



Estimation of seasonal morpho-sedimentary changes at headland bound and exposed beaches along south Maharashtra, west coast of India

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Abstract

Knowledge on seasonal variation of morpho-sedimentary processes of tropical beaches is essential to evaluate inter annual variations to devising best protection strategy for the coastal zone. A study was taken up to understand the seasonal changes of physical processes at the headland bound and compared with exposed beaches. The spatio-temporal morpho-sedimentary dynamics were carried out through beach profiles, sediment samples, and simulated wave climates across two complete annual cycle. The beach profile survey was carried out using RTK-GPS, wherein the GRADISTAT was used for analysing sediment samples. The seasonal wave climates were studied with the SWAN model coupled with WAVEWATCH III. Observation shows, the sediment environment at headland bound beach is strongly dominated by fine sand throughout the year, whereas the exposed beach is illustrated from fine to medium sand across seasonal scale. The seasonal change in beach morphology occurs considerably in the exposed beach than that compared to headland bound. Successively, the occurrence of shoreline retreat is shown maximum up to 20 m in at the exposed beach during the monsoon. Both the locations showed strong seasonal variation in the wave energy as well as direction, whereas the nearshore wave energy at exposed beach is comparatively high with an average of 8342 J/m^2 than the headland bound due to less deviation in the wave propagation. The analysis of seasonal wave pattern together with beach morpho-sedimentary processes exhibit the influence of wave conditions at the exposed beach when compared with headland bound beach and so the study implies for offset morphological changes and tailored management to protect the beaches from natural coastal hazards.

Keywords GIS 3D spatial analyst · Beach morphology · Coastal processes · Sediment analysis · Wave modeling

Introduction

Sandy beaches are valuable to coastal community since they support a variety of social, cultural and economic activities and provide protection from coastal hazards. But the natural processes impose stress on sandy beaches; have led to widespread morphological changes and degradation of these beaches with consequences for social realms. Beach sand volume, shoreline change, sediment size, wave induced sediment transport rate etc are very vital parameters to know the status of beach health and to decide a beach conservation measures. Digital elevation models and geomorphometric

analyses are useful geospatial tools to quantify the volume of material in various stages of beach evolution. Geospatial analysis allows to use a suitable data store, integration, analysis and interpretation of beach morphological changes at varying time and space scale (Allen et al. 2012). The change in volume of the beach is found to be highly correlated with shoreline changes. Shoreline monitoring provides a useful estimate of total sand storage (Dail et al. 2000). Higher density of beach profiles higher the accuracy of volume estimation that brings out an adequate result of surface morpho-dynamic assessment. Beach profile measurement is an important tool for elucidating morphological trends, such as erosion and accretion, and for predicting the evolution of coastal landforms (Udhaba Dora et al. 2012; Silveira et al. 2013; Dora et al. 2014). The real-time kinematic global positioning system (RTK-GPS) have been used in field surveys to measure and estimate the shoreline as well as the beach volume changes. GIS provides a platform to store and

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visualize the coastal morpho-dynamic changes in two and three dimensions (Chandrasekar and Sheik Mujabar 2010). Many of the coastal management studies have employed GIS for mapping of morphological changes and erosion patterns. The digital shoreline analysis system (DSAS) has been recognized as one of the most dominant tool for quantifying the shoreline changes on temporal scales as it provides the information in digital form (Thieler et al. 2009). To avoid the bias in the seasonal shoreline, a mean shoreline position could be derived from the different temporal shorelines to assess the beach shoreline change (Almonacid-Caballer et al. 2016). The beach sedimentary environments are classified based on the grain size analysis (Blatt et al. 1972) and that gives important hints on the sediment provenance, transport trends and depositional conditions (Folk and Ward 1957). Mean size, sorting and skewness are important parameters to describe the sedimentary environments and also distinguish the different wave energy conditions (Nordstrom 1977). The coastal morphology is mainly controlled by waves, current and tides in addition to the sediment characteristics and these parameters have an empirical relationship with each other (Bernabeu et al. 2003). The wind and wave climate is responsible for coastal morpho-sedimentary processes. So the simulation of spatio-temporal wave model is highly supportive apart from field observations since in situ measurements that use multiple instruments are expensive, and time consuming. This information reveals that the numerical models are essential for understanding wave energy in space and time, and its impact on morpho-sedimentary processes (Dora and Kumar 2017). The sea surface waves of a region control the near shore morpho-sedimentary processes (Joevivek and Chandrasekar 2014; Suanez and Bruzzi 1999). Thus, the Beach morphological changes and sediment characteristics are proportionate to the variability of the wave energy. Thereby, a study was considered to distinguish the proportionate among the sedimentary environment, beach morphology and nearshore waves at different wave energy environment which lies in wave dominated coast. The response of beach morpho-dynamics by influence of waves on the seasonal scale, entail more appropriate protection measures to conserve alongshore. This study suggests that the need for beach management along Ganapathypule and effective rehabilitation of the beach.

Study area

The study sites are Bhatye and Ganapathypule located in the coast of Ratnagiri district, part of South Maharashtra, west coast of India (Fig. 1). This area is hilly, narrow and much dissected with transverse ridges of Western Ghats and at many places extending promontories into the Arabian Sea. The study sites are composed of gneisses and in a few gneissic interruptions and the rocks are invariably capped by

laterite and in subordinate amount of bauxite. The tertiary sediments are sandwiched between the laterite (Suryawanshi and Golekar 2014). The Ganapathypule is exposed type of beach far flung from the rocky headlands. This beach is gentle to average slope and showed dissipative to intermediate nature. Bhatye beach bounded between the two headlands in north and south. The Kajali river in Bhatye is regulated the topography and the river supplies high quantity of sediment to the beach and influences on the sediment transport along the beach. The beaches along the south Maharashtra coast are interrupted by headlands and rocky outcrops due to which the shoreline is irregular and associated with features like cliffs, notches, promontories, sea caves, embayment, submerged shoals and offshore islands. Along the Maharashtra coast, there are several prominent creeks/estuaries including Bhatye creek, Pawas creek, Vijaydurg creek make this coast highly dynamic (Chandramohan et al. 1993). The river run off plays vital role in enormous sediment transport during SW monsoon and minimum during other seasons which caters to the beach morphological change during those seasons (Samiksha et al. 2014). The beaches of the study area are a place of anthropogenic activities as there is a temple in Ganapathypule with unplanned construction, and Bhatye is a beach used for recreation as it is near by the city Ratnagiri. Therefore, an integrated approach to beach management, with emphasis on minimizing the impacts on natural process while maximizing the sustainability of sandy beaches, is essential.

Materials and methods

Geospatial survey and analysis

The beach morphology study was based on the change in beach volume (CBV), change in beach area (CBA), change in beach width (CBW), change in beach slope (CBS) and beach shoreline change (BSC), which were estimated from the cross-shore profiles monitored every seasons of the year (2014–2015) using RTKGPS (Trimble GPS GNSS R8 Model 3). Field surveys were carried out during three seasons namely post-monsoon (February 2014–2015), pre-monsoon (May 2014–2015) and monsoon (September 2014–2015) for annual cycle along the Bhatye and Ganapathypule beaches. During field surveys X, Y and Z were obtained by using RTK-GPS for points distributed relative to the beach morphology (Andrews et al. 2002) carried out with temporary bench mark (TBM).

