ORIGINAL ARTICLE

CrossMark

Wave–beach sediment interaction with shoreline changes along a headland bounded pocket beach, West coast of India

S. Sathish[1] · R. S. Kankara[1] · S. Chenthamil Selvan[1] · M. Umamaheswari[1] · K. Rasheed[1]

Abstract

Grain size analysis was carried out to understand the behavior of sediment distribution in a pocket beach and to examine the relationship between the sediment distribution on surficial beach sediments with the wave energy and shoreline changes. Three seasons surficial beach sediment were sampled, and statistical characteristics were analyzed for September 2014, February 2015, and July 2015. The Mike-21 spectral wave model was utilized to estimate the wave energy distribution and shoreline changes were also mapped using Resourcesat-2 (LISS IV) satellite images and net shoreline movement method was adopted for shoreline change analysis. Because, shoreline changes directly indicate the erosion and accretion pattern of coastal zones. The analyzed sediment statistical parameters were correlated with the wave energy and shoreline changes. Based on the correlation, it was found that wave determines the sediment distribution pattern on Vengurla sandy beach. The result suggests that the beach sediment was mostly medium sand with moderately well sorted, fine skewed to coarse skewed with platykurtic, mesokurtic, and leptokurtic characteristics. The study area was under influenced medium wave to high wave action. The backshore samples have an average skewness of 0.030 Φ, which suggests depositional settings, whereas the bermline and foreshore have an average skewness of − 0.392 and −0.075 Φ, respectively, illustrating the erosional conditions. The sediment categorization results indicated that the backshore is stable, while the bermline is partly eroded as well as accreting in nature. The results show that the wave energy is playing a vital role in sediment distribution and transportation.

Keywords Grain size · Wave energy · Beach processes · Gradistat · Spectral wave model · Shoreline change analysis

Introduction

Categorization of beach sediments is widely based on the grain size pattern and depositional processes. The grain size is an imperative physical property of sediment (Anithamary et al. 2011). The grain size statistical parameters such as

✉ S. Sathish
  sathishs@icmam.gov.in

  R. S. Kankara
  kankara@icmam.gov.in

  S. Chenthamil Selvan
  selvan@icmam.gov.in

  M. Umamaheswari
  umamaheswari@icmam.gov.in

  K. Rasheed
  rasheedpku@yahoo.co.in

[1] Integrated Coastal and Marine Area Management-Project Directorate, Ministry of Earth Sciences, Government of India, NIOT-Campus, Velachery, Chennai 600100, India

mean, skewness, kurtosis and standard deviation are a helpful measure for deciding the speed of sediment deposition (McCave 2008). Grain size distribution is one of the regularly utilized strategies to study the beach sediment characteristics, beach processes, designing of filters for dam construction, soil and water movement, beach nourishment, and coastal engineering. (Krumbein 1934, 1938; Inman 1952; Folk and Ward 1957; Friedman 1961; Visher 1969 and Nordstrom 1977). For beach nourishment, a number of techniques have been used to recognize the suitable sand sources for beach fill material and to anticipate the volume of material expected to influence the beach fill. The most reliable prediction of fill behavior is obtained when applying sediment grain size parameters of the native and borrows area, fill geometry and some measures of wave climate (Swart 1991). Moreover, grain size information is utilized by geologist to examine the surface processes identified with the dynamic states of transportation and deposition. While engineers apply grain size to know the penetrability and steadiness under load, hydrologists use grain size properties

🖄 Springer

for considering the development of subsurface liquids (Blatt et al. 1972; McCave and Syvitski 1991). Realizing the wide application of sediment grain size analysis for shoreline management and to understand the coastal processes, the present work was carried out to correlate the wave energy and shoreline change with sediment features and to assess the distribution of wave energy along the Vengurla beach, West coast of India.

Study area

Vengurla, a small town is positioned between 15°51′N and 73°38′E along the coastal region of Sindhudurg district of Maharashtra, West coast of India (Fig. 1). The study area is a bay with a coastline of 5 km and bounded by headlands on the northern and southern sides. A small channel drains into the sea, near the northern headland and scattered sand dunes are located all along the Vengurla coast. There is less interaction between the sand dunes and the sea water, because sand dune is located away from the high water line and is well stabilized by vegetation. The climatic conditions of the study region are strongly controlled by the geographical conditions. The annual mean precipitation is 2922 mm (Mandale et al. 2017). The winds and waves change seasonally. The monthly mean wave breaking height is around 0.7 m from September to April and exceeds 1 m from May to August. The predominant wave directions in this area are South West (SW), West South West (WSW), West (W), and West North West (WNW). The southwesterly waves move the sediment northwards, whereas the WNW waves transport the sediment southwards (Gujar et al. 2008). The tides are predominantly semi-diurnal, and the tidal range varies from 0.5 to 2.0 m. In general, waves, coastal currents, precipitation, and hinterland processes regulate the sediment distribution in coastal zones.
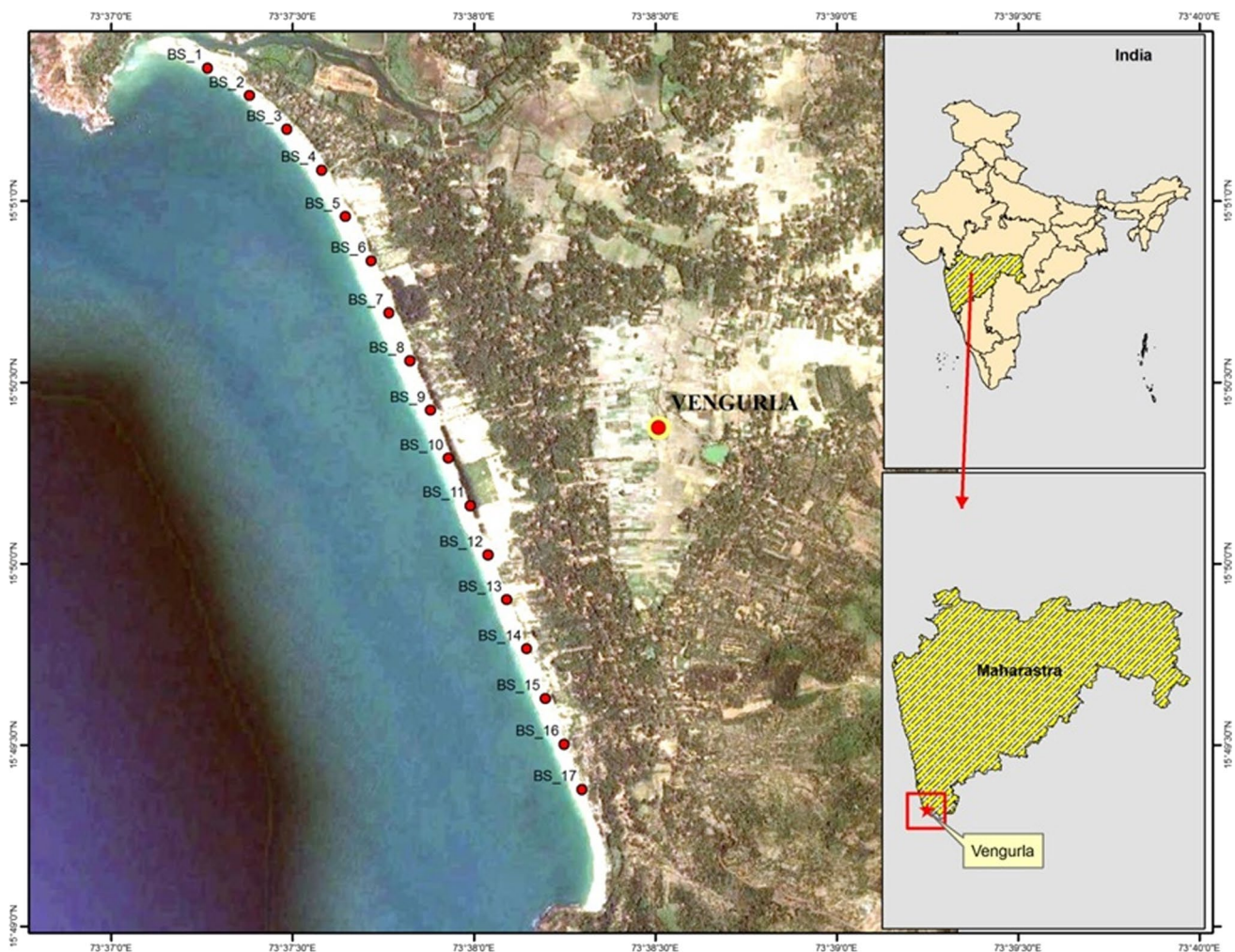

