Journal of
Coastal Zone Management

Hegde, et al., J Coast Zone Manag 2015, 18:2
DOI: 10.4172/2473-3350.1000402

Research Article Open Access

Evolution of Diverging Spits Across the Tropical River Mouths, Central West Coast of India

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Abstract

The evolution of a diverging spit-one growing northward and another southward across the Baindur and Yadamavina River mouths along the Central west coast of India is examined using remote sensing data, seasonal variations in the foreshore profiles, textural characteristics of the foreshore sediments, and wave-current patterns. Remote sensing data indicated lengthening of the southern spit across the Yedamavina River by 168 m between the period 1973 and 1989, while the northern spit across the Baindur River showed relative stability. Finer sediments were observed towards the ends of the spit in both northern and southern spits. Waves approach from the west between March and May, generating wave divergence and convergence cause sediment movement on either side. The alongshore current is northward from October to November and southward from December to February. This reversal in the direction of alongshore drifts, and wave divergence prevailing in this tropical climate favor sediments movement on either side leading to diverging spits to develop. As a result of the diverging spits, both the rivers are shifting their mouths in the respective directions leading to erosion of the opposite bank. In order to prevent the erosion due to shifting of the river mouths, sediments flux to the central part of the mainland shoreline from which sediments move either side leading to spit growth needs to be checked.

Keywords: Diverging spits; Tropical climate; Central west coast; Remote sensing; Textural characteristics; Foreshore profiles

Introduction

Spits are geomorphic features parallel to the coasts that are formed by accumulations of sediments at the ocean and bay sides of inlets, river mouths, and headland sides. Spit systems develop either due to sea level changes, subsidence, storm events sediment supply etc. [1]. High sediment supply and low accommodation result in spit development [2]. Sediments transported from the mainland shoreline and deposited at the distal end of the spit are responsible for building and lengthening the spits [3,4]. Hence, spits are the most reliable and useful geomorphic indicators for quantitative and qualitative measurement of the net shore drift [5,6]. However, there is evidence from spit orientations that growth can occur opposite to the net long shore drift [7]. Therefore, spits are important for understanding sediment drift as well as morphodynamics of the inlets [3]. Previous studies on spits have indicated that a combination of factors, including channel geometry, wave refraction, tidal flow, sediment influx, sea level variations, and alongshore drift, are responsible for the development of spits and inlets [8-12,3]. The model developed by Petersen et al. (2008) models spit stability and evolution in response to long shore transport and wave climates. In tropical estuarine regions, which experience cyclic variations in both sediment and water influx, wind and wave patterns also undergo seasonal variation both in the direction of approach and energy. Therefore, periodic reversal in the alongshore current (up-coast and down-coast) is a common phenomenon. The net result is that there is a complex adjustment between the wave-current systems and sediment dynamics in the estuarine regions; hence spit evolution is also highly variable both in time and space.

Coastal rivers in India are subjected to two periods of monsoons (southwest and northeast), as a result, experience unique sediment dynamics. Chandramohan and Nayak used alongshore transport models and found a net southerly alongshore drift for the west coast of India; this is contrary to the ground observation of spits growing northward [13]. Many field studies on the open beaches of the Central West Coast (CWC) of India and pocket beaches [14,15] revealed large variability in the alongshore drift. Although studies have been carried out on the spits growing northward, southward, or on paired spits there have been few studies dealing with the evolution and dynamics of diverging spits that grow within under the same hydro-geo environmental conditions (e.g. rainfall, river flow, wind and waves, and sediment pattern) [5,16]. As a result of the spits, rivers are shifting their mouths in the respective direction leading to erosion of the opposite bank [16]. To prevent the erosion due to shifting of the river mouths, sea walls are constructed, but sea walls are collapsed implying that construction of the sea walls on the opposite direction is not a viable solution [17]. Identifying the mechanisms causing diverging spits can provide insight into sediment movement and the sediment source to address the erosion, related to spit growth. In this paper, a diverging spit growing northward across the Baindur River and southward across the Yadamavina River from a common mainland is analyzed to understand their evolution and its

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Received April 06, 2015; **Accepted** April 18, 2015; **Published** April 28, 2015

Citation: Hegde VS, Nayak SR, Krishnaprasad PA, Rajawat AS, Shalini R, et al. (2015) Evolution of Diverging Spits Across the Tropical River Mouths, Central West Coast of India. J Coast Zone Manag 18: 402. doi: 10.4172/2473-3350.1000402

implications for coastal zone management

Materials and Methods

The present study is based on the observation of satellite images from 1973 to 2006 and data to ground truth these images, including seasonal variations in the foreshore profiles, foreshore sediment characteristics, wave and current patterns, and wave energy distribution in the near-shore.

Satellite data products and geometric correction

Geo-rectified Landsat Multi Spectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM) images covering the study area for the years 1973, 1989, and 2000 were downloaded from Landsat (www.landsat.org). Remote sensing satellite data from the Linear Image Self Scanning (LISS) III satellite between 2002 and 2006 were obtained from the National Remote Sensing Centre (NRSC, Hyderabad, India). Details of the data sets are presented in Table 1. Geo-referencing of the LISS-III data was performed by selecting 25 permanent ground reference points in both Landsat and IRS images, and then re-sampled in Universal Transverse Mercator (UTM) projection system and World Geodetic System (WGS 84) datum. During the geo-referencing process, the Root Mean Square Error (RMSE) for the geo-corrected image was less than 0.4 pixels. To study the tidal conditions, we selected a rocky island in the near-shore as a reference point and inferred the tidal conditions based on the emergence and submergence of the rocky island as viewed in the satellite data, corresponding with low and high tide, respectively. Satellite data were also used to delineate the land/water boundary and inundated areas. The near shore islands appeared in all the images used in the present paper, suggesting that they experienced similar tidal conditions. Band 4 (near infrared region of the spectrum) of the geo-corrected satellite images was processed in ERDAS 9.0 v software to delineate land and water. The boundary between the land and water (the shoreline) was carefully vectorized. The digitized shorelines for the years 1973, 1989, and 2000 in vector format (ARCGIS shape-file) were used as input to the ArcMap 9.0 Digital Shoreline Analysis System (DSAS). The shoreline of 1973 is considered as the baseline condition in DSAS and is used to estimate the shoreline change.

