformation of fine to coarse skewed at Kakinada and coarse to symmetrical skewed sediment at Visakhapatnam indicates removal and addition of fine sand from the respective locations (Fig. 5b).

Sediment Kurtosis

Kurtosis of sediment grain size distribution measures the ratio of sorting at its extreme portion of sediment distribution to the sorting of central portion. Kurtosis is not a sensitive parameter to measure the accretion and erosion of sedimentary environment (Friedman, 1961) rather provides information about quality, state and condition of peakedness or flatness of the sediment distribution. It is represented mathematically as $KU = (\phi_{95} - \phi_5)/2.44(\phi_{75} - \phi_{25})$. Sediments at backshore regions are mesokurtic by nature during September while at Kakinada sediments are leptokurtic by nature (Fig. 6). During January, sediments are mostly leptokurtic at southern and northern region of coast while mesokurtic type at the central portion of the coast at Chennai and Visakhapatnam and Gopalpur. Foreshore sediments are mostly mesokurtic at southern and northern reach of east coast while platykurtic sediments at its central region during September. However, sediments are leptokurtic in southern and mesokurtic in north region with platykurtic in central region of east coast of India during the January. The mesokurtic sediments towards north region indicates sorting of extreme portion of sediment distribution is poor compared to central portion representing accretion environment during the January.

Bivariate Plots

Bivariate plots between sediment statistical parameters such as mean, sorting, skewness and kurtosis is often helpful to interpret the energy conditions, mode of transportation and deposition. Passega (1957), Visher (1969), Folk and Ward (1957) and others described that trends in the bivariate plots might indicate mode of deposition and results in identifying the environments. The bivariate plot between

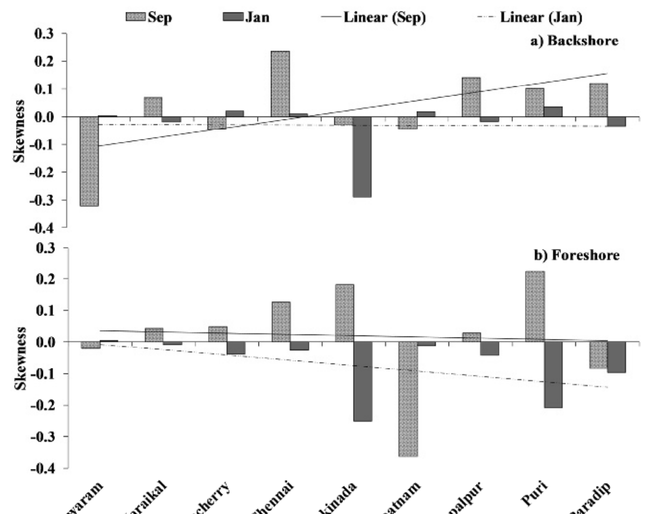

Fig.5. Beach sediment skewness distributions along east coast of India **(a)** Backshore **(b)** Foreshore

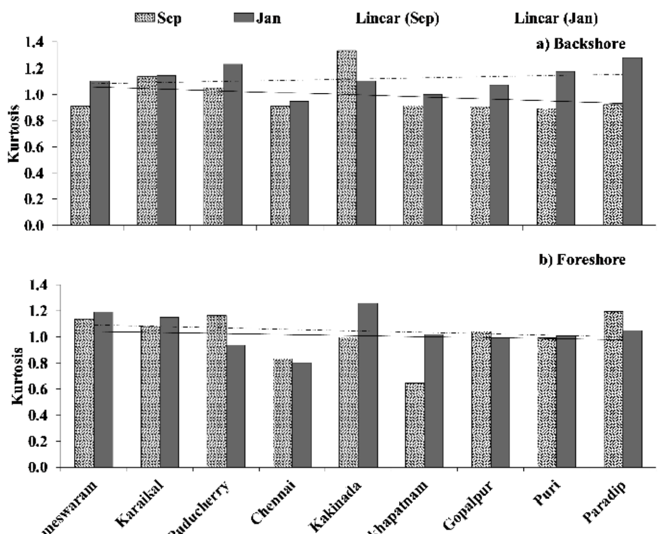

Fig.6. Beach sediment kurtosis distributions along east coast of India **(a)** Backshore **(b)** Foreshore

