

Short-term observation of beach dynamics using cross-shore profiles and foreshore sediment

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Abstract

Cross-shore beach profiles and textural characteristics of foreshore sediment were analyzed for understanding an annual cycle of intertidal beach dynamics at Devbag, an Island sheltered estuarine coast. This study is carried out as response to the shoreline management project proposed by Ministry of Earth Science, India. Cross-shore transects were monitored in a monthly interval during February 2008 to February 2010 along with collection of beach surface sediment samples. Change in beach volume over an annual cycle showed a slow rate of sediment accretion at the Devbag beach where the maximum accretion was found at dissipative zone. During the year 2008-09, the volume of sediment accretion was 24.23 m³/m with an average beach width and slope of 91m and 3.3° respectively. During 2009-10, the accreted beach volume was 33.54 m³/m with an average beach width and slope of 132 m and 2.6° respectively. The beach along the coast was varying from extremely gentle to a slightly steeper slope which showed dissipative to reflective nature. The Beach was dominated by both fine and medium sands. More quantity of unimodal and bimodal sediment was found with moderately well sorted and moderately sorted behaviour. No significant correlation in beach morpho-sedimentary characteristics was found due to the non-uniform trend in beach morphodynamics and textural characteristics. Present study emphasizes the need to observe the beach changes over inter-annual seasons before planning coastal protection measures. The results of the study will be helpful for formulating an effective coastal zone management plan at Devbag, Kali estuary, west coast of India.

Key words: Beach profiles, Erosion, Accretion, Central Tendency, Sorting, Skewness.

1. Introduction

Along Karnataka coast, west coast of India, 75% of the coastline is covered with sandy beaches (Kumar et al., 2006). The intertidal zone of sandy beaches is a highly dynamical zone caused by natural (tide, wave and wind) as well as human activities (Short and Hesp, 1982; Niedoroda et al., 1984; Wright and Short, 1984; Larson et al., 2000; Capo et al., 2006; Scott et al., 2011; Van Rijn, 2011). Seasonal variations of beach erosion and/or accretion and also spatio-temporal evolution of beach profiles provides useful information for the scientific understanding of coastal processes and management (Andrade and Ferreira, 2006; Gujar et al., 2011). Beach profiles are important tools for elucidating long-term trends, such as erosion and accretion, and for predicting the future evolution of coastal landforms (Guillen et al., 1999; Cooper et al., 2000). Grain size analysis is an essential tool for classifying sedimentary environments (Blott and Pye, 2001) and also provides important clues to the sediment provenance, transport history and depositional conditions (Folk and Ward, 1957; Friedman, 1979; Bui et al., 1989). Mean size, sorting and skewness are the most useful parameters to describe the sediment (Friedman, 1961; Edwards, 2001) and also distinguish the different wave energy environments (Nordstrom, 1977). Further both beach profile and grain size analyses help to predict the equilibrium beach profile (Dean, 1977). Hence, quantification of these morpho-sedimentary parameters will be relevant for an effective coastal-zone/shoreline management plan and thus highly supportive in fostering economic growth of an estuarine coastal zone.

Large scale erosion was observed along the Devbag beach during June 2006 and in order to protect the beach, Government of Karnataka requested the central Government to construct coastal protection measures. Since site specific data on coastal dynamics and beach morphology was not available, a study was carried out to generate this data and plan coastal protection measures and shoreline management plans. In accordance to the shoreline management project proposed by Ministry of Earth Science, India, short term beach morphodynamics at Devbag was analyzed using monitored cross-shore profiles and the statistical characteristics of foreshore sediment. Study area, Devbag is an Island sheltered estuarine beach located at the north side of Kali River mouth, Karwar (Figure 1). The Kali River originated from the Western Ghats drains into the Arabian Sea at $14^{\circ} 50' 35.634''\text{N}$; $74^{\circ} 07' 10.625''\text{E}$ to $14^{\circ} 50' 16.905''\text{N}$; $74^{\circ} 07' 31.196''\text{E}$ and has a width of around 800 m near the coast. Devbag beach covers ~2 km along the shoreline with a non-uniform foreshore and negligible width of backshore zone. Offshore region of Karwar shoreline has few small islands known as Kurmagadgudda, Shimisgudda, Devgadgudda, Mandalgudda, Karkaigudda and East Island (NHO, 2008). The coastal processes of this domain have been analyzed by some researchers using

both measured and remote sensing data (Nayak and Chavadi, 1988; Veerayya and Pankajakshan, 1988; Mislankar and Antao, 1992; Nigam and Khare, 1995; Nayak, 1996; Hanamgond and Mitra, 2007). Mislankar and Antao (1992) have shown that the Sadashivagad (north of Devbag) beach undergoes a slow rate of accretion whereas Karwar beach is subjected to strong winnowing and accretion. Chandramohan et al. (1992) observed maximum alongshore current of 0.24m/s (predominantly northward) in the Karwar beach (south of Devbag). Using remote sensing data Hanamgond and Mitra (2007) observed that, the quantity of beach erosion during the years 2000-2003 is 1.5 times more than the net erosion during 1989-2000 which shows that the erosion of land was dominant during 2000-2003. In this study, the intra and inter-seasonal cross-shore beach dynamics at different locations along Devbag coast was examined during February 2008 to February 2010, and an analysis was carried out on the variation of textural characteristics of beach sediment.

2. Materials and methods

At Devbag beach the tide varies in micro tidal range (< 2m) during most of the period with the lowest low tide and highest high tide levels as -0.19 and 2.36 m respectively (Indian tide table, 2008, 2009 and 2010). The intra and inter-seasonal cross-shore beach changes were obtained for the period of two years using monthly monitored beach profiles. Beach profiles were monitored at three selected locations (BM1, BM2 and BM3 from north to south) along the shoreline using a dumpy level and measuring staff. All individual beach profiles were monitored from selected benchmarks to the low water line at 5 m and/or closer intervals at the beach berm. At BM1 location, the benchmark base point was at a distance of 25 m from the highest high tide line (HHTL) collected during the study period whereas the base point at BM2 and BM3 were respectively at a distance of 35 and 90 m from HHTL. The 25 m distance at BM1 was covered by road and the seawall whereas the 35 and 90 m distances at BM2 and BM3 were covered by vegetation and plantation respectively. Along the three locations, total 75 beach profiles were monitored where each location was having 25 beach profiles individually and the seasonal monitored profiles are presented in Figure 2. The beach at BM1 was open and also protected by a seawall and the BM2 location is an island sheltered zone whereas the beach at BM3 is continually interacting with ebb and flood currents.

Beach slope (θ) was calculated using right angle triangle trigonometric formula (Eq. 1),

$$\text{Sin } (\theta) = \text{Opposite} / \text{Hypotenuse} \quad \dots \text{ Eq. 1}$$

The change in beach volume (accretion [+] /erosion [-]) for unit beach length was calculated for the maximum common beach elevation of two selected beach profiles using trapezoid (trapezium) formula (Eq. 2),

$$\text{Volume per unit length (m}^3\text{/m)} = A = ((P1+P2) * (B/2)) \quad \dots \text{Eq. 2}$$

where the displacement (B) between two parallel lines (P1 and P2) can be calculated using Pythagoras right angle triangle formula such as

$$B^2 = H^2 - P^2, \quad \dots \text{Eq 3}$$

where P = Opposite (beach elevation) and B = Adjacent (beach width), H = Hypotenuse (monitored beach profile) of a right angle triangle. In the present study, P1 and P2 are the two selected beach elevations from a baseline (Figure 3).

The study domain is under the influence of the three seasons such as pre-monsoon (February to May), summer monsoon (June to September) and post-monsoon/winter-monsoon (October to January). Hence the seasonal changes in beach volume were calculated using the profiles monitored in four month intervals where the monthly changes in beach volume were calculated using monthly monitored profiles and the annual changes in beach volume was calculated using yearly monitored profiles. It clearly indicates that the seasonal and annual changes of beach volume are not the net result of monthly changes in beach volume. The two years study was carried out separately for the years 2008-09 (first annual cycle) and 2009-10 (second annual cycle). Geographic position of three locations was collected using Ceeducer-Pro (DGPS Instrument) manufactured by Brutton International Pty. Ltd., Australia. Along with monitoring beach profiles, total 144 number of sediment samples was collected during the two years along the water line (WL) and high water line (HWL) at the three selected locations. The distance between the WL and HWL was varying with respect to space and time depending upon the tidal variation and beach slope. Laboratory analysis (sediment distribution) of sediment samples was carried out using electromagnetic sieve shaker machine consisting of 7 sieves having mesh sizes 2, 1, 0.5, 0.425, 0.212, 0.125, 0.075 mm and pan. Seasonally collected sediment samples are presented in the frequency distribution curve (Figure 2).