Fig. 1 Study area with sampling locations

Materials and methods

Fieldwork was carried out to collect the beach sediments and measurement of the nearshore wave energy. Surficial sediment samples were collected from the study area for three different periods (September, 2014; February, 2015; and July, 2015) at 17 cross beach transects such as foreshore (FS), bermline (BL), and backshore (BS). All the sediment samples were collected at 250 m interval. Simultaneously, sampling locations were recorded by handheld GPS. All the samples were collected in polyethylene bags and brought to the laboratory for further analysis. After removing the dead shells, the samples were washed with water and dried at 60° C in a hot air oven. A Retsch sieve shaker (AS 200) with 7 sieves of 75, 125, 180, 250, 355, 500, and 1000 μm size was used to fractionate the sediment. The fractionated sediment size was further analyzed by GRADISTAT statistical package based upon Folk and Ward (1957) method.

To understand the role of waves on changes in the shoreline and sediment characteristics, the spectral wave model MIKE 21 SW (DHI software package) was set up in the study region. The model was calibrated and validated with measured wave data (significant wave height, wave period, and wave direction) collected at 15 m depth during 2014 year. The model simulated for one year (2014) with time step of 120 s. The accuracy of the modeled results is shown (table) in terms of statistical measures such as Root Mean Square Error(RMSE), Scatter Index(SI), and Pearson's correlation coefficient(R) (Table 4). Wave energy was computed at the locations where the sediment samples were collected. Comparing the wave energy with features of sediment samples at 51 stations was not feasible. To overcome this shortfall, samples collected near the headlands were only used for comparison purpose. Sediments and wave energy were correlated, and a simple relative method was used to explain the relationship between wave and sediment characteristics. In addition, curve fitting method was used to study the relationship among the sediment variables with the goal of defining the best fit model. It is the way of making a mathematical function which has the best fit to the series of data points. Curve fitting can connect either interpolation, where a precise fit to the information is required, or smooth, in which a smooth function is built that generally with fits the data. Regression analysis concentrates more on questions of statistical inference such as how much uncertainty is present in a curve that is fit for data with random errors. Fitted curves help in data visualization and to understand the values of a function when no data are usable. Extrapolation indicates the purpose of a fitted curve beyond the scope of watched data and is liable to a level of uncertainty, since it

may repeat the method applied to make the curve as much as it reflects the observed information. To comprehend the spatial extent of erosion and accretion pattern along the Vengurla coast, shoreline change analysis was carried out using two LISS IV data (1st February, 2014 and 2nd February, 2015). The satellite images were procured from National Remote Sensing Centre (NRSC), India. Image rectification was applied to eliminate the image distortion and bring them to geographic projection (geographic Lat/Lon) with WGS84 datum. Finally, in ArcGIS environment, the geometrically corrected LISS IV images were used for shoreline change analysis. Sediments were compared with wave energy and shoreline change analysis. A simple relative method was used to explain the relationship between wave and sediment characteristics with shoreline changes.

Results

Sediment analysis

The mean, standard deviation, skewness, and kurtosis parameters were computed to understand the particle size properties and sediment distribution pattern for September 2014, February 2015, and July 2015 sediments. The results of the three seasons were converted into Folk and Ward phi statistical scale and it was found that the beach sediments are primarily composed of sand particles. For September 2014 samples, statistical properties of grain sizes and its interpretations are shown in Fig. 2. The back shore (BS) sediment is coarse sand to medium sand (0.709–2.416), very well sorted to moderately well sorted, strong coarse to strongly fine skewed and kurtosis values confirm platykurtic to very leptokurtic. However, the bermline (BL) sediment was medium to fine sand (1.608–2.338). Standard deviation values indicate moderately well sorted to well sorted, skewness is symmetrical to coarse skewed, and kurtosis occurred from platykurtic to very leptokurtic. In FS, the mean values show medium sand to fine sand (1.807–2.439), the standard deviation values suggest a well sorted to moderately well sorted, the skewness varied from course to fine, and the kurtosis depicts platykurtic to very leptokurtic. For February 2015 samples, the statistical properties of grain sizes and its interpretations are shown in Fig. 3. It is clearly seen that sediment of BS has medium to fine sand (1.079–2.538), very well to moderately sorted, strongly coarse to strongly fine skewed, and platykurtic to very leptokurtic nature (Fig. 3). However, BL sediments were medium to fine sand (1.414–2.322). Standard deviation values demonstrate that well sorted to moderately sorted, skewness is strongly coarse skewed to near symmetrical, and kurtosis was from platykurtic to very leptokurtic. For FS, the mean values indicate medium sand to fine sand(1.662–2.334), the standard deviation values

Fig. 2 Statistical properties of sediments (Sept, 2014)

