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Research Article

Quantitative Analysis and Characterization of Grain Size Distribution-Study from Recent Coastal Sediments of Chandipur, East Coast India

[1]Sourav Dey, [2]Souvik Sen and [3]Joyjit Dey

[1]Department of Geology and Geophysics, Indian Institute of Technology Kharagpur, Kharagpur, 721 302 West Bengal, India
[2]Geologix Limited, Dynasty Building, Level-4, Wing-A, Andheri Kurla Road, Andheri East, 400 059 Mumbai, India
[3]School of Earth and Environment, University of Leeds, Leeds, United Kingdom

Abstract

Background and Objective: Characterization of sediment grain size and sorting on a beach are key input parameter to morphological models. The aim for analysis of these parameters helps to identify the spatial sediment distribution in active sedimentation environment. **Materials and Methods:** Recent coastal sediments has been studied from Chandipur beach, India; which has been designated as "Important Coastal and Marine Biodiversity Area" (ICMBA) for the coastal preservation as well as improved supervision of threatened and delicate coastal and marine flora and fauna. **Results:** Grain size variability on the present-day Chandipur beach has been interpreted. Statistical correlations between grain size, sorting and relative distance from beach/estuary have been recognized. **Conclusion:** Beach sands have been found coarser and well sorted with respect to the ones near estuary and upper tidal flat. Active sediment transport from estuary mouth by shore parallel current resulted in a mixing zone, resulting in poorly sorted sediment accumulation.

Key words: Grain size, spatial distribution, chandipur coastal sediments, morphological models, depositional environment

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Corresponding Author: Souvik Sen, Geologix Limited, Dynasty Building, Level-4, Wing-A, Andheri Kurla Road, Andheri East, 400 059 Mumbai, India

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Analysis of grain size and sorting is a classical tool for sediment characterization and depositional environment. These two parameters are directly linked and affected by the transportation and deposition, thus providing critical information about provenance and morphological modeling[1,2]. As the redistribution of different grain sizes takes place, the local morphology changes owing to subtle changes in erodibility and transportability[3,4]. In addition to this direct relationship, as local morphology, grain size and slope change, the hydrodynamics change in response[5,6]. Further, it is hypothesized that variations in size and sorting of sediment along the foreshore affect larger-scale profile morphology through feedback with forcing wave conditions[6]. Coastal environment is very dynamic as multiple factors play together (i.e. wind, longshore currents, fluvial processes etc.)[5-7]. Coastal areas are very vulnerable to erosion and have immediate effects on life and properties in the nearby areas[8-10]. It becomes very important to understand the sediment supply-transportation-deposition behavior in the coastal areas, as these actively shape the shoreline[11-13]. Sand banks are quite important for coastal environments since they are known to be an ideal habitat for many marine species[8,13-15], they protect the coasts during storms and can be a source of sediments for beach nourishments.

Bardhan *et al.*[16] studied the eastern Indian coastal sediments from Chandipur, Gangasagar and Bakkhali between the Mahanadi River and Hooghly River estuaries on the paleontological aspects and used bivalves as proxies to understand post Flandrian transgressive event. Chakrabarti[17,18] investigated coastal tidal flats between Sagar Island, West Bengal and Chandipur, Orissa to document the sediment size variation spatially. Saha *et al.*[19] analyzed coastal configuration from Henry's island from the eastern coast and commented on the sediment grain size distribution.

The main objective of this study was to understand the grain size distribution and sorting characteristics of modern coastal sediments in Chandipur beach, eastern India. The scope involves the identification of spatial variation of sedimen to logical parameters towards open sea as well as towards Buribalam estuary mouth, which is the active sedimentation zone.

