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Sediment Characterization and Monsoonal Impact on Beach Morphology at the Three Beaches along the Karachi Coast, Pakistan

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Abstract: Sediment characteristics plays important role in the determination and functioning of coastal ecosystems. The present study is an attempt to evaluate the variability in sediment characteristics of the three beaches: Clifton, Sandspit and Buleji, at the Karachi coast. The samples were collected during pre-monsoon and south-west monsoon seasons to evaluate the seasonal differences. The sediments of the three sites showed variations in moisture content, organic matter and grain size. The highest mean moisture (27.17%) and organic contents (3.5 %) were recorded from the sediments of Clifton. The maximum fraction of sediments (> 80 %) consist of fine to very fine sand at all studied sites. The sediments of Clifton were high in very fine sand fraction and low in coarse sand fraction as compared to Sandspit and Buleji. The sediments of all the three studied sites are moderately sorted, negatively coarse-skewed and showed leptokurtic distribution. The studied beaches of Clifton, Sandspit and Buleji shows dissimilarity in sediment characteristics as indicated through Cluster and PCA analysis. The monsoonal influence on sediment characteristics was also observed at all the three studied beaches. The strong wave action during SW monsoon season results in the deposition of the coarser sediments at the high tide level thus increasing the steepness of the beaches.

Keywords: Grain size, clifton, sandspit, buleji, monsoon.

Introduction

Marine sediments are derived primarily either from wind-blown material or from biogenic material. The sources of sandy sediments in the coastal areas and ocean are rivers and erosion of rocks. Beaches exposed to oceanic waves are steep with coarse sediments whereas, sheltered areas accumulate fine sand and mud. The importance of sediment characteristics is widely accepted in the ecological studies (e.g., Canfield et al, 1993; Grey, 2002; Arshad et al., 2017) as they provide information on the ongoing as well as past biological and chemical processes. Sediments also provide habitat that act as substrate for organisms. Sedimentary composition of the coastal environment plays a vital role in the abundance and diversity of macrobenthic communities (Defeo and McLachlan, 2005).

Sandy beaches occupy three quarters of world's shoreline (Bascom, 1980). The exposed sandy beaches are physically dynamic benthic environment and one of the more extended intertidal systems worldwide (Lecari & Defeo, 2003). The Sandy shores are composed of fine-grained sediments which have a capacity of retaining water. The distribution and abundance of benthic organisms in exposed sandy beaches depends on the sediment characteristics along with wave action (McLachlan and Brown, 2006). The interaction between the sediment type and wave-tide regime was reported to construct morphodynamics gradients from reflective to dissipative beach (Short, 1999). Beach profile morphology showed both short-term and long-term spatial and temporal variations (e.g., Inman et al., 1993; Coco et al., 2014; McCall et al., 2015). The information of sediment characteristics helps to understand the beach morphology which is very crucial in beach management. Information on the textural composition is scarcely available from the coastal areas of Pakistan (Ibrahim et al., 1992). The aims of the present study were to (i) evaluate the variability in sediment characteristics of the three busiest sandy beaches at the Karachi coast and (ii) to find out the monsoonal impacts on the beach geomorphology.

Material and Methods

Sediments from three beaches; Clifton (C), Sandspit (S), and Buleji (B) were collected for this study (Fig. 1). A total of 84 Samples for the analysis of sediments were collected from two stations at each study site during March to September to cover pre-monsoon and South-West monsoon season. Stations C1 and C2 at Clifton, stations S1 and S2 at Sandspit and stations B1 and B2 at the sandy part of Buleji beach were selected. At each station, the samples were collected at both high tide mark (HT) and low tide mark (LT) through hand corer and only surface sediments (0-1 cm) were analyzed.

For the determination of moisture in sediments a known amount of wet sediment samples was dried at 80ºC for 24 hours. The loss in weight was used to calculate percentage of moisture content in the sediments. Organic matter in sediments was analyzed by igniting samples at 450 ^{O}C for 8 hours. The organic content was estimated as the loss of weight after ignition and expressed as percentage of the dry sediment weight. For grain size analysis sediment were air-dried, homogenized and passed through a series of sieves.