Beach profiling and sediment sampling

Locations were selected for observations, including foreshore profiling and sediment sampling, using the satellite imagery. For the foreshore profiling, eight stations were selected so that they represented the entire beach: one station (S_m15) to the north of the Baindur River, two stations (B16 and 17) on the northern spit (Baindur), one station on the mainland in Baindur (B18), one station on the mainland of Uppunda (Up19), and three stations (Up 20, Up 21 and Up 22) on the southern spit (Figure 1). Bimonthly beach profiles were measured following the stake and horizon method of Emery [18] at each of the eight stations.

Satellite data used	Resolution	Period
LANDSAT MSS	57m	1973
LANDSAT TM	30m	1989
LANDSAT ETM	16m	2000
IRS LISS -III	23.5m	2002
IRS LISS -III	23.5m	2006

Table 1: Details of the satellite data used in the present study and their Resolutions.

Locations of the stations were recorded using a Garmin Global Positioning System (GPS) device with two dimensional (x,y; longitude, latitude) spatial resolution of ± 7 m. All of the surveys were carried out during low tide and during the middle of the lunar months that had the minimum tidal range. Profiles were carried out 15 to 20 m beyond the low-water line (up to 1.2 m water depth). Seasonal variations in the configuration of spits during low tide were mapped by walking along the low water line and around the spits and recording coordinates (x y) of the spits with GPS. Foreshore sediment samples were collected during profiling along the survey line by a 5 cm diameter PVC pipe driving the core to a depth of 5 cm from the surface.

Waves and currents were recorded during the survey. Wave data, including breaker height and wave periods, were studied by observing the number of wave crests passing a reference point (ranging rod) in the surf zone for 10 minutes during low tide time. The alongshore current direction and speed were recorded for 15 minutes using a drift bottle.

Granulometric analysis

Approximately 50 g of the foreshore sediment samples were generated from the ½ kg of sample collected after coning and quartering and preliminary treatment (after Ingram, [19]). These were subjected to sieve analysis at ¼ φ interval in a Rotap sieve shaker using American Society for Testing Material sieves for 15 minutes. The weight (0.001 g) of the sediment fraction in each sieve pan was used to derive the grain size characteristics [20]. Spatial variations in the sediment characteristics are used to derive direction of transport following McLaren and Bowles [21]. By integration of the wave pattern, textural variations of the sediments and foreshore profile modifications, a sediment circulation pattern is derived for the area.

Study area

The study area forms part of the CWC of India, extending between Baindur on the north and Uppunda on the south ($13^0$47' to $13^0$53' N and $74^0$35' to $74^0$38' E (Figure 1). The CWC is oriented north-northwest (NNW) and south-southeast (SSE). The Baindur and the Yadamavina rivers join the Arabian Sea in this coastal stretch. The Baindur River has a catchment of 99 km^2 and the Yadamavina River has catchment size of 85 km^2. Both the rivers originate on the Western Ghats, flow through narrow gorges, rapids in the Ghat region and Join the Arabian Sea. There are two spits: one grows southward across the Yadamavina River and the other grows northward across the Baindur River. These form a diverging spit system. There are 8.2 km separating the distal ends of these spits and 4 km of mainland coast between these spits. Geologically, the area consists of migmatitic gneissic complex, locally capped by laterites and Quaternary alluvium. The coast is characterized by features such as islands and submerged rock bodies, headlands jutting into the sea, and drowned valleys. These features point to its submerging nature, while features like spits, old raised beaches, and wave cut platforms signify emergent nature; this suggests a compound shoreline.

Wind and wave climate

The study area experiences a tropical climate, and receives an average annual rainfall of 600 cm. 85% of the rain fall occurs between June and September, while the river flow reduces between February and May. Tidal ranges in the study area were < 2 m, and as per the criteria of Davis [22], the shoreline can be classified with a micro-tidal condition. Wind patterns in the study area are presented in Table 1. During October to February, the wind changes direction from north and northeast and blows towards southwest to south to the south of 16^0 N. This trend continues until March [23]. The wave height in the breaker

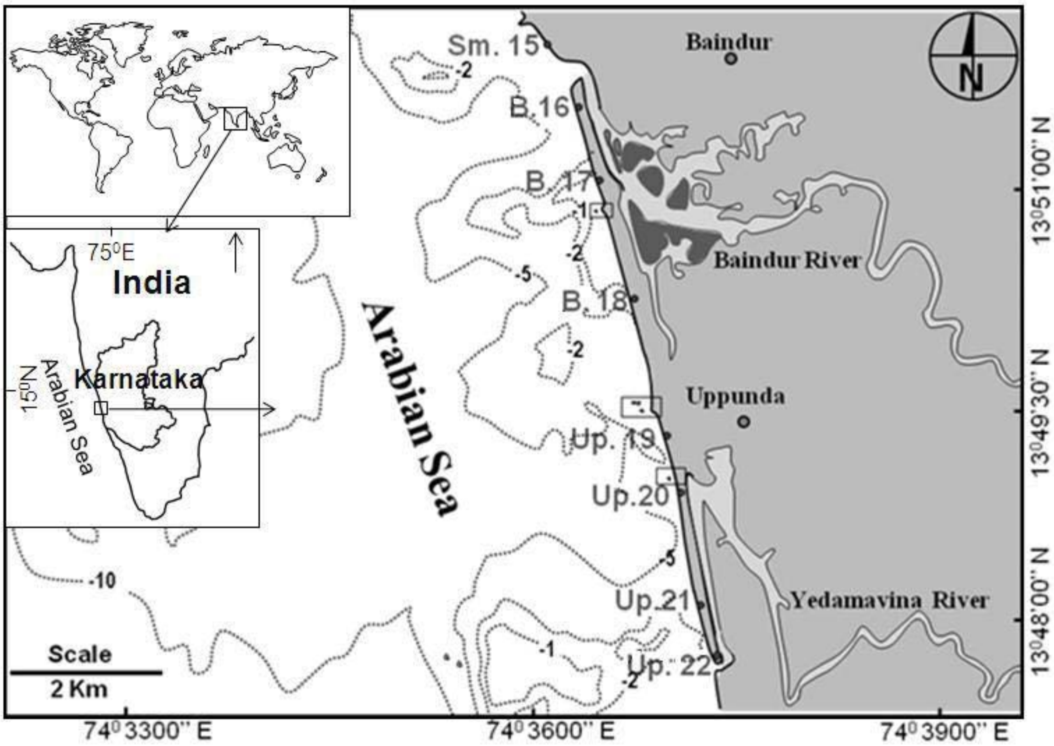

Figure 1: (a) The study area showing spits of two adjacent rivers growing in opposite directions to form a diverging spit system; representative stations for observational data collection. Small rocky islands/promontories near station B17 and Up19 (highlighted in rectangles). (b) Monthly averages of wind speed and approaching direction to the coast for 2008-2009 (derived from Quick scat data).