The survey has been followed for two annual cycles along the beaches with the same TBM to assess the dynamics of beach morphology. The vertical and horizontal accuracies of RTK-GPS is generally less than ± 5 cm. The beach transects were collected at a regular interval of 2 m across the beach

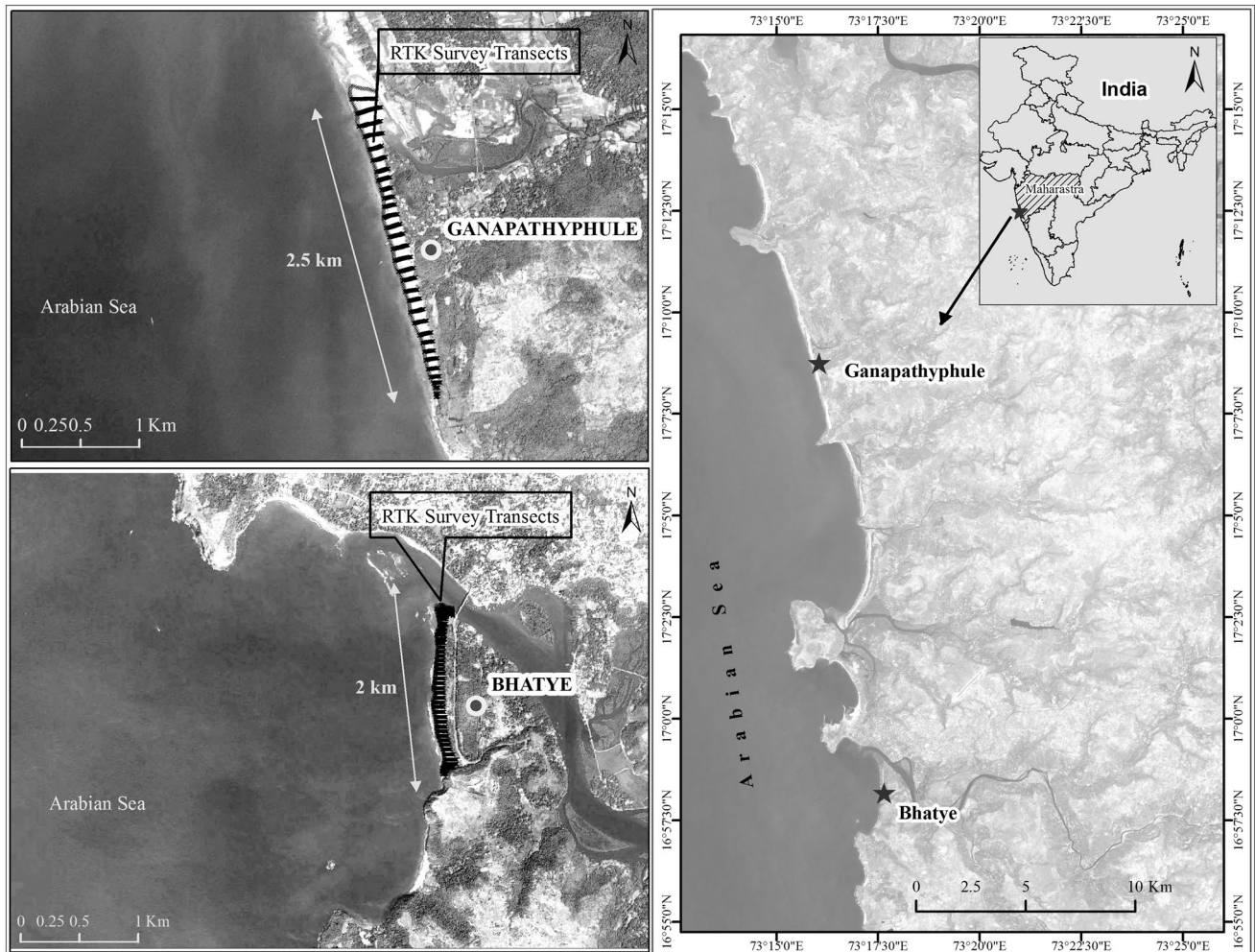


Fig. 1 Geographic location of the study sites along south Maharashtra, west coast India

with high-resolution post-spacing from beach toe to the vegetation line and across the beaches. There were profiles collected at every 20 m distance along the beach to investigate overall beach behaviour, an average beach profile was also calculated using data from alongshore and are presented in (Fig. 1). There were about 75–80 profiles collected for each season. The profile data sets were used to calculate the change in beach volume (CBW) from the reference datum. Digital elevation model (DEM) in GIS aids the morphological change analysis of any topography. DEMs are created using the uniform squared grid cells and interpolated for the continuous surface from the points using inverse distance weighting (IDW) interpolation method.

The assessment of recent change in elevation and sand volumes for the beaches was based on computation of before and after raster surface differences between the interpolated surfaces using geo-statistical analyst. IDW interpolation a better fit between measured data and interpolated data. To investigate beach behaviour, the individual profiles were

examined, and the average beach surfaces of the seasons were used to analyse the entire beach morphology change. The DEM was clipped into a common boundary to find the average DEM of the season, using the raster calculator. The elevation values of the average DEMs were converted to Δz values from which the volumetric measurement of the beach was calculated using the function $\text{DEM Image} \times (\sqrt{\text{pixel size}})$ given in GIS Raster Calculator.

The 'cut and fill' analysis directly compares the volume of two surface models and is able to display areas and volumes of surface material that have been modified by the removal or addition over time. In each DTM, of the beach anomalous negative values were reduced to zero in the subtractions matrix to compensate for error commonly introduced during the interpolation method. The first step of the process was to build accurate beach profile terrain topography for all the beaches. This is typically the case of topography data used for beach profile and volume calculation. In addition, triangular irregular network, (DTM) three-dimensional surfaces

were created to represent the surface using contiguous, non-overlapping triangular faces, with a height value of each triangular node. The TIN surface was utilized to create average slope across the beaches.

This analysis is used to compute the volume change of the beaches.

Beach slope estimation

The change in beach slope (CBS) was calculated from the directional East–West and North–South gradients. Considering the size of the area, a 3×3 set of elevation points were chosen to estimate the directional gradients for maximum slope. The resultant slope images of different seasons overlaid with the foreshore points extracted from transects. (Foreshore points were generated from the transects that were used for shoreline change analysis in DSAS). The foreshore slope values were extracted (spatial analyst tool) at two points. The difference between the seasonal slope values were used for correlation assessment with shoreline change.

Change in beach area (CBA) from the surface was calculated based on method discussed by Jenness (2004) in the Arc GIS extension tool, where the surface areas of a cell in a 3D image were computed from the elevation values from that cell and adjacent eight cells. The center points of the cells surrounded by eight other cells are used to calculate the Euclidian distance between center and adjacent cells. The lengths between the cells are calculated using the Pythagorean theorem. The triangles are located in three-dimensional space, so that the area of the triangle represents the true surface area of the space. Summing the eight triangles brings out the true area of the surface which is more than the planimetric area.

Seasonal shoreline change

The beach shoreline change (BSC) would be easily and quickly determined for any coastal area using the digital shoreline analysis system. The high water lines (HWL) marked as waterlines were tracked as shorelines in the field for all seasons using RTK-GPS as part of the study. The accuracy of these data can be considered less than ± 5 cm. Continuous shoreline positions were acquired close to the

high tide time of the seasons collected for the 2014–2015 (two annual cycle) (Table 1). One seasonal mean shoreline (SMS) was obtained from the field collected shoreline positions for three different seasons for further analysis. The mean coordinates (x, y) were generated from the transects and connected with line which then used as a seasonal mean shoreline position of the year. The shorelines that were generated from this analysis were considered as SMS position. The mean standard deviation between field tracked shorelines of each seasons were 2.1–2.8 m (Table 1). The SMS were then used to calculate the change in shoreline positions at different seasons.

Digital shoreline analysis system (DSAS) an extension of Arc GIS software tools was used to calculate the multiple shoreline change. The transects were generated for every 10 m distance covering the study area at a user specified length and perpendicular to the base line. Since the main objective of this work is to characterize the evolution beaches (which are reflected by the seasonal and cyclical changes with an alternating pattern of erosion and accretion) the NSM (net shoreline movement) method was selected for this purpose. The net shoreline movement analysis provides a distance between the oldest and youngest shoreline at each transect.

Beach sediment analysis

The beach sediment samples were collected for two consequent seasons post-monsoon and monsoon of 2015 along with fore shore (FS), berm line (BL) and back shore (BS). The sample locations had varying distance between the FS and BS with respect to space depending upon the tidal variation at the time of collection. A sieve shaker consisting of 7 sieves with mesh sizes 75, 125, 180, 250, 355, 500, and 1000 μm was used to determine the grain sizes. The statistical parameters such as mean, standard deviation, skewness and kurtosis were inferred by the method of Folk and Ward (1957) adopting the updated version of the GRADISTAT grain size distribution and statistical package. The Mode reflects the frequent occurrence of the grain sizes in the sample. Mean is the average value of the total distributed grains and median presents the grain size of exactly 50% of a cumulative percentage of total distributed sediment. Sorting

Table 1 Standard deviation of the shoreline changes estimated along three different seasons during two annual cycles

Season	Field shoreline tracking Bhatye		Standard deviation (m) (2014–2015) shorelines	Field shoreline tracking Ganapathypule		Mean standard deviation (m) (2014–2015) shorelines
Post-monsoon	24-02-2014	17-02-2015	2.3	23-02-2014	18-02-2015	2.1
Pre-monsoon	22-05-2014	28-05-2015	2.6	20-05-2014	29-05-2015	2.5
Monsoon	24-09-2014	12-10-2015	2.8	25-09-2014	14-10-2015	2.6

is the low or high variance of distributed grain size of the sample. Skewness shows the asymmetry of kurtosis which reveals the peakedness/flatness of a frequency distribution curve. The sediments were categorized as per the modified form of Wentworth (1922) scale. The sorting, skewness and kurtosis characteristics were based on the geometric (modified) Folk and Ward (1957) graphical measures.