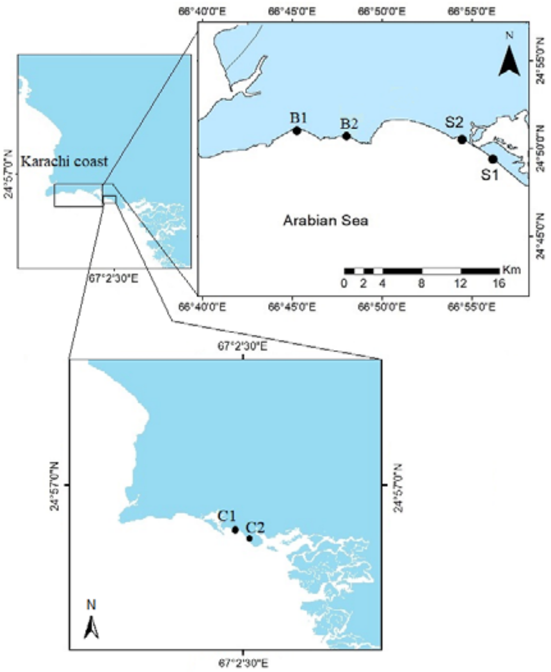

Fig. 1 Map of study sites showing positions of stations at Clifton (C1; C2), Sandspit (S1; S2) and Buleji (B1; B2).

The samples contained on each sieve were measured and used to calculate the percentage of the sediment size using Udden-Wentworth scale (Buchanan, 1984). Graphic mean, Inclusive graphic standard deviation, Skewness and Kurtosis was calculated according to Folk and Ward, 1957; Friedman, 1961; Blott and Pye, 2001. The graphic mean was calculated by using formula $M = \Phi16 + \Phi\ 50 + \Phi\ 84\ /\ 3$ (Folk, 1974); Inclusive graphic standard deviation was calculated by $D = \Phi\ 84 - \Phi\ 16\ /\ 4$ and was used to find out sorting.

<0.35 = Very well sorted

0.35-0.50 = well sorted

0.50 -0.80 = moderately well sorted

0.80 -1.40 = Moderately sorted

1.40 - 2.00 = Poorly sorted

2.00-2.60 = very poorly sorted

>2060 = Extremely poorly sorted

Skewness was calculated according to:

$$S = \frac{\Phi\ 84 + \Phi\ 16 - 2(\Phi\ 50)}{2\ (\Phi\ 84 - \Phi\ 16)} + \frac{\Phi\ 95 + \Phi\ 5 - 2(\Phi\ 50)}{2\ (\Phi\ 95 - \Phi\ 5)}$$

And Kurtosis by, $K = \frac{\Phi\ 95 - \Phi\ 5}{2.44\ (\Phi\ 75 - \Phi\ 25)}$

For statistical analysis, the data was transformed and normalized. Principal Component analysis (PCA) based on Spearman rank correlation and Cluster analysis based on Euclidean distances was performed to find out correlation between sediment characteristics and the study sites.

Results and Discussion

Distribution of moisture and organic content

Moisture content in sediments was comparatively higher at low tidal mark (LT) than high tide mark (HT) at all the three studied sites (Fig 2). The moisture content in sediments during pre-monsoon season at the three studied sites was ranged between 2.1 % – 28. 85 %. The highest value of moisture content was obtained from the sediments of CL1 (28.85 %). At Sandspit, comparatively higher values were obtained from station S1 and from station B2 at Buleji. The highest moisture content in sediments during South-West monsoon season within sites was recorded from stations CL2 (29.1 %) at Clifton, SL2 (19.48 %) at Sandspit, and BL2 (7.8 %) at Buleji. Fine Grain fraction at sites favors the retention of moisture at Clifton and Sandspit. The concentration of organic matter in sediments of studied sites was shown in Figure 3. The concentration of organic matter in sediments ranged between 0.9 % to 3.9 % in pre-monsoon season and 1.2 % to 4.1 % during South-West monsoon season. Overall, the concentration of organic matter was higher at station 1 at Clifton and Buleji and station 2 at Sandspit (Fig 3). The highest values of organic matter in the sediments during south-west monsoon season at Clifton were recorded from station CL1 (4.1 %). At Sandspit and Buleji the higher organic content was recorded from SH2 (2.03 %) and BL1 (2.13 %) respectively. The drainage of sewage water at Clifton and deposition of decomposing algae at high tidal mark and low tidal mark at Sandspit and Buleji appears to be the possible cause of higher organic matter in the sediments.