zone varies from < 1 m during November to December to ~2 m during June to August (the southwest monsoon). Hence, as per the criteria of [24], the study area is a wave-dominated coast. Alongshore currents are southerly from January to February, northerly from April to June, but from June to August due to near normal approach of the waves, cellular currents are developed which cause wave divergence and convergence [17,25]. Such cellular current pattern during the period is related to the near-normal approach of the waves [25]. During September, long period, low energy, swell waves near –perpendicular to the coast prevail and favor accretion processes of the beach [26]. In general, the wave refraction patterns observed in the area conform to the observation made by Sonu (1972) that meandering currents occur for oblique wave approach and cellular currents for normal incidence.

Wind parameters of speed and directions were derived from Quicksckat data (http://www.remss.com/qscat) for 2008 and 2009. Wind speed varied during each of the four seasons: pre-monsoon, transitional period, southwest monsoon, and post-monsoon. During the pre-monsoon season, wind azimuth directions showed two trends: from 5^0 to 120^0 there was a seaward breeze, while from 310^0 to 360^0 there was a landward breeze which is relatively narrows (Figure 2). The later had speeds < 8 m/sec, resulting in swell waves during the pre-monsoon season period. During the transitional period from April to May, the dominant direction of the wind approach was from 270^0 to 315^0 (from W, WNW) and was landward. Increases in the speed of the wind were observed during this transitional period; prevailing W and WNW approaching waves during the period can be attributed to this wind set up. During the southwest monsoon from June to August, the wind azimuth direction was 240 to 270^0, (from SW, WSW and W) and the wind speed ranged from 4-15 m/sec. The majority of the winds had speeds > 8 m/sec, which was responsible for storm waves that prevailed during that period. During the post-monsoon from September to December, winds approached the coast from WSW and W and their speed decreased to < 10 m/sec with a prevailing seaward breeze (i.e. azimuth $0–120^0$).

The significant wave height (H_{mo}) in the nearshore off the study area was < 1.5 m (Range: 0.2-1.4) during the fair weather season, and > 3 m (Range: 0.6-3.4 m) during the storms during the southwest monsoon. The average fair weather wave height (H_{mo}) was 0.6 m, while the height during the monsoon and post-monsoon seasons were 1.5 m and 0.7 m, respectively [27].

Results

Remote sensing study-decadal and seasonal shoreline changes

Analysis of the decadal morphological evolution of the spits using satellite images (Figures 3a and 3b) indicated that from 1973-2006, the northern spit (growing northward across the Baindur River) was stable while the southern spit (growing southward across the Uppunda River) grew 168 ± 30 m towards the south between 1973-1989 (Figures 3b and 3c) but experienced no growth between 1989-2006 (Figure 3a). From 1973-1989, accretion occurred in the spit while erosion occurred on the southern bank (opposite to the spit). It is observed from the several cross sections of the tidal inlet that they are geometrically stable (Figure not presented). This implies that spit growth is not due to inlet migration [28]; southward growth of the Uppunda spit is therefore at the expense of opposite bank. A wall was constructed to prevent

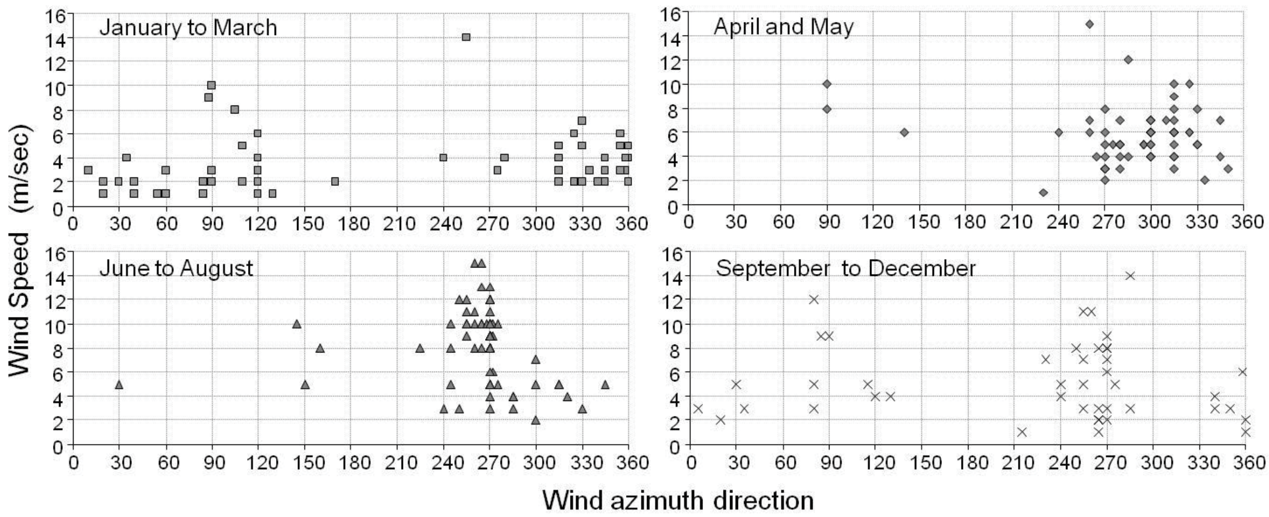

Figure 2: Plot of Wind azimuth directions verses wind speed for the pre-monsoon (January to March), transitional period (April to May), monsoon (June to August) and post-monsoon (September to December).