MATERIALS AND METHODS

Study area: The study area, Chandipur is situated in Balasore district, Orissa, eastern coast of India (Fig. 1). The coastal

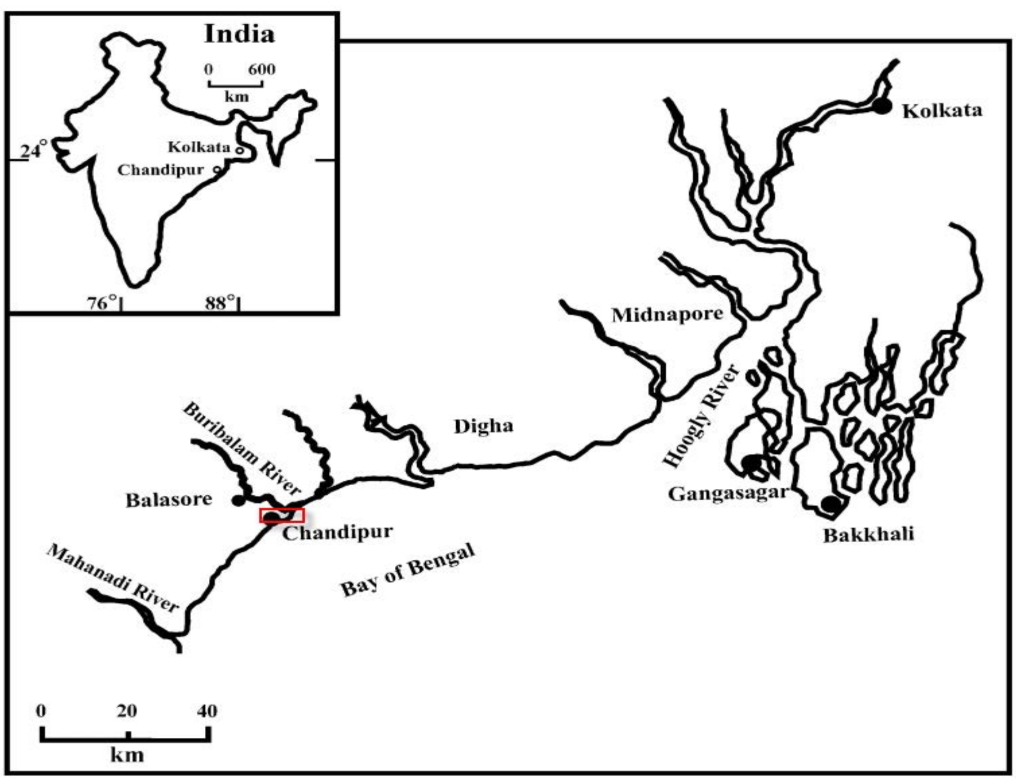

Fig. 1: Study area in Chandipur, marked by red square along the east coast, India