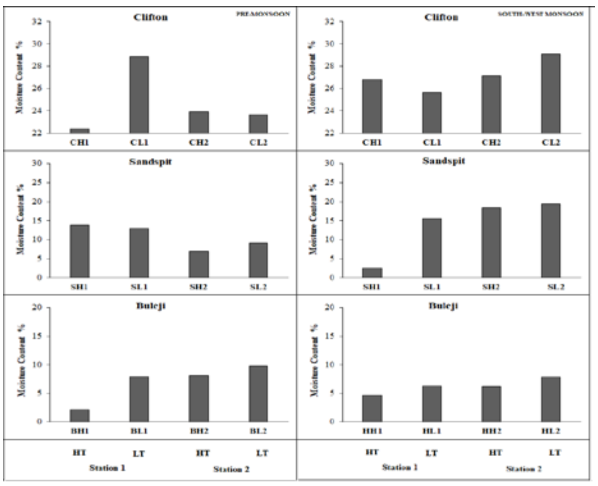

Fig. 2 Distribution of moisture content (%) in the sediments of studied stations at Clifton, Sandspit and Buleji during SW-monsoon Season. HT= High tide; LT = Low tide.

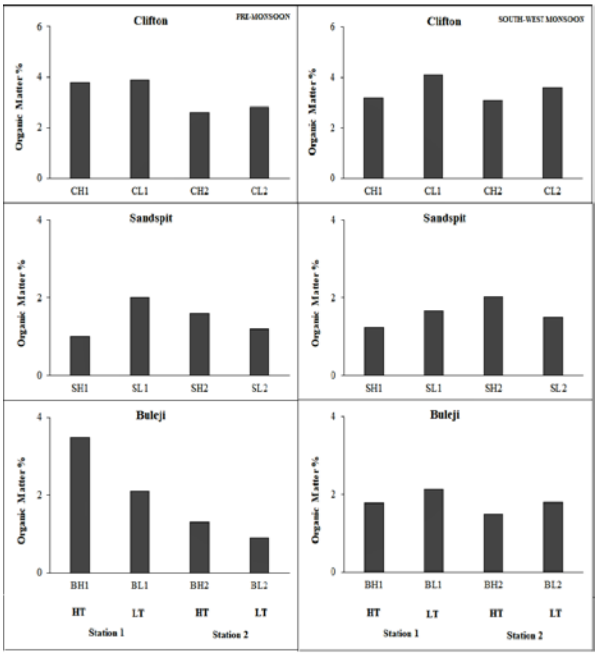

Fig. 3 Distribution of organic matter (%) in the sediments of studied stations at Clifton, Sandspit and Buleji during SW-monsoon Season. HT= High tide; LT = Low tide.

Grain size distribution during pre-monsoon and south-west monsoon

The maximum fraction of sediments (> 80 %) consist of fine to very fine sand at all studied sites during pre-monsoon and South-West monsoon season (Fig 4). Coarse sand fraction was not recorded at Clifton during pre-monsoon season, whereas the silt fraction (< 4 Φ) was recorded from both stations C1 and C2 at HT and LT marks (Fig 4a). At Sandspit the coarse sand fraction was higher in the sediments of SH2 at HT in pre-monsoon season (Fig 4a). Very fine sand fraction at Buleji was lowest at station BH1 at HT (Fig 4a) and highest at BH2 during pre-monsoon season.

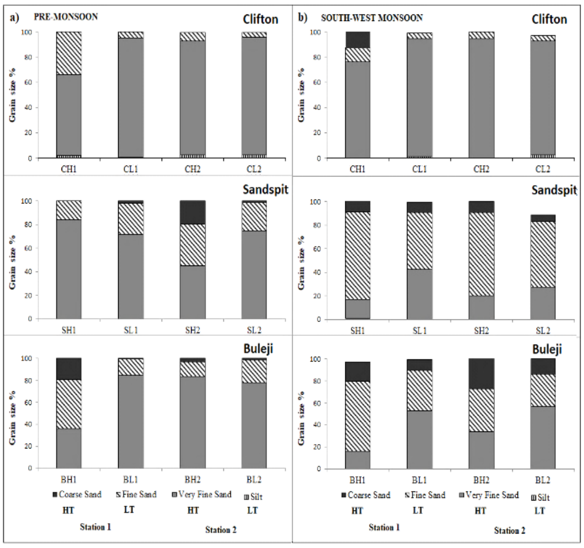

Fig. 4 Distribution of grain size (%) in the sediments of studied stations at Clifton, Sandspit and Buleji during pre-monsoon (**a**) and South-West monsoon season (**b**). HT= High tide; LT = Low tide.