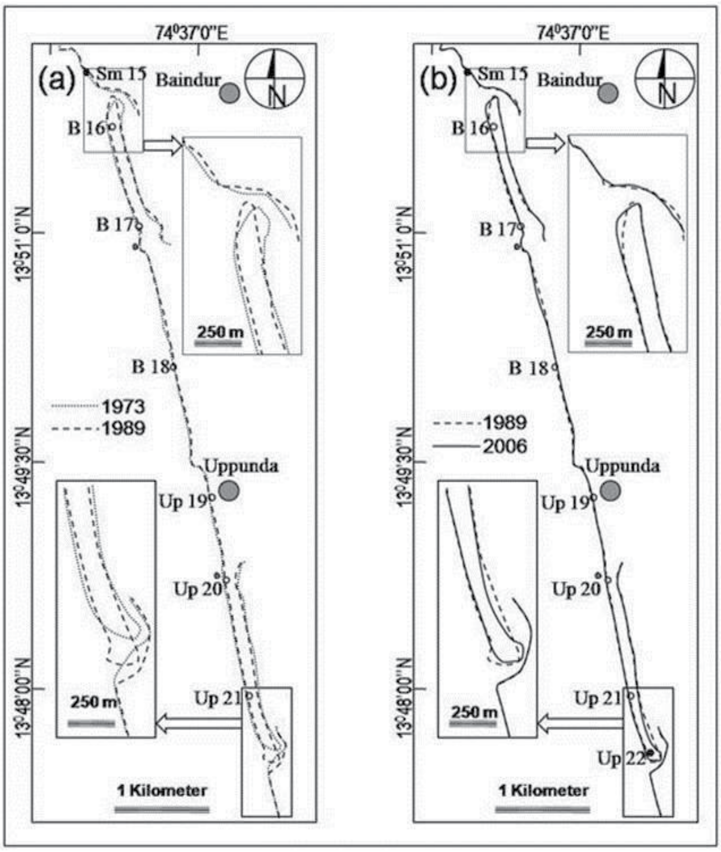

Figure 3: Decadal changes in shoreline position(a) The map showing rocky islands (R_b, R and R_u), specific locations of monitoring stations and super imposed vectorized shorelines from the satellite images of 1973, 1989 and 2006. (b) Changes in length of the spits between 1973 and 2006. (c) Changes detected between 1972 and 2006 at the distal end of Yedamavina river mouth.

erosion of the opposite bank at the Uppunda, which may have checked the erosion and led to the southward growth of the Uppunda spit. In order to restrict the further growth of the spit, a large-scale dredging operation is ongoing in the Uppunda estuary.

Baindur (Northern) spit

Analyses of the satellite data of the northern spit (Baindur) showed significant seasonal changes (Figure 4). A paired spit (from north to south and south to north across the river) system is observed across the Baindur River; however, the spit growing from the south is long and persistent while the spit growing from the north across the river appears and disappears seasonally. During October (2008), the spit on the south grew straight and wide. But in February (2009), when alongshore transport was southward, the spit from the north across the Baindur River developed bending landward while the spit on the south was narrowed, particularly at its tip. This implies sediment starvation or sediment loss in the spit on the south. During February, wide surf waves approach nearly normal to the coast and undergo a large refraction (Hedge et al., 2009). Due to microtidal conditions, and prevailing low, dimensionless fall velocity favor development of a wide variety of surf features, including submerged bar (c.f. Masselink and Short, 1993).These features develop into ebb delta like (Figures 4a,4f and 4g) and as submerged alongshore bars (Figure 4e). But they are not observed during March and October even during low tide time which corroborate that they are submerged bars rather than are ebb deltas (Figures 4b and 4d). Due to the effect of river current, the bars develop crecent shape (Figure 4c), and waves propogating against the crecent shaped bar suffer divergence that lead to erosion of beaches away from the river mouth. During March, the bar disappeared, the river mouth widened, the southern spit eroded further, and the tip of the spit detached from the main spit. In the next month, April, the northern spit at Baindur further lengthened, the southern spit split into one alongshore bar and one hook type-bend/recurved spit. Google earth image of April 2010 also depicted the same feature (Figure 4d). In the subsequent month of May, the detached part of the spit-tip was welded into the main spit. Once again, in October, the configuration repeated as was observed in the previous October. However such cyclic feature is not observed in the southern spit (Uppunda).

Beach profile and volume change studies

Superimposed beach profiles of the study area and the changes in beach volumes in different seasons are presented in Figures 5 and 6. From the profile variations, it is observed that

a) During southwest monsoon (May-August 2008) erosion occurred at all the stations in the Baindur and Uppunda spits. In general, the Baindur spit experienced more erosion, particularly in the part close to the river mouth (stn. B16). The Uppunda spit experienced more erosion in the mainland of the spit (stn. Up19).

b) During the post-monsoon season (August-October 2008), all the stations showed deposition. However, there was spatial variation in the mode of accretion. In the Baindur spit, the lower foreshore experienced accretion while in the Uppunda spit, the lower foreshore experienced erosion while the upper foreshore experienced accretion.

c) Deposition continued until January 2009. However, in the mainland end of the Uppunda spit (stn. Up19), the upper foreshore showed accretion at the expense of the lower foreshore while at the distal end of the spit (stn. Up22), lower foreshore experienced accretion at the expense of the upper foreshore. This implies that there was local redistribution of materials on the foreshore.

d) From January-March 2009, when the wind approached from the west, the central part of the Baindur spit (northern) experienced accretion (stn. B18) at the expense of either ends while the Uppunda (southern) mainland and mainland end of the spit experienced erosion. The spit end did not show any significant change, a feature also observed in satellite images (Figure 5).