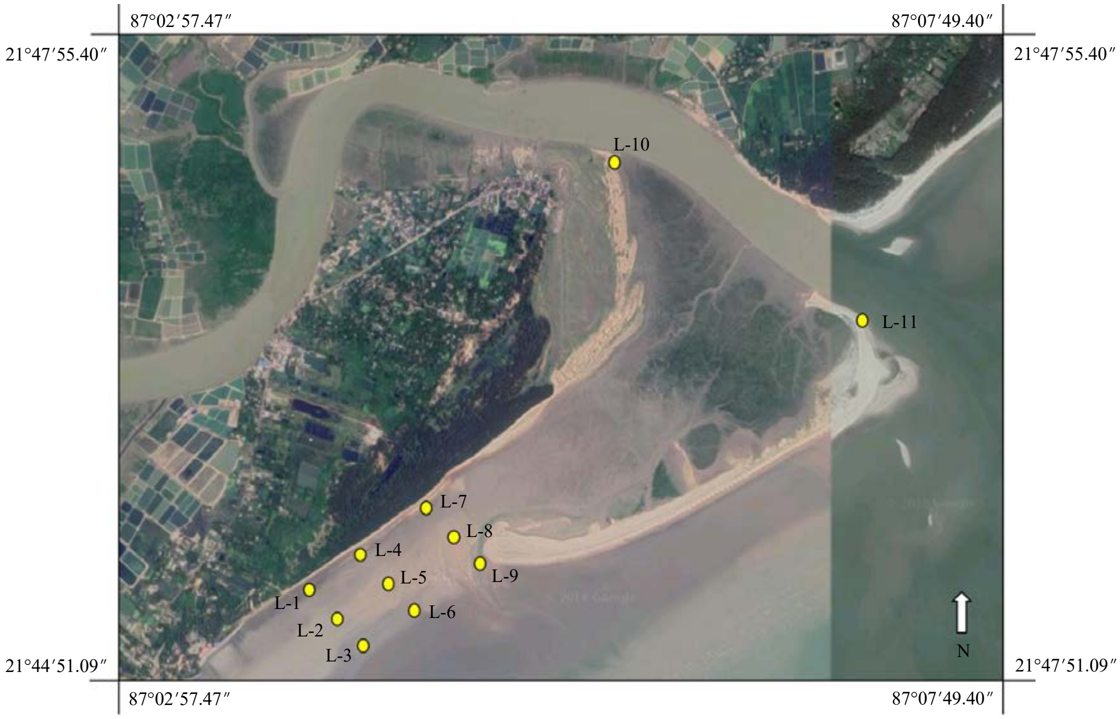

Fig. 2: Study area along with sampling locations of coastal sediments, Chandipur

sediments belong to Quaternary fluviomarine origin developed during post-glacial Flandrian transgression (6.5 Ka onwards) during the Holocene[20-21]. The Chandipur coastal area has broadly two geomorphologically distinct zones, land part (away from sea) is characterized by the fluvial processes from the Buribalam river, seaward part is a long beach, parallel to the coastline of the Bay of Bengal[11]. Beach has distinctive dune field and a very low dipping (<3°) silty intertidal flat, along with a shore parallel, sandy longitudinal bar at Buribalam estuary mouth[16]. The intertidal flat is quite wide, approximately 1-4 km. The intertidal mud flat of Chandipur is an exclusive coastal ecosystem which hosts red crabs, endangered horseshoe crabs, sea turtles and varied intertidal benthic fauna. This ecosystem is under threat because of amplified tourism activities. The other part of this coastline is controlled by Indian Army as an integrated test range. Chandipur coastline belongs to one of the identified "Important Coastal and Marine Biodiversity Area" (ICMBA) for the better management of coastal and marine flora and fauna. The study area lies between 21°44′ N-21°47′ N and 87°02′E-87°07′E (Fig. 2), covering a stretch along NE trending Chandipur coastline, ending at Buribalam river estuary mouth. This study was conducted from December, 2016-January, 2019.

Table 1: Location coordinates of the sampling stations in the study area

Stations	Distance from coastline (m)	Distance from estuary mouth (m)	Latitude	Longitude
L-1	100	1995	21°27'9.24"N	87°02'34.90"E
L-2	330	1195	21°27'3.44"N	87°02'39.27"E
L-3	650	695	21°26'57.73"N	87°02'42.84"E
L-4	110	1990	21°27'17.07"N	87°02'47.05"E
L-5	340	1190	21°27'10.86"N	87°02'51.48"E
L-6	645	690	21°27'6.21"N	87°02'54.84"E
L-7	105	2000	21°27'28.02"N	87°03'03.97"E
L-8	335	1200	21°27'22.50"N	87°03'08.64"E
L-9	640	700	21°27'18.32"N	87°03'12.57"E
L-10	40	22	21°28'26.53"N	87°03'36.43"E
L-11	1035	20	21°28'01.49"N	87°04'16.27"E

Sample processing and calculation: A detailed field work had been carried out along the long stretch of Chandipur coastline. Modern day beach sediment samples have been collected from eleven locations, presented in Fig. 2. Table 1 represents the coordinates of the sampling stations. Surface sediments were removed to avoid any kind of dilution in analyses and sediments were collected from 1 m×1 m grids and preserved in ziploc plastic bags. Collected sediments were dried in sunlight and 300 g sediment from each of the eleven locations was further dried on oven for 1 h at 50°C temperature. Once fully dried, samples were sieved using Table Sieve Shaker. Various mesh sizes have been used for