The presence of higher coarse sand fraction at Clifton (Fig 4b) was only noted at station CH1 (12.8 %) during SW monsoon season which also includes shell fragments. The coarse sand fraction was present in the sediments of both stations at Sandspit and Buleji (Fig 4b). Very fine sand fraction was higher at station SL1 (42.5 %). The grain size is a widely used proxy to detect sediment transport due to change in wave energy (Rosa et al., 2013; Prodger et al., 2017). Overall, the grain size increases at the upper beach at the three studied sites. The deposition of coarse sand and shell fragments at coast is controlled by the strong wave action during SW monsoon season. The strong wave action was also reported to prevent the deposition of fine-grained sediments (Malvarez et al., 2001; Reniers et al., 2013; Prodger et al., 2017).

Comparative analysis of sediment characteristics between sites

The comparison of sediment characteristics was shown in Table 1. The sediment colour at Sandspit and Buleji was light brown and at Clifton from dark gray to light gray. The sediment temperature shows slight fluctuation which were in response to variable air temperature as a consequence of seasonal variations. Overall, the concentration of moisture content in the sediments was lowest at Buleji and highest at Clifton (Table 1). Comparatively higher values of sedimentary organic matter were recorded from Clifton which indicates the presence of organic pollution. The organic pollution at Clifton was reported to change the diversity and density of benthic organisms (Arshad and Farooq, 2018). Grain size analysis of three studied sites indicates that the sediments of Clifton was high in very fine sand fraction as compared to Sandspit and Buleji which have higher fine sand fraction and coarse sand fraction (Table 1). The graphic mean Φ was higher at Clifton (2.43 Φ) as compared to Sandspit and Buleji. The value of 2.43 Φ indicates that the sediment of Clifton was finest. The calculated grain size properties were given in Table 2. The grain mode consists of fine sand. The median grain size was 2.5 Φ at Clifton and 1.9 Φ and 1.8 Φ for Sandspit and Buleji. The grain size data indicates that sediments of Clifton were moderately sorted (D = 1.11), and sediments of Sandspit and Buleji were moderately well sorted (D = 0.73 and 0.78 respectively). The present results confirm the earlier results which indicates that most of the coastal marine sediments are moderately sorted sands (Edwards, 2001).

Table 1 Comparison of sediment characteristics of three studied sites showing range (lowest and highest values) and mean values.

	Clifton		Sandspit		Buleji	
	Range	Mean	Range	Mean	Range	Mean
Sediment Temperature	18 - 30	24	17 - 29	23	17 - 30	23.5
Moisture Content	25 - 29	27.17	2.4 - 18.5	13.7	4.6 - 7.3	6.1
Organic Matter %	3.1 - 4.1	3.5	1.2 - 2.0	1.61	1.5 - 2.1	1.8
Coarse Sand %	3.2 - 12.8	3.19	5.7 - 10.0	8.5	10.2 - 27.1	17.95
Fine Sand %	4.1 - 11.3	6.32	48 - 73.9	61.95	29.6 - 63.2	42.2
Very Fine Sand %	75.5 - 94.4	88.63	16 - 42.5	26.5	16 - 56.7	39.82

The skewness data indicates that the sediments of the three studied sites were negatively coarse-skewed (S = -0.02 to -0.375). The sediments of Clifton showed extremely leptokurtic (K = 3.95) distribution whereas the sediments of Sandspit and Buleji showed very leptokurtic (K = 1.5) to leptokurtic distribution respectively (Table 2). The fine beach sands were reported to possess leptokurtic distribution (Friedmann, 1962).

Table 2 Comparison of grain size properties of Clifton, Sandspit and Buleji.