Wave climate modeling

The wave propagation and transformation was simulated in the SWAN model coupled with WAVEWATCH III from January to December, 2014. The SWAN model has been implemented in a third generation and non-stationary mode with spherical coordinates with providing two dimensional spectral boundary extracted from WAVEWATCH III. The SWAN model executed along with an active physical processes of bottom friction, white capping, triad–wave–wave interaction (for shallow water). The wave simulation in the SWAN model was based on a two–dimensional and third generation model. To get a realistic bathymetry of finer grid resolution, the waves were simulated at $11 \times 11 \text{ m}^2$ over a rectangular domain with spherical coordinates, while the domain was placed perfectly over the x - and y -axes without any tilt ($\text{alpc} = 0$). The grid resolution in θ -space (mdc) was 24, and the resolution of the frequency-space (msc) was 24, which represents that the number of the frequency was 25. The lowest discrete frequency (low) and the highest discrete frequency (high) considered in this study was 0.04118 and 0.40561 Hz, respectively. Chart No. 213(2006) of the Naval (currently, the National) Hydrographic Office was used for reference bathymetry. The JONSWAP spectrum (Haselmann et al. 1973) was used to define the wave spectra at the boundary of the computational grid. Based on the spectral observation over the coastal region by Kumar and Kumar (2008), the peak enhancement factor (γ) was considered 1.6 in the SWAN run.

The correlation between the slope and grain size have been enunciated to show synchronization and difference during all seasons. The wave energy was calculated for the particular month of the every season when the sediment samples were collected. The beach sediment samples were collected to assess the grain size. The foreshore slope has been extracted from the TIN images using the Arc GIS spatial analyst.

Results and discussion

Beach morpho-dynamics analysis

The analysis RTK-GPS data clearly depicts the morphological changes during the annual cycles in the form of DEM.

The seasonal DEMs are shown in (Fig. 2) considered to be the actual morphology of the seasons.

The beach width is proportionate to the beach volume, and also to accretion, erosion pattern of the coast. The average beach width increased during the pre-monsoon, and decreased during the monsoon and post-monsoon (Fig. 3).

It is noticed from the volume analysis that beach built up during the pre-monsoon season and loss of sand during monsoon. The computed volume of headland bound beach was 160,586, 196,376 and 134,330 m^3 during post-monsoon, pre-monsoon and monsoon respectively. However, the exposed beach has about 1.5 times higher sand headland bound beach i.e., 240,595, 285,802 and 228,938 m^3 during post-monsoon, pre-monsoon and monsoon respectively.

GIS-based cut and fill which is grid comparison analysis was utilized to analyze the gain and loss of the beach volume from the DTM files. The DTM grids are compared the surfaces directly gives the results of modified surfaces as the volume gain and loss. The results show a trend of increased volume gain in the post-monsoon to pre-monsoon seasons and it is decreasing towards monsoon (Fig. 4). Similarly, at Bhatye beach which has the wide beach width has the annual seasonal maximum gain of 122,352 m^3 during post- to pre-monsoon and the maximum volume loss are $-72,551 \text{ m}^3$ during pre-monsoon to monsoon, resulting a net gain. However, the Ganapathypule beach has contrast nature to Bhatye beach. The volume change in Ganapathypule is found to be net loss. The maximum annual gain in Ganapathypule figures out to be 78,361 m^3 during the post-monsoon and the maximum annual loss in the region is 113,735 m^3 during the monsoon.

Beach shoreline changes

Seasonal shoreline changes for both beaches were computed in the form the net shoreline movement (NSM) during each season. The results of the NSM showed the seasonal erosion and accretion pattern for both beaches. It may be is noted that along Maharashtra coast, due to the winds and wave conditions with the onset of southwest (SW) monsoon the littoral transport allows erosion at rapid rate and it continues till August during which the beaches have minimum sediment storage (Kunte and Wagle 2001). Bhatye beach shows the trend of increased accretion of 12 m between post-monsoon to pre-monsoon where the area under accretion is 3128 m^2 . During the pre-monsoon to monsoon, accretion was reduced and erosion was found to be -11.9 m (Fig. 5) and the area under erosion was -8296 m^2 .

Ganapathypule beach exhibits the shoreline accretion of 14 m between post-monsoon to pre-monsoon during which the accretion area is 5564 m^2 . The maximum shoreline retreat found in this region is 20 m during pre-monsoon to monsoon and the area under erosion is 8213 m^2 (Fig. 6).

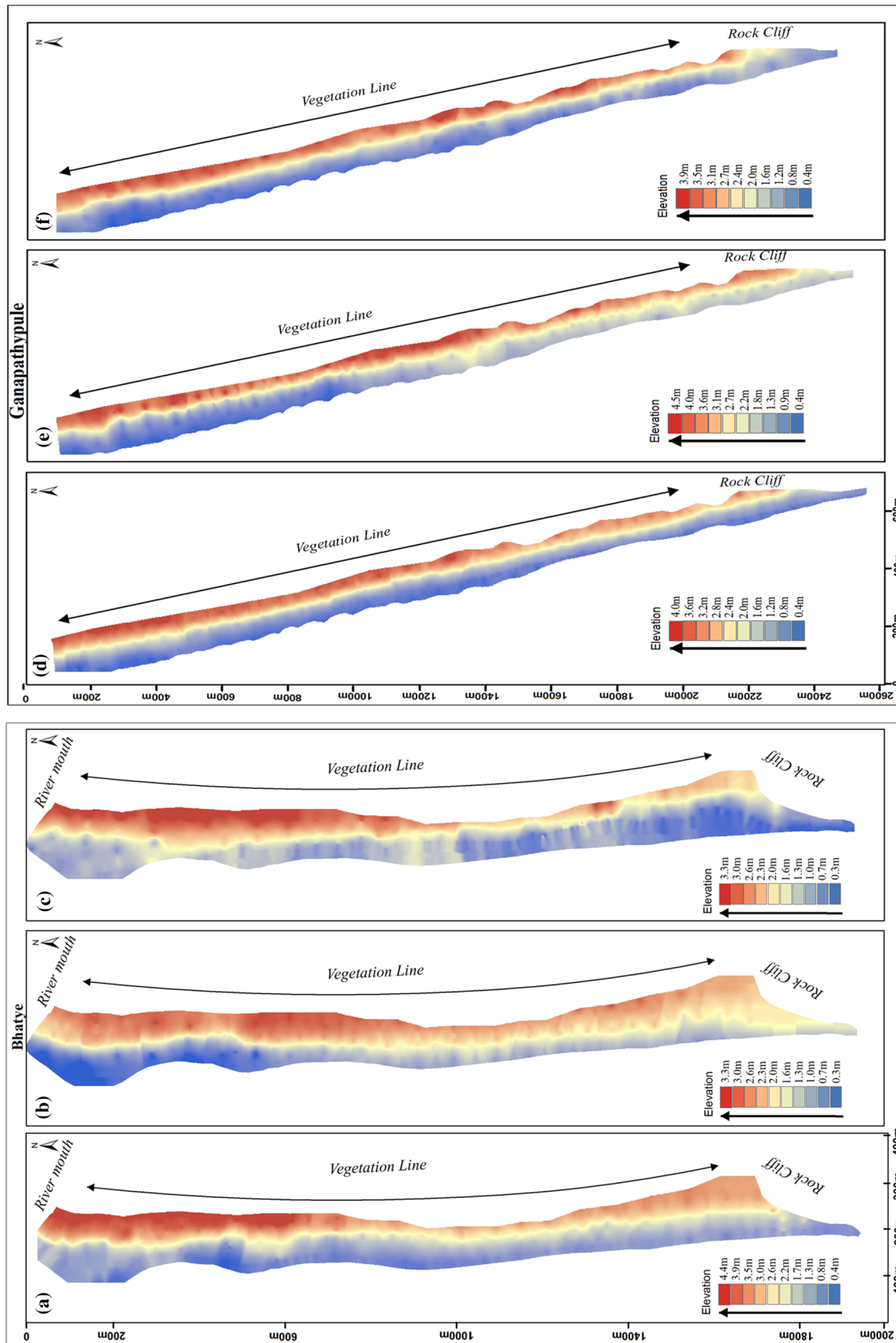


Fig. 2 Seasonal average digital elevation models (DEMs) for calculation of beach morphology. The **a** post-monsoon, **b** pre-monsoon and **c** monsoon are for the headland bound beach, whereas **d** post-monsoon, **e** pre-monsoon, **f** monsoon are for the exposed beach. Elevation is in meters above the estimated mean sea level