e) During the pre-monsoon season (March-May 2009), storm

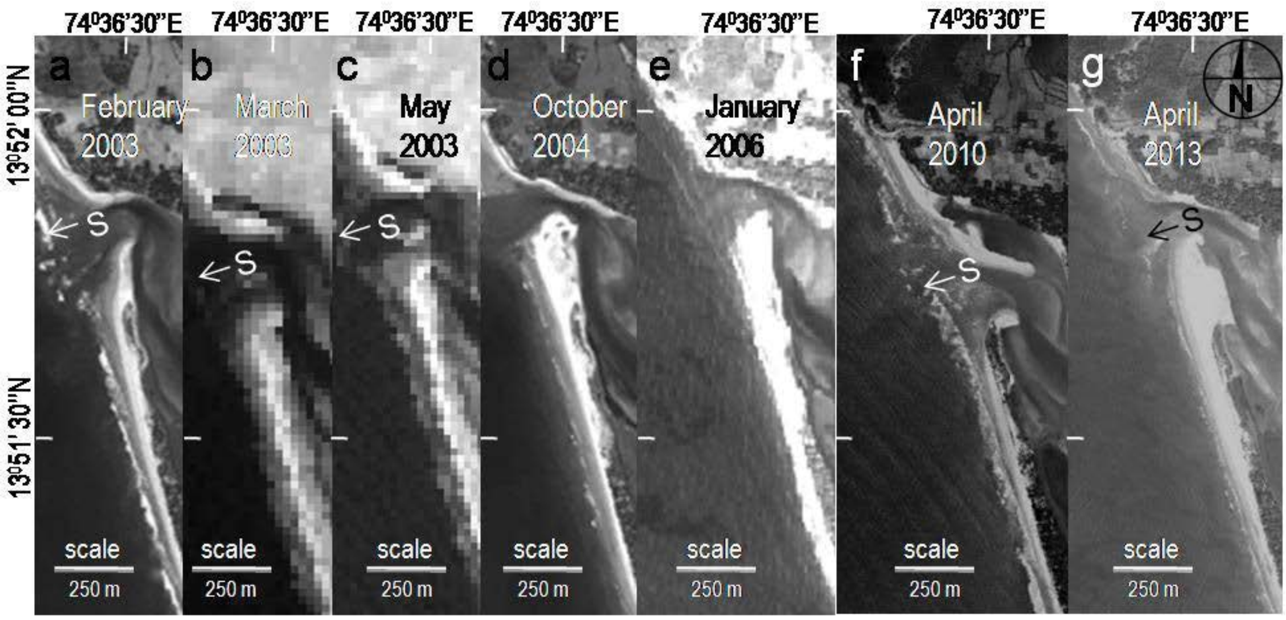

Figure 4: Periodic river mouth dynamics of the Baindur River showing nearly cyclicity in spit end configuration, appearance and disappearance of the submerged bar and its welding to the spit end. S: submerged bar in front of the river mouth.

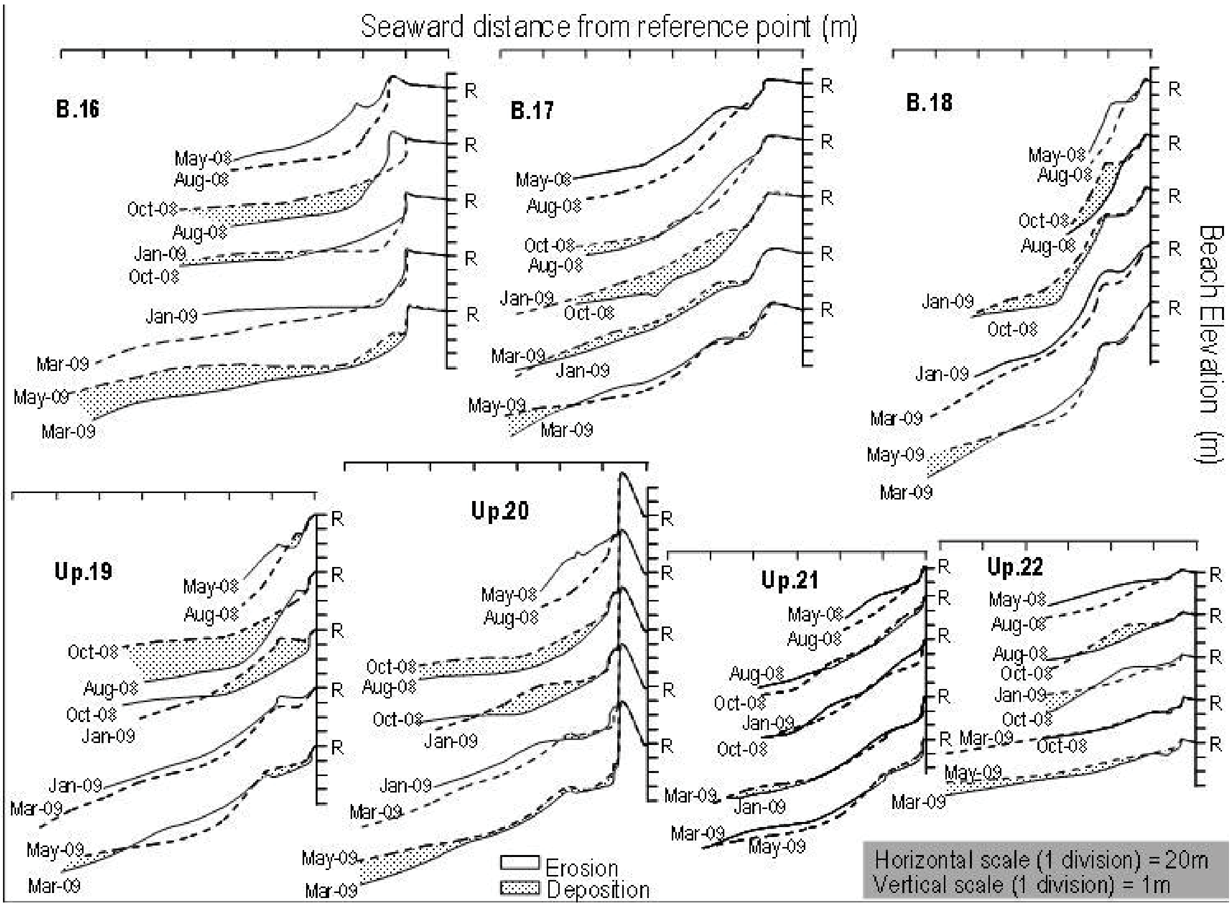

Figure 5: Superimposed consecutive beach profiles indicating foreshore erosion during monsoon and deposition during post-monsoon and local redistribution between lower foreshore and upper foreshore at different representative stations.

waves start. The portion of the spit closest to the river mouth in both the Baindur and the Uppunda spits experienced accretion while the stations farther (stn. B18, Up19, Up20, Up21, and Up22) showed minor erosion or accretion.

f) Seasonal volume changes were higher near the river mouths in the northern spit (B16 and B17), whereas in the southern spit, changes were higher in the portion of the spit away from the river mouth (stn. Up19 and Up20) (Figure 6).

