

Influence of morphodynamic variability over seasonal beach sediments and its probable effect on coastal development.

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Abstract

Seasonal variations and effect of oceanographic processes such as erosion and / or accretion along beaches are important to understand their impact on coastal morphological variations. Detailed investigations were taken up to analyse the volumetric and morphologic variations of the beaches between Pirwadi (latitude 16° 12' N, longitude 73° 26.55' E) and Sarjekot (latitude 16° 05' N, longitude 73° 27.80' E) of South Maharashtra, Central West Coast of India. This stretch is known for its rich deposits of ilmenite, magnetite and chromite. This study is based on the results of seasonal topographic profiles carried out between October 2004 and December 2005. The volume variations of the sediments i.e., an account of accretion and / or erosion was estimated considering the October 2004 profile as the base reference, over which the values of other seasons are compared. The results of beach profiling from Pirwadi to Talashil indicate the seasonal variations in the beach configuration and the gradient. Maximum sand accumulation was found at Tondavali (beach profile BP 3) during December 2005, resulting in an increase of about 57% of volume. Severe erosion was noticed at Tondavali (BP 4) during August 2005 resulting in a loss of about 139% of volume compared to October 2004. Erosion has resulted due to changes in intensity of oceanographic process due to variable coastal configuration, beach gradient, waves, rip currents and epehermal monsoonal seaward streams, while deposition is influenced due to littoral currents and contribution of river sediments near the mouth region. Therefore, considering the sensitivity of the fragile coastal system. The future developmental activities (mining, tourism etc) need to be planned in tandem with the required protective measures.

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Introduction

The variations in coastal morphology and sediments mainly depend upon local environmental conditions, sediment type contributed, wave conditions, nature of beaches, surf zones (dissipative or reflective or intermediate) and coastal configuration. The temporal and spatial variations result not only in depositional morphology but also in hydrodynamic behavior (Wright and Short, 1984)

Several studies regarding the morphodynamic variabilities have been carried out along Australian beaches (Bessa and Angulo, 2003; Gruber et al. 2003; Luciana et al. 2003; Short ,1979a; Short, 1979b; Short and Wright, 1981; Wright and Short,1984; Wright et al. 1979a; 1979b; 1982a; 1982b; 1982c; 1983) studied the volumetric variations, equilibrium of beach, shore face profile and seasonal changes in beach profiles along South Brazil while (Khoshnavan, 2007) evaluated morphodynamics along beaches of Caspian Sea coast. Similar studies were mainly carried out along the south-west coast of India where rich deposits of heavy mineral placers are present. These studies were mainly related to the hydrodynamic processes and heavy mineral budget (Baba, 1979; Black et al. 2008; Hameed et al. 2007; Malik et al. 1987; Moni, 1980; Murty and Varadachari, 1980; Prakash et al, 2007; Rajith et al. 2008).

The southern coastline of Maharashtra, Central West Coast of India, is known for its rich placer deposits of ilmenite, magnetite and chromite (Gujar et al. 2004; 2008; 2010) which are derived from the Pre-Cambrian and Mesozoic rocks (Gujar et al. 2009) Besides the influence of strong monsoonal waves, in future placer sand mining in the area could decide the trend of beach erosion. As there is a close linkage between the beaches and the inner shelf areas, the effect of placer sand mining could be experienced on the beaches as long as the quantum of mined sand is either equal to or greater than the replenishment of sand from nearby areas by natural processes. Severe erosion could result in the event the quantum of mining crosses the limit. Although placer sand mining may cause erosion along the beaches and inner shelf areas, the extent of mining and time taken for the impact could be long if the volume of sand extracted is less than that brought and deposited on the beach by natural processes (Prakash et al, 2007; Rajith et al. 2008) However, so far no detail investigations were taken up to understand the seasonal morphological variations of the beaches and trends of depletion and replenishment of the beach placers.