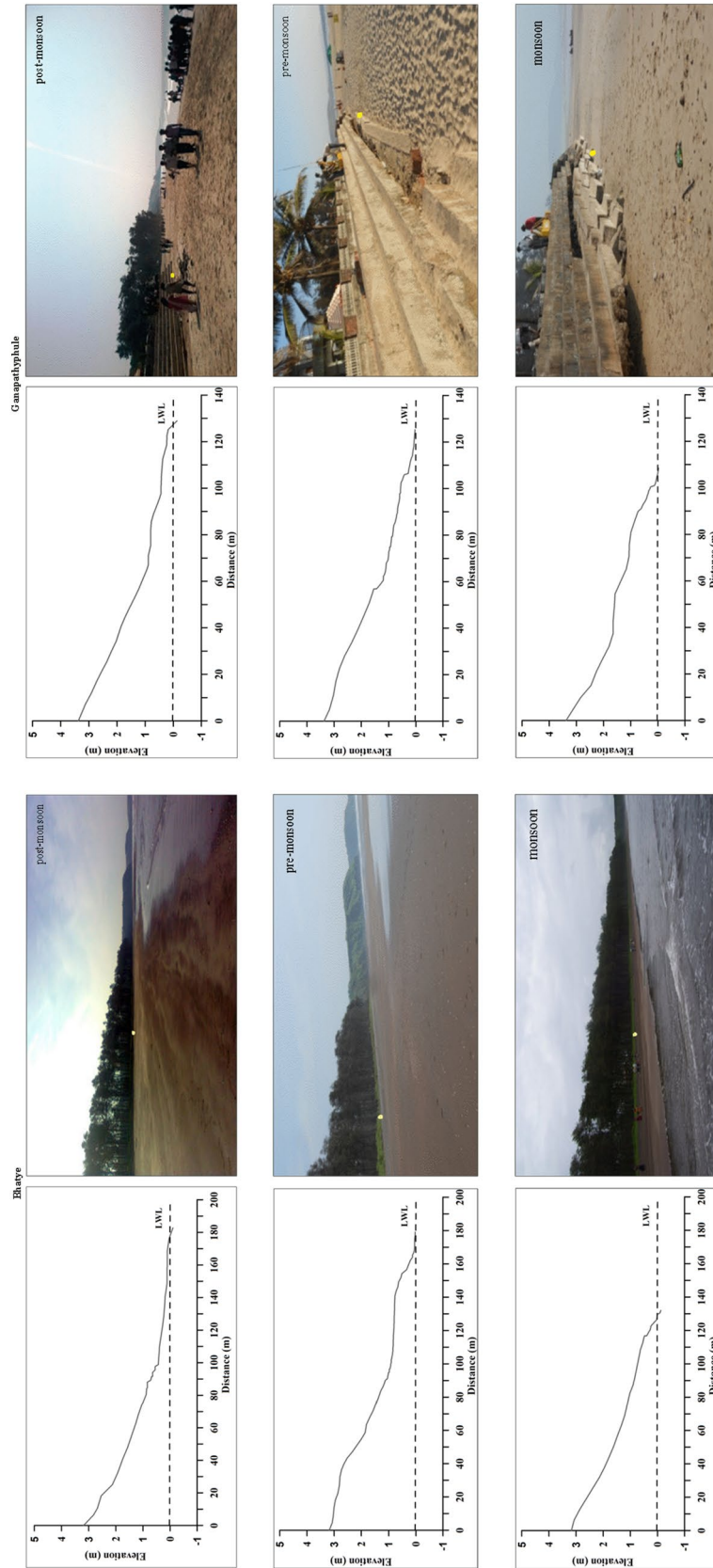


Fig. 3 Seasonal field observation of beaches and cross-shore beach profiles of selected benchmarks (yellow spots) collected during the three seasons at Bhatye and Ganpathypule beaches

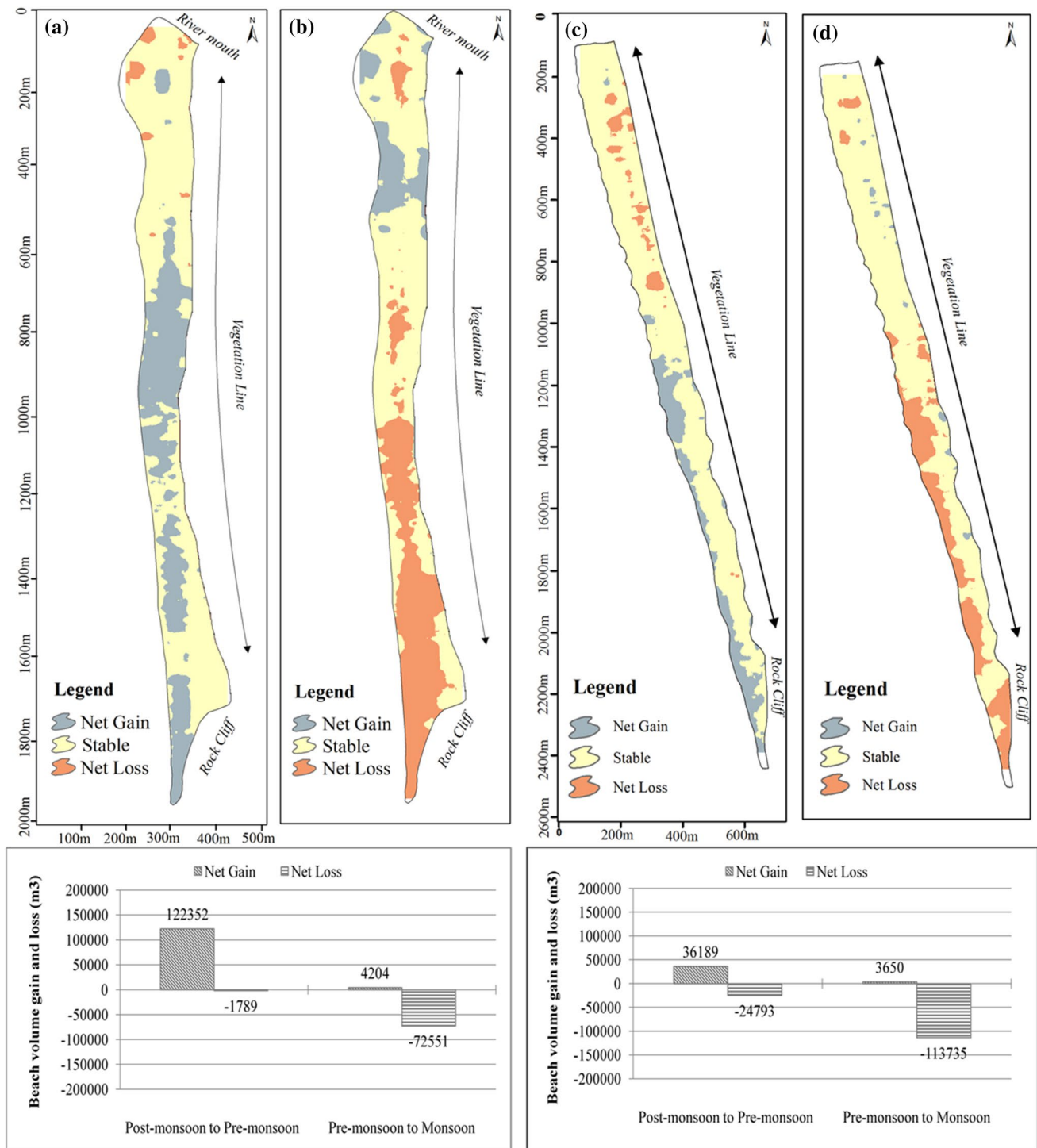


Fig. 4 Seasonal net gain and loss of beach volume at the headland bound beach: **a** from post-monsoon to pre-monsoon and **b** pre-monsoon to monsoon, and at the exposed beach: **c** from post-monsoon to pre-monsoon and **d** pre-monsoon to monsoon

Though the width of the Ganapathypule beach is less wider than Bhatye the area of erosion along this beach more when compared with.