Textural characteristics

Baindur Spit: Among the textural parameters, grain-size, sorting-coefficient, and skewness are the most widely used parameters. In general, sediments on the spits were medium-grained and moderately well-sorted. During May, August and October (2008), the grain-size showed northward fining-trend in the Baindur spit (northern spit) with corresponding improvement in trend of sorting (Figure 7), implying a northward transport of sediments [21]. Foreshore sands during August were coarser than that in May. In January (2009), the distal end of the Baindur spit (stn. B16) showed coarser grains than in previous months. It is observed from the profile data that this locations experienced erosion in January, while stn. B17 and B18 (the central part of the area), which experienced accretion, showed poorly-sorted finer sized sands on the foreshore. The grain-size trend did not show any significant changes between March and January, while the sorting trend was poorer both in the distal and proximal end, implying poor efficiency of the waves and hence lower wave energies. The textural characteristics indicated both positive and negative skewedness at stations B18 and Up19 (Figure 8) between January and March. The presence of both positive and negative skewedness is a common feature in the zone of influx of sediments [29]. Similar grain-size trends in May (2008 and 2009) and August (2008 and 2009) confirm these observations of sediment movement. The observed fining of sediments towards the spit-ends from stn. B18 to stn. B16 in May confirms the alongshore effects towards the north in northern spit. This alongshore fining during May, along with higher accretion towards the spit end and the dominance of finer-size of the sands suggest that on reaching the rivers, the alongshore terminates resulting in accretion and growth of the spit.

Uppunda Spit: In the southern spit (Uppunda), sediments show a northward fining trend in May (2008 and 2009) but a southward trend in August (2008) and October (2008) at all stations except stn. Up22, which is close to the river mouth. Similar trends were observed in sorting: sorting improved southward except at the distal end of the spit (stn. Up22). Presence of coarser grains on the foreshore compared to May (2009) indicates selective removal of fines from the foreshore. In the Uppunda spit, there is a southward fining trend (from stn. Up19 to stn. Up22) implying alongshore drift southward.

Bivariant plots have been used to discriminate various sources [30]. In

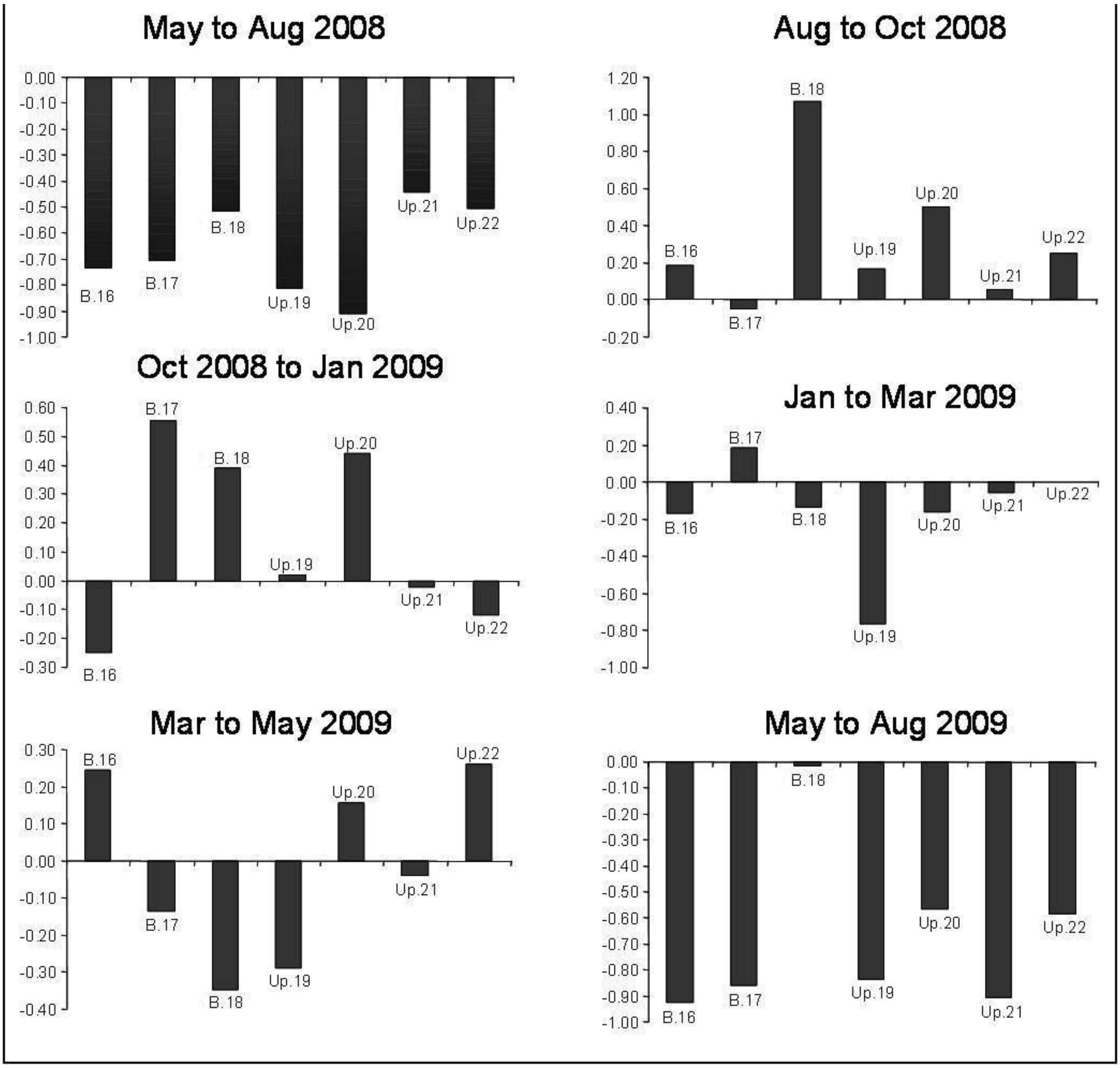

Figure 6: Length normalized Seasonal beach volume changes in the study area. X axis stations, Y axis Volume change in M^3/m. Note monsoonal erosion, post-monsoonal accretion minor erosion during January to March and redistribution of foreshore materials between March to May.

the bivariant discrimination diagram of the mean size versus sorting [30], the foreshore sediments of the two locations B18 and Up19 showed riverine characteristics (Figure 9) during the post-monsoon seasons, whereas the other stations (except the distal ends of the spits) showed beach characteristics. This suggests that sediments brought by rivers during monsoon and deposited in the near-shore are moving onto the shore during the post-monsoon season through these stns. Since these sediments are not modified by wave action, they retained their riverine characteristics. Hence, stns B18 and Up 19 represent the zone of influx of sediments onto the beach.