Our objective was to analyse the volumetric and morphologic variations of the beaches between Pirwadi (latitude 16° 12' N, longitude 73° 26.55' E) and Sarjekot (latitude 16° 05' N, longitude 73° 27.80' E) South Maharashtra, Central West Coast of India (Fig. 1) and their implications on the coastal developmental activities. This study is based on the results of seasonal topographic profiling and sediment sampling carried out between October 2004 and December 2005, under the aegis of the national project on beach placers.

Methodology

Seasonal beach profiling (BP) was initiated from post-monsoon in October 2004, followed by pre-monsoon profiling between March and April 2005 and subsequently, monsoon season profiling was undertaken in August 2005. In addition to these profiles one additional profiling was carried out between November and December 2005 to observe the post-monsoon variations, if any. Eight topographic profiles across the study area were established (seasonally) between October 2004 and December 2005. Bench mark pillars were set up at all the eight sites (BP 1 to BP 8). Ceeducer DGPS (Differential Global Positioning System) was used for obtaining the horizontal location (Geographical co-ordinates) of these benchmarks. The vertical control of these benchmarks was carried out by observing the tidal variations on that particular day (two high waters and two low waters) and later reduced to mean sea level (Table 1). For this the Malvan Harbour predicted tide table (2004) published by Maharashtra Maritime Board was used.

The vertical spot heights during the profiling were determined using an automatic level (Carl Zeiss make) and the calculations of the beach sediment volume variations were performed using a software (in GWBASIC) developed by (Ganesan, 2006). The main inputs for this program are the vertical heights reduced to mean sea level and the distance interval between successive locations along the profile.

The logic of computation is that along the profile from the benchmark pillar, quadrilateral blocks are made at distance of 5 m interval. Consequently we have two vertical heights and one distance between two successive locations along the profile (from mean sea level). This becomes a quadrilateral, whose area can be computed by splitting the quadrilateral into a rectangle and a right angled triangle (Fig. 2). The area of the rectangle = (K x D) or (J x D) where "K" or "J" are vertical heights. The area of the right angled triangle = $\frac{1}{2}$ (a x D), where "a" is the vertical side of the triangle (obtained by getting the difference from the two vertical sides of the quadrilateral (J-K) and "D" is the distance between data

points. The total of the above two components would give the area of the quadrilateral. The volume of sand / mineral can be computed by multiplying the area of the quadrilateral into 1 m width of the beach, which gives volume in cubic meters per meter length of the beach.

Wave refraction patterns for SW, NW and W directions for periods 6, 8, 10, 12 and 14 seconds were obtained using Mike 21, a software developed by Danish Hydraulic Institute, Denmark, and these patterns were used for delineating the wave energy conditions (based on wave heights) prevailing in the area. Representative sediment sampling was carried out all along the area. The samples were studied for their grain size statistical parameters and heavy mineral content following (Folk, 1968)

Geomorphology of the area

The area under investigation forms a part of the Southern Maharashtra coast line. The coastline is oriented in North-North West to South-South East direction and is represented by a narrow submerged coastal plain lying between rivers Achara in the north and Gad in the south, (Gujar et al. 2010) (Fig. 1). The offshore islands (Fig. 1) in the area probably are the remnants of the headlands that were detached either due to erosion or tectonic activity. The coastal strip is about 90-150 m wide, has a gentle to moderate foreshore backed by a narrow berm and sand dune ridges of variable dimensions. A sand bar situated at the mouth of the river Gad has beaches on its seaward limits, a tapering end on the river side and is oblique on the sea side. These features suggest that the waves help in keeping the inlet open (Karlekar, 1981). The river mouths of Achara and Gad are drowned with about 1/3rd of their lower courses being under the influence of tide while in upstream the steep sided river valleys do not show widening indicating recent developments of the drainage patterns.