Fig. 3: Methodology of sample collection to preparation for grain size and sorting analysis

grain size analyses, which are 425, 300, 150, 125, 90 and 75 µm. Figure 3 briefly demonstrates the method of sample collection at study area too sample preparation in laboratory. After kinetic sieving, grain size (φ) values of different weights were obtained and used for various statistical parameters. Calculation methods of various output parameters have been discussed below.

Krumbein[22] provided the phi scale (φ) for grain size, which basically translates the Wentworth grain size scale[23] into a logarithmic scale. The equation is as follows:

$$\phi = -\text{Log}_2\,(d) \tag{1}$$

where, d is the particle diameter (mm).

Phi scale eases the statistical analysis (mean, skewness etc.) performed on grain size data. Sieving is an established method in classical grains size analysis. Sieve analysis data are plotted as histogram distribution curve and frequency distribution curve to get definitive outlook of sedimentation pattern and spatial grain size distribution as well as depositional environment. From grain size graphical representation, a mean grain size (M) can be interpreted, which represents a typical grain size middle property or a central location value from the distribution[5]. Following is the equation to measure graphic mean (M):

$$M = \frac{\phi 16 + \phi 50 + \phi 84}{3} \tag{2}$$

where, φ_{16}, φ_{50} and φ_{84} are the grain sizes at 16, 50 and 84% of the sample by weight respectively (percentiles). The Φ_{50} represents the graphical median value.

McCammon[24] suggested inclusion of the central section and extremes of data distribution[25-27] to characterize the sediment distribution, which is known as Sorting (S). Sorting is calculated by McCammon[24]:

$$S = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6} \tag{3}$$

RESULTS

Statistical mean grain size (phi) and sorting (phi) from the recent coastal sediments have been studied. Data has been presented in Table 2. Result shows average coarse to medium grained sand distribution (L1, 4 and 7) closest to beach whereas the traverse along L-3, 6 and 9 reveals a finer mean grain size, being the furthest sampling points from beach (Fig. 4). Figure 4 evidently picks decrease in grain size from beach to tidal flat as well as towards estuary.

L-10 and L-11 records very fine to fine sands, being on active sedimentation zone of the estuary. A distinct grain size increase (decreasing phi values) away from estuary mouth can be found in Fig. 5a. Figure 5b reflects a gradual decrease in grain size from medium-coarse sand to fine sands

