

Deformation of textural characteristics and sedimentology along micro-tidal estuarine beaches

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Received 28 November 2012; revised 03 July 2013

Deformation in the textural characteristics of three selected beaches (Pavinkurve, Kundapura and Padukare) along Karnataka shoreline, west coast of India was examined. Study showed the beaches are significantly composed of unimodal to bimodal, fine to medium sand, moderately well sorted to moderately sorted, positive to negative skewed, and platykurtic to leptokurtic sediments. Spatio-temporal variation of mean grain size showed significant influence of breaking waves on beach sediments whereas sorting characteristics exhibited the impact of alongshore current on the intertidal sedimentary environment. Also very fine sands at gentle beach slope and very coarse sands at steeper slope exhibits the role of beach morphology on foreshore surface grains. The slow process of sediment removal/accumulation reveals a marginal variation in skewness and kurtosis characteristic and also exhibits a poor correlation in textural characteristics.

[**Keywords:** Beach morphology, Central tendency, Sorting, Skewness, Kurtosis, Karnataka coast]

Introduction

Beach sediment is a foremost parameter for a coastal researcher/engineer/designer due to its various applications for sorting out a coastal environment. Sedimentary process at foreshore zone is a highly dynamical whereas textural characteristics are significantly controlled by associated morphology and hydrodynamic conditions. Since past few decades the sedimentary environments has been examined by their statistical properties such as central tendency, sorting, skewness and kurtosis whereas spatio-temporal variation of textural characteristics reveals source, transport direction, depositional conditions of beach sediment, and also exhibits the process of associated coastal hydrodynamics¹⁻¹⁰. Sediment characteristics are useful for understanding beach morphodynamics and predicting equilibrium beach profile¹¹, and also handy for designing engineering structures to solve coastal problems. Textural analysis along west coast of India except Karnataka shoreline was studied by different researchers¹²⁻¹⁹. Along Karnataka shoreline about 75% of coastline was identified as sandy beaches²⁰. Sedimentary environment of some beaches along Karnataka coast was also studied in the past²¹⁻²⁸. Some of the remaining beaches were considered in this study based on data collected for 2 years during

February 2009 to February 2011 as a part of the shoreline management project promoted by Ministry of Earth Science, India.

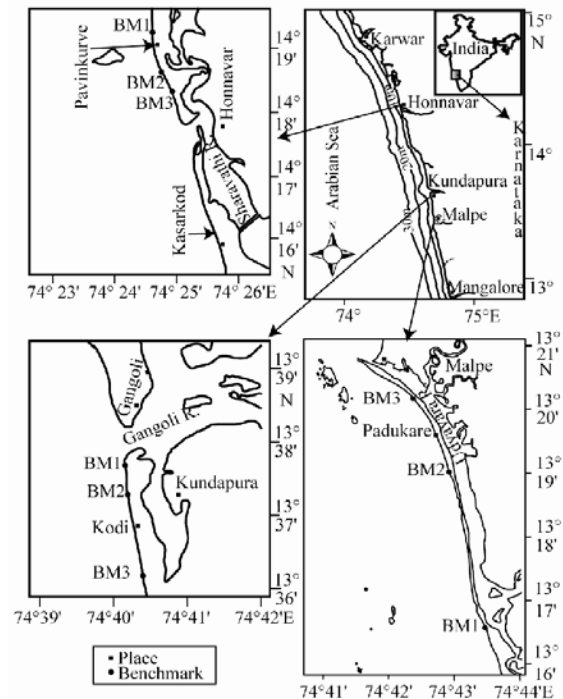


Figure 1: Study area covers three beaches along Karnataka shoreline, west coast of India

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Intertidal sedimentary environment of selected beaches along Karnataka coast (Fig. 1) was analyzed in considering its importance towards coastal dwelling human society, in their living and development. Dora et al.²⁹ studied the sedimentary environment of these beaches based on limited data collected during March 2008-February 2009. Along Karnataka shoreline, tide is varying in micro-tidal range and characterized as mixed and semi-diurnal³⁰. At Mangalore which is 60 km south of Malpe, the average tidal range is 1.22 m during spring tide and 0.56 m during neap tide. At Karwar which is 100 km north of Pavinkurve, the average tidal range is 1.58 m during spring tide and 0.72 m during neap tide. Average monthly sea level at Karwar varies from 1.06 m in September to 1.3 m in January³¹. Study area covers three beaches namely Pavinkurve (north of Sharavathi river mouth, Honnavar), Kundapura (south of Gangoli river mouth, Coondapoor) and Padukare (south of Udyavara river mouth, Malpe) from north to south along Karnataka shoreline, west coast of India (Fig. 1). Shoreline along study region is bounded by Western Ghats in the east and Arabian Sea in the west. There are some islands located off Karnataka shoreline and the major one is St. Mary's Island located 4 km off the coast near Malpe. At Pavinkurve beach, the study area covered ~2.0 km along the shoreline whereas at Kundapura and Padukare beach, the study area was ~3.0 and ~7.0 km respectively.

Materials and Methods

About 450 sediment samples were collected at nine locations along water line (WL) and high water line (HWL) of three beaches along Karnataka shoreline in monthly intervals during February 2009 to February 2011. Two years analysis was carried out separately such as first annual cycle from February 2009 to February 2010, and second annual cycle from February 2010 to February 2011. Grain size distribution was carried out in laboratory using electromagnetic sieve shaker machine that contains six sieves having mesh sizes 2000, 1000, 500, 250, 125, 63 μm and pan. Sedimentary environment of three beaches was analyzed according to their textural characteristics such as central tendency, sorting, skewness and kurtosis parameters. Categorization of statistical parameters was obtained in GRADISTAT package⁸ following logarithmic Folk and Ward¹ graphical measures (Table 1). Smaller phi (ϕ) value indicates bigger natural grain size (μm).