	Clifton	Sandspit	Buleji
Graphic STD. DEV (D) Φ	1.11	0.73	0.78
Graphic Mean Φ	2.43	1.78	1.8
Median Grain Size	2.5	1.9	1.8
Grain Size Mode	Fine sand	Fine sand	Fine sand
Skewness (Sk)	-0.375	-0.131	-0.02
	negatively coarse skewed	negatively coarse skewed	negatively coarse skewed
Kurtosis(K)	3.95	1.5	1.025
	Extremely leptokurtic	Very leptokurtic	Leptokurtic

The Principal component analysis (PCA) shows affinity of study sites with sediment parameters (Fig 5). The PC1 axis accounts for 89.3 % PC2 for 10.7 % variability, respectively. Organic content and fine sand fraction appear to be positively correlated at the PC 1 axis whereas moisture content and coarse sand fraction at PC 2 axis for the studied sites.

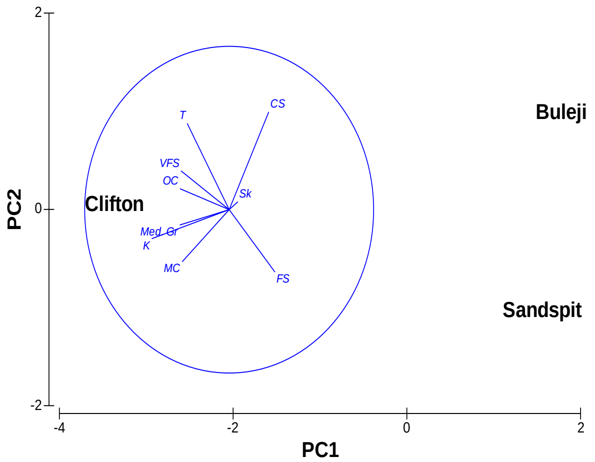

Fig. 5 PCA analysis of studied variables (transformed and normalized) at three sites showing variability of 89.3 % at PC1 axis and 10.7 % at PC2, respectively. T= Sediment temperature; CS= Coarse sand; FS= Fine sand; VFS= Very fine sand; MC= moisture content; OC = Organic content; Med.Gr = Median Grain size; Sk= Skewness; K = Kurtosis.

The beaches of Sandspit and Buleji showed similarity ($r = 0.891$; $F= 30.8$; $p < 0.001$) in sediment characteristics in contrast to the sediment characteristics of Clifton beach which were different from the other two studied beaches ($r = 0.318$; $F= 302$; $p < 0.05$). This was further proved by the cluster analysis (Fig 6) which also shows the separation of the Clifton beach from the other two sites. Studies have indicated in past that beach sediments showed variations according to wave energy and height (Thornton et al., 2007; Thorpe et al., 2014). The variations in the textural composition between the three studied beaches might also be due to the differences in wave energy, height and coastal configuration. The high energy waves during SW monsoon season increases the deposition of coarse sand at the landward side.

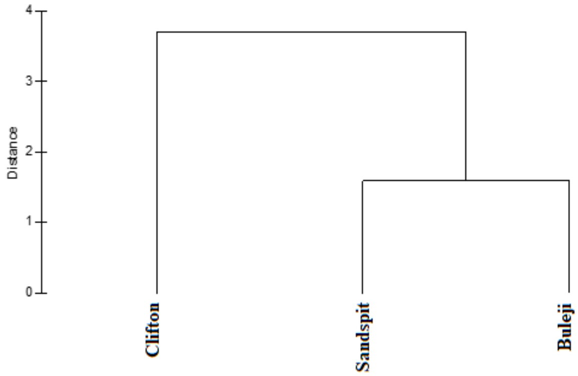

Fig 6. Cluster analysis of study sites based on sediments parameters.

Conclusion

This study aimed to compare the sediment characteristics of three beaches. The studied beaches of Clifton, Sandspit and Buleji shows variation in sediment characteristics. Variations in sediment characteristics were also recorded with respect to monsoon season. The study indicates the change in beach profiles due to change in wave energy in monsoon season. The strong wave action during SW monsoon season results in the deposition of the coarser sediments at the high tide level thus increasing the steepness of the beaches. The gentle movement of water before SW monsoon promotes the deposition of very fine sand fraction at all the three studied beaches. As sediments provides habitat to benthic organisms, the variation in sediment characteristics indicate diversity in the benthic environment. The higher values of organic matter in the sediments of Clifton indicates organic pollution which requires management. Long term beach profile study is required to better understand the change in beach morphodynamics.

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