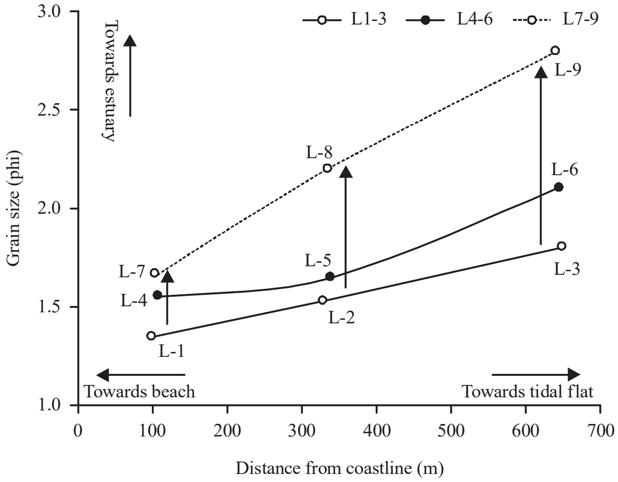

Fig. 4: Mean grain size variation from beach to estuary and towards estuary

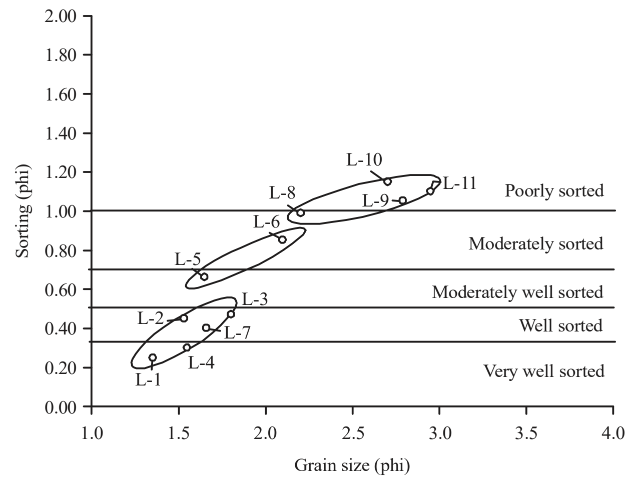

Fig. 6: Grain size vs. sorting at various sampling stations

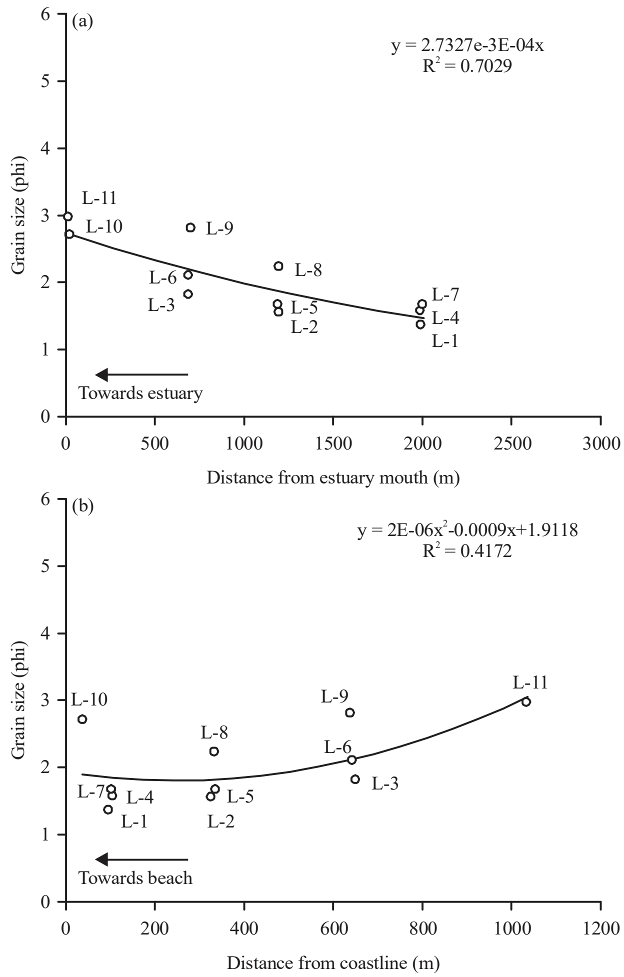

Fig. 5(a-b): Grain size variation away from (a) Estuary mouth and (b) Coastline

Source: Folk *et al.*[28]

Table 2: Mean grain size and sorting values, as interpreted from various sampling stations

Stations	Mean (phi)	Sorting (phi)	Wentworth size class
L-1	1.35	0.25	Medium-coarse sand
L-2	1.53	0.45	Medium sand
L-3	1.80	0.47	Fine-medium sand
L-4	1.55	0.30	Medium sand
L-5	1.65	0.66	Medium-fine sand
L-6	2.10	0.85	Fine sand
L-7	1.66	0.40	Medium sand
L-8	2.20	0.99	Fine sand
L-9	2.79	1.05	Fine sand
L-10	2.70	1.15	Very fine-fine sand
L-11	2.95	1.10	Very fine-fine sand

(increasing phi values) from beach to tidal flat area. Both these interpretations have been supported by a strong correlation in data plots.