Results and Discussion

Pavinkurve beach, Honnavar

During first annual cycle, the tendency of textural characteristics showed Pavinkurve beach was composed of unimodal (U) to trimodal (T), fine sand (Fs) to coarse sand (Cs), well sorted (WS) to poorly sorted (PS), fine skewed (FSK) to very coarse skewed (VCSk), and platykurtic (P) to very leptokurtic (VL) sediments. Annual average of mean (M_Z), median (D_{50}) and sorting (σ_1) was respectively 1.86, 1.90, and 0.75 ϕ whereas the skewness (Sk_1) and kurtosis (K_G) was respectively -0.08 and 1.16 (Table 2). During complete annual cycle, beach sediments were 46% of unimodal and 53% of bimodal (B) whereas remaining samples showed as trimodal nature. Mean grain size showed the beach was composed of about 35% of fine sand and 62% of medium sand (Ms) along with three percentages of coarse sand. Sorting characteristic of beach sediment exhibited about 48% of moderately well sorted (MWS), 29% of moderately sorted (MS) along with 17 and 6% of poorly sorted and well sorted nature. Also the beach showed about 49% of symmetrical (S) and 36% of coarse skewed (CSk) sediments along with eight and seven percentages of fine skewed and very coarse skewed nature. In addition the sediments exhibited about 26, 24 and 43% of platykurtic, mesokurtic (M) and leptokurtic (L) nature whereas remaining samples showed very leptokurtic nature. It revealed that the beach was significantly composed of U-B, Fs-Ms, MWS-PS, S-CSk and P-L sediments.

During second annual cycle, the textures showed Pavinkurve beach was composed of unimodal to bimodal, fine to coarse sand, very well sorted (VWS) to poorly sorted, fine to very coarse skewed, and platykurtic to very leptokurtic sediments. Annual average of mean (M_Z), median (D_{50}) and sorting were respectively 1.97, 1.99 and 0.68 ϕ whereas skewness and kurtosis were respectively -0.04 and 1.08 (Table 2). During complete annual cycle, about 85% of beach sediments showed unimodal nature whereas remaining 15% samples were found as bimodal activity. Approximately equal quantity of fine (49%) and medium (50%) sand was identified whereas remaining samples showed as coarse sand. More sediment samples were found as moderately well sorted (59%) along with 26% as moderately sorted sediment whereas remaining sediments showed as poorly sorted (8%), well sorted (6%) and very well sorted (1%) nature.

Table 1: Categorization of textural characteristics of beach sediments following logarithmic Folk and Ward (1957) graphical measures

Mean (M _Z)	Range (φ)	Sorting (σ ₁)	Range (φ)	Skewness (Sk _i)	Range	Kurtosis (K _G)	Range
Very Fine sand (VFs)	3 to 4	Very Well Sorted (VWS)	< 0.35	Very Fine Skewed (VFSk)	+0.3 to +1.0	Very Platykurtic (VP)	< 0.67
Fine sand (Fs)	2 to 3	Well Sorted (WS)	0.35 to 0.50	Fine Skewed (FSk)	+0.1 to +0.3	Platykurtic (P)	0.67 to 0.90
Medium sand (Ms)	1 to 2	Moderately Well Sorted (MWS)	0.50 to 0.70	Symmetrical (S)	-0.1 to +0.1	Mesokurtic (M)	0.90 to 1.11
Coarse sand (Cs)	0 to 1	Moderately Sorted (MS)	0.70 to 1.00	Coarse Skewed (CSk)	-0.3 to -0.1	Leptokurtic (L)	1.1 to 1.50
Very Coarse sand (VCs)	-1 to 0	Poorly Sorted (PS)	1.00 to 2.00	Very Coarse Skewed (VCSk)	-1.0 to -0.3	Very Leptokurtic (VL)	1.50 to 3.00
						Extremely Leptokurtic (EL)	> 3.00

Table 2: Range and annual average values of textural characteristics of foreshore surface sediments at Pavinkurve beach

Years and locations		Textural characteristics															
		Mean (φ)			Median (φ)			Sorting (φ)			Skewness			Kurtosis			
		Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	
Feb 2009 to Feb 2010	BM1	WL	1.30	2.56	1.78	1.35	2.54	1.80	0.55	1.16	0.85	-0.21	0.28	-0.04	0.84	2.08	1.29
		HWL	1.67	2.44	1.97	1.67	2.51	1.98	0.51	1.18	0.72	-0.31	0.23	0.00	0.78	1.41	1.03
	BM2	WL	0.80	2.64	1.80	0.78	2.65	1.85	0.64	1.21	0.84	-0.42	0.06	-0.09	0.76	2.46	1.20
		HWL	1.41	2.62	2.00	1.57	2.62	2.04	0.46	0.88	0.64	-0.36	0.09	-0.11	0.74	1.57	1.10
	BM3	WL	0.88	2.67	1.67	0.76	2.65	1.74	0.50	1.21	0.80	-0.35	0.09	-0.15	0.82	1.53	1.15
		HWL	1.46	2.69	1.94	1.61	2.66	1.99	0.46	1.07	0.64	-0.36	0.15	-0.10	0.82	1.53	1.16
Feb 2010 to Feb 2011	BM1	WL	1.43	2.44	1.92	1.37	2.46	1.90	0.51	1.15	0.74	-0.20	0.23	0.06	0.79	1.34	0.96
		HWL	1.66	2.52	2.18	1.59	2.52	2.20	0.54	0.81	0.66	-0.21	0.12	-0.06	0.82	1.37	1.14
	BM2	WL	1.14	2.52	1.98	1.24	2.52	2.06	0.42	1.02	0.74	-0.36	0.21	-0.12	0.82	1.73	1.14
		HWL	0.48	2.50	2.00	0.48	2.53	2.00	0.43	0.78	0.57	-0.19	0.22	-0.01	0.74	1.65	1.14
	BM3	WL	1.08	2.37	1.74	1.25	2.41	1.79	0.56	1.12	0.78	-0.29	0.08	-0.13	0.74	1.41	1.10
		HWL	1.53	2.51	1.99	1.53	2.51	1.98	0.32	0.76	0.58	-0.19	0.24	0.04	0.74	1.37	0.99

Majority of sediment samples showed symmetrical (49%) nature whereas fine skewed and coarse skewed sediments were respectively 19 and 29%, and remaining sediments were characterized by very coarse skewed nature. Simultaneously platykurtic, mesokurtic and leptokurtic sediments were found 29, 26 and 42% whereas remaining sediments were very leptokurtic nature. During second annual cycle, the beach was significantly composed of Fs-Ms, MWS-MS, FSk-CSk and P-L sediments whereas majority of sediment samples were characterized by unimodal nature.