Discussion

From the profile variations, in general, four trends were observed: a) erosion of the foreshore and offshore movement of the sediments during the monsoon season (June-August); b) onshore movement of materials and accretion during September to November; c) southerly alongshore drifts in January-February; and d) redistribution of sediments on the upper/lower foreshore or alongshore. In June-September, short period swell waves prevailed along the coast with higher breaker height, a condition that favors beach erosion, and deposition of the eroded materials in the near-shore. In addition, sediment influx from the river and their subsequent deposition in the near-shore during the monsoon season results in a wide and gentle surf zone. Prevailing micro-tidal conditions and low, dimensionless fall velocities of the materials create a wide variety of surf features, including bars [31]. From late September to November, wind speed decreased along the coast, facilitating long period swell waves to prevail. With the long period swell waves, and wave breaker height <1 m onshore pulses dominate [32] and the

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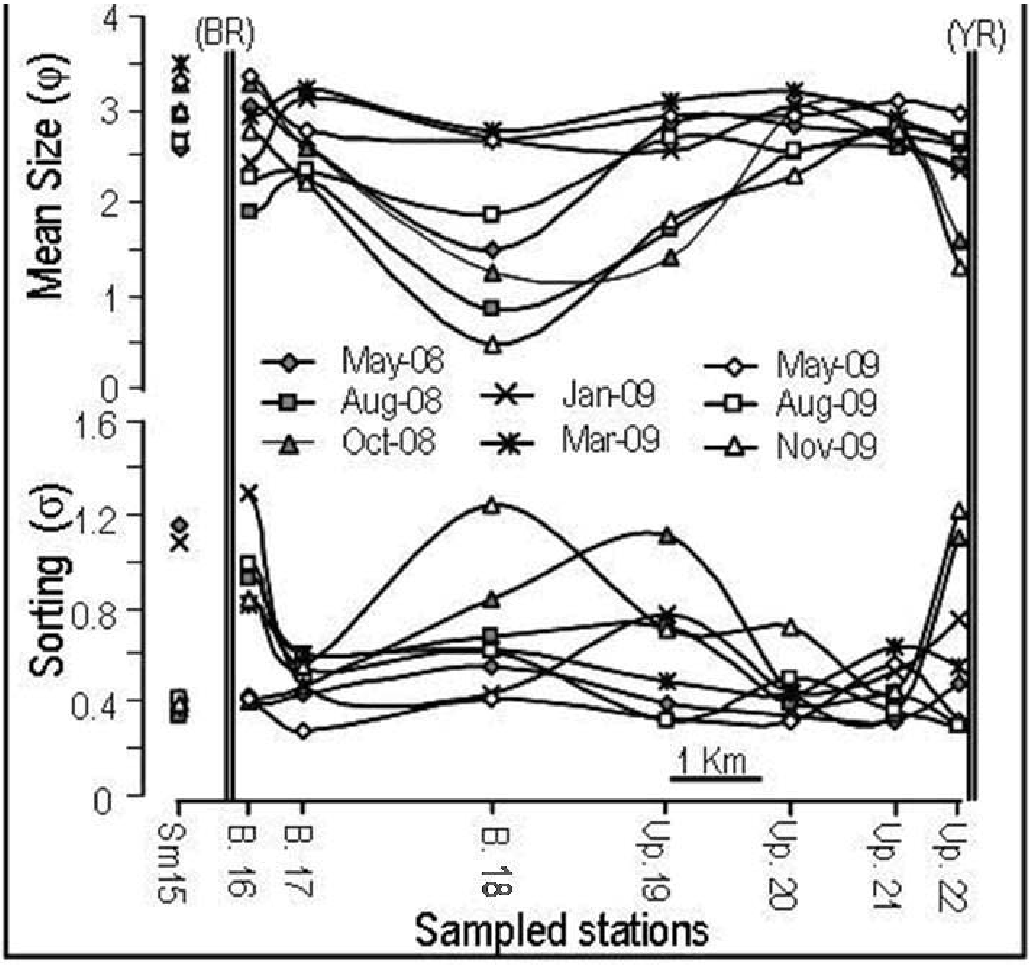

Figure 7: Temporal and spatial variation in the textural parameters (mean size and sorting) between Baindur River (BR) and Yedamavina River (YR) mouth, at Uppunda, Central West Coast of India.

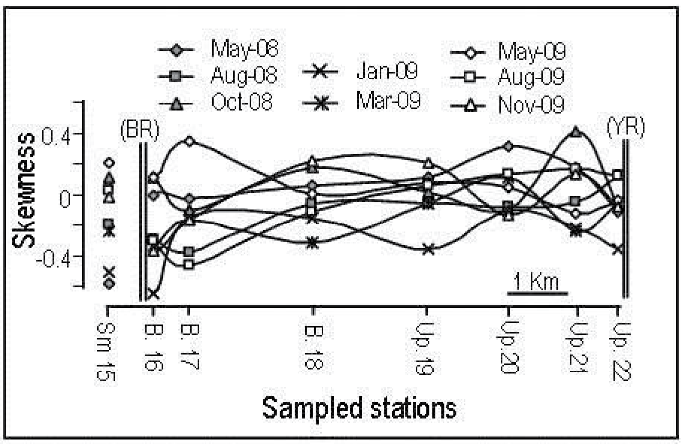

Figure 8: Temporal and spatial variation in the Skewedness between Baindur River (BR) and Yedamavina River (YR) mouth, Central West Coast of India.