Beach sediment analysis at Vengurla during Sep, 2014
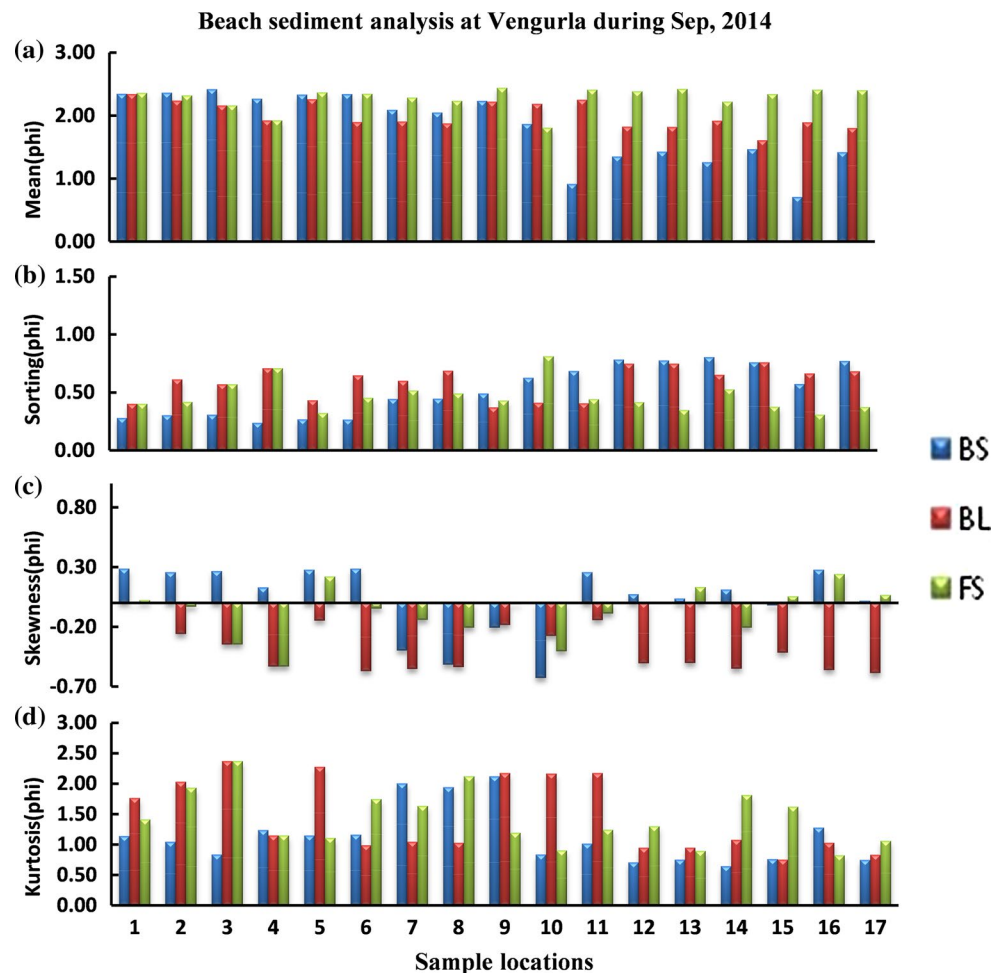
indicate a well sorted to moderately sorted, the skewness differed from strong coarse skewed to coarse skewed, and the kurtosis represents platykurtic to very leptokurtic. The properties of grain sizes and its interpretations for July 2015 are represented in Fig. 4. For BS, the mean values show coarse sand to fine sand(0.821–2.355), the standard deviation of a large portion of the BS samples shows very well sorted to moderately sorted, skewness varied from coarse skewed to strongly fine skewed, and kurtosis values portray platykurtic to very leptokurtic. For the examination of BL, the mean values are coarse sand to fine sand (0.889 to 2.430). Standard deviation esteems demonstrate that well sorted to modestly arrange, the skewness is coarse skewed to fine skewed, and kurtosis ranged from platykurtic to very leptokurtic. In FS, the mean value indicates coarse sand to fine sand (0.597–2.332), the standard deviation values infer well sorted to moderately sorted, the skewness is shifting from course to fine, and the kurtosis delineates platykurtic to very leptokurtic. To comprehend the erosion/accretion pattern and sediment behavior by the end of the monsoon season of the area, sediment analysis was concluded for September, 2014 data. The skewness values were utilized

to compare with the shoreline change analysis result. The negative skewness values signify coarse-skewed material, while the positive values have fine skewed. The negative skewness was found in the northern and southern part of the investigation area, which has a headland on account of the common high wave vitality condition and wave meeting happens at the headlands. This is likewise bolstered by the erosive action of the waves. Friedman (1962) suggested that extremely high or low values of kurtosis imply that part of the sediment achieved sorting elsewhere in a high energy condition. There are a few components affected to textural attributes of beach front sediments. They are made out of the climatic state of the contiguous land, the tide, littoral transport, length, and vitality of the sediment transport (Masselink et al. 2012). Carranza-Edwards (2001) used grain size, to discuss the sources and hydrodynamic conditions of marine sediments. Statistical approach is normally connected to disentangle the fundamental correlations among samples and recognize the distribution pattern. Sedimentologists expose the particle sizes by numerical moments (Krumbein and Pettijohn 1938), comprehensive graphical and statistical methods (Folk 1974).

Fig. 3 Statistical properties of sediments (Feb, 2015)