The shoreline position is in equilibrium (maintaining its shape as it moves landward or seaward), with the change in

total volume or the net gain and loss of the beach. Shoreline change and beach volume change are well correlated (Farris and List 2007) and the correlation is high both spatially and temporally. To substantiate the results of gain and loss of beach volume the correlation coefficient was calculated

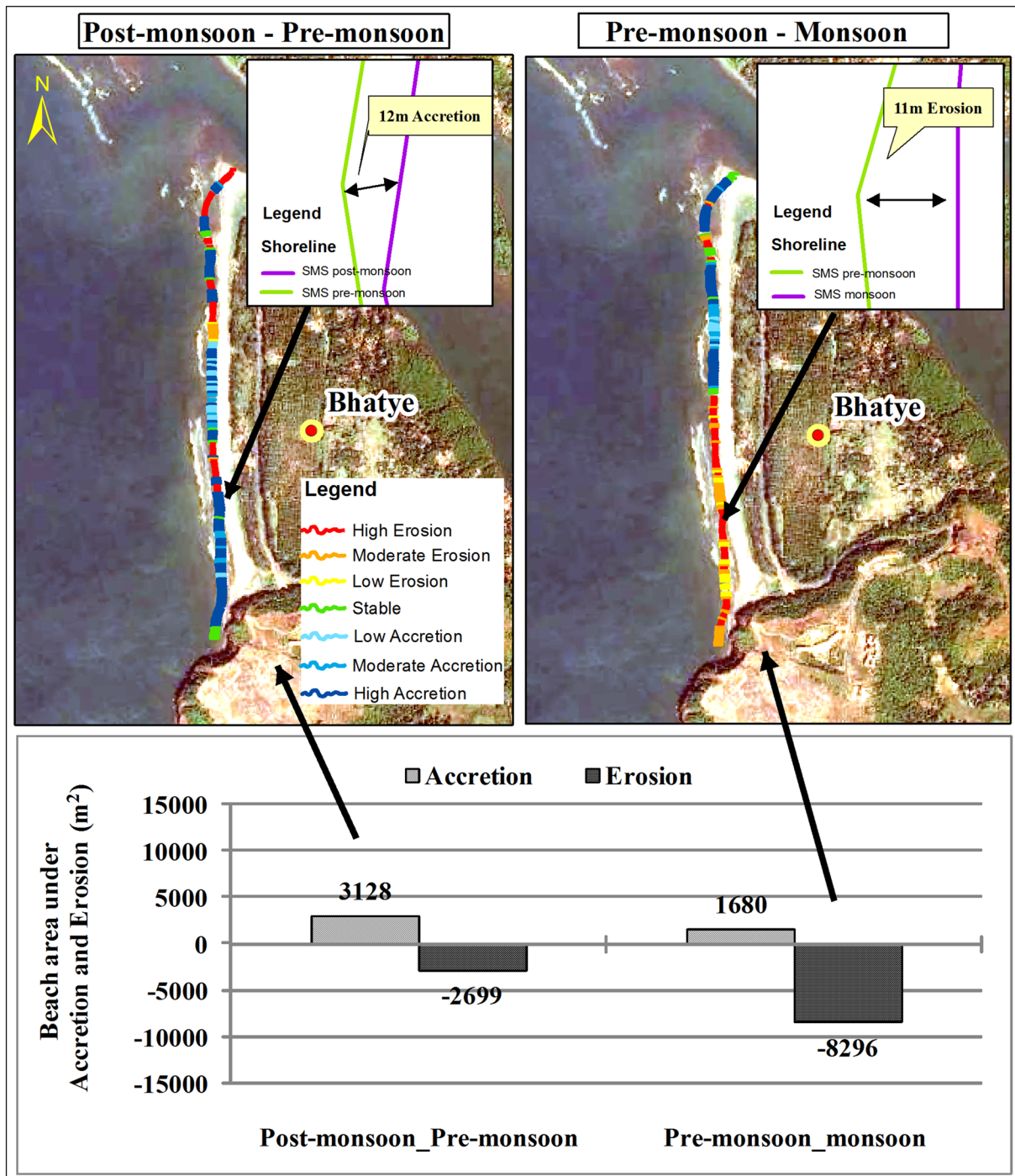


Fig. 5 Area of beach accretion and erosion during post-monsoon to pre-monsoon along Bhatye. The change in beach width has shown in meters and the area under erosion is in meters square

and it showed $r=0.82$ which is in strong positive correlation between beach volume and the shoreline position.

The relationship between the nearshore slope and the shoreline change were compared in this study. The shoreline erosion and accretion pattern is also influenced by the degree of slope of the beaches. Several studies have found

that narrow the beach width, steeper the beach slope, similarly in this study it is found that less beach volume observed in erosion phase during the monsoon due to the influence of nearshore wave.

When there is high CBS during the pre-monsoon indicating less erosion and the same phenomena was also observed

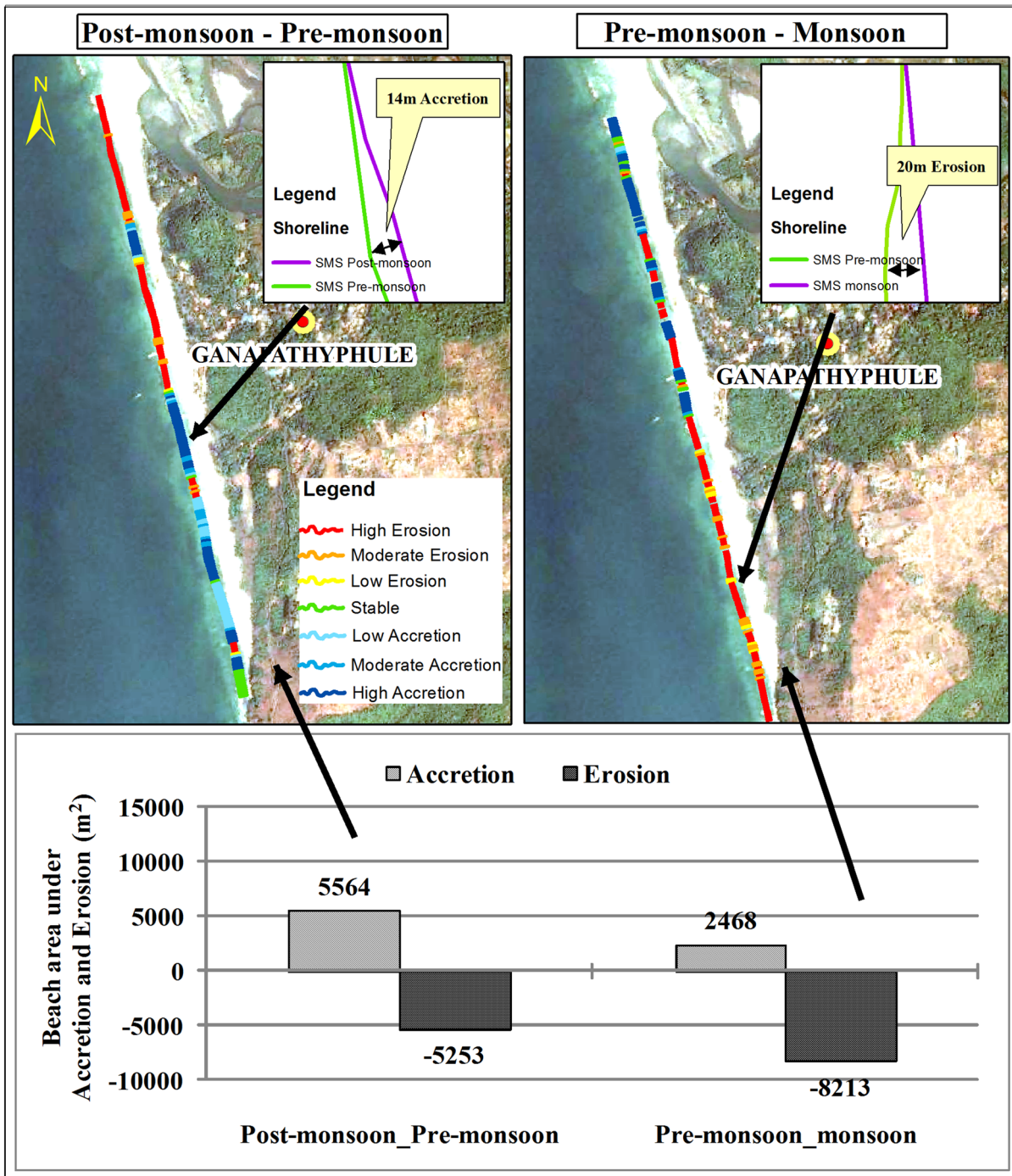


Fig. 6 Area of beach accretion and erosion during post-monsoon to pre-monsoon along Ganapathypule. The unit is as Fig. 5

by Carter (1988). Usually the shoreline change is expected to reflect a cumulative summary of processes which have impacted the coast through time (Dolan et al. 1991). The BSC in Ganapathypule is less comparatively with other seasons as the CBS peaks more during the post-monsoon. Monsoon season in Ganapathypule is the time for most change in beach morphology. The CBS is very less that is 2.9° and the

BSC is ever more which is 8% of erosion when compared with the total CBA during this monsoon.