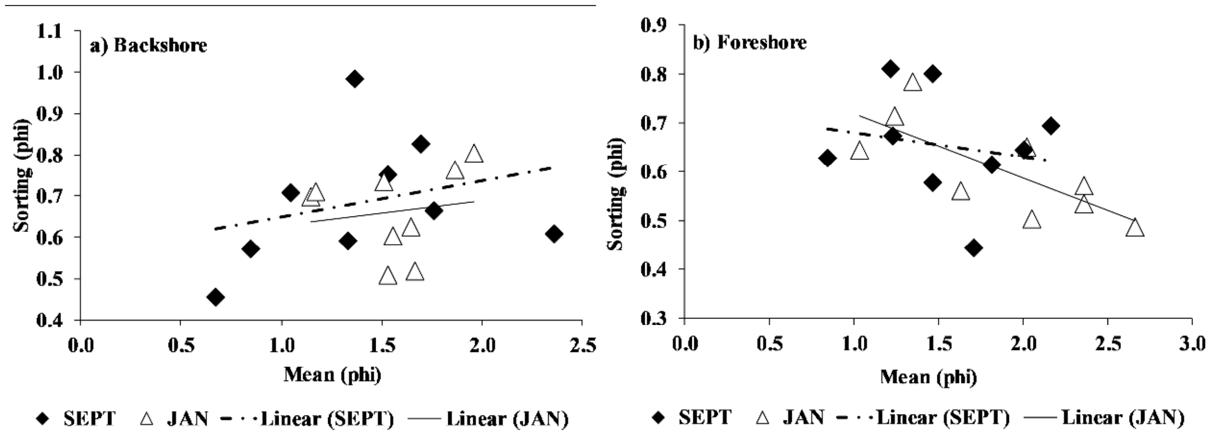

Fig.7. Bivariate plots (Mean vs Sorting) **(a)** Backshore **(b)** Foreshore

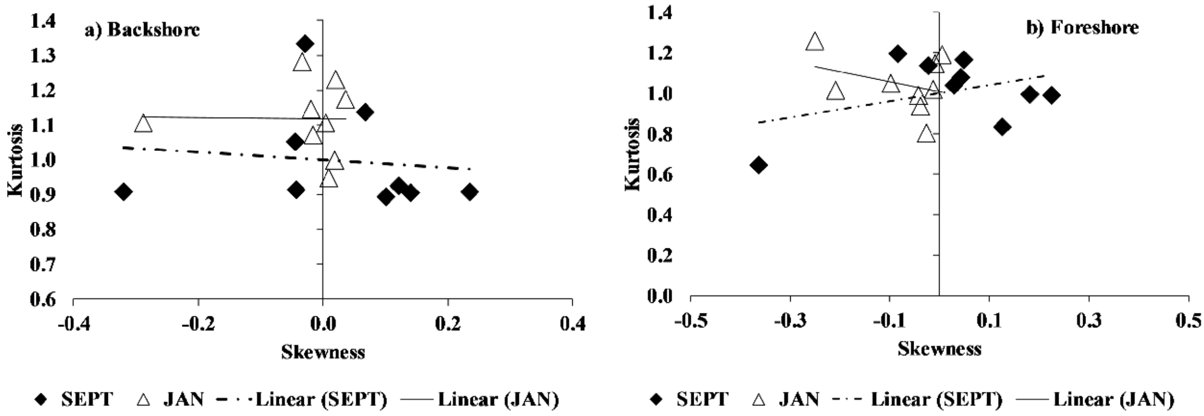

Fig.8. Bivariate plots (Skewness vs Kurtosis) **(a)** Backshore **(b)** Foreshore

mean grain size and sorting shows higher variation at foreshore region than backshore (Fig. 7a). The increasing trend line at backshore area represents fine sediments are associated with poor sorted characteristics while decline trend in foreshore depicts finer sand associated with well sorted sediments (Fig. 7b). During September, sorting increases with increase of mean size while decrease sediment sorting associated with increase value of grain size during January.

The bivariate plot of skewness and kurtosis at backshore region depicts symmetrical beach sediments are mesokurtic and leptokurtic by nature. The linear trend line shows increase sediment skewness decreases sediment kurtosis during September while no change is visible during January in backshore region. The trend line during September depicts increase value of sediment skewness associated with mesokurtic to leptokurtic sediments at foreshore environment, while negative trend is observed for January. During both periods, change in sediment skewness and kurtosis are insignificant for