Beach sediment analysis at Vengurla during Feb, 2015
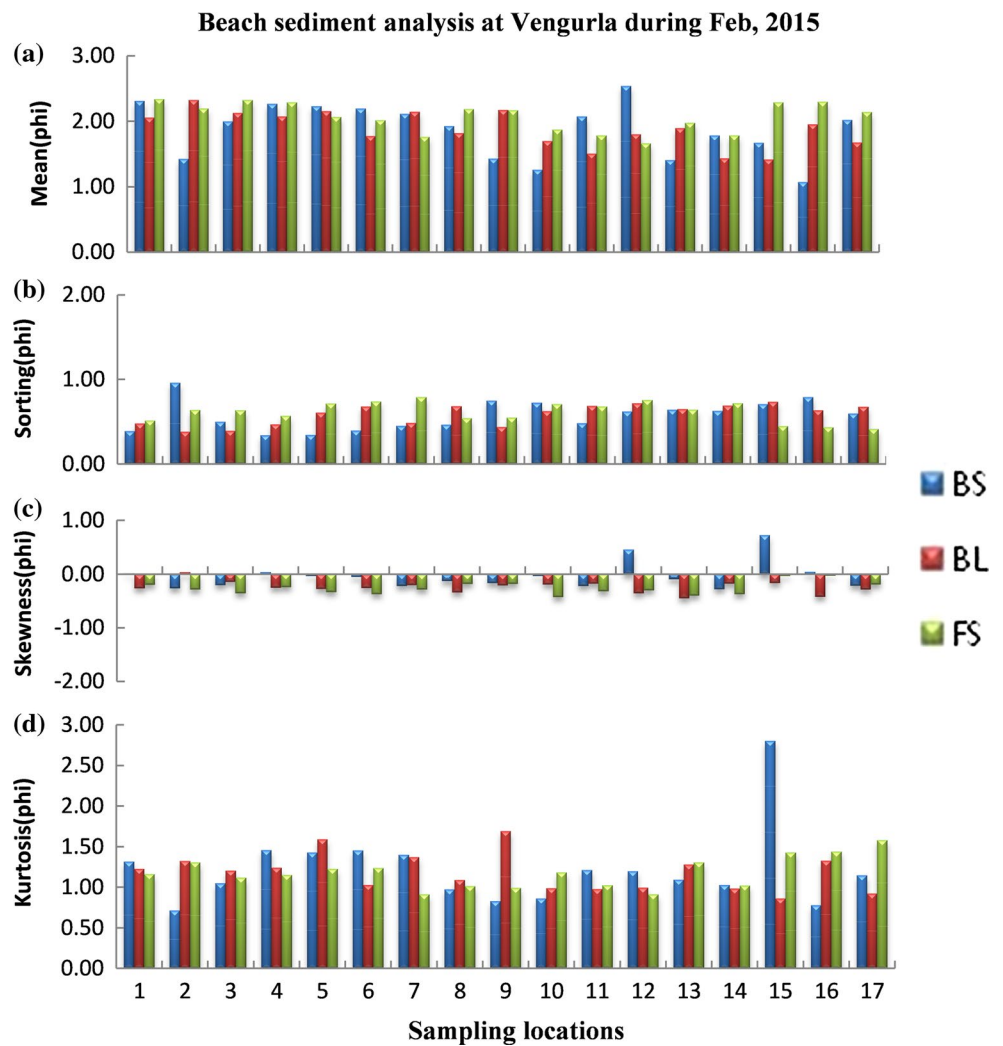
## Bivariate plot analysis of Sept, 2014 sediments

The polynomial and linear correlation bivariate plot analysis was carried out (Fig. 5) for sediments collected during Sep 2014. In the polynomial correlation (Table 1) and linear correlation (Table 2) of R^2 values are shown here. For BS sediments, Mean Vs sorting plot of the present samples depicts that the nature of the sediments is bimodal; however, the fine sand is a dominant constituent. The plot between the mean and skewness reveals most of the samples fall under the positive values and few are under the negative skewness values and clearly indicates the mixture of two types of sediment sizes. The mean Vs kurtosis plot shows high leptokurtic values followed by platykurtic, indicating that the sediment in BS is stable in nature. For BL, the mean Vs sorting values demonstrates the different variety of sizes and it dominated by bimodal. The mean Vs skewness plot explains the mixture of positive as well as negative values, mean Vs kurtosis graph shows leptokurtic is high and subordinately mesokurtic values, the BL of the study area has partly scoured and as

well as in accreting nature. Whereas for FS sediments, the mean Vs sorting indicates the fine sand is dominant, whereas the plot between the mean and skewness reveals the positive and negative skewness equally contributes. Mean Vs kurtosis gives both the leptokurtic and mesokurtic and the leptokurtic and mesokurtic are occures by impact of high wave energy condition, so the FS area is showing an erosive tendency.

Influence of wave in sediment distribution

During field survey, wave was measured at 15 m water depth off Vengurla region (Fig. 6). Additionally, wave model was generated (Fig. 7) and the modeled wave parameters demonstrate good match with measured wave data (Table 3). Beach morphology generally understood by examining the contribution of wave energy (usually described by Significant or mean wave height) and tidal range (Davis and Hayes, 1984; Masselink and Short 1993).The simulated wave data were used to observe the impact of the wave on sediment

Fig. 4 Statistical properties of sediments (July, 2015)

Beach sediment analysis at Vengurla during July, 2015
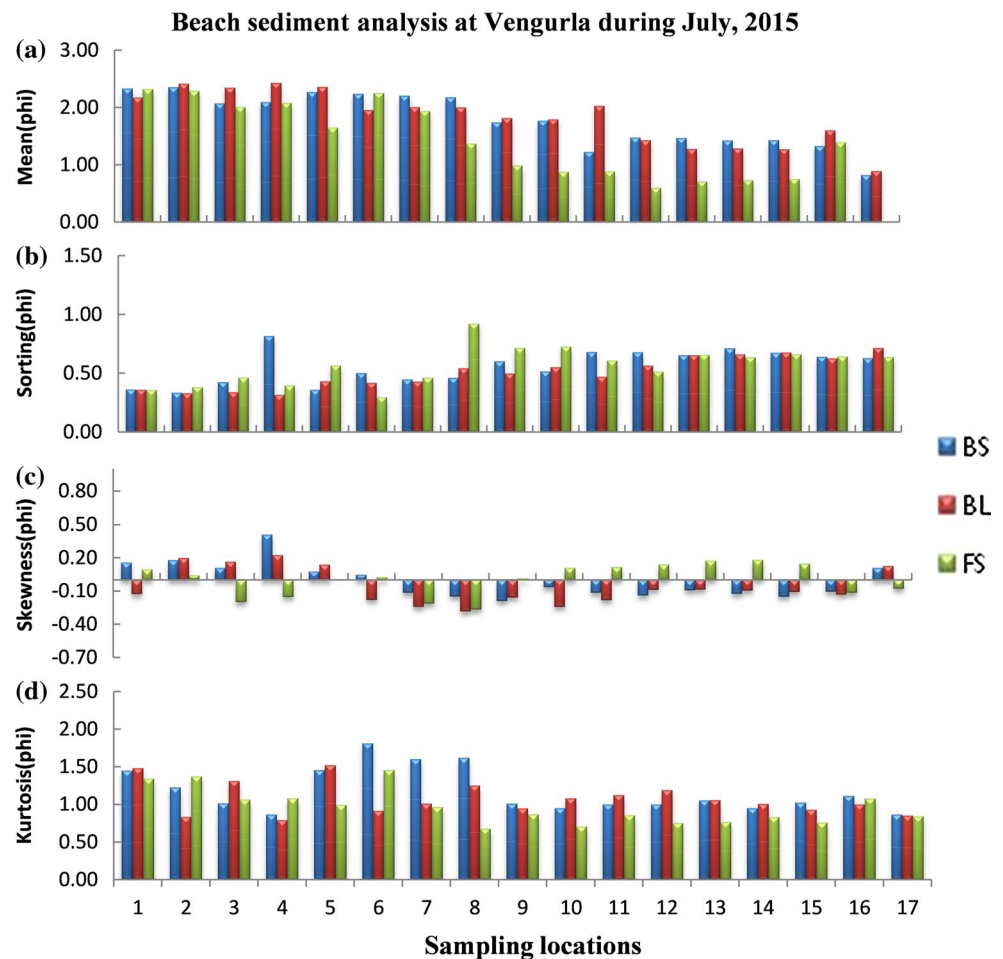
distribution and shoreline change analysis in a beach environment. Figure shows the modeled significant wave height along the Vengurla coast. The lower wave height or wave energy (Hs < 0.5 m) was observed in the northern end region of coastline. The wave height or wave energy increases in further locations and is expected to erode the area. The wave energy was extracted for September month in nearby regions of sediment locations and interpreted with the skewness value of sediments. This shows the degree of contribution of wave in the distribution of sediments along the shore (Table 5).