At Pavinkurve beach, monthly mean grain size showed a good trend and exhibited seasonal variation of M_z at BM2 and BM3 whereas the M_z during summer monsoon showed bigger natural grains and smaller grains were found during remaining period (Fig. 2). As summer monsoon waves are high energetic compared to pre and post monsoon waves³²⁻³³, the M_z trend exhibits the influence of wave energy on grain size. At BM1, there was no trend in M_z due to the presence of Basavarajdurg Island which obstructs summer monsoon high waves and hence coarser particles were not existed significantly during summer monsoon. Also during maximum period the WL sediments were bigger in natural size compared to HWL sediments. There was no significant seasonal variation in sorting, skewness and kurtosis characteristics. More WL sediments showed poorly sorted nature which was influenced by breaking waves whereas better sorted sediments were comparatively more along HWL where alongshore current occurs significantly. Hegde et al.²⁷ observed the summer monsoon high wave result better sorted sediment. Non-uniform trend in skewness characteristics showed a frequently occurrence of sediment erosion and accretion whereas a narrow bent in skewness of consecutive months showed the beach was under slow process in removal/replenishment of finer particles. In skewness trend, the inter crossing sections of WL and HWL sediments showed that the lower intertidal zone was accreted (eroded) while an erosion (accretion) of sediments at upper intertidal zone whereas the upward (downward) direction of both WL and HWL trends exhibited the accretion (removal) of finer particles along the beach. Also a

random trend was identified in kurtosis characteristic along both WL and HWL sediments which indicates a frequently change in the quantity of different grain sizes accumulated in the sedimentary environment. From first to second annual cycle the quantity of unimodal, fine sand, moderately well sorted and fine skewed sediments were increased whereas bimodal, medium sand, poorly sorted and also coarse and very coarse skewed sediments were decreased. During second annual cycle, the beach was accreted with fine sands by alongshore current whereas the accreted sediments were approximately uniform in their shape and size. There was no significant change in kurtosis characteristic during both annual cycles. Two years of study showed Pavinkurve beach was significantly composed of unimodal to bimodal, fine to medium sand, moderately well sorted to moderately sorted, symmetrical to coarse skewed, and platykurtic to leptokurtic sediments (Fig. 2). During March 2008-February 2009, Dora et al.²⁹ observed moderately well sorted medium sand with coarse skewed and platykurtic nature. Hegde et al.^{26-27,34} observed the sedimentary environment at Honnavar (close to Pavinkurve beach) composed of bimodal to polymodal, medium, and negative (coarse) skewed to symmetrical nature.

Kundapura beach, Coondapoor

During the first annual cycle, the textural characteristics at Kundapura beach composed of unimodal to trimodal, fine to very coarse sand (VCs), well sorted to poorly sorted, very fine skewed (VFSk) to very coarse skewed, and platykurtic to very leptokurtic sediments. Annual average of mean, median and sorting was respectively 1.38, 1.41 and 0.80 ϕ whereas skewness and kurtosis was respectively -0.04 and 1.10 (Table 3). Unimodal and bimodal sediments were characterized about 42 and 52% whereas remaining sediments showed trimodal nature. Approximately equal quantity of fine (32%), medium (33%) and coarse (28%) sand was found along with seven percentages of very coarse sand. Majority of sediments showed moderately sorted (54%) nature along with 32% of moderately well sorted and 13% of poorly sorted sediments whereas remaining samples were characterized by well sorted sediments.

Skewness characteristic of sediments showed ~10% of very fine skewed (VFSk), 14% of fine skewed, 28% of symmetrical, 38% of coarse skewed and 10% of very coarse skewed nature. In addition sediments exhibited ~39% of platykurtic, 25% of mesokurtic and 28% of leptokurtic nature

whereas remaining samples were very leptokurtic nature. During first annual cycle the beach was mainly composed of U-B, Fs-Cs, MWS-MS, and P-L along with positive (fine & very fine) to negative (coarse and very coarse) skewed sediments.