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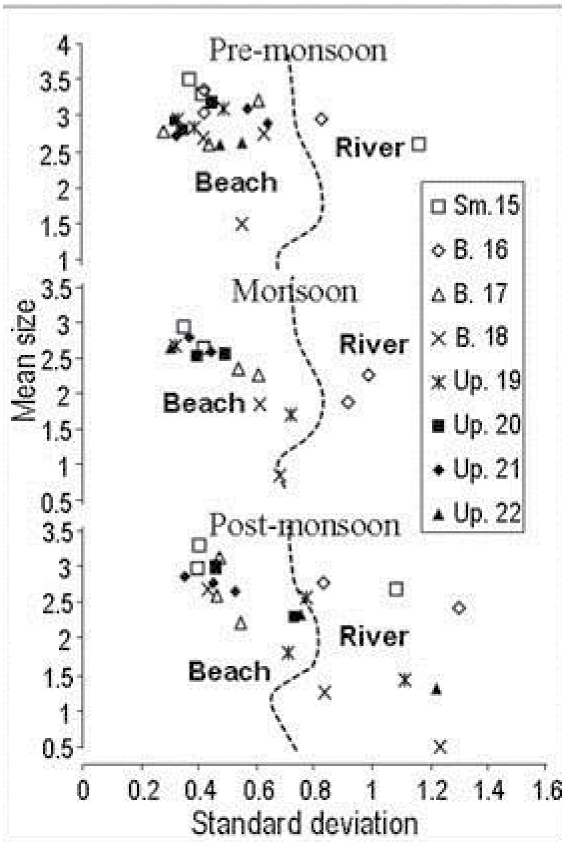

Figure 9: Bivariant plot, Mean grain size versus Standard deviation (after, Friedman, 1967) indicating riverine characteristics of the foreshore sediments at the central part of the mainland.

sediments have tendency to creep back on to the shore. The breaking waves sweep across the crest of the bar and transfer the materials from the seaward side to the landward side, resulting in their migration to the landward side [33]. This results in replenishment of the foreshore sediments.

It is generally agreed that distal ends of the spits point to the direction of net sediment drift [5,6]. Development of diverging spit requires a special condition, such as alongshore drift in the opposite direction from the sediment divider, and a sheltered effect during the reversal of alongshore drift. These conditions ensure that the developed spits do not erode. Due to NNW oriented coast for the wind approaching from W and WNW generate southerly alongshore drift while for waves approaching from SW generate northerly along shore drift. During February to March for nearly normal approach of the waves wide surf zone, fairly well developed land sea breez [25], waves undergo large refraction leading to wave divergence and convergence. In the study area, the distal ends of the spits across the Baindur and the Uppunda point spit grew towards the north and south, respectively; therefore, the alongshore drift from a sediment divider generally from the zone of wave divergence. In the zone of divergence due to low wave energy, deposition occurs [17] and the foreshore grew convex seaward, further facilitating the divergence of waves. Therefore, sediment movement occurred on either side. The narrow range in the grain-size values – from medium to fine-size and moderately sorted to well-sorted sands imply that limited variation in wave energies appear to be conducive for spit growth; strong wave actions, tidal currents, or river forces may erode the spits.

In the study area, the flow in the river is not sufficient to cut across the spits during low-flow conditions (when it is not a monsoon season). On the contrary, the rivers that intersect the coast obstruct the alongshore drift, favoring sediment deposition at the obstruction point and causing spits to develop while protecting the spits when the alongshore current is from the opposite direction. As the southerly alongshore drift reached the river from north, it terminated at the river and depositing materials there while the portion to the south of the river mouth was protected through the shelter effect of the river. Further south of the mouth, the southerly alongshore drift was contributed sediments to the southerly growing spit. Many studies have indicated that a beach length ~0.5 km is sufficient to develop alongshore drift [34,14]. This implies that the longer the beach, the larger the alongshore drift. In a long beach, a significant quantity of alongshore drift can occur on both sides, leading to diverging spit system.

For a spit to develop sediment supply is another important factor, especially when both the rivers are separated by a short distance and have small catchments. These sources can include local sources (from mainland shoreline erosion) and riverine and offshore sources. Textural characteristics indicated both positive and negative skewedness at stn B18 and Up19 (Figure 7), which suggest that these two locations are in the flux zone [14,29,35,36]. These imply that during the monsoon, river sediments that were deposited in the near-shore moved landward during the on-shore swell to the central part of the shoreline (stn. B18 and Up19). They then moved by alongshore drift, leading to spit growth one north to the north of the influx zone (B18 and another to the south of the Up19, respectively). A process of foreshore accretion at the expense of offshore reservoir of sands [17,26] along with textural characteristics corroborates the mechanism explained above.

Implications

Spit growth, narrowing of the river mouths, shifting of the river moths, and erosion of the opposite banks are common problems along the central west coast of India [16]. Experience has revealed that sea walls constructed to prevent erosion of the opposite bank did not help to prevent erosion, because of the pressure induced due to spit growths, sea walls are collapsed [17]. Erosion of the spit-end and movement of the materials into the estuary and causing siltation in the estuary are also common. To prevent this, dredging is often adopted along the coast. However, dredging is a recurring cost. Therefore, prevention of the spit growth and checking the growth rate of the spit is considered a viable means of coastal zone management under the circumstances. The foregoing account indicates that diverging spits are related to wave divergence. Wave divergence occurs due to shoal features, a convex part of the beach, or hard structures such as rocky parts. All of these can cause wave divergence and act as a sediment divider that later develops into alongshore drifts and lead to spit growth. To limit spit growth under such circumstances, sediment influx into the zone of divergence can be controlled or sand mining can be performed in the zone of wave divergence. However, care must be taken so that these actions do not lead to sediment-starved waves, which can then cause erosion elsewhere. For instances, during the monsoon all stations experience erosion, while during beach growth, sediment influx is at stns. B18 and Up20. Sand mining in these two locations during the period of accretion theoretically should help to check spit growths. The quantity of mining must be equal to the materials that are deposited in the location. Hence studies such as the one presented in this paper enable more efficient management of coasts.

Conclusions

From the above discussion, we conclude that for diverging spits to develop it is essential that there is a sediment divider, alongshore drift on either side from the divider, sediment influx, and a sheltered effect. Along the tropical coast, a reversal in the direction of the alongshore drift is common due to cyclic variation in wave approach; therefore, alongshore drifts in both directions occur. Geomorphic features such as a sediment divider are due to the emergent and submerging nature of the shoreline, long shoreline to develop alongshore transport and sediment influx exist, hence, diverging spits develop. Small rivers joining the sea are not only a source of sediments, but also help to terminate the alongshore drift, and provide shelter for the opposite side, favoring development of diverging spit. Knowledge of the mechanisms of spit development can be used for efficient and cost effective management of the coast.

Acknowledgements

The authors are thankful to the Ministry of Earth Science, Government of India and to the Ocean and Atmospheric Science and Technology Cell in Marine Geology and Geophysics of -Mangalore University for the financial support in the form of Project grants (MoES/11-MRDF/1/47/p/06) during the tenure of which the above work was carried out. The authors also thank the authorities of the SDMCET Dharwad for the facility extended to carry out the work.

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