Statistical parameters such as central tendency (mean, mode and median), sorting, skewness and kurtosis of individual sediment samples were obtained using GRADISTAT - a grain analysis package (Blott and Pye, 2001) following Geometric Folk and Ward (1957) Graphical Measures. Mode indicates the most frequently occurring grain sizes in a sediment sample. Mean value is the

average of the total distributed grains and median presents the grain size of exact 50% of a cumulative percentage of total distributed sediment. Sorting shows the low or high variance of distributed grain size of a sediment sample. Skewness measures the asymmetry where kurtosis reveals the peakedness/flatness of a frequency distribution curve (Friedman, 1962). All collected sediments were categorized as per the grain mean size following the modified form of Udden (1914) and Wentworth (1922) scale. The sorting, skewness and kurtosis characteristics of beach sediments were classified following the Geometric (modified) Folk and Ward (1957) Graphical Measures. The value of mean grain size (M_G), sorting (σ_G), skewness (Sk_G) and kurtosis (K_G) were extracted using GRADISTAT package following the equations respectively Eq 4, Eq 5, Eq 6 and Eq 7.

$$M_G = \exp\left(\frac{\ln P_{10} + \ln P_{50} + \ln P_{90}}{3}\right) \quad \dots \text{Eq. 4}$$

$$\sigma_G = \exp\left(\frac{\ln P_{10} - \ln P_{90}}{4} + \frac{\ln P_3 - \ln P_{93}}{6.6}\right) \quad \dots \text{Eq. 5}$$

$$Sk_G = \frac{\ln P_{10} + \ln P_{90} - 2(\ln P_{50})}{2(\ln P_{90} - \ln P_{10})} + \frac{\ln P_3 + \ln P_{93} - 2(\ln P_{50})}{2(\ln P_{93} - \ln P_3)} \quad \dots \text{Eq. 6}$$

$$K_G = \frac{\ln P_3 - \ln P_{93}}{2.44(\ln P_{25} - \ln P_{75})} \quad \dots \text{Eq. 7}$$

The P_x is the grain diameter in metric at the cumulative percentile value of x.

3. Results and discussion

3.1 Beach morphodynamics

3.1.1 Beach width and slope

In two years study, a narrow beach width was found during summer monsoon (July-September) due to the wave setup with heavy precipitation and also the water discharge through Kali River. At BM1 and BM3, a wide beach width was observed during January to April depending upon the depositional condition. At BM2, the beach width was wide during October due to the maximum quantity of sediment accretion during summer monsoon. Slow rate of beach changes was identified at BM1 whereas the beach width was decreased from 70 to 60 m during first annual cycle which was again increased from 60 to 70 m during second annual cycle. At BM2, an increase in beach width (100 to 240 m) was found during first annual cycle which was again increased up to 265 m during second annual cycle. At BM3, an increase in beach width (55 to 165 m) was observed during 2008-09 which

was again decreased up to 75m during 2009-10 (Table 1). The annual variation in beach width showed a slow rate of erosion in the lower intertidal zone at the BM1 during 2008-09, but sediment accretion was found at BM2 and BM3. During 2009-10, the beach width was slightly increased at BM1 and BM2 but the beach was significantly decreased at BM3. During two years an annual increase in beach width was found at BM2 whereas the beach at BM1 and BM3 was acting reversely with each other but not significantly. A non-uniform change in beach width at the three locations was due to the presence of islands at the nearshore zone.

The variation in beach slope was found along with the change in beach width. Along the three locations, beach slopes varied between 0.62° and 7.32° (Table 1). During first annual, the mean beach slope at BM1, BM2 and BM3 was identified as 3.85° , 1.63° and 4.38° respectively and that was 3.11° , 0.97° and 3.86° during second annual. The decrease in mean beach slope from first to second annual cycle showed an accretion of sediments. During two years, the beach at BM1 was identified from moderate (1:33) to steep slope (slope $> 1:10$) whereas the average slope (1:20) was observed more frequently. The beach at BM2 varied among flat/extremely gentle (slope $< 1:50$) to average slope whereas the extremely gentle and gentle slope (1:50) was found more frequently. The beach at BM3 varied among moderate to steep slope whereas the average slope was found significantly. In the ratio the first part indicates beach elevation and second one is beach width. At BM1 and BM3, the steep slope was found during summer monsoon but during pre and post-monsoon, the beach varied from moderate to average slope. At BM2, the moderate slope was identified during pre-monsoon of 2008 whereas the remaining period the beach was identified by extremely gentle to gentle slope. This study revealed that the steeper beach slope can be found at higher wave condition which is similar to the result of Short (1999). The two years field observation showed that at BM1 and BM3 the beach was characterized by slightly reflective nature whereas a dissipative beach was observed at BM2, an island sheltered zone.

3.1.2 Beach volume

Monthly change in beach volume showed a continuous sediment accretion at BM1 during post monsoon in 2008-09 and also at BM2 during summer monsoon in 2009-10, but in remaining period beach showed both erosion and accretion frequently. At BM1, the highest beach change was found with erosion and the volume of eroded sediment was $56.79 \text{ m}^3/\text{m}$ during May to June in 2008-09 and $20.96 \text{ m}^3/\text{m}$ during July to August in 2009-10 (Table 2). At BM2, the maximum change in beach volume was found with sediment accretion and the volume of accreted sediment was $137.80 \text{ m}^3/\text{m}$ during July to August in 2008-09 and $81.14 \text{ m}^3/\text{m}$ during September to October in 2009-10. But at

BM3, during first annual cycle the highest change in beach volume was found during January to February with sediment accretion (+55.15 m³/m) whereas in second annual cycle the maximum beach change was found during June to July with sediment erosion (-102.39 m³/m). During two years a non-uniform change in beach volume was observed along the three selected locations.

In first annual cycle, during pre-monsoon the beach sediments winnowed at all three locations whereas an increase in the volume of eroded sediment was found away from the Kali River mouth. It results a cross-shore sediment transport along the shoreline. During summer monsoon, the beach sediments winnowed at BM1 by wave action but an accretion of sediments was found at BM2 and BM3. Also the volume of accreted sediment at BM2 was much larger than that found at BM3. This large quantity of sediment accretion was due to the sediment discharge through Kali River and also the nearshore sediment transport by high energy south-west waves. Nayak et al. (2010) also found significant deposition of sediments around river mouth during summer monsoon by the interaction of high waves and river discharge. During post-monsoon, the beach sediments winnowed at BM2 but the beach at BM1 and BM3 was found with sediment accretion. This was due to the result of tidal current (ebb and flood) that generated with water level variation which transported fine sands to both sides of the BM2 location. Net result showed a slow rate of sediment erosion at BM1 but the beach at BM2 and BM3 was found with an accretion of sediments. In second annual cycle during pre-monsoon, accretion of sediments was found at BM1 and BM2 but the beach sediments winnowed at BM3 by tidal current. During summer-monsoon, sediments accreted at BM2 whereas eroded beach was found at BM1 and BM3. Volume of sediment accretion at the island sheltered zone (BM2) was much more than the eroded beach sediments found at BM1 and BM3. This indicates the transportation of nearshore sediments with the occurrence of high wave activities. During post-monsoon, at BM2 the sediments removed from the beach and accumulation of sediments was found at BM1 and BM3 which was similar to the observation during the first annual cycle. Annual change in beach volume showed an accretion of sediments at BM1 and BM2 but at BM3 the sediments winnowed from the beach and exhibited an erosion zone (Table 2). Inter-annual variations indicate that for coastal management, observation covering a year is not sufficient to understand the seasonal variations.