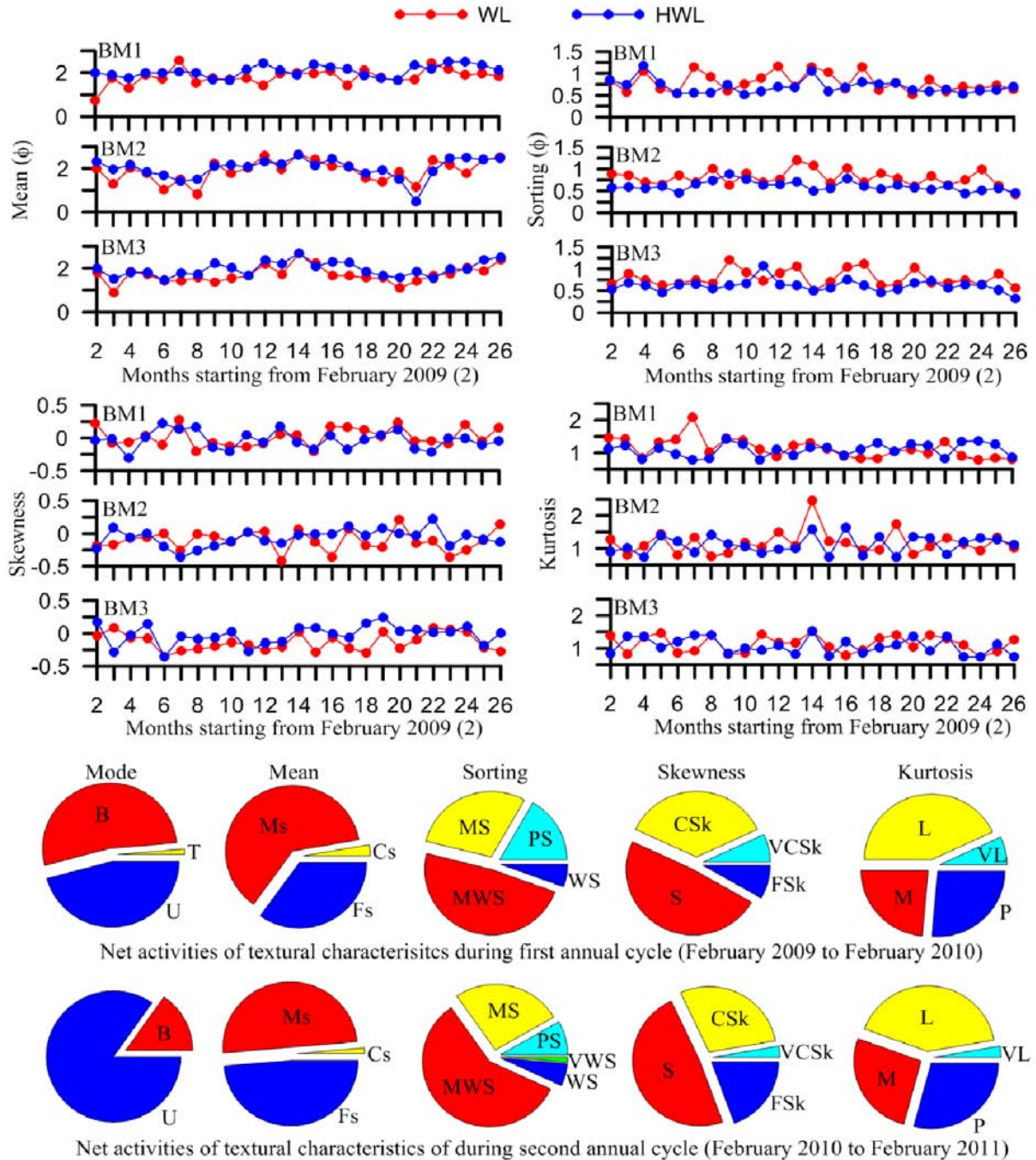


Figure 2: Net activities of textural characteristics of surface sediments at Pavinkurve beach during February 2009 to February 2011

During second annual cycle, Kundapura beach was composed of unimodal to trimodal, fine to very coarse sand, very well sorted to poorly sorted, very fine to very coarse skewed, and platykurtic to very leptokurtic sediments. Annual average of mean, median and sorting was 1.45, 1.46 and 0.71 ϕ whereas skewness and kurtosis was respectively 0.01 and 1.10 (Table 3). During complete annual cycle, beach was dominated by unimodal sediments (84%) along with 15% of bimodal nature whereas remaining samples showed trimodal activity. More sediment samples were found as fine (33%) and medium (40%) sands whereas remaining samples showed coarse (17%) and very coarse (10%) sands. Majority of sediment samples were characterized by moderately well sorted (50%) and moderately sorted (30%) whereas remaining sediments showed as poorly sorted (8%), well sorted (7%) and very well sorted (1%) nature. The fine skewed (25%), symmetrical (35%) and coarse skewed (32%) sediments were found close to each other whereas remaining sediments were found as very fine skewed (7%) and very coarse skewed (1%) nature. In addition, the sediments exhibited approximately equal quantity of platykurtic (32%), mesokurtic (29%) and leptokurtic (33%) nature whereas remaining sediments were characterized by very leptokurtic nature. It showed that during second annual cycle the beach was significantly composed of Fs-Ms, MWS-MS, FSk-CSk and P-L sediments whereas beach was dominated by unimodal sediments.

At Kundapura beach, monthly mean grain size showed a good trend and exhibited seasonal variation of M_z at BM2 and BM3 (Fig. 3) along with the variation of wave activity. But the M_z trend at BM1 was poor as it is located very close to Gangoli river mouth and also the intertidal zone at BM1 is very steep whereas no breaking waves occur that observed during field study. It also identified that the M_z trend of WL and HWL sediments were overlapping during maximum period which exhibited a dominance of wave activities on sedimentary environment from WL to HWL. There was no seasonal trend in sorting,

skewness and kurtosis characteristics as that observed at Pavinkurve beach. At BM2 and BM3, the degree of sorting of HWL sediments was more compared to WL sediments. At BM1, the degree of sorting of beach sediments along both WL and HWL showed very close to each other during maximum period due to significant influence of currents during all the period. Imhansoloeva et al.³⁵ observed the grain size distribution of beach sediments was controlled by high current and strong wave energy. The random trend found in skewness and kurtosis characteristics was similar to the phenomenon that identified at Pavinkurve beach.

From first to second annual cycle, the quantity of unimodal sediments were significantly increased whereas sediments of bimodal and trimodal nature decreased. There was no change in quantity of fine sands but a marginal change was found in medium, coarse and very coarse sand. The very coarse sand was identified at steeper slope where the gravity effect or shear sorting in backwash influences significantly³⁶. From first to second annual cycle the quantity of better sorted (MWS, WS and VWS) sediments were increased whereas poorly sorted sediments were decreased. It showed the influence of alongshore current on intertidal sedimentary environment of Kundapura beach was more during second annual cycle compared to first annual cycle. Blackley and Heathershaw³⁷ found that the wave and tidal currents significantly affect on sorting of beach sediments. It also observed that the quantity of symmetrical sediments was increased along with positive (fine and very fine) skewed nature whereas negative skewed sediments were decreased. From first to second annual cycle, the decreased quantity in platykurtic and increased quantity in leptokurtic sediments showed an increase in grain uniformity. All the textural characteristics together showed a slow process of sediment accretion during second annual cycle. Two years study showed Kundapura beach was significantly composed of unimodal to bimodal, fine to coarse sand, moderately well sorted to moderately sorted, positive to negative skewed, and platykurtic to leptokurtic sediments (Fig. 3).