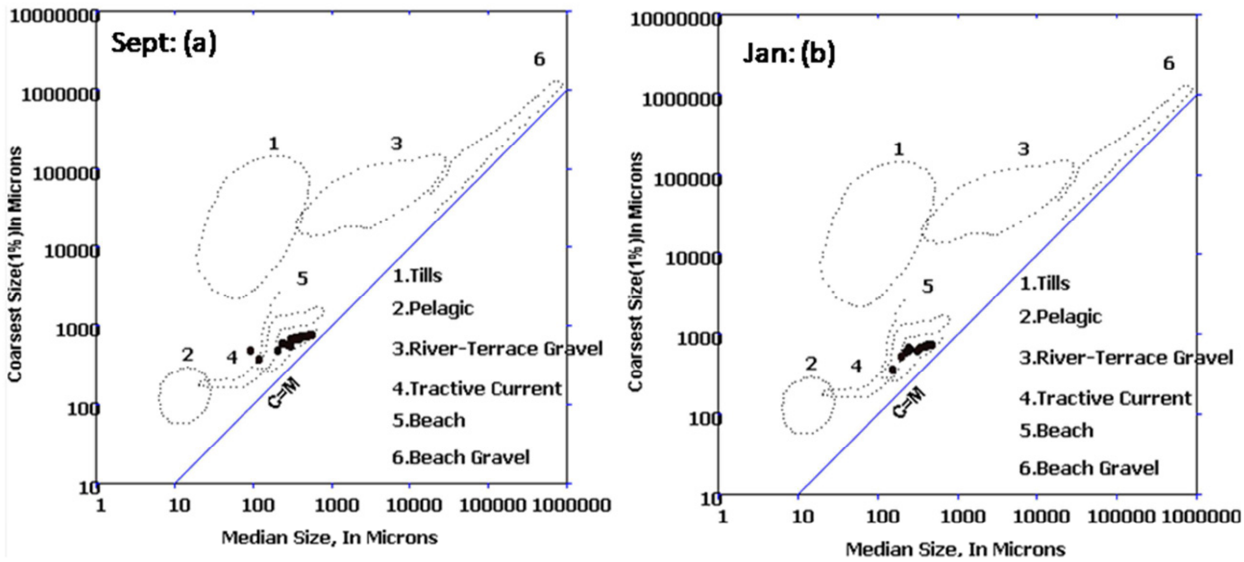

Fig.9. CM diagram (source of sediment) **(a)** September, **(b)** January.

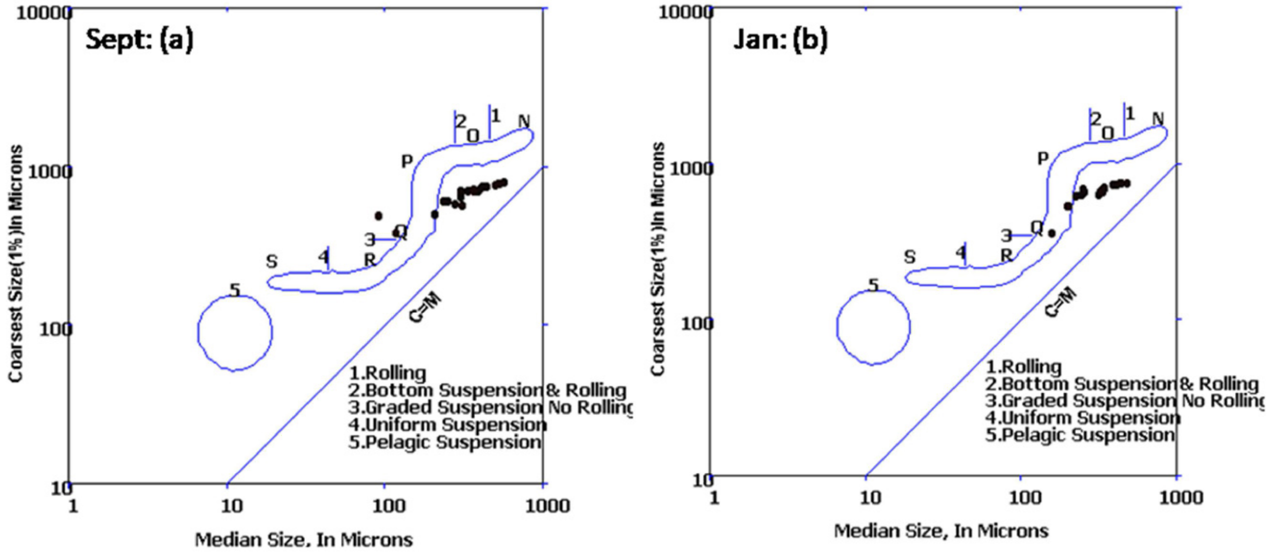

Fig.10. CM diagram (mode of transport) **(a)** September, **(b)** January.