During both years, the three locations together quantitatively showed that the beach was under a slow rate of sediment accretion which is similar to the result of Mislankar and Antao (1992). Net sediment accretion was 24.23 m³/m during 2008-09 and 33.54 m³/m during 2009-10. Erosion and accretion was observed frequently along the coast, whereas sediment accretion was found significantly at the

island sheltered dissipative zone (BM2). The monthly and seasonal observation showed a non-uniform change in beach volume along the three locations which indicate both longshore and cross-shore sediment transport. Turker and Kabdasli (2007) observed that cross-shore sediment transport affects the beach profile significantly. The change in beach width and change in beach volume was found significantly at island sheltered dissipative zone but the beach slope was changing frequently at both open coast and also the beach close to river mouth (Figure 4). Lorang et al. (1993) observed that the erosion at dissipative beach is comparatively more than that at the reflective beach whereas Samsuddin and Suchindan (1987) observed that the alongshore current is significantly related to the beach erosion/accretion. This analyses revealed that the Devbag beach was under the influence of both alongshore and cross-shore current.

3.2 Beach sedimentology

3.2.1 Textural characteristics

Central tendency (mode, mean and median), sorting, skewness and kurtosis describe the general behaviour of beach sediment. At Devbag, beach sediments mainly showed unimodal (U) and bimodal (B) behaviours where a very less quantity of trimodal (T) sediment was found. Primary mode was identified at the grain diameter of 168.5, 318.5, 750 μm with respect to space and time where the secondary mode was found at 318.5, 750, 2100 μm and tertiary mode was observed at 750 and 2100 μm . Secondary and tertiary mode at a grain diameter of 2100 μm was identified only in slightly gravel sand textural group which observed at BM3 along WL during summer monsoon with high wave condition. During 2008-09, the median (D_{50}) value varied between 166 and 359 μm with an average value of 269 μm and during 2009-10 that varied in 163-633 μm with an average value of 259 μm . During second annual cycle, an increase in median range was observed by approximately same average value due to the presence of coarse sand along WL at BM3 during summer monsoon. During two years the mean grain size varied in 163-576 μm with an average value of 270 μm and showed more quantity of fine sand (Fs) and medium sand (Ms) along with negligible quantity of coarse sand (Cs). The grain sorting tendency varied in 1.31-2.51 μm with an average value of 1.58 μm and the sediments were characterized among well sorted (WS) to poorly sorted (PS). The skewness was found from -0.29 to 0.41 with an average value of 0.04 and characterized among fine skewed (FSk) to very coarse skewed (VCSk). Kurtosis of beach sediment varied from 0.74 to 1.78 with an average value of 1.1 and those were characterized among platykurtic (P) to very leptokurtic (VL). At both WL and HWL, a random trend was identified in the variation of all the textural

characteristics (Figure 5). But the sediment samples along WL at BM3 showed coarser sand with poorly sorted nature during summer monsoon where the remaining period sediment samples were characterized from fine to medium sand with well sorted to moderately sorted nature. Hegde et al. (2007) observed the summer monsoon high waves result better sorted sediment which is contradicting the present result. It showed that the wave action is not only the external parameter for sorting out beach sediments. There was no significant trend in seasonal variation of textural characteristics due to the presence of islands which obstruct the south-west high waves during summer monsoon. It revealed that the variation of textural characteristics depend upon the extreme change in the corresponding hydrodynamics.

Two years sediment samples showed a dominance of unimodal sand at dissipative zone (BM2) whereas the intermediate and reflective zone (BM1 and BM3) was found with both unimodal and bimodal sands. Also the quantity of unimodal sand was exceeded the bimodal sand along HWL whereas a reverse result was observed along WL. More quantity of fine sand was found at BM2 compared to the other two locations due to the sheltered zone of Kurmagadgudda and Shimisgudda Island. The beach at BM1 and BM3 showed more quantity of medium sand due to the direct approach of waves. Also few quantity of coarse sand was found at BM3 during summer monsoon in second annual cycle with the result of high wave activity and also due to the gravitational effect (Bryant, 1982). This showed that the grain size increases with increase in wave energy which is similar to the result of Samsuddin (1989). At all three locations the moderately well sorted (MWS) sediment was found significantly. Along with the MWS sediment a considerable quantity of moderately sorted (MS) sediment was found at WL whereas the well sorted (WS) sediment was found at HWL. It reveals the role of alongshore current in formation of better sorted sediment. Also few quantity of poorly sorted (PS) sediment was found along the shoreline but the MWS sediment was dominating the beach. Chaudhri et al. (1981) observed that moderately sorted sand was predominant on the beaches along west coast of India. Also the sediment samples usually showed as fine skewed (FSk), symmetrical (S) and coarse skewed (CSk) nature whereas few samples were found by very coarse skewed (VCSk) at the intermediate and reflective zone. Majority of sediment samples having CSk and VCSk nature were found at intermediate and reflective zone compared to dissipative zone and also those were identified significantly along WL compared to HWL. It results that the low wave activity and alongshore current together occur positive skewed sediment and high wave activity increases the negative skewed sediment. The positive skewed samples were relatively less whereas negative skewed were relatively more, indicates that the beach was undergoing erosion or non-deposition (Duane, 1964). Also strongly fine skewed and fine skewed sediment generally

implies the introduction of fine material or removal of coarser fraction (Friedman, 1961). In addition the sediment samples were characterized by platykurtic (P), mesokurtic (M) and leptokurtic (L) nature along with few quantity of very leptokurtic (VL) sediment. The quantity of platykurtic sediment was exceeded the leptokurtic at dissipative zone and an opposite result was found at the intermediate and also reflective zone (Table 3). It showed that the platykurtic to very platykurtic and leptokurtic to very leptokurtic sediment can be identified significantly in extremely low and high wave energy environments respectively. All the characteristics of beach sediment revealed that the wave approach (wave energy and direction) to the coast plays an important role in the variation of sediment characteristics. Imhansoloeva et al. (2011) also observed that the high current and strong wave energy are responsible for the grain size distribution on the beach.

3.2.2 Sedimentary environment

Sedimentary environment of Devbag beach was characterized by the textural activities. During first annual cycle the beach sediment showed 74 % of unimodal and 25 % of bimodal along with one percentage of trimodal sand. Fine sand was found about 31 % whereas the medium sand was 69 % of the total collected samples. Moderately well sorted sediment was about 62 % whereas the remaining samples were characterized by well sorted (20 %), moderately sorted (17 %), and poorly sorted (1 %) nature. The quantity of fine skewed (31 %), symmetrical (36 %) and coarse skewed (32 %) sediments were very close to each other whereas one percentage of very coarse skewed sediment also observed. Similarly, the sediments were characterized approximately by the same quantity of platykurtic (27 %), mesokurtic (33 %) and leptokurtic (36 %) sediments along with four percentages of very leptokurtic sediment.

During second annual cycle a slightly decrease in the quantity of unimodal sand was observed along with an increase of bimodal sand where the unimodal and bimodal sand was respectively 67 and 32 % during 2009-10. But a significant variation was found in mean grain size where the quantity of fine and medium sand was 53 and 46 % along with one percentage of coarse sand. Also the well sorted sediment decreased along with an increase of moderately sorted and poorly sorted sediment whereas the beach showed about the same quantity of moderately well sorted sediment during both years. During 2009-10, the moderately well sorted and moderately sorted sediment was 60 and 26 % whereas the remaining samples showed about 4 % of well sorted and 10 % of poorly sorted. There was no significant change in skewness and kurtosis characteristics of beach sediment but during second annual cycle the very coarse skewed sediment was 8 % which was only 1 % during first annual cycle (Figure 6). Two years observation showed that the Devbag beach was significantly

dominated by fine to medium sand having unimodal to bimodal, moderately well sorted to moderately sorted sediment, fine to coarse skewed and platykurtic to leptokurtic nature.

3.3 Morpho-sedimentary correlations

The monthly change in beach morphodynamic parameters (width, slope and volume) showed poor ($R^2 < 0.3$) to moderate ($0.5 \leq R^2 < 0.7$) correlation whereas the mild ($0.3 \leq R^2 < 0.5$) and moderate correlation was found significantly along the shoreline. The change in beach width (CBW) and the change in beach slope (CBS) showed a negative correlation whereas the correlation between CBW and change in beach volume (CBV) was positive. Simultaneously a negative correlation was found between the CBS and CBV (Figure 7). The correlation at dissipative zone (BM2) was comparatively strong compared to the intermediate (BM1) and reflective (BM3) zone. At dissipative zone the CBW versus CBS, CBS versus CBV and also CBV versus CBW showed moderate correlation having the values respectively 0.66, 0.64 and 0.63 which are close to strong ($R^2 \geq 0.7$) correlation. At BM1, those were observed with the value of 0.34, 0.56 and 0.21 whereas at BM3 those were found respectively 0.35, 0.19 and 0.29. The strong correlation can be found if the beach profile changes uniformly whereas the poor correlation results along with a non-uniform change in beach profile. The poor to strong correlation in the change in beach morphodynamics reveals the presence of both alongshore and cross-shore sediment transport along Devbag beach.