Shoreline change analysis

Coastal landforms and its orientation are mainly controlled by various oceanographic parameters such as waves, tides, currents, rainfall, storms, and sea level change (Albert and Jorge 1998; Morton and Miller 2005). Beach sediment transports are influenced by this interaction which tends to change the morphology of the coast (Griggs and Tait 1988). The sequential shoreline change study is useful to

understand the seasonal deviations and other natural calamity like cyclone and storm surge which directly impacts the coastal region. The shoreline change analysis was performed by using Digital Shoreline Analysis System (DSAS) in the ArcGIS 10.3 version (Thieler et al. 2009). To study the annual behavioral change rate, Net Shoreline Movement (NSM) method was adopted to calculate the total distance of shoreline change. Net shoreline movement determines the total distance between the oldest and youngest shorelines.

Resourcesat- 2 (LISS-IV) satellite data was used to calculate the shoreline change study. Two different years satellite data were used to study the shoreline change (Table 4). Satellite acquisition date is selected in such a way that it is well matched with the sediment field survey period. ERDAS IMAGINE 2013 software was used to rectify the satellite images (Projection: UTM, Datum: WGS-84). Due to the homogeneous resolution, pixel miss interpretation is omitted from the analysis. Wet-dry line was considered as a proxy to extract the shoreline position from satellite imagery. The shoreline rate obtained from the analysis is classified into two categories as negative sign indicates erosion and positive sign indicates accretion. Erosion was observed on either side of
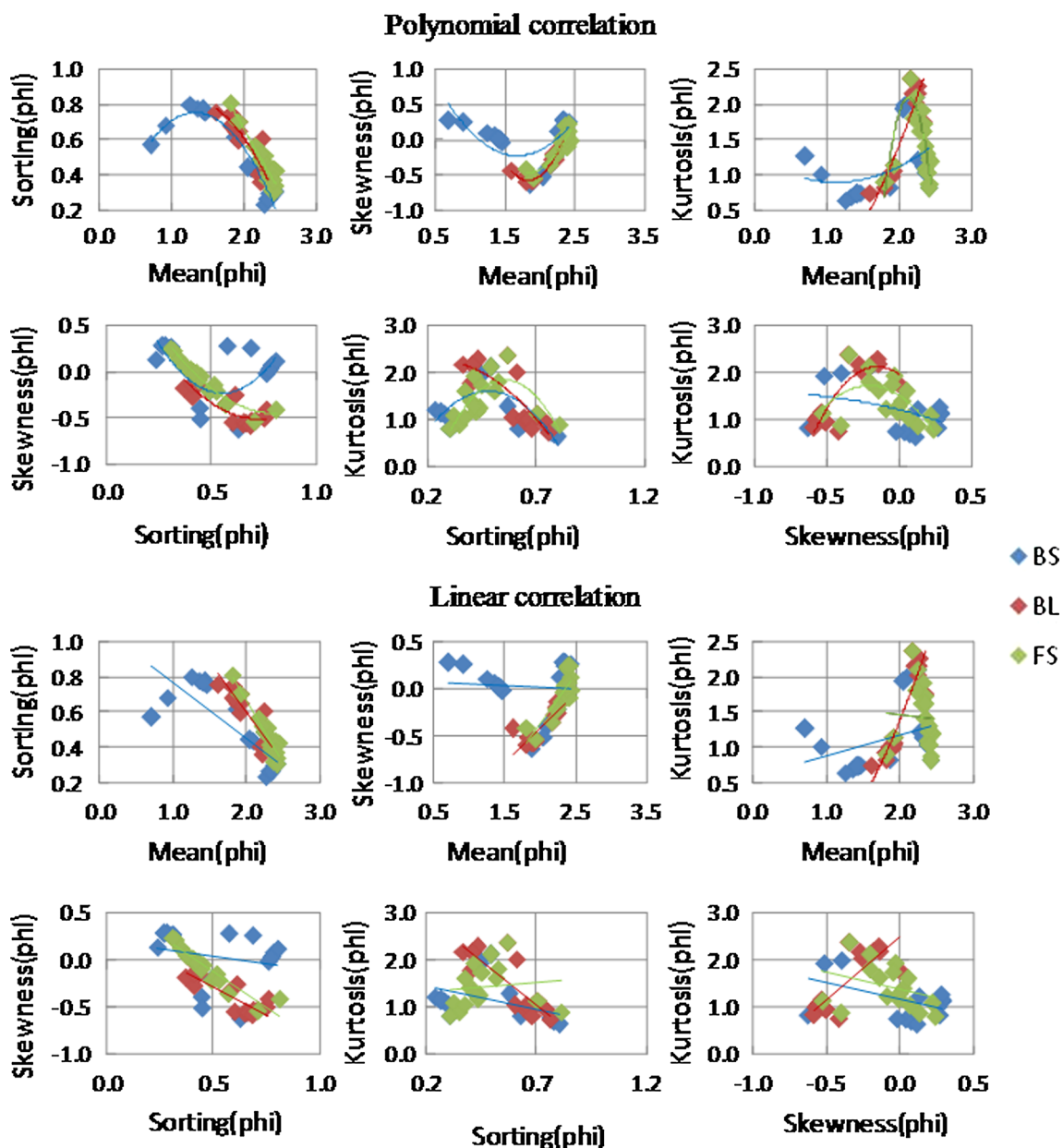
Fig. 5 Polynomial and linear correlation of sediment

Table 1 Polynomial correlation R^2 values (phi)