The study area falls under humid tropical zone with an annual rainfall of the order of 2500 to 3000 mm while the wave climate does not change much along the area. The tidal range in the area varies from 1 to 2 m. The predominant wave directions are from SW, NW, and W with periods ranging from 6 to 14 seconds (Folk, 1968; Ganesan, 2006; Gujar et al. 2008; 2009; 2010; Karlekar, 1981; Reddy, 1976). The average breaking height of the wave changes from season to season (0.03 m in winter and 2.20 m in monsoon) and with variable long shore transport rates during different seasons. For the waves from SW, the direction of sediment transport is towards north and for the waves from west the sediment transport is not likely to be in one direction whereas for the waves from NW, the sediment transport tendency is towards south. However, on the whole the long shore transport direction is greater towards south than in the north (Chandramohan et al. 1989; 1993). These longshore currents flow parallel to the coast and

results in rip currents that flow perpendicular to the coast near the lower reaches of Tondavali (Fig. 1). A study of aerial photographs showed the presence of these rip currents (Wagle 1987). These rip currents are generated due to variations in the nearshore topography, rocky outcrops along the coast and presence of islands and cause erosion of sediments from surf zone during the period of high wave energy.

Beach Morphology

The beaches presently investigated are Pirwadi, Hirlewadi, Bagwadi, Tondavali (upper and lower) and Talashil (Fig. 1). The beaches in the north and south are bounded by promontories (Aadwadi in the North and Sarjekot in the South) and forms a part of a sand bar and have a linear configuration with minor variations mainly at lower Tondavali and in the area between Upper Tondavali and Bagwadi. Similar variations in the configuration are also present between Talashil and Bagwadi whereas north of Bagwadi upto Pirwadi a straight stretch of beach is present.

A seasonal change in the gradient of the beaches is conspicuous (Table 2). During pre-monsoon time the gradient of the beaches ranges from 1:11 to 1:70 in foreshore and 1:10 to 1:50 in backshore, during monsoon the foreshore gradient ranges from 1:10 to 1:23 and backshore from 1:11 to 1:60; while during post-monsoon the foreshore gradient ranges from 1:12 to 1:90 and backshore from 1:10 to 1:80 (Table 3). The beaches are dissipative in nature and waves are the dominating forces that lead to their modifications. The backshore area (beyond the existing high tide line) is represented by berms and sand dunes with vegetations (Fig. 3a). Berms are narrow in width and two to five sand dune ridges of variable heights (1-4 m) are observed almost throughout the area. The significant morphological changes that occur during the monsoon season mainly take place due to the combined effect of heavy wind and monsoonal waves. The waves reach even upto the frontal sand dune ridges (100 m at BP1 and BP4 and 145 m at BP7 from the low tide line to the shore, Fig. 1) and result in an under cutting of the dunes leading to exposure of the heavy mineral-rich layers also slumped material commonly occur at the base of the dunes and berms (Fig. 3b). Furthermore, some of the sand, rich in the heavy minerals, gets transported seawards due to the effect of strong retreating currents generated by these waves.

During periods of heavy monsoon, the run-offs from the adjacent coastal land, fills up the intermittent gap located leeward side of the dunes. This leads to the formation of runnel-like features along which the water flows continuously parallel to the shore line. On reaching an outlet the temporary monsoonal stream cuts across the beach to meet the sea (Fig. 3c). Such features are mostly noticed in the

northern area between Hirlewadi and Bagwadi, where the temporary monsoonal streams carries with them sediments laden with heavy minerals.

Another note worthy feature formed during the monsoon season is temporary berms in the inter-tidal region that have accumulation of heavy minerals (Fig. 3d). These berms were seen to shift according to the wave direction and beach configuration. The sand bar in the area south of Talashil (Fig. 3e) undergoes morphological changes during the monsoon. Due to heavy flooding, the river Gad enters in to the backshore area through a narrow passage just a few meters south of beach profile BP 1 (Fig. 3f). Around the same place, in the foreshore region the configuration of the beach changes from semi-arcuate to arcuate due to heavy erosion by waves.

Results

The 8 beach profiles obtained between October 2004 and December 2005 are presented in figure 4 and table 3. The volume variations of the sediments i.e., an account of accretion and erosion, was estimated with reference to the October 2004 profile which was taken as base, with which the values of other seasons are compared and these are presented in table 3. In addition, the details of wave heights, prevailing directions