A poor correlation was found between the textural characteristics of beach sediment which is similar to the earlier observation obtained at other beaches along west coast of India (Dora et al. 2011). More sediments were significantly characterized by fine to medium, moderately well sorted to moderately sorted, fine to coarse skewed and platykurtic to leptokurtic nature. The remaining sediments were characterized by trimodal, well sorted, poorly sorted, very coarse skewed and very leptokurtic nature which were not analyzed elaborately because of their scarce representation in the present study. Bivariate plots show the co-existence of textural characteristics in the sediment samples (Figure 7). The fine sand exhibited moderately well sorted, fine to coarse skewed nature whereas the medium sand showed moderately sorted, symmetrical to coarse skewed nature. McLaren and Bowles (1985) observed the finer sediments exhibit negative skewed nature. The moderately well sorted sediments exhibited fine to medium sands, fine to coarse skewed nature whereas the moderately sorted sediment showed significantly medium sands, symmetrical to negative skewed nature. The fine skewed sediments showed fine to medium sand, well sorted to moderately well sorted nature. The symmetrical sediments were found with fine to medium sand, moderately well sorted nature whereas the coarse skewed sediment showed fine to medium sand, moderately well

sorted to moderately sorted nature. Also the fine skewed sediments were varying platykurtic to mesokurtic but symmetrical and coarse skewed sediment showed platykurtic to leptokurtic nature. The platykurtic and mesokurtic sediments showed fine to medium sand, moderately well sorted, fine to coarse skewed nature whereas the leptokurtic sediment showed medium sand, moderately well sorted to moderately sorted, symmetrical to coarse skewed nature (Table 4).

Also a poor correlation was found on the textural characteristics with respect to beach slope and erosion/accretion (Figure 7). All types of beach slopes showed more percentage of unimodal sediment compared to bimodal sediment whereas the steep beach was found with few quantity of trimodal sediment. Only the flat beach was dominated by fine sand where the remaining beach slopes from gentle to steep were identified with both fine and medium sand. It also observed that there was no significant correlation in grain size versus beach slope. Reis and Gama (2010) observed that the beach face slope varies with sand grain size raised to the power $4/3$ which was not found in the present study. More quantity of moderately well sorted sediment was observed in all types of beach slopes except gentle slope where more quantity of moderately sorted sediment was observed. Maximum poorly sorted sediment was found at steep beach. A non-uniform activity of skewness and kurtosis behaviours was observed from flat to steep slopes which showed very poor correlation between beach slope and skewness and also slope versus kurtosis characteristic. In this observation, there was no correlation found between textural characteristics and beach accretion/erosion. Cin (1976) observed that the sediment of eroded beach composed of coarse sand, negative skewed, leptokurtic nature. VijayaLakshmi et al. (2010) reported that the positive skewed sediments indicate unidirectional sediment transport and beach is in depositional state. It revealed that the correlation in morpho-sedimentary characteristics can be found at the beaches having significant change in erosion/accretion with wide range in the textural characteristics.

4. Conclusion

The cross-shore profiles and textural characteristics are essential tools to estimate equilibrium beach, to design/build coastal engineering structures, for planning the shoreline protection strategy and also required in coastal models used for predicting beach dynamics. The field observation on beach dynamics during February 2008 to February 2010 showed both erosion and accretion and the net result over an annual cycle was sediment accretion. The beach sedimentary environment was significantly characterized by fine to medium sand having unimodal to bimodal activities and moderately well sorted to moderately sorted nature. The short term beach erosion along the Devbag shoreline can be minimized by increasing the beach width through beach nourishment. The well

graded (poorly sorted) sediment helps to form a well settled environment by creating less porosity and hence reduces the beach erosion. As the beach was significantly characterized by fine to medium sand and moderately well sorted to moderately sorted sediment, the beach nourishment is to be done using the sediments having grain size more than the average of mean grain size (270 μm) obtained during two years observation along Devbag coast. Poor to moderate correlation in the beach morphology and textural characteristics was observed along with a non-uniform trend in the variation of morpho-sedimentary characteristics. The study emphasizes the need to observe the beach changes over an inter-annual variation along different seasons before planning the coastal protection measures.

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Figure caption

Figure 1: Study area covering three selected locations (BM1, BM2 and BM3) along Devbag beach, north of the Kali River mouth, Karwar, west coast of India.

Figure 2: Seasonally monitored beach profiles and percentage distribution curve of sediment samples at three selected locations (BM1, BM2 and BM3) along Devbag coast.

Figure 3: Pictorial description of beach slope and volume using monitored cross-shore profiles.

Figure 4: Monthly change in beach width, slope and volume at the three selected locations (BM1, BM2 and BM3) along Devbag coast.

Figure 5: Monthly variation of textural characteristics of beach sediment at three selected locations BM1, BM2 and BM3) along Devbag coast.

Figure 6: Annual net activity of textural characteristics of beach sediment collected along Devbag coast.

Figure 7: The correlation of beach morphodynamics and textural characteristics of surface sediment collected along Devbag coast.

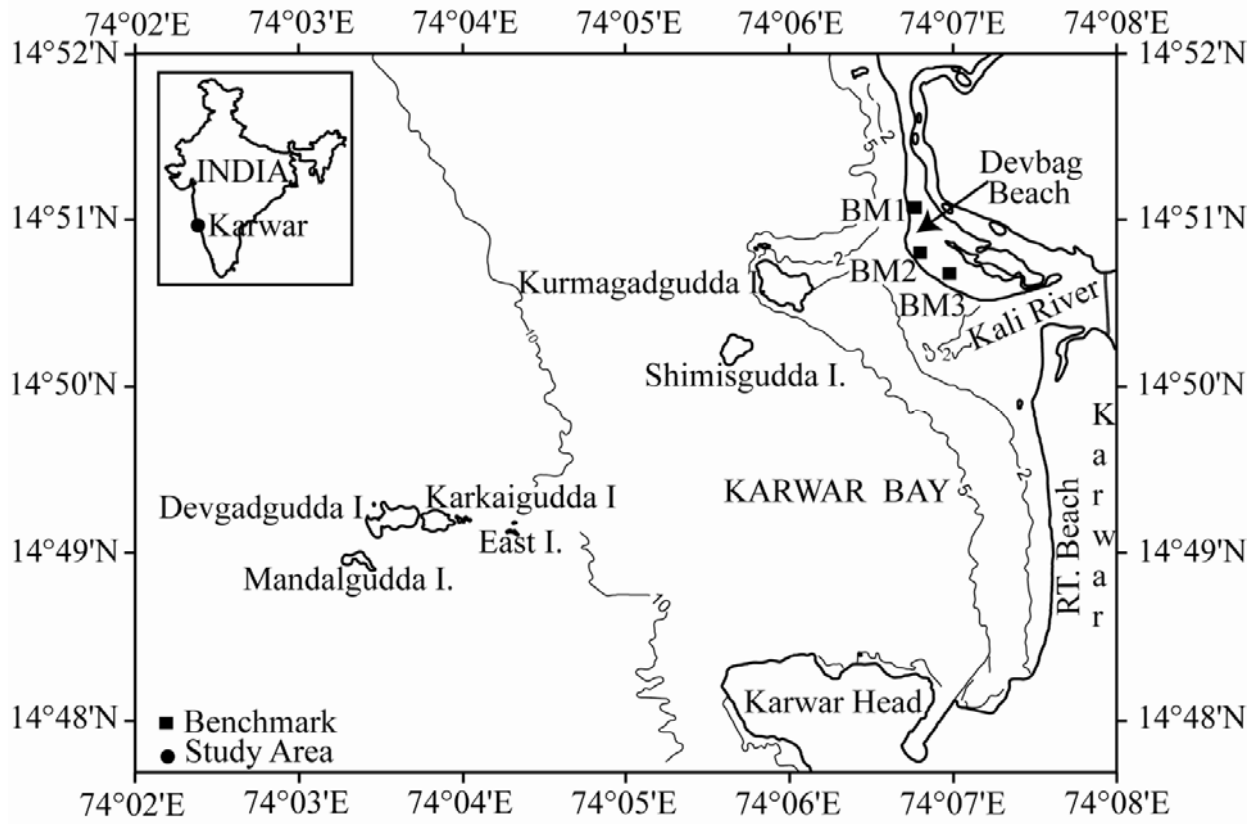


Figure 1: Study area covering three selected locations (BM1, BM2 and BM3) along Devbag beach, north of the Kali River mouth, Karwar, west coast of India.