Plots	Mean versus sorting	Mean versus skewness	Mean versus kurtosis	Sorting versus skewness	Sorting versus kurtosis	Skewness versus kurtosis
BS	0.935	0.400	0.157	0.383	0.625	0.200
BL	0.802	0.974	0.845	0.755	0.724	0.771
FS	0.892	0.791	0.763	0.959	0.605	0.419

the headlands and middle part of the study area which was clearly shown in Fig. 8. Erosion and accretion were compared with Skewness values, as skewness is directly connected to accretion/erosion pattern of the beach (King 1972; McLaren and Bowles 1985; Sajeev et al. 1996). Negative skewness indicates erosion and positive skewness shows accretion. From

Table 2 Linear correlation R^2 values (phi)

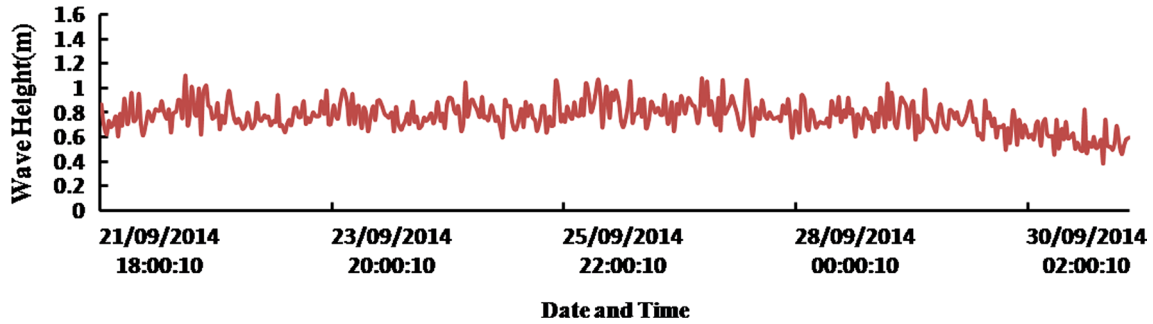| Plots	Mean versus sorting	Mean versus skewness	Mean versus kurtosis	Sorting versus skewness	Sorting versus kurtosis	Skewness versus kurtosis
BS	0.670	0.005	0.133	0.052	0.184	0.195
BL	0.790	0.726	0.842	0.703	0.707	0.670
FS	0.893	0.735	0.002	0.881	0.013	0.117

Fig. 6 Measured wave data at Vengurla offshore region
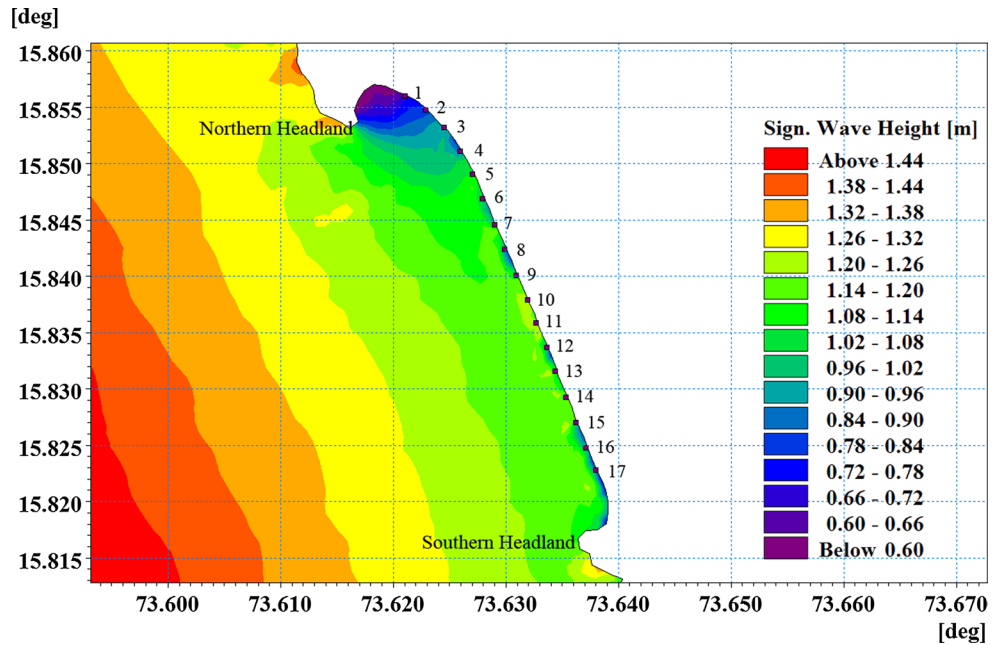
Fig. 7 Modeled wave parameter for Vengurla region

Table 3 Statistical indices of wave parameters between measured and simulated

Parameters	R	SI	RMSE
Significant wave height (m)	0.95	0.21	0.41
Wave period (s)	0.78	0.11	0.83

the comparison study, it was noticed that 90% of the skewness value matched with the analyzed shoreline results (Table 5). Hence, it shows that negative skewness is directly proportional to the coastal erosion.

Table 4 Satellite image information

Satellite	Sensor	Pixel size (m)	Date of acquisition	Season	Data source
Resourcesat-2	LISS-IV	5.8	01.02.2014	Post monsoon	NRSC
Resourcesat-2	LISS-IV	5.8	02.02.2015	Post monsoon	NRSC

Discussion

In general, the sediment pattern in the beach area is mainly controlled by the hydrodynamic processes, river inputs and other hinterland processes (Yuanita and Tingsanchali 2008). Although there are no river inputs in the study area, so the wave energy mainly controls the sediment distribution in Vengurla beach. In skewness graph (Figs. 2, 3 and 4), the energy variation was noted in the FS, BL, and BS. In headland area, the negative skewness was noticed which clearly indicates high energy condition. The sediment distribution, modeling output and shoreline change analysis shows, the sediment distribution in the coastal area is controlled by wave energy during the monsoon period. The sampling transects BS1, BS2, BS3, BS4, BS5 and BS14, BS15, BS16, BS17 are situated adjacent to northern and southern headland area, respectively, where the erosive tendency is more prevalent. In this regard, the average skewness value of BS samples having a 0.030 Φ indicates a depositional settings, whereas the BL and FS with average of − 0.392 and − 0.075 Φ, respectively, illustrate scouring condition and erosive nature of the study area (Bryant 1982). A seawall is constructed behind BS, near northern and southern headlands in order to protect the beach and control the high erosive activity (Fig. 9). Based on the grains size analysis, wave energy is high in the headland area and during monsoon the water reaches up to the seawall. Therefore, the seawalls prevent the entry of water to the nearby villages. The sediment circulation along the beaches is the impact of the interaction between the sediment source, wave strength, and the general incline of the beach (Komar 1998). To identify the relationship between the statistical properties of sediments, we selected different curve fitting methods like exponential, logarithmic, polynomial as well as linear. Among these four, the linear and polynomial (Fig. 5) method was applied to find the best fit due to negative values in the skewness which is not applicable to the exponential and logarithmic functions. The study showed that the polynomial equation has good agreement among the sediment properties compared to linear correlation. The linear curve fitting values range from 0.005 to 0.670 in the BS sediments, whereas it was 0.670–0.842 and 0.002–0.893 in the BL and FS sediments, respectively. The polynomial curve fitting values were 0.157–0.935, 0.724–0.974, and 0.419–0.959 for the BS, BL, and FS respectively..