The morpho-dynamic analysis at Bhatye beach shows its uniqueness. The CBS is more and BSC is very less during the pre-monsoon season which may be because of the river discharge more during this season. The CBS during the monsoon is less (1.7°) when compared with the fair seasons

and BSC has higher degree of erosion covering about 9.3% of total area. The post-monsoon season in Bhatye morphodynamic characters differ more from the monsoon season. The CBS is moderate of 3.5° and erosion was noticed to only 1.3% out of the total area when compared with the monsoon season.

The exposed beach at Ganapathypule was observed to have a different pattern of slope and shoreline change. The slope is very less during the pre-monsoon and the shoreline change also is significantly less. Similarly the CBS is high (4.4°) during the monsoon and BSC is more that is 3.7% out of the total area under erosion.

Wave influenced beach morphology

Waves are key forcing factor for shaping beach morphology. The wave propagation model was setup to understand the nearshore wave characteristics along both beaches. From the analysis, it was observed that waves propagates in wide band during the three different seasons. The predominant waves (D_p) at Ratnagiri was observed from WNW direction (230° – 300°) with the wave height up to 1.4 m at this region. According to Douglas sea scale (Met2010) the wave height of this region was categorized as low waves (H_m $0 < 2$ m). The wave period (T_p) ranged from 3 to 7 s and the peak wave period 7 s in this region was approaching the coast in a narrow range ($250^\circ \pm 5^\circ$) during monsoon (Fig. 6). According to the classification of Bromirski et al. (2005), it was observed that the wave period during the monsoon was intermediate waves. The short wave period ($T_p < 6$ s) was observed during post-monsoon and pre-monsoon (Fig. 7). It is evident, that during the seasonal scale, high-energy waves frequently existed for the monsoon, whereas low energy waves occurred during the non-monsoon period. According to Hughes and Cowell (1987) the morphology of the beach is strongly related to breaking wave height during energetic wave condition. Ortega-Sánchez et al. (2008) reported that the long wave periods for any wave heights are responsible to beach morpho-dynamics. Hence, the beach morpho-dynamics at the study locations was strongly due to wave height.

The nearshore waves during post-monsoon about 25% and they were from 300° direction with wave periods from 3.0 to 6.4 s while the wave height 0.9–1 m directly hitting the coast forcing a morphological change. The observation shows that the prevailing wave climate at Ratnagiri does not impact the Bhatye beach directly due to the presence of headland. This phenomena deduced as per the change in the shoreline behavior of this region showing a well developed shadow region on north of the beach during post-monsoon to pre-monsoon. The quantity of fine sand was more in Bhatye (Table 1) during post-monsoon which indicates that the influence of wave action was less due to the presence of headlands on either side of the beach. Ganapathypule beach

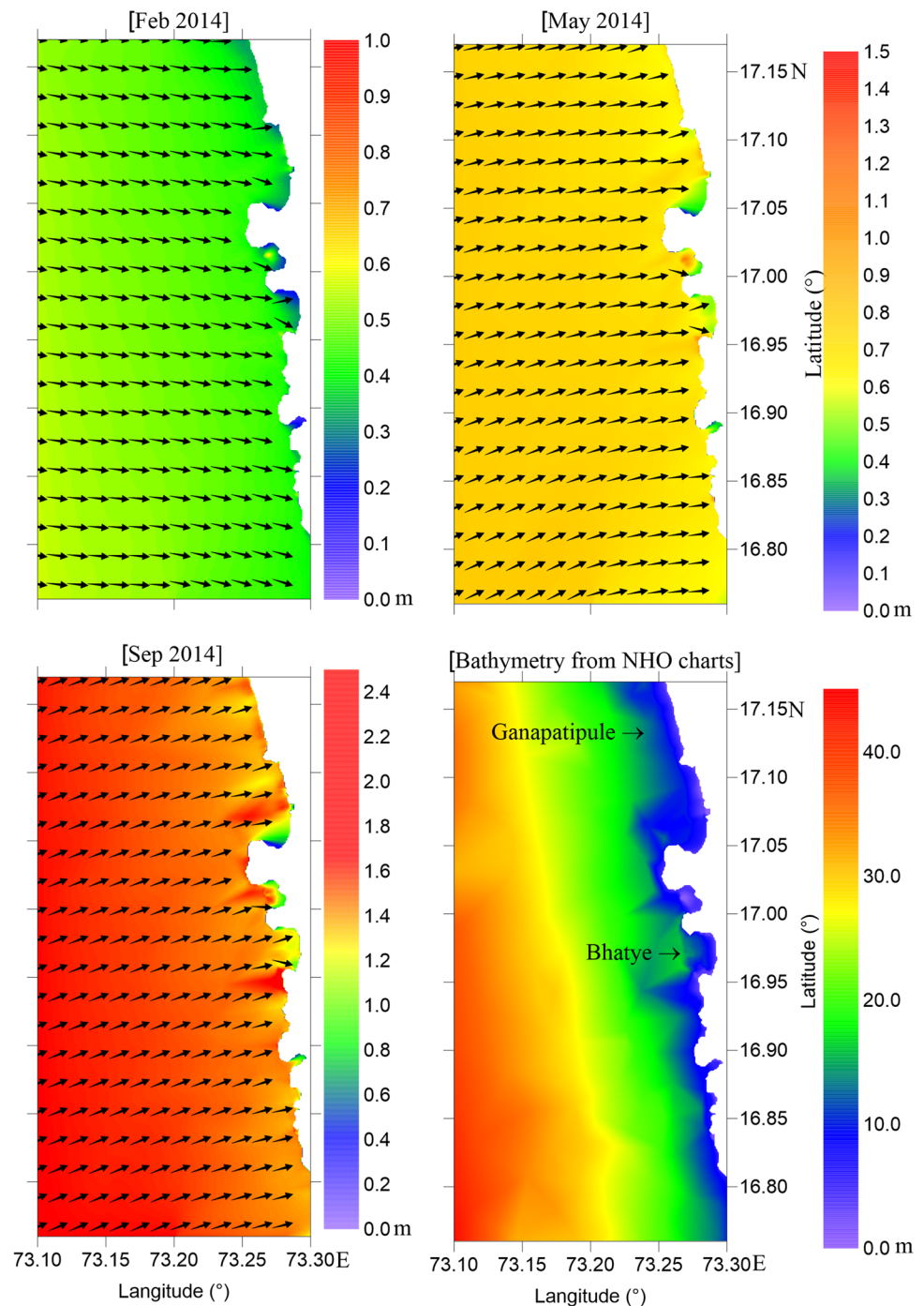
does not show any shadow region with regard to the shoreline change as it directly exposed to the prevailing wave climate in the region. The characteristics along Bhatye during this period show 100% unimode in WL and BL, whereas HTL has unimode and bimode as well. The exposed beach Ganapathypule beach shows 90% of unimode and 10% bimode in WL and BL, but HTL does have the bimode at all during this season. The fine sand was found to be more than the medium sand during post-monsoon along Ganapathypule beach.

The monsoon period has the 43% of wave from 230° and the wave period is 3.6–7 s with the wave height of 0.8–0.9 m and this intermediate wave period during low wave condition in monsoon caused more erosion throughout the beach in Ganapathypule. In this study, it was established that the exposed beaches experiencing more erosion and erosion is distributed throughout the beach. The sediment quantity shows more of coarse to medium sand than fine sand due to excess wave activity during this season. Whereas Bhatye faced the erosion on northern portion of the beach and there is also a well marked shadow region in the southern region of the beach as the erosion is controlled by the southern headland of the beach. The sediment textural characteristics of the exposed beach show 75% unimode and 25% bimode in WL and in BL it is 87% unimode and 13% bimode, whereas HTL has only 62% unimode, 25% bimode and uniquely 12% trimode.