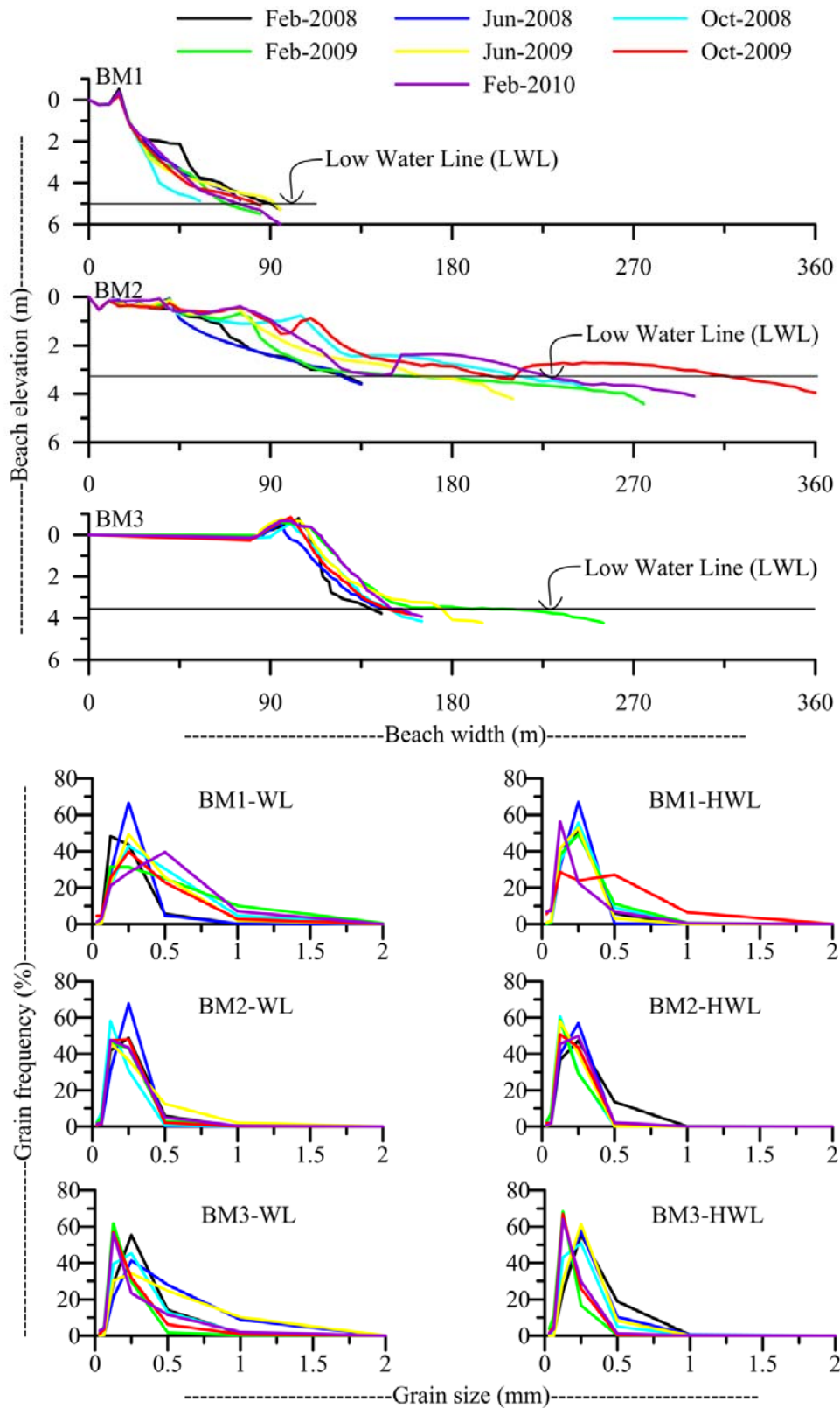
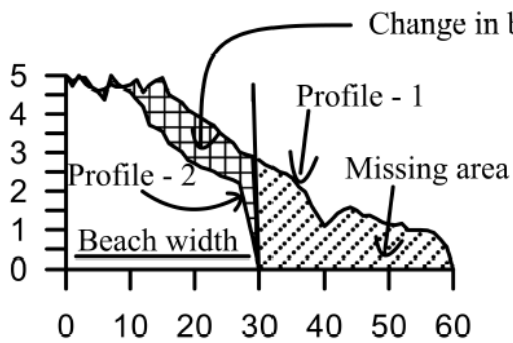
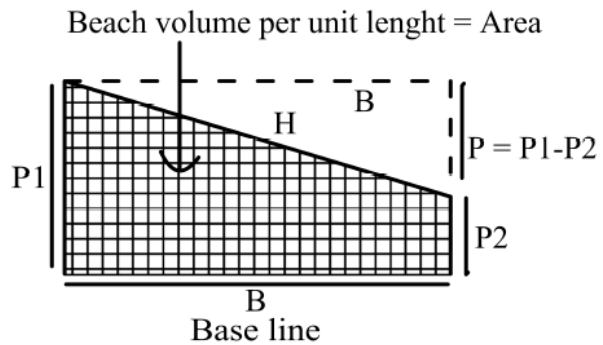
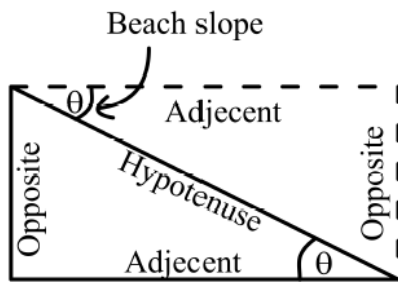


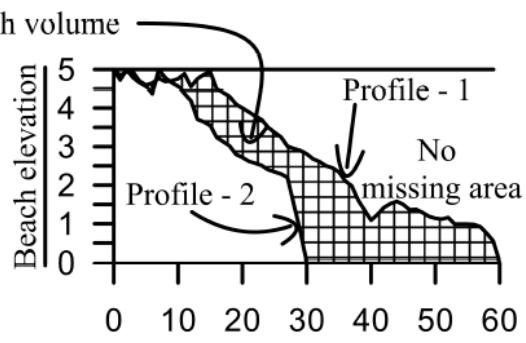
Figure 2: Seasonally monitored beach profiles and percentage distribution curve of sediment samples at three selected locations (BM1, BM2 and BM3) along Devbag coast.

$$\sin(\theta) = \text{Opposite} / \text{Hypotenuse}$$

$$\text{Trapizoid area, } A = ((P1+P2)/2)*B$$



Change in beach volume in maximum common beach width of two profiles



Change in beach volume in maximum common beach elevation of two profiles

Figure 3: Pictorial description of beach slope and volume using monitored cross-shore profiles.