The analysis exhibited that there was no linear correlation between wave energy and sediment properties in the bay region associated with summer monsoon irregular wave climate (Emilia Guisado Pintado 2007). Dora et al. (2011) addressed the wave and beach sediment interaction on open coast beaches (Pavinkurve, Kundapura, and Padukare) of Karnataka coast, West coast of India and the results unveils the differences in grain size measurement were more along foreshore because of the impact of persistent wave movement contrasted with the backshore zone of open coast. The measured properties of sediment samples demonstrate that the shorelines along the investigation zone were dominated by medium sand with unimodal and bimodal characters. The coarse sand with moderately well sorted and moderately sorted was found with high wave vitality condition. In any case, in the beachfront tract of the present area, the measurable properties delineate that the medium to fine sand with well sorted to moderately well sorted was found along with high wave energy condition at foreshore region. The study demonstrated that the adversely skewed sediments indicate erosion all along the study region. Sathish et al. (2015) carried out the textural description of beach sediments along the Tamil Nadu, East Coast of India and it was accounted that the negatively and positively skewed sediments demonstrating the deposition and erosion trend respectively. From different cases of environment condition such as open beaches and pocket beaches, the study is clearly evidenced when the interaction of wave with beach sediments.

Conclusion

Grain size distribution of Vengurla beach illustrates good agreement with wave energy and shoreline change study. The grain size and wave energy analyses demonstrate the influence of spatial variations of wave energy as a control on sediment sizes and its presence across a sandy beach. Additionally, the result implies that the role of wave energy on sedimentation for the beach formation (Malvarez et al. 2001). In summation, the methodological approach of the present study is the combination of field data collection, numerical modeling, and shoreline change analysis. The calculated statistical parameters of sediment and model output explain that the sediments distribution results coincide with wave climate. The present study explains that the condition of wave energy across as well as
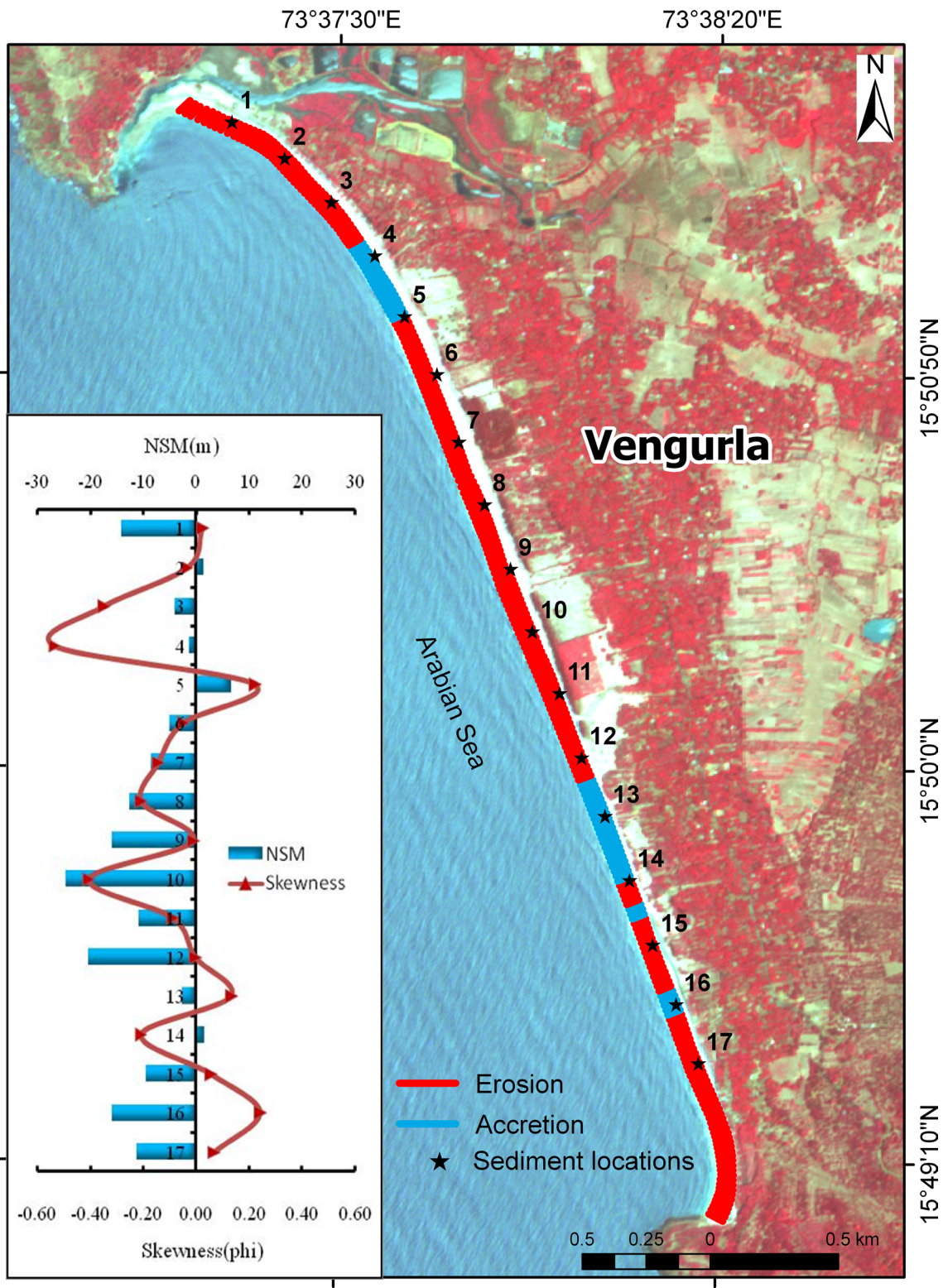
Fig. 8 Comparison of skewness value with shoreline rate

Table 5 Comparison of skewness with net shoreline movements (NSM), significant wave height and D$_{50}$ (φ) (Foreshore)