Wave, grain size and slope correlation

The wave energy computed from simulated wave climate in the study region was used to find its relation to the beach slope and grain size. For exposed beach (Ganapathypule), wave energy was 68.2–3181.4 J/m² with an annual average of 356.8 m, 1.9° , 950.4 J/m². However, the diameter of seasonal mean grain size varied from 140.8 to 1000.0 μ m, and the beach slope was from 0.8° to 3.6° . The variation of grain size was strongly correlated with wave energy as well as beach slope during monsoon than that observed during pre and post-monsoons. The correlation coefficient between grain size and wave energy was 0.9 during monsoon, whereas that was 0.6 and 0.3 during pre- and post-monsoon, respectively. The correlation coefficient between grain size and beach slope was 0.9 during monsoon, whereas that was 0.8 and 0.8 during pre- and post-monsoon, respectively (Fig. 8). The observation showed that the correlation among the parameters were comparatively good in seasonal scale than observed in annual scale. The annual correlation between grain to wave energy at Bhatye was 0.96 (*R*), where the correlation of grain size to beach slope and beach slope to wave energy was 0.61 and 0.59, respectively. These correlations at Ganapathypule were 0.58, 0.69, and 0.39 respectively. This study showed that the correlation of grain size to

Fig. 7 The monthly average simulated wave climate at Bhatye and Ganapathypule during post-monsoon (Feb 2014), pre-monsoon (May 2014) and monsoon (Sept 2014) is represented by the wave direction (deg) and height (m)



wave energy as well as beach slope to wave energy at open coast was comparatively less than that observed at headland bound beach. This was due to wider range of data in grains size as well as beach slope during the annual cycle at the open coast, Ganapathypule. However, grain size to beach slope showed good correlation at Headland bound beach (Bhatye) compared to open coast (Ganapathypule) as the headland bound beach is comparatively less influence by wave energy.

The head land bound beach is compatible with the small wave forcing that makes only insignificant adjustment of the foreshore morphology through slope change and grain size change. The grain size variations in the beach revealed progressive coarsening only southwards during monsoon. The seasonal mean grain size varies from 135 to 450 μm and the foreshore slope ranged from 0.2° to 2.9° . The correlation coefficient between grain size and wave energy was 0.9 during monsoon and it was found to have

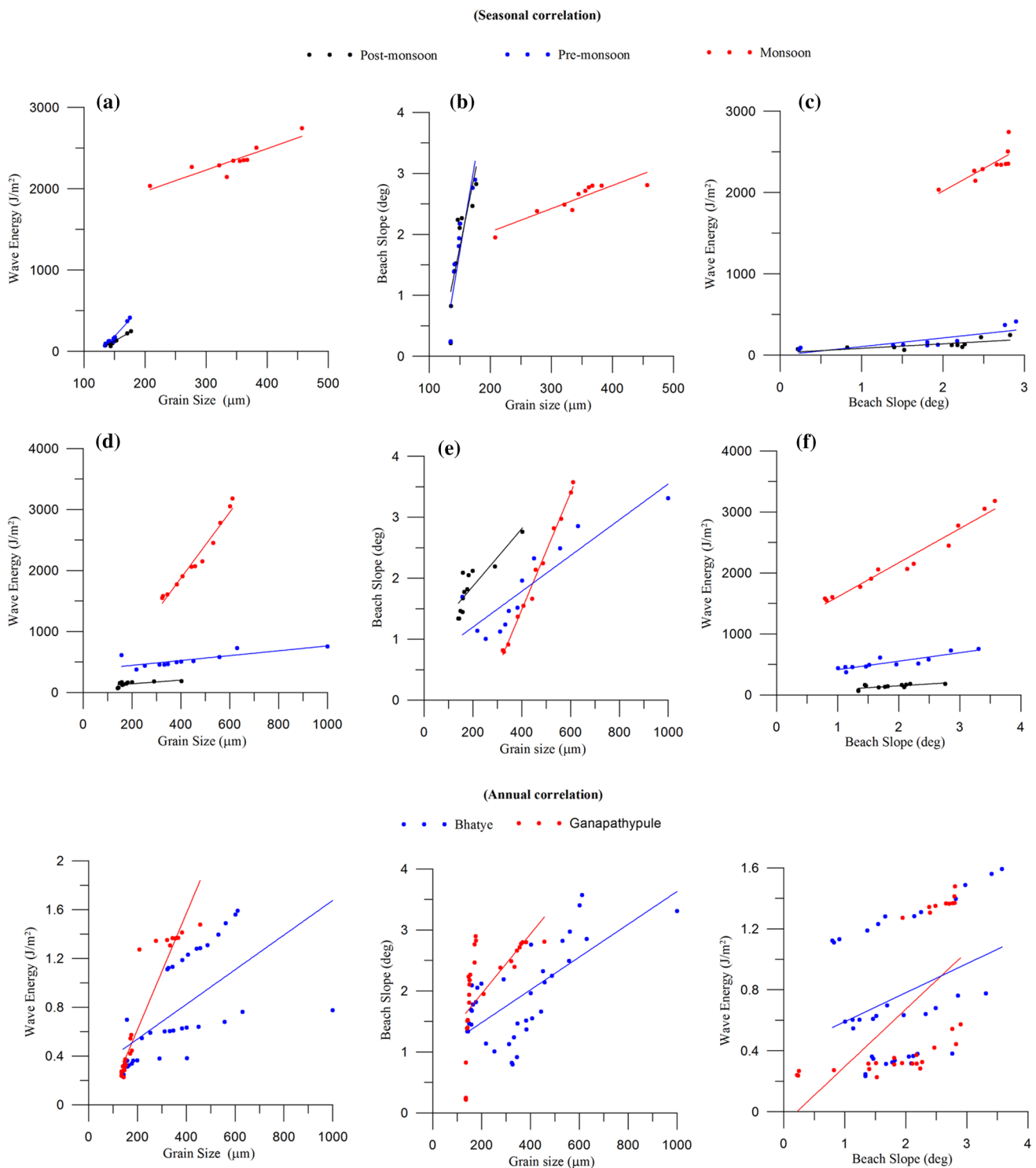


Fig. 8 The seasonal correlation among wave energy, grain size, and beach slope at the headland bound beach (a–c), and at the exposed beach (d–f)

similar trend during pre- and post-monsoon. The correlation coefficient between grain size and beach slope was 0.9 during monsoon, whereas that was 0.8 and 0.9 during pre- and post-monsoon, respectively. Despite the general

grain size variation tendency, the data reveal that grain size is not entirely proportional to foreshore slope and the wave energy. The fact is that the beach is supplied with sediments from the river.

The correlations between the nearshore slope and shoreline change were assessed. This showed maximum beach accretion during pre-monsoon and maximum erosion during monsoon season found at Ganapathypule was balanced by changes in beach slope. Retreating sectors produce more sediment per unit area of erosion than the amount of sediments required to create an identical accretion surface (Anfuso et al. 2011; Sathish et al. 2018). The relationship in beach characteristics of BSC and CBS at both the beaches varied seasonally up to moderate correlation. The correlation at Ganapathypule was comparatively more than Bhatye beach for all the three seasons (Fig. 9). The variation was due to different coastal morphology. Further, considerable variation in the correlation at the two locations was observed during pre-monsoon to monsoon period, whereas that was very close during post- to pre-monsoon.

Sediment textural changes

In general the activities of beach sediment are described by the central tendency (mode, mean and median), sorting, skewness and kurtosis. The exposed beach Ganapathypule showed unimodal during post-monsoon and bimodal during

monsoon, whereas the headland bound beach showed unimodal tendency and less bimodal during both the seasons. There was also a trimodal found at Ganapathypule beach during the monsoon. The Primary Mode at Bhatye during the post- and pre-monsoon ranged from 152 to 215 μm and monsoon ranged from 100 to 750 μm whereas Ganapathypule the sediment diameter in primary mode showed a range of 152–427 μm during the post- and pre-monsoon, and 69–750 μm during monsoon. The secondary mode was observed between 69 and 427 μm at headland bound beach and 215–422 μm at exposed beach during post-monsoon and monsoon, the tertiary mode ranged from 302 μm was found during monsoon at Ganapathypule along the BS. The median (D_{50}) was found between 103 and 177 μm at Bhatye during post-monsoon and monsoon. However, the exposed beach Ganapathypule showed a higher range from 140 to 1000 μm during the monsoon. The grain sorting varied from 1.31 to 1.81 μm during post-monsoon and it was 1.23–1.94 μm during the monsoon in the headland bound beach. Exposed beach showed tendency of 1.47–2.13 μm during post-monsoon and during monsoon 1.35–2.18 μm and the sediment unlike the headland bound beach was moderately well sorted along BS at Ganapathypule. The