backshore sediments while significant and reverse in foreshore region (Fig. 8)

CM Diagram

Passega (1957) interpreted distinct pattern of CM diagrams considering coarsest one percentile of grain size (C) against the median grain size (M) of sediment on a double log paper. This CM diagrams often depicts various mode of sediment transport as well as provides information on the sources of sediment origin. CM diagram was prepared following the procedures of Passega (1964; 1957) since it offers a platform for evaluating mode of transport as well as sources of sediments. During both periods, CM diagram depicts sources of sediment are mostly from beach and tractive current. In other words, absence of sediments from pelagic, tills, river-terrace gravel and beach gravel (Fig. 9) environments represents riverine sediment has no contribution on coastal zone evolution. Besides, sediment mode of transport is mainly rolling, bottom suspension and rolling and graded suspension no rolling types during September while bottom suspension and rolling; graded suspension no rolling during January (Fig. 10). The absence of rolling mechanism during January could be a cause for absence of beach sediment transport due to weakening of wind speed at beach surface environment. Besides, presence of rolling mode of transport during September could be important factor for changing beach geomorphology which needs to be accounted during modelling the geomorphology of beach environment.

CONCLUSION

The study reveals mean size trend is decreasing from south to north during September at backshore region while increasing trend from south to north during January at foreshore region. Prevalence of southwest monsoon induced high wave energy field makes medium sand scenario at foreshore region. Mean grain size showed decreasing (increase) trend towards the north along the coast during south-west (north-east) monsoon while no trend is visible during January (September) in backshore (foreshore) environment. The decreasing (increase) trend in mean grain size during September (January) indicates dominance of aeolian transport and accretion of fine sands in backshore (foreshore) environment respectively. During both periods, variations of sediment sorting are insignificant at backshore region while it showed decreasing trend from south to north in foreshore environment indicating an accretional environment compared to other stations. Backshore (foreshore) sediments showed positive (negative) trend in skewness during September (January) while no trend is visible during January (September) respectively. The CM plot indicates no input of sediments from river, pelagic environment along the coast while sediments are mostly originated from beach and tractive current environments with prime mode of transport process is rolling, bottom suspension and graded suspension during the September while bottom suspension and rolling; graded suspension no rolling during January respectively for both the backshore and foreshore environments. The sediment texture and mode of transport process during monsoon seasons could serve valuable information for planning and decision making process during the coastal management program.

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References:

Bangaku Naidu, K., Reddy, K.S.N., Ravi Sekhar, Ch., Ganapati Rao,P., and Murali Krishna, K.N. (2016) Grain Size Distributionof Coastal Sands between Gosthani and ChampavathiRivers Confluence, East Coast of India, Andhra Pradesh. Jour. Indian Geophys. Union, v.20(3), pp.351-361.

Baral, R., Pradhan, S., Samal, R.N. and Mishra, S.K. (2018) Shoreline Change Analysis at Chilika Lagoon Coast, India Using Digital Shoreline Analysis System. Jour. Indian Soc. Remote Sens., v.46, pp.1637.

Blott, S. J., and Pye, K. (2001) GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms, v.26(11), pp.1237–1248.

Chandramohan, P. and Nayak, B.U. (1991) Longshore sediment transport along the Indian coast. Indian Jour. Geo-Marine Sci., v.20(2), pp.110-114.

Chandrasekar, N. (1992) Beach placer mineral exploration along the Central Tamilnadu coast, Madurai.Ph.D. Thesis, Kamaraj Univ., Madurai, 293p.

Chauhan, O.S. (1986) Beach cycles and associated sediment movements at Puri and Konarak beaches of Orissa. Unpubld. Ph.D. Thesis. Garhwal University, 160p.

Chauhan, O.S. (1992) Sediment dynamics of Puri and Konark beaches along northeast coast of India. Indian Jour. Marine Sci., v.21, pp.201-206.

Clark, M.W. (1981) More skewed against than skewing. Internat. Assoc. Sedimentologists. Spec. Publ., no.5, pp.111–121.