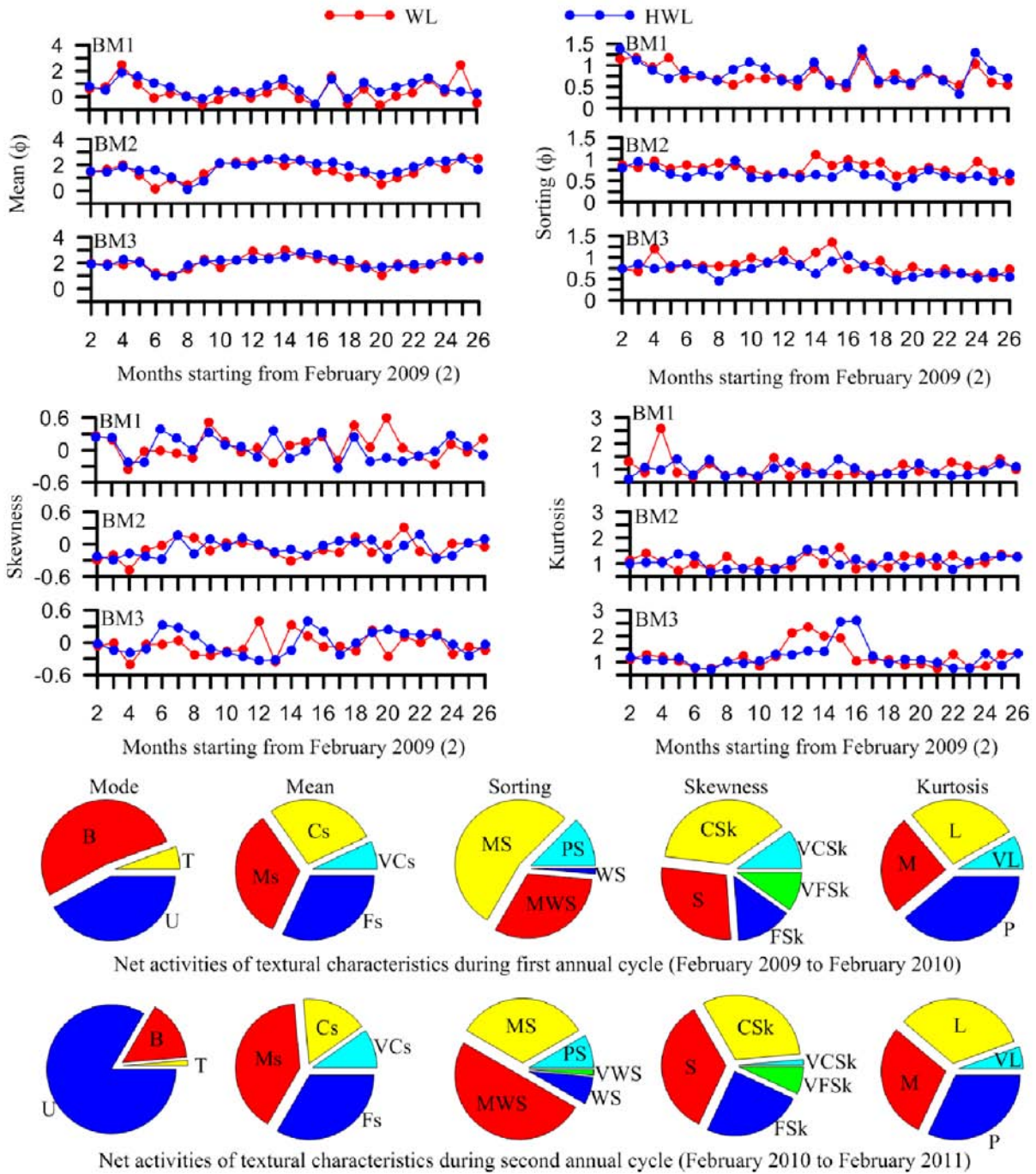


Figure 3: Net activities of textural characteristics of surface sediments at Kundapura beach during February 2009 to February 2011

Padukare beach, Malpe

During first annual cycle, the range of textural characteristics showed Padukare beach was composed of unimodal to bimodal, very fine to very coarse sand, moderately well sorted to poorly

sorted, very fine to very coarse skewed, and platykurtic to extremely leptokurtic sediments. Annual average of mean, median and sorting was respectively 1.75, 1.81 and 0.89 ϕ whereas skewness and kurtosis was respectively -0.09 and

1.23 (Table 4). During complete annual cycle, unimodal and bimodal sediments were respectively 43 and 57%. More quantity of fine (38%) and medium sand (47%) was found whereas remaining samples showed very fine (1%), coarse (11%) and very coarse (3%) sand. Majority of sediments were characterized by moderately sorted (53%) whereas beach showed 21% of moderately well sorted and 26% of poorly sorted sediments. Also beach sediments exhibited about 21% of fine skewed, 15% of symmetrical, 39% of coarse skewed and 19% of very coarse skewed nature along with six percentage of very fine skewed activity. In addition, about 31% of platykurtic, 21% of mesokurtic, 28% of leptokurtic and 19% of very leptokurtic sediments were found whereas remaining samples showed extremely leptokurtic nature. It showed that during first annual cycle, beach was significantly composed of U-B, Fs-Ms, MWS-PS, FSk-VCSk and P-VL sediments. During second annual cycle, the range of textural characteristics showed Padukare beach was composed of unimodal to trimodal, very fine to coarse sand, well sorted to poorly sorted, very fine to very coarse skewed, and very platykurtic (VP) to very leptokurtic sediments. Annual average of mean, median and sorting was 1.85, 1.93 and 0.87 ϕ whereas skewness and

kurtosis was respectively -0.12 and 1.06 (Table 4). During complete annual cycle, beach sediments showed ~73% of unimodal and 26% of bimodal nature whereas remaining samples were characterized by trimodal activity. The fine sand was about 51% and medium sand was 35% whereas beach showed 13% of coarse sand. Remaining samples were characterized by very fine sand (VFs) at gentle beach slope (BM3). The beach exhibited approximately equal quantity of moderately well sorted (32%), moderately sorted (33%) and poorly sorted (31%) sediments whereas remaining samples were characterized by well sorted nature. Majority of beach sediments exhibited coarse skewed (50%) along with 21% of symmetrical and 15% of very coarse skewed nature whereas fine skewed and very fine skewed sediments were respectively eight and six percentages. In addition, the beach exhibited about 21% of platykurtic, 39% of mesokurtic and 29% of leptokurtic sediments whereas very leptokurtic and very platykurtic sediments were seven and four percentages respectively. It revealed that during second annual cycle, beach was significantly composed of U-B, Fs-Ms, MWS-PS, S-CSk and P-L sediments.