Mean grain size vs. sorting values at various sampling locations have presented in Fig. 6. Classification has been used while interpreting Fig. 5a and b. Three distinct sorting clusters have been identified. L-8, 9, 10 and L-11 reveals poor sorting (increasing sorting phi values). L-6 and L-5 indicate moderate to poor and moderate sorting characteristics respectively. L-1, 2, 3, 4and L-7 display very good degree sorting.

Location map was concerned to understand the effect of relative distance from estuary mouth on spatial variation of grain size and sorting. L-1, 4 and L-7 reveals coarse to medium mean grain size (1.35-1.66 phi) and very well sorting (0.25-0.40 phi). Being located on the beach and far away from estuarine mouth, high energy waves are dominant force acting on these locations responsible for such uniform sediment characteristics in these three sampling stations. L-10 and L-11 are located on estuary bank and estuary mouth

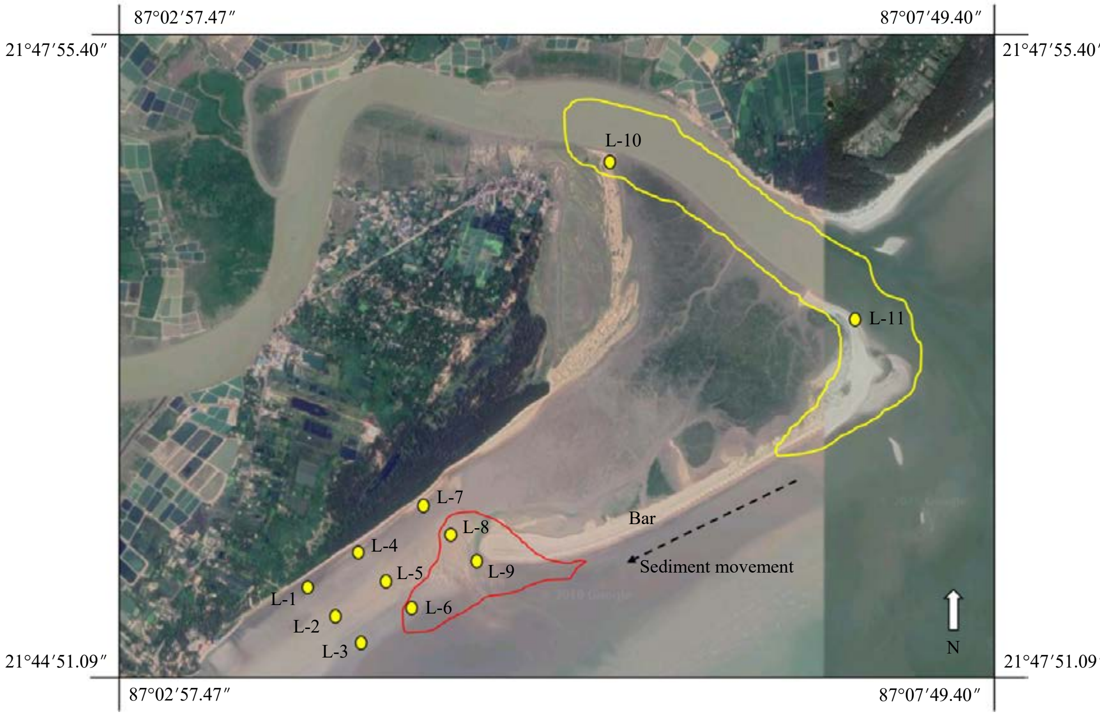

Fig. 7: Active estuarine sedimentation zone, marked by yellow, arrow indicates shore parallel sediment transfer from bar area to away, zone marked by red indicates active sediment mixing zone resulting poor sorting

respectively, which is the active sedimentation zone. And hence very fine to fine mean grain size (2.70-2.95 phi) with poor sorting (>1.00 phi) have been identified in these two locations. L-9 and L-11 are located in either flanks of the estuary mouth bar, although L-9 is away from mouth when compared to L-11. Both these station are characterized by poor sediment sorting and close mean grain size values (2.79-2.95 phi). Moderate to poor sorting at L-6, 8 and L-9 points to the effect sediment mixing resulted from shore parallel current moving sediment from estuary mouth towards these locations. Active estuarine sedimentation and potential mixing zones have been mapped and demarcated in map (Fig. 7).