Dinesh, A.C., (2008) G-Stat-A software in VB6 for grain size statistical analysis,

CM Diagrams, Trend Diagrams etc. Designed and developed by A.C Dinesh, Marine Wing, GSI, Mangalore.
Duane, D.B. (1964) Significance of skewness in recent sediments, western Pamlico Sound, North Carolina. Jour. Sediment. Petrol., v.34, 864-874.
Dube, S. K., Rao, A. D., Sinha, P. C., Murty, T. S., and Bahulayan, N. (1997) Storm surge in the Bay of Bengal and Arabian Sea: The problem and its prediction. Mausam, v.48, pp.283–304.
Folk, R. L. and Ward, W. C. (1957) A study in the significance of grain size parameters. Jour. Sediment. Petrol., v.7, pp.3–26.
Friedman, G.M. (1961) Distinction between dune, beach and river sand from their textural characteristics. Jour. Sediment. Petrol., v.31(2), pp.514-529.
Griffiths, J.C. (1951) Size versus sorting in some Caribbean sediments. Jour. Geol., 59(1), 211-243.
Ingram, R. L. (1970) Sieve analysis, procedures in sedimentary petrology, Wiley-inre science, New York, pp.49-67
Inman, D.I. and Chamberlin, T.K. (1955) Particle size distribution in nearshore sediments 'Finding Ancient Shoreline.' Soc. Econ. Paleontol. Mineral., Spec. Publ., no.3, 106-1227p.
Karunakarudu, T., Jagannadha Rao, M., Ganesh, B., Avataram, P. and Naidu, A.G.S.S. (2013) Studies on textural characteristicsof ErraKalva River, west Godavari District, Andhra Pradesh,East Coast of India. Internat. Jour. Geomatics and Geosci., v.4(2), pp.280-295.
Komar, P.D. (1998) Beach Processes and Sedimentation, New Jersey: Prentice Hall.
Mishra, P., Mohanty, P.K., Murty, A.S.N., Sugimoto, T. (2001) Beach profile studies near an artificial open-coast port along south Orissa, east coast of India. Jour. Coastal Res., Spec. Issue, v.34, pp.164–171
Mohanty, P. K., Patra, S. K., Bramha, S., Seth, B., Pradhan, U. K., Behera, B., P. Mishra and U. S. Panda (2012) Impact of groins on beach morphology: A case study near Gopalpur Port, east coast of India. Jour. Coastal Res., v.28(1), pp.132–142.
Monalisha, M., & Panda, G. K. (2018) Coastal erosion and shoreline change in Ganjam coast along East Coast of India. Jour. Earth Sci. Climatic Change, v.9, pp.467.
Passega, R. (1957) Texture as characteristics of clastic deposition. Bull. AAPG, v.41(9), pp.1952-1984.
Passega, R. (1964) Grain size representation by CM pattern as a geological tool. Jour. Sediment. Petrol., v.34(4), pp.830-847.
Pentney, R.M. and Dickson, M.E. (2012) Digital Grain Size Analysis of a Mixed Sand and Gravel Beach. Jour. Coastal Res., v.279, pp.196–201.
Rao, V. R., Murthy, M. V. R., Bhat, M. and Reddy, N. T. (2009) Littoral sediment transport and shoreline changes along Ennore on the southeast coast of India: Field observations and numerical modeling. Geomorphology, v.112(1-2), pp.158–166. DOI:10.1016/j.geomorph.2009.05.015
Sahu, B. K. (1964) Depositional mechanism from size analysis of clasticsediments. Jour. Sediment. Petrol., v.34(1), pp.73-83.
Schott, F. and McCreary, J.P. (2001) The Monsoon Circulation of the Indian Ocean. Progress in Oceanography, v.51, pp.1-123.
Shetye, S.R, Gouveia, A., Shenoi, S. S. C., Sundar, D., Michael, G .S. and Nampoothri, G. (1993) The western boundary current in the seasonal sub-tropical gyre in the Bay of Bengal. Jour. Geophys. Res., v.98, pp.945–954.
Singh, O. P., Khan, T. M. A. and Rahman, M. S. (2001) Has the frequency of intense tropical cyclones increased in the north Indian Ocean?, Curr. Sci., v.80, pp.575–580.
Sly, P.G., Thomas, R. L. and Pelletier, B. R. (1982) Comparison of sediment energy-texture relationships in marine and lacustrine environments. Hydrobiologia, v.91, pp.71–84.
Suvarna, B., Posendra Mohan, C. H. and Sunitha, V. (2017) Textural Analysis of Coastal Sands from Ramakrishna Beach -Bhimunipatnam tract (Visakhapatnam) East Coast of India. Jour. Indian Geophys. Union, v.21(3), pp.207-213.
Taira, A. and Scholle, P.A. (1979) Origin of bimodal sands in some modern environments. Jour. Sediment. Res., v.49(3), pp.777-786.
Visher, G.S. (1969) Grain size distribution and depositional process. Jour. Sediment. Petrol., v.39(3), pp.1074-1106.

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