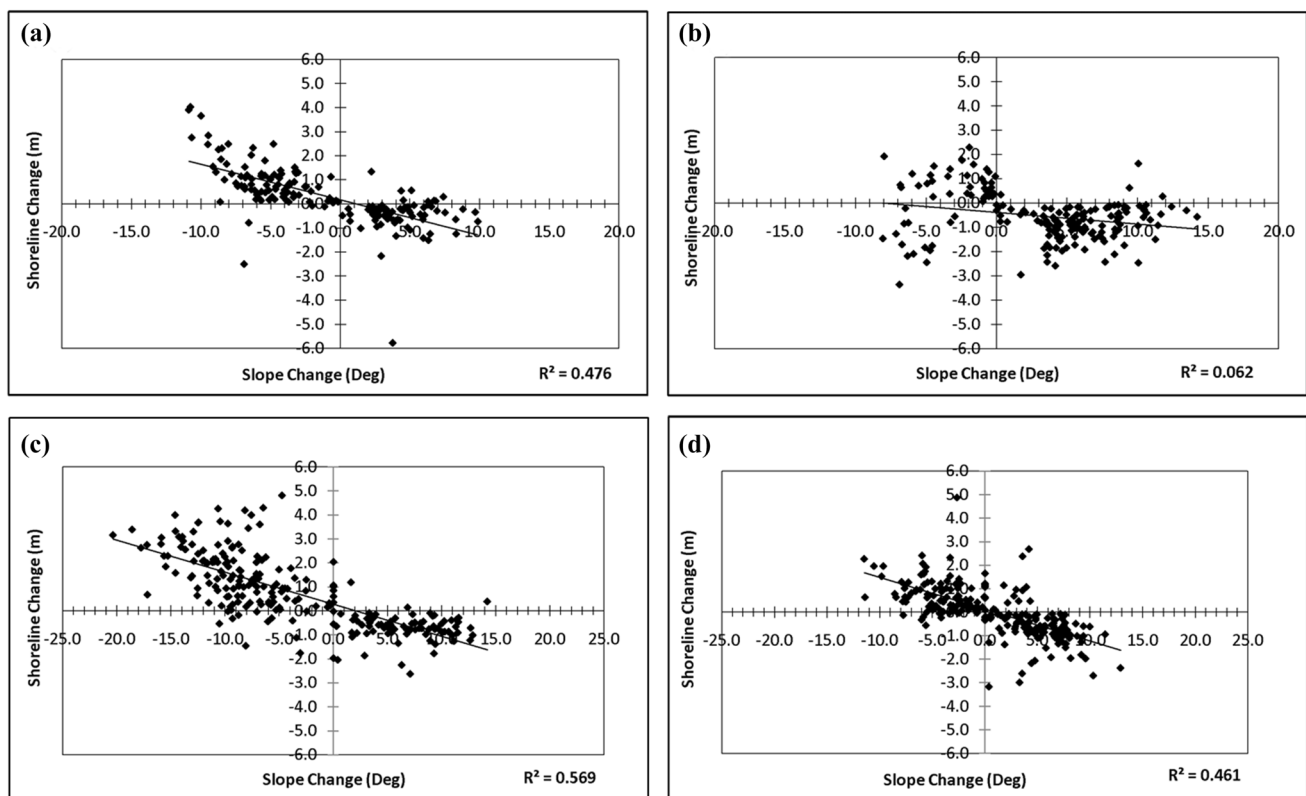


Fig. 9 Correlation between seasonal shoreline change and beach slope change along the headland bound beach is represented by **a** post-monsoon to pre-monsoon, **b** pre-monsoon to monsoon; and for

the exposed beach that are **c** from post-monsoon to pre-monsoon, **d** pre-monsoon to monsoon

skewness was found to be in the range of -0.01 to 0.4 at Bhatye, it was -0.0 to 0.2 during both seasons; whereas at Ganapathypule it varied from -0.0 to 0.2 during post-monsoon and -0.0 to 0.3 during monsoon. The skewness in the headland bound beach categorized into fine skewed to coarse skewed. But in case of exposed beach the skewness found to fine skewed only during monsoon and coarse skew found during both the seasons. The Kurtosis of beach sediment varied from 0.7 to 1.8 along the headland bound beach and it differed at exposed beach between 0.6 and 1.3 which are characterized in to mesokurtic at Bhatye beach and platykurtic at Ganapathypule (Table 2).

The textural characteristics of the sediments during the two seasons at Bhatye due to presence of headlands on either side of the beach; whereas Ganapathypule differed from headland bound beach. The greater impact of headlands along Bhatye beach determines the textural characteristics of the sediments during the seasons.

Conclusion

The seasonal variations in beach sediment volume, and textural characteristics along with wave climate variability provide the greater insight in inter annual assessment of geomorphological features of coasts. A comparative analysis between exposed and headland bound beaches would help in

prioritization of effective management and resources allocation for rehabilitation. In the present study, the beaches at Bhatye and Ganapathypule are observed as strongly composed of fine to medium sand, well sorted to moderately sorted, fine to coarse skewed, platy to leptokurtic, and unimodal in nature, where both the beaches interact with strong seasonal wave climate. The two locations, headland bound, and exposed beach, exhibited different behavior in their seasonal change in morphology, sediment characteristics, as well as wave climate. The beach morphology study with seasonal cross-shore profiles revealed a moderate variation in its characters such as width, slope, volume and shoreline change at the headland bound beach, whereas the exposed beach has considerable change in morphology and sediment characteristics. The findings of this study revealed that the change in beach morphology is strongly controlled by the wave action at the exposed beach, where the beach have a trend of morphological changes between the seasons. However, the headland bound beach are controlled by coastal morphology and the seasonal variation is minor. The correlation coefficient matrix proves that there is a strong correlation with the results of shoreline change and slope. Further, the correlation among the beach slope, mean grain size, and wave energy revealed that the correlation varies along with the change in wave climate.

An aforementioned results of seasonal morphological changes of two types of beaches suggests that the exposed

Table 2 Textural classification (%) of beach sediments collected at the two beaches

Sediment behaviour	Range	BHATYE									GANAPATHYPHULE								
		Post-monsoon 2014			Pre-monsoon 2014			Monsoon 2014			Post-monsoon 2014			Pre-monsoon 2014			Monsoon 2014		
		FS	BL	BS	FS	BL	BS	FS	BL	BS	FS	BL	BS	FS	BL	BS	FS	BL	BS
Mode	U	100	100	90.9	100	100	95.2	100	87.5	87.5	90.9	90.9	100	92.5	91.4	100	75	87.5	62.5
	B	0	0	9.1	0	0	4.8	0	12.5	12.5	9.1	9.1	0	7.5	8.6	0	25	12.5	25
	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	FS	100	100	100	100	100	100	92.5	77.3	75.1	63.6	81.8	81.8	58.1	84.5	83.7	50	37.5	25
	MS	0	0	0	0	0	0	7.5	22.7	24.9	36.4	18.2	18.2	41.9	15.5	16.3	37.5	62.5	37.5
	CS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.5	0	37.5
Sorting	WS	27.3	9.1	0	25.4	6.8	0	25	0	0	18.2	18.2	0	19.3	16.2	0	12.5	0	0
	MWS	72.7	81.8	36.4	74.6	82.5	32.3	75	87.5	50	54.5	63.6	18.2	53.8	62.5	15.4	37.5	50	25
	MS	0	9.1	63.6	0	10.7	67.7	0	0	0	27.3	9.1	81.8	26.9	8.6	84.6	50	50	50
Skewness	PS	0	0	0	0	0	0	0	0	0	0	9.1	0	0	12.7	0	0	0	25
	FSK	9.1	27.3	0	9.3	26.4	0	25	37.5	0	0	0	0	0	0	0	50	12.5	37.5
	S	63.6	54.5	45.5	60.4	50.5	48.2	50	50	62.5	90.9	72.7	36.4	88.5	69.1	34	37.5	62.5	37.5
Kurtosis	CSK	27.3	18.2	54.5	30.3	23.1	51.8	25	12.5	37.5	9.1	18.2	54.5	11.5	30.9	66	12.5	12.5	0
	V CSK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.5	0
	P	9.1	9.1	0	9.1	8.5	0	0	0	0	9.1	9.1	9.1	8.5	8.3	8.9	37.5	37.5	37.5
	M	45.5	63.6	45.5	45	60.8	45.2	50	50	75	63.6	36.4	54.5	60.5	36.3	52	12.5	25	50
	L	45.5	18.2	45.5	45.9	20.1	45.8	50	37.5	12.5	36.4	54.5	36.4	31	55.4	39.1	50	37.5	12.5
	VL	0	9.1	9.1	0	10.6	9	0	12.5	12.5	0	0	0	0	0	0	0	0	0

beache faces continual degradation of its sand volume and there by requires a planning to conserve it from the further degradation. A protective structure like sea wall or groynes or beach nourishment can be a solution to maintain such beaches from wave attack.

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