Sediment locations	Net shoreline movement (m) (in one year)	Skewness (Phi)	Mean significant wave height (m)	D$_{50}$ (φ) (foreshore)
1	− 14.13	0.02	0.45	2.307
2	1.25	− 0.03	0.54	2.279
3	− 3.98	− 0.35	0.62	2.248
4	− 1.42	− 0.53	0.63	2.186
5	6.41	0.22	0.71	2.314
6	− 5.08	− 0.05	0.74	2.297
7	− 8.56	− 0.14	0.75	2.283
8	− 12.67	− 0.21	0.76	2.250
9	− 15.8	− 0.01	0.78	2.392
10	− 24.53	− 0.40	0.79	2.054
11	− 10.80	− 0.09	0.81	2.376
12	− 20.4	0.00	0.77	2.336
13	− 2.79	0.13	0.79	2.375
14	1.35	− 0.21	0.80	2.255
15	− 9.40	0.06	0.78	2.292
16	− 15.81	0.24	0.75	2.360
17	− 11.31	0.07	0.77	2.353

Fig. 9 Seawalls near **a** northern and **b** southern headland

along the Vengurla beach and it varies according to the state of the wave energy. Based on the grain size analysis result, the sediment categorization depicts that the BS has a stable status, the BL is partly eroded as well as accreting in nature, but the FS reveals an erosive tendency. However, the results demonstrate that the requirements of different seasonal data set for further investigation of sediment distribution on pocket beach and comparison with an open beach processes.

References

Albert P, Jorge G (1998) Coastal changes in the Ebro delta natural and human factors. J Coast Conserv 4(1):17–26

Anithamary I, Ramkumar T, Venkatramanan S (2011) Grain size characteristics of the Coleroon estuary sediments, Tamilnadu, east coast of India, Carpathian. J Earth Environ Sci 6(2):151–157

Blatt Harvey, Middleton, Gerard V, Murray, Raymond C (1972) Origin of sedimentary rocks. Prentice-Hall, Englewood Cliffs, N.J

Bryant E (1982) Behaviour of grain size characteristics on reflective and dissipative foreshores, Broken Bay, Australia. J Sediment Pet 52(2):431–450

Carranza-Edwards A (2001) Grain size and sorting in modern beach sands. J Coast Res 17(1):38–52

Davis RA, Hayes MO (1984) What isawave-dominatedcoast? Mar Geol 60:313–329

DHI, MIKE 21 (2014) Spectral wave module scientific documentation. Dansk hydraulisk institute distributions. J Sedimentary Res 55(4)

Dora GU, Kumar VS, Philip CS, Johnson G, Vinayaraj P, Gowthaman R (2011) Textural characteristics of foreshore sediments along Karnataka shoreline, west coast of India. Int J Sediment Res 26(2011):364–377

Emilia Guisado Pintado (2007) Wave-sediment interactions on a high energy beach system. J Maps 3:14–22

Folk RL (1974) Petrology of sedimentary rocks. Hemphill Publishing Co, Austin

Folk RL, Ward WC (1957) Brazos River Bar-a study in the significance of grain size parameters. J Sediment Petrol 27:3–26

Friedman GM (1961) Distinction between dune, beach and river sands from their textural characteristics. J Sediment Petrol 31:514–529

Friedman GM (1962) On sorting, sorting coefficients, and the log-normality of the grain size distribution of sandstones. J Geol 70:737–753

Griggs GB, Tait JP (1988) The effects of coastal protection structures on beaches along Northern Monterey Bay, California. J Coast Res (special issue 4):93–111

Gujar AR, Angusamy N, Rajamanickam GV (2008) Wave refraction patterns and their role in sediment redistribution along South Konkan, Maharashtra, India. Geo Acta 7:69–79

Inman DL (1952) Measures for describing size of sediments. J Sediment Petrol 19:125–145

King CAM (1972) Beaches and coasts. Edward Arnold, London, p 569

Komar PD (1998) Beach processes and sedimentation, 2nd edn. Prentice Hall, New Jersey, p 544

Krumbein WC (1934) Size frequency distributions of sediments. J Sediment Petrol 4:65–77

Krumbein WC (1938) Size frequency distribution of sediments and the normal phi curve. J Sediment Petrol 8:84–90

Krumbein WC, Pettijohn FJ (1938) Manual of sedimentary petrography. Appleton-Century-Gofts, New York

Malvarez GC, Cooper JAG, Jackson DWT (2001) Relationships between wave-induced currents and sediment grain size on a sandy tidal-flat. J Sediment Res 71(5):705–712

Mandale VP, Mahale DM, Nandgude SB, Gharde KD, Thokal RT (2017) Spatio-temporal rainfall trends in Konkan Region of Maharashtra State. Adv Agric Res Technol J 1:11

Masselink G, Short AD (1993) The effect of tide range on beach morphodynamics and morphology: a conceptual model. J Coast Res 9:785–800

Masselink G, Hughes M, Knight J (2012) Introduction to coastal processes and geomorphology, 2nd edn. Routledge, London

McCave IN (2008) Size sorting during transport and deposition of fine sediments: sortable silt and flow speed. In: Rebesco M, Camerlenghi A (eds) Contourites, Developments in sedimentology, vol 60. Elsevier, Amsterdam, pp 121–142

McCave IN, Syvitski JPM (1991) Principles and methods of particle size analysis. Cambridge University Press, New York, pp 3–21

Mclaren P, Bowles D (1985) The effects of sediment transport on grain-size distributions. J Sediment Petrol 55:457–470

Morton RA, Miller TL (2005). National assessment of shoreline change: part 2: Historical shoreline changes and associated coastal land loss along the US Southeast Atlantic Coast: US Geological Survey Open-file Report 2005-1401

Nordstrom KF (1977) The use of grain size statistics to distinguish between high-and moderate energy beach environments. J Sediment Petrol 47:1287–1294

Sajeev R, Sankaranarayanan VN, Chandramohan P, Nampoodiripad KSN (1996) Seasonal changes of the sediment size distribution and stability along the beaches of Kerala, south west coast of India. Indian J Mar Sci 25:216–220

Sathish S, Selvan SC, Kankara RS, Manikandan M, Arockiaraj S, Rajan B (2015) Textural characterization of sediments along Tamil Nadu coast, East coast of India. Proc Eng 116:794–801

Swart DH (1991) Beach nourishment and particle size effects. Coast Eng 16:61–81

Thieler ER, Himmelstoss EA, Zichichi JL, Ergul A (2009) Digital shoreline analysis system (DSAS) version 4.0—an ArcGIS extension for calculating shoreline change: U.S. geological survey open-file report 2008–1278

Visher GS (1969) Grain size distribution and depositional processes. J Sediment Petrol 39:1074–1106

Yuanita N, Tingsanchali T (2008) Development of a river delta: a case study of Cimanuk river mouth, Indonesia. Hydrol Process 22(18):3785–3801