Table 3: Range and annual average values of textural characteristics of foreshore surface sediments at Kundapura beach

Years and locations		Textural characteristics															
		Mean (ϕ)			Median (ϕ)			Sorting (ϕ)			Skewness			Kurtosis			
		Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	
Feb 2009 to Feb 2010	BM1	WL	-0.62	2.48	0.43	-0.77	2.59	0.42	0.51	1.18	0.79	-0.36	0.52	0.01	0.68	2.59	1.06
		HWL	-0.15	1.84	0.74	-0.28	1.96	0.70	0.63	1.13	0.85	-0.23	0.38	0.08	0.72	1.40	1.00
	BM2	WL	0.16	2.41	1.54	0.25	2.52	1.62	0.62	1.11	0.81	-0.48	0.17	-0.09	0.73	1.48	1.03
		HWL	0.12	2.49	1.63	0.19	2.57	1.66	0.57	0.98	0.70	-0.29	0.17	-0.09	0.68	1.55	1.07
	BM3	WL	1.05	3.00	2.00	0.99	2.92	2.06	0.68	1.20	0.90	-0.41	0.39	-0.07	0.74	2.36	1.31
		HWL	0.96	2.45	1.96	0.80	2.54	1.99	0.45	0.91	0.75	-0.34	0.33	-0.09	0.71	1.43	1.10
Feb 2010 to Feb 2011	BM1	WL	-0.64	2.47	0.35	-0.81	2.47	0.34	0.48	1.23	0.70	-0.26	0.60	0.10	0.77	1.40	1.00
		HWL	-0.58	1.48	0.59	-0.62	1.71	0.62	0.34	1.36	0.76	-0.34	0.33	-0.02	0.72	1.40	0.97
	BM2	WL	0.49	2.57	1.64	0.49	2.53	1.67	0.49	0.99	0.77	-0.25	0.31	-0.05	0.79	1.63	1.14
		HWL	1.25	2.51	1.95	1.33	2.51	1.96	0.37	0.82	0.61	-0.26	0.18	-0.04	0.78	1.27	1.09
	BM3	WL	1.08	2.62	1.99	1.20	2.63	2.02	0.53	1.36	0.75	-0.27	0.23	-0.03	0.75	1.94	1.11
		HWL	1.61	2.83	2.17	1.59	2.72	2.16	0.48	1.04	0.67	-0.25	0.39	0.08	0.76	2.59	1.29

Table 4: Range and annual average values of textural characteristics of foreshore surface sediments at Padukare beach

Years and locations		Textural characteristics															
		Mean (ϕ)			Median (ϕ)			Sorting (ϕ)			Skewness			Kurtosis			
		Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	
Feb 2009 to Feb 2010	BM1	WL	-0.07	2.34	1.52	-0.14	2.51	1.59	0.55	1.32	0.96	-0.49	0.24	-0.08	0.79	2.13	1.09
		HWL	1.18	2.66	1.95	1.36	2.63	2.05	0.58	1.21	0.82	-0.30	0.21	-0.13	0.71	2.47	1.35
	BM2	WL	-0.01	2.45	1.24	-0.06	2.58	1.30	0.68	1.39	0.92	-0.41	0.27	-0.09	0.71	1.84	1.01
		HWL	0.25	2.69	1.42	0.31	2.65	1.49	0.54	0.99	0.78	-0.38	0.20	-0.13	0.80	2.15	1.13
	BM3	WL	1.33	2.61	1.93	1.54	2.75	2.07	0.76	1.41	1.04	-0.43	0.09	-0.21	0.74	3.00	1.39
		HWL	1.82	3.65	2.41	1.83	3.05	2.36	0.54	1.68	0.82	-0.37	0.51	0.11	0.76	2.52	1.38
Feb 2010 to Feb 2011	BM1	WL	0.17	2.43	1.47	-0.02	2.53	1.54	0.62	1.76	1.00	-0.40	0.28	-0.08	0.58	1.56	0.99
		HWL	1.13	2.72	2.09	1.25	2.64	2.15	0.46	0.92	0.69	-0.41	0.25	-0.16	0.85	1.40	1.11
	BM2	WL	0.02	2.37	1.27	-0.11	2.50	1.40	0.65	1.51	1.05	-0.61	0.39	-0.13	0.59	1.28	0.93
		HWL	1.29	2.47	1.88	1.36	2.55	1.94	0.55	1.13	0.76	-0.30	0.15	-0.13	0.74	1.54	1.00
	BM3	WL	0.28	3.15	2.07	-0.05	3.29	2.19	0.48	1.46	0.96	-0.45	0.46	-0.18	0.88	1.57	1.13
		HWL	1.53	2.76	2.30	1.73	2.91	2.33	0.51	1.25	0.76	-0.28	0.33	-0.05	0.74	1.96	1.18

During two years study period, Padukare beach sediments showed a non-uniform trend in their monthly activity of textural characteristics and exhibited poor seasonal variation (Fig. 4). Existence of coarser particles during pre and post-monsoon as well as summer monsoon period showed the beach was predominantly medium to coarse sands but finer sand was found at BM3 due to the gentle beach slope at this location. During maximum period, beach sediments showed bigger natural grains along WL compared to HWL sediments due to the influence of breaking waves. Poorly sorted sediments were found along WL whereas HWL sediments showed comparatively better sorted nature with the interaction of alongshore current. There was no unique trend in skewness and kurtosis characteristics of WL and HWL sediments which showed same result as those identified at other two beaches.