█ Increase in beach width, Decrease in beach slope, Increase in beach volume
█ Decrease in beach width, Increase in beach slope, Decrease in beach volume

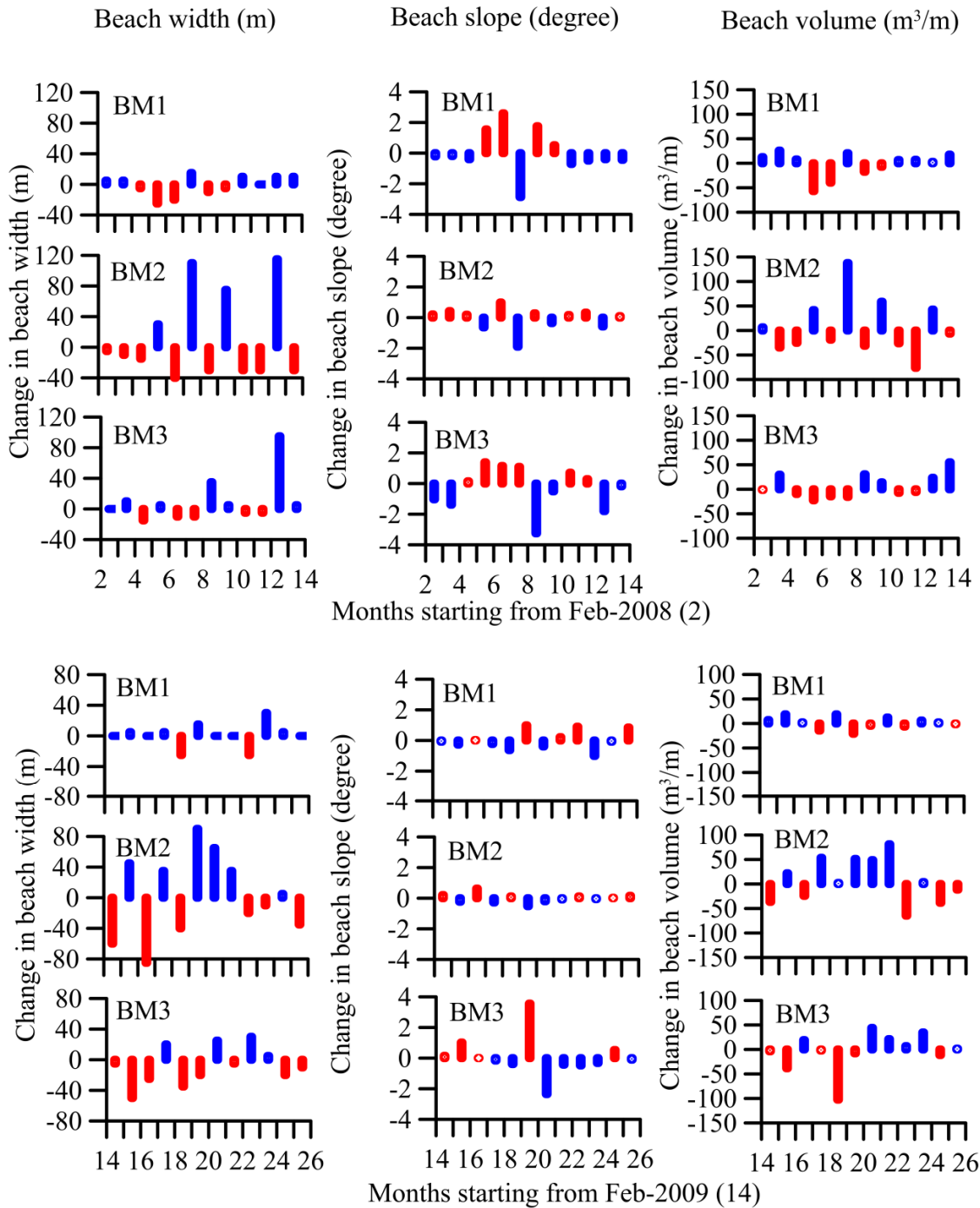


Figure 4: Monthly change in beach width, slope and volume at the three selected locations (BM1, BM2 and BM3) along Devbag coast.

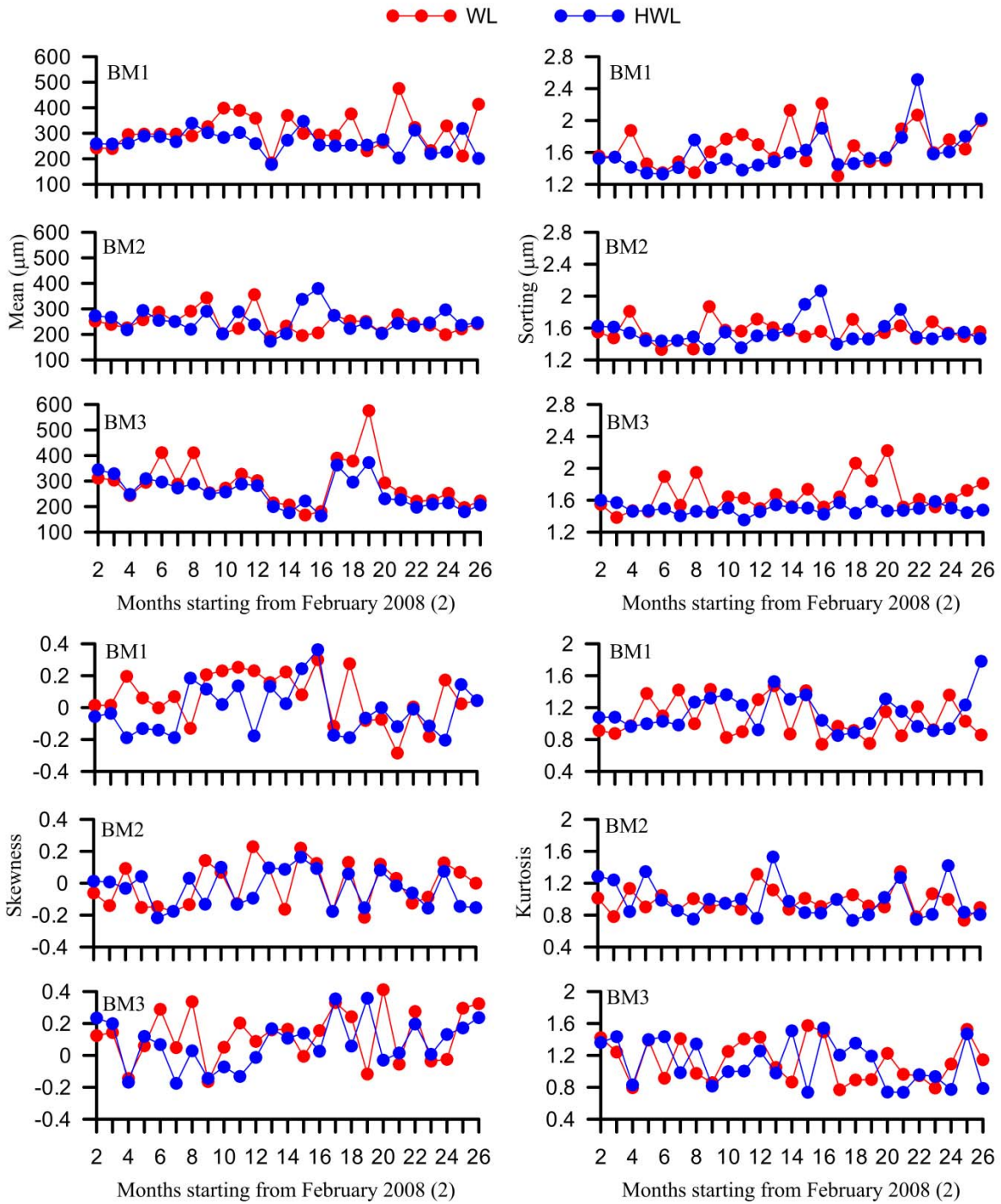


Figure 5: Monthly variation of textural characteristics of beach sediment at three selected locations (BM1, BM2 and BM3) along Devbag coast