Result shows that beach sands are relatively coarser grained (coarse-medium sands) and well sorted, resulting from high energy wave action. This uniform sediment characteristics have been pretty consistent along the beach, parallel to the coastline. Traverse from beach to tidal flat to sea (foreshore-backshore-inshore direction) display a gradual decrease in grain size because of diminishing wave energy effect. Traverse along L1-2-3, L4-5-6 and L7-8-9 provides the decreasing grain size pattern from beach to tidal flat. Fine grained sands are dominant towards estuary revealing very poor sorting, as can be seen in L-10 and L-11. An intermediate sorting and grain size distribution has been found in three sampling stations (L6, 8 and L-9). This is a result of sediment mixing phenomenon by shore parallel currents responsible for sediment transportation from estuary mouth to these locations. Figure 7 demonstrates the active mixing zone in study area map.

DISCUSSION

This study interprets the lateral variation of grain size and sorting in the coastal sediments of Chandipur. Sampling points closest to the beach (L1, 4 and 7) indicates coarse to medium mean grain size (1.35-1.66 phi) and very well sorting (0.25-0.40 phi). Very fine to fine mean grain size (2.70-2.95 phi) with poor sorting (>1.00 phi) have been recorded in the locations close to estuary bank and estuary mouth (L-10 and L-11) in the upper tidal flat. Sediment mixing phenomenon by shore parallel currents resulted in intermediate sorting and grain size distribution for the in-between sampling stations (L6, 8 and L-9).

Chakrabarti[17,18] interpreted mostly of fine sand (2-3 phi) in the upper tidal flat along with a seasonal influx of muddy sediments (fine grained) through the tidal creeks draining the upland areas. Saha *et al.*[19] suggested that the sand transportation by tidal currents might have resulted in sediment mixing, which resulted in fine to very fine sand size sediment distribution therefore. They advocated the reduction of sorting by the mixing of two size population-sand and silt[20]. Bardhan *et al.*[16] identifies that the contact between beach and tidal flat is marked by abrupt gradient change along with variations in grain size. Folk and Ward[28] classified sorting <0.35 as very well sorted, 0.35-0.50 as well sorted, 0.50-0.71 as moderately well sorted, 0.71-1.00 as moderately sorted and >1.00 as poorly sorted.

It is suggested to deploy the coastal sediment sample collection and statistical analysis in Chandipur area in different months of the year to decipher the temporal variation of sediment distribution and identify potential seasonal sediment flux, if in place. With more number of closely placed sampling points, a minute spatial sediment variation can be modeled.

CONCLUSION

This work employs graphical method to estimate the statistical distribution of mean grain size and sorting behavior of coastal sediments from Chandipur, eastern India. Variation of these statistical parameters has been documented and a spatial correlation between the sampling points has been presented. The sediment mixing pattern near estuary and mouth bar has been established in this study and that might be a potential path for active pollutant contamination towards the tidal flat zone, a rich habitat for microorganisms.

SIGNIFICANCE STATEMENT

Characterization of sediment grain size and sorting on a beach are key input parameter to morphological models. The analysis of these parameters helps to identify the spatial sediment distribution in active sedimentation environment. As the redistribution of different grain sizes takes place, the local morphology changes owing to subtle changes in erodibility and transportability. This study captures the spatial distribution of modern day coastal sediments and deciphers the active sediment mixing zone. The Buribalam River flows through a populated human settlement and present urban drainage and local small scale river side industries are prominent sources of pollutants which are directly or indirectly being mixed up in river water and reaches the sea/estuarine without any barrier. The study area, although being a designated ecologically sensitive zone, is therefore very vulnerable to potential pollutant affected.

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