The textural characteristics at Padukare beach showed little complex process compared to other two beaches. From first to second annual cycle, the quantity of unimodal sediments increased along with the increased quantity of fine sand whereas the bimodal and medium sand decreased. Also, the quantity of moderately sorted sediments decreased whereas both moderately well sorted and poorly sorted sediments increased along with little quantity

of well sorted sediments. Even though the quantity of fine sand was increased, the fine skewed sediment was decreased and coarse skewed sediment was increased. Approximately equal quantity of symmetrical and very coarse skewed sediments were identified during both annual cycles. The positive skewed samples were relatively less whereas negative skewed were relatively more, indicating beach was undergoing erosion or non-deposition³⁸. Also strongly fine skewed and fine skewed sediment generally implies the introduction of fine material or removal of coarser fraction². Approximately same quantity of leptokurtic sediments were found during both years. The quantity of mesokurtic sediments were increased from first to second annual cycle whereas very leptokurtic and platykurtic sediments were decreased significantly. Also the quantity of extremely leptokurtic sediments was decreased whereas few quantities of very platykurtic sediments were found which revealed a complex pattern in the sedimentary environment. Two years study showed that the Padukare beach was significantly composed of unimodal to bimodal, fine to medium sand, moderately well sorted to poorly sorted, positive to negative skewed, and platykurtic to leptokurtic sediments (Fig. 4).

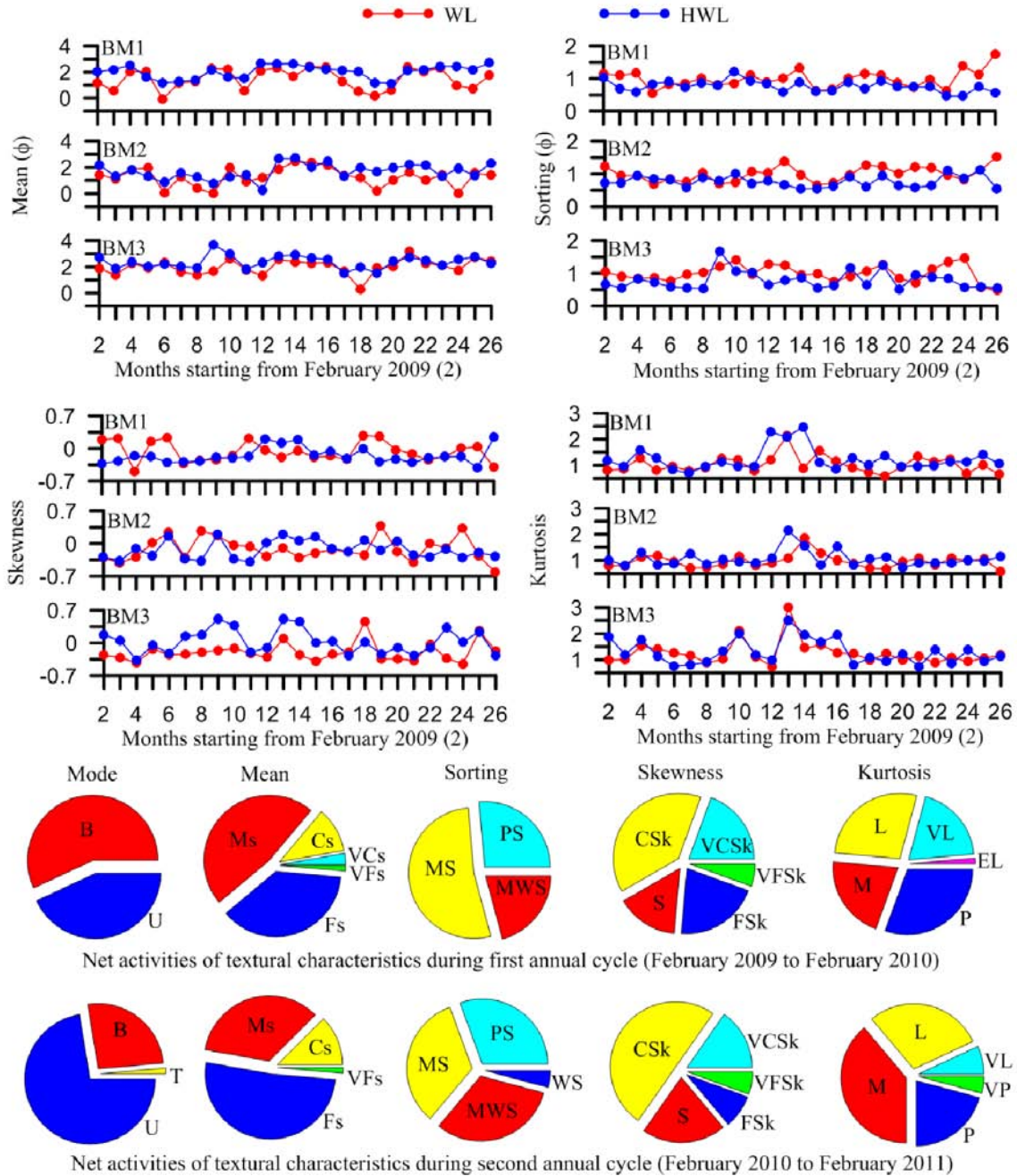


Figure 4: Net activities of textural characteristics of surface sediments at Padukare beach during February 2009 to February 2011

All three beaches together significantly composed of unimodal to bimodal, fine to medium sand, moderately well sorted to moderately sorted, symmetrical to coarse skewed, and platykurtic to leptokurtic sediments. Chaudhri et al.¹³ observed

that moderately sorted sands are predominant on the beaches of west coast of India. The textural characteristics showed poor correlation to each other (Fig. 5) which was similar to the observation of the earlier study²⁹. During first to second annual