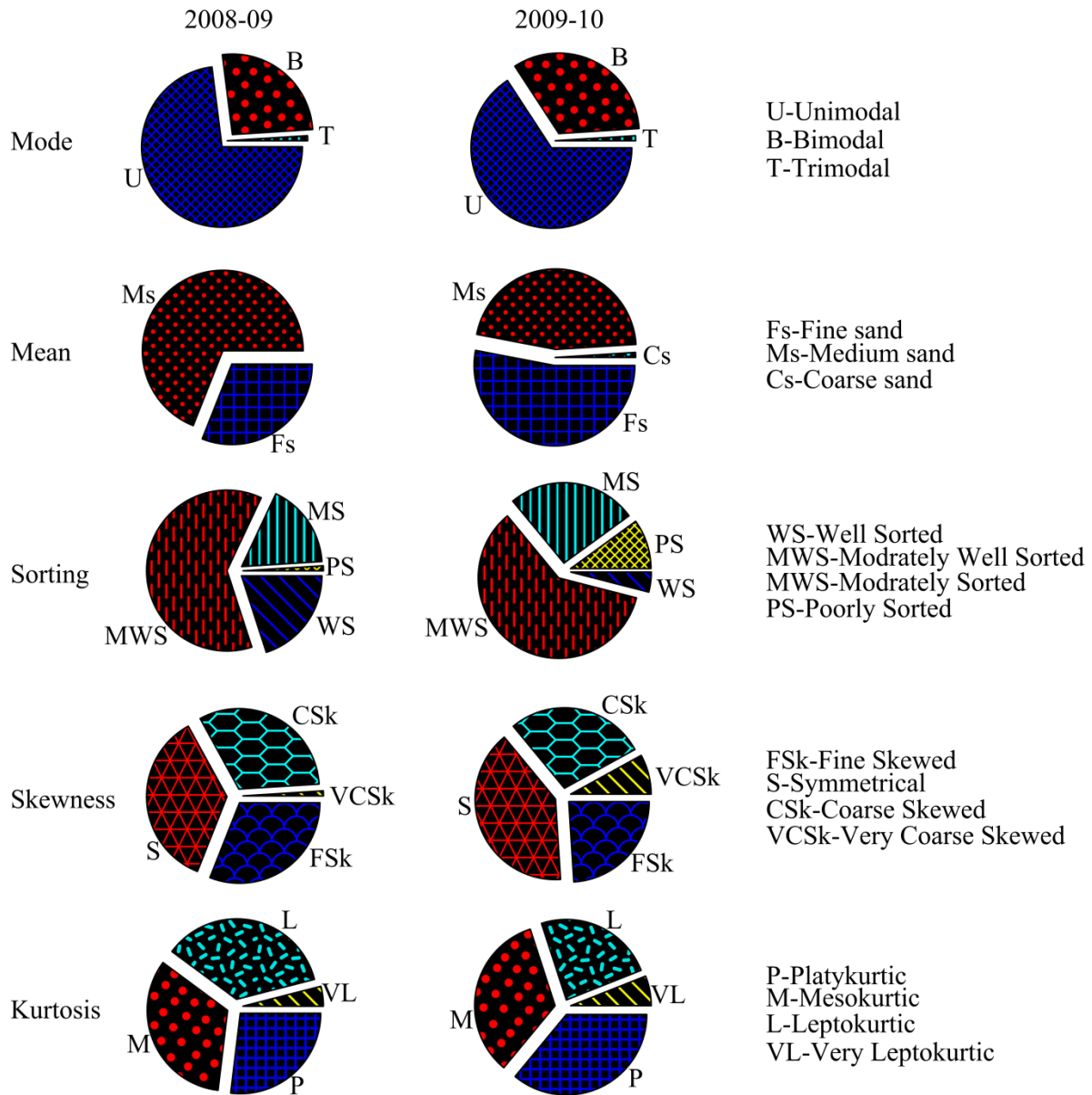


Figure 6: Annual net activity of textural characteristics of beach sediment collected along Devbag coast.

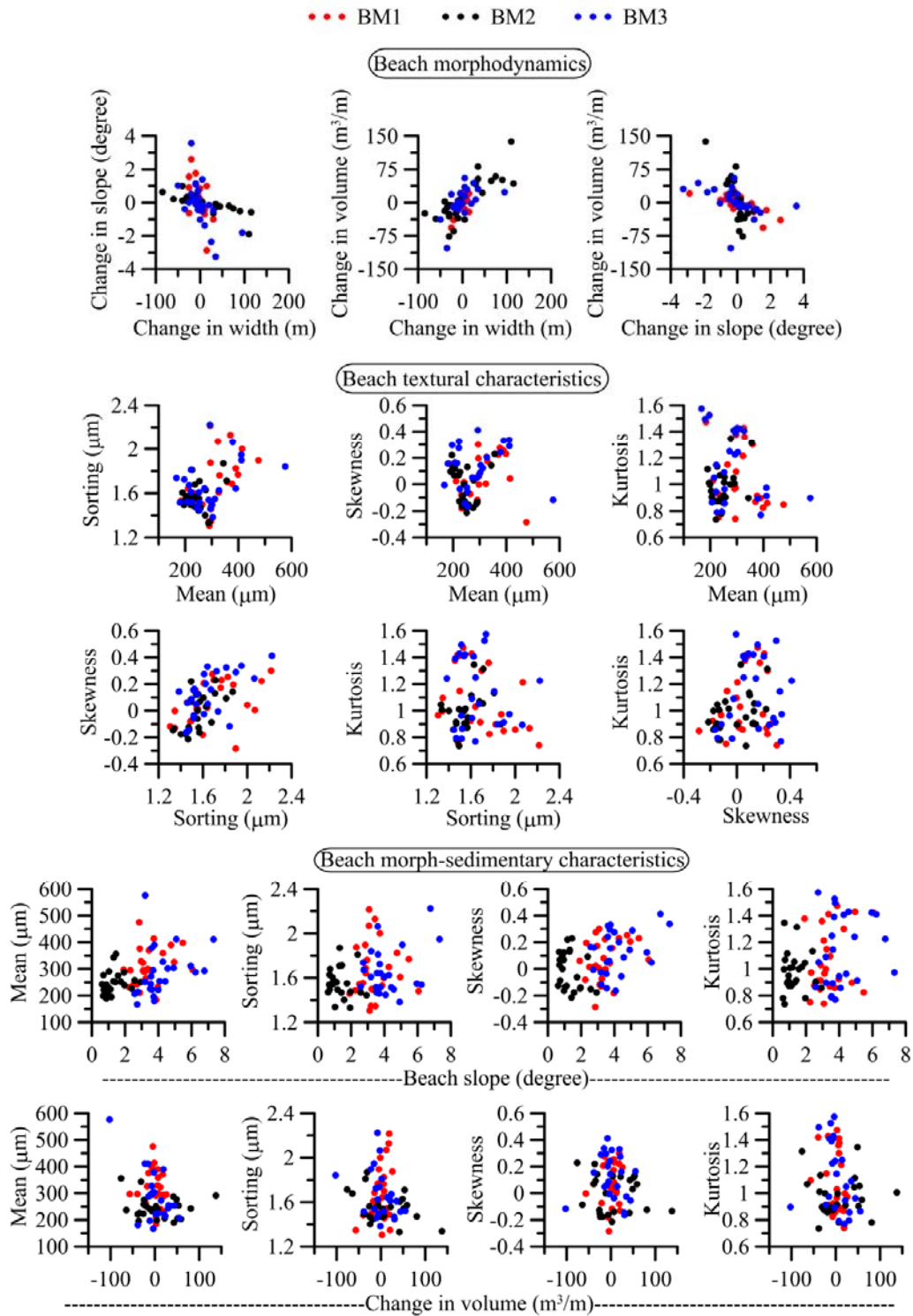


Figure 7: The correlation of beach morphodynamics and textural characteristics of surface sediment collected along Devbag coast.

Table 1: Monthly variations of beach width and slope at three selected locations along Devbag beach

Month and year	BM1		BM2		BM3	
	14° 51' 15.12''N 74° 06' 42.27''E		14° 50' 52.98''N 74° 06' 44.64''E		14° 50' 43.16''N 74° 06' 56.24''E	
	Beach width (m)	Beach slope (degree)	Beach width (m)	Beach slope (degree)	Beach width (m)	Beach slope (degree)
Feb-08	70	2.71	100	1.75	55	5.95
Mar-08	75	2.50	95	1.96	55	4.92
Apr-08	80	2.31	85	2.39	65	3.54
May-08	75	1.91	70	2.58	50	3.69
Jun-08	50	3.46	100	1.94	55	5.08
Jul-08	30	6.06	60	2.93	45	6.23
Aug-08	45	3.19	170	1.03	35	7.32
Sep-08	35	4.95	140	1.31	70	4.07
Oct-08	30	5.47	215	0.95	75	3.56
Nov-08	40	4.76	185	1.12	70	4.27
Dec-08	40	4.27	155	1.45	65	4.56
Jan-09	50	3.87	270	0.87	160	2.76
Feb-09	60	3.43	240	0.97	165	2.58
Mar-09	60	3.35	180	1.18	160	2.73
Apr-09	65	3.08	225	0.95	110	3.75
May-09	65	3.11	140	1.58	85	3.76
Jun-09	70	2.88	175	1.30	105	3.60
Jul-09	45	2.25	135	1.42	70	3.21
Aug-09	60	3.24	225	0.90	50	6.77
Sep-09	60	2.85	290	0.70	75	4.42
Oct-09	60	3.07	325	0.62	70	3.99
Nov-09	35	3.97	305	0.74	100	3.51
Dec-09	65	2.96	295	0.68	105	3.19
Jan-10	70	2.88	300	0.71	85	3.72
Feb-10	70	3.73	265	0.87	75	3.62

Table 2: Variation in beach elevation and volume at three selected locations along Devbag beach.