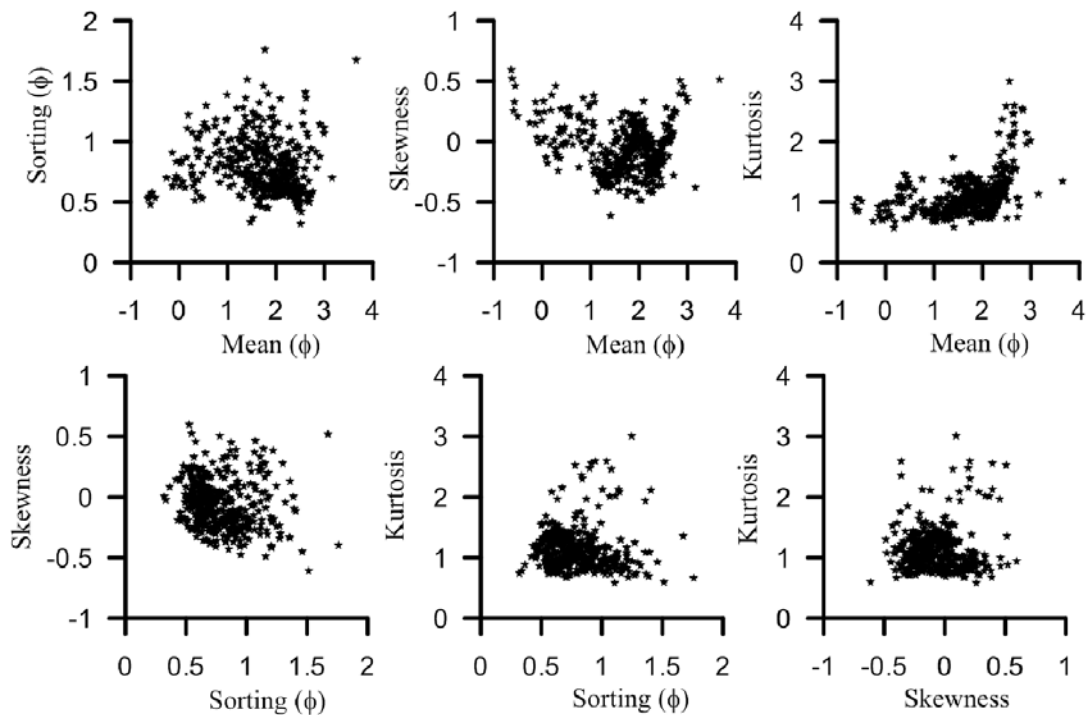
cycle, at Pavinkurve beach, an increased quantity of moderately well sorted and fine skewed sediments was found while fine sands were increased. Earlier researchers^{9,39} also found that the sediments exhibit well sorted nature along with fine sands. Kundapura beach showed that the moderately well sorted and fine skewed sediments were increased with an increased quantity of medium sands. But Padukare beach sediment exhibited poorly sorted and coarse skewed sediment with increased quantity of fine sands. It also observed that the very leptokurtic as well as platykurtic sediments were decreased with an increased quantity of fine sands. Present analysis revealed that a significant relation between the textural characteristics can be identified only in the extreme condition of sediment process. Also two beach profiles, those were collected at Kundapura (BM1 during August, 2010) and Padukare (BM3 during September, 2010) clearly distinguished the grain size variation with respect to extreme change in beach slope (Fig. 6). An existence of finer particles at gentle or close to gentle slope and coarser particles at steeper slope exhibited the grain size variation along with beach morphology.

Conclusion

Textural characteristics showed that the beaches were under slow process with non-uniform sediment erosion and accretion whereas the mean characteristics exhibit an accretion of finer particles from first to second annual cycle. Further the slow process of sediment accretion/erosion showed a poor correlation between the textural characteristics. Study observed that the beach sedimentary environment is controlled by wave action and beach morphology significantly.

Acknowledgement

Present study was part of the project on shoreline management plans for Karnataka coast. Authors thank Integrated Coastal and Marine Area Management Project Directorate (ICMAM PD), Ministry of Earth Sciences, New Delhi for funding the project. Director, National Institute of Oceanography, Goa and Director, ICMAM PD, Chennai provided encouragement to carry out the study. This is NIO contribution 5414.



Textural characteristics of beach sediments

Figure 5: Bivariate plots of textural characteristics of foreshore sediments.

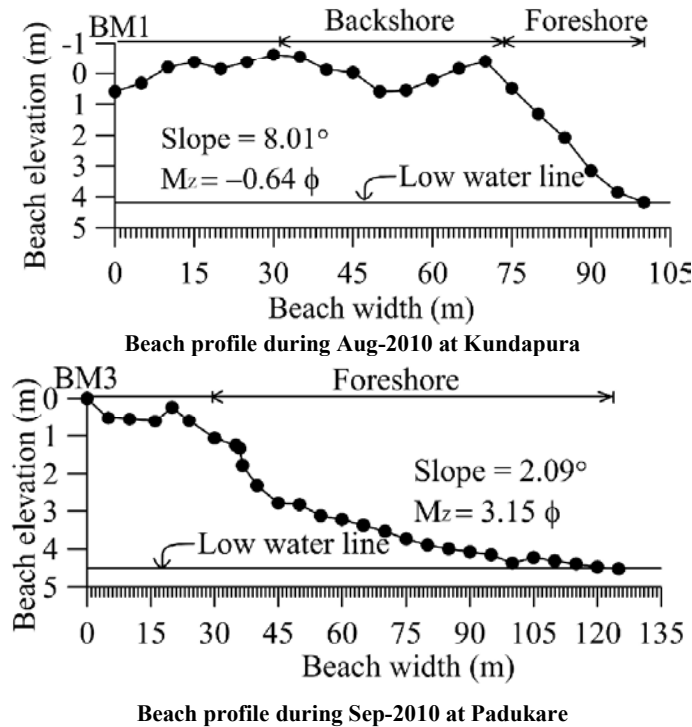


Figure 6: Monitored beach profiles at steeper and gentle foreshore zones

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