Time Duration	BM1		BM2		BM3		
	Beach Elevation (m)	Change in volume (m ³ /m)	Beach Elevation (m)	Change in volume (m ³ /m)	Beach Elevation (m)	Change in volume (m ³ /m)	
Feb-2008 to Feb-2009	Monthly						
	Feb-Mar	3.26	+12.60	3.15	+6.52	3.87	-1.31
	Mar-Apr	3.22	+25.89	3.30	-34.78	3.26	+29.75
	Apr-May	2.49	+7.84	3.31	-25.09	3.13	-9.64
	May-Jun	2.50	-56.79	3.38	+41.74	3.09	-22.51
	Jun-Jul	3.02	-39.64	3.07	-18.81	3.73	-14.39
	Jul-Aug	2.50	+20.55	3.06	+137.80	3.61	-15.59
	Aug-Sep	2.50	-17.41	3.10	-31.17	3.61	+30.60
	Sep-Oct	2.93	-7.31	3.20	+58.78	3.85	+14.25
	Oct-Nov	3.05	+6.70	3.17	-26.03	4.30	-7.27
	Nov-Dec	3.12	+7.19	3.61	-76.15	4.28	-5.51
	Dec-Jan	2.97	+2.84	3.93	+42.78	4.33	+23.47
	Jan-Feb	3.54	+17.64	3.94	-6.40	4.65	+55.15
	Seasonally						
Pre-monsoon	3.02	-23.92	3.33	-10.56	3.73	-4.13	
Summer monsoon	3.02	-41.11	3.27	+158.76	3.73	+20.78	
Post-monsoon	2.95	+30.60	3.17	-104.68	4.50	+82.68	
Annually							
2008-09	3.37	-44.16	3.19	+47.96	4.11	+68.88	
Feb-2009 to Feb-2010	Monthly						
	Feb-Mar	3.50	+7.06	3.79	-36.50	4.28	-3.73
	Mar-Apr	3.49	+18.73	3.73	+21.98	4.37	-38.36
	Apr-May	3.52	+2.47	3.86	-24.22	4.48	+19.19
	May-Jun	3.52	-14.48	3.88	+53.51	4.48	-2.25
	Jun-Jul	3.33	+18.74	3.42	+2.28	4.78	-102.39
	Jul-Aug	3.23	-20.96	3.35	+51.21	4.71	-7.81
	Aug-Sep	3.19	-4.63	3.54	+48.81	4.71	+44.06
	Sep-Oct	3.21	+12.28	3.54	+81.14	4.17	+21.09
	Oct-Nov	2.43	-6.28	3.49	-64.60	4.17	+6.86
	Nov-Dec	2.42	+6.15	3.51	+4.07	4.43	+34.78
	Dec-Jan	3.35	+2.41	3.62	-38.34	4.44	-11.38
	Jan-Feb	3.78	-1.49	4.03	-11.53	4.49	+1.75
	Seasonally						
Pre-monsoon	3.41	+12.94	3.98	+9.13	4.78	-46.05	
Summer monsoon	3.31	-9.15	3.73	+201.09	4.37	-34.64	
Post-monsoon	3.43	+2.30	3.88	-105.82	4.23	+32.37	
Annually							
2009-10	3.84	+6.40	4.03	+124.33	4.33	-30.12	

Table 3: Textural characteristics of beach sediments (%) at three selected locations along Devbag beach.

	Characteristics and behaviors	Range	First annual cycle (2008-09)						Second annual cycle (2009-10)					
			BM1		BM2		BM3		BM1		BM2		BM3	
			WL	HWL	WL	HWL	WL	HWL	WL	HWL	WL	HWL	WL	HWL
Mode	Unimodal	---	50	83	75	92	58	83	42	67	83	67	58	83
	Bimodal	---	50	17	25	8	34	17	58	33	17	33	34	17
	Trimodal	---	---	---	---	8	---	---	---	---	---	---	8	---
Mean (μm)	Fine Sand	125-250	17	8	50	58	25	25	25	33	67	67	50	75
	Medium Sand	250-500	83	92	50	42	75	75	75	67	33	33	42	25
	Coarse Sand	500-1000	---	---	---	---	---	---	---	---	---	---	8	---
Sorting (μm)	Well Sorted	1.27-1.41	17	50	17	8	8	17	8	---	8	8	---	---
	Moderately Well Sorted	1.41-1.62	42	50	58	92	50	83	33	50	67	67	42	100
	Moderately Sorted	1.62-2.00	33	---	25	---	42	---	42	33	25	17	42	---
	Poorly Sorted	2.00-4.00	8	---	---	---	---	---	17	17	---	8	16	---
Skewness	Fine Skewed	-0.1 to -0.3	8	42	58	25	17	33	25	42	25	42	8	---
	Symmetrical	-0.1 to +0.1	33	25	25	67	33	33	50	33	33	50	33	42
	Coarse Skewed	+0.1 to +0.3	59	33	17	8	42	34	25	17	42	8	34	42
	Very Coarse Skewed	+0.3 to +1.0	---	---	---	---	8	---	---	8	---	---	25	16
Kurtosis	Platykurtic	0.67-0.90	33	---	42	42	25	17	33	17	25	66	33	42
	Mesokurtic	0.90-1.11	25	50	33	33	25	33	33	42	67	17	25	17
	Leptokurtic	1.11-1.50	42	42	25	17	50	42	34	33	8	17	25	33
	Very Leptokurtic	1.50-3.00	---	8	---	8	---	8	---	8	---	---	17	8

Table 4: Textural classification (%) of beach sediment collected at Devbag during 2008-10.

Characteristics and behaviors	Mode			Mean		Sorting					Skewness			Kurtosis				
	Unimodal (U)	Bimodal (B)	Trimodal (T)	Fine Sand (Fs)	Medium Sand (Ms)	Coarse Sand (Cs)	Well Sorted (WS)	Moderately Well Sorted (MWS)	Moderately Sorted (MS)	Poorly Sorted (PS)	Fine Skewed (FSk)	Symmetrical (S)	Coarse Skewed (CSk)	Very Coarse Skewed (VCSk)	Platykurtic (P)	Mesokurtic (M)	Leptokurtic (L)	Very Leptokurtic (VL)
Mode	U	---	---	57	43	0	17	76	6	1	36	42	22	0	33	41	19	7
	B	---	---	8	90	2	0	28	58	14	5	32	52	11	29	14	57	0
	T	---	---	0	100	0	0	0	50	50	0	0	0	100	0	50	50	0
Mean	Fs	95	5	0	---	---	17	76	6	1	36	42	22	0	33	41	19	7
	Ms	49	48	3	---	---	0	28	58	14	5	32	52	11	29	14	57	0
	Cs	0	100	0	---	---	0	0	50	50	0	0	0	100	0	50	50	0
Sorting	WS	100	0	0	0	100	0	---	---	---	85	4	11	0	0	89	11	0
	MWS	87	13	0	57	43	0	---	---	---	27	46	24	3	38	27	30	5
	MS	17	79	4	27	70	3	---	---	---	8	25	55	12	24	30	40	6
	PS	7	86	7	7	93	0	---	---	---	0	29	64	7	71	7	15	7
Skewness	FSk	94	6	0	38	59	3	32	59	9	0	---	---	---	47	50	3	0
	S	76	24	0	47	53	0	2	76	15	7	---	---	---	27	24	42	7
	CSk	52	48	0	45	55	0	7	49	37	7	---	---	---	26	31	36	7
	VCSk	0	42	58	9	91	0	0	17	76	9	---	---	---	9	58	33	0
Kurtosis	P	74	26	0	59	39	2	0	73	18	9	39	36	23	2	---	---	---
	M	85	13	2	38	62	0	29	50	19	2	42	27	27	4	---	---	---
	L	44	53	3	20	80	0	6	60	28	6	3	51	35	11	---	---	---
	VL	100	0	0	100	0	0	0	62	25	13	0	54	46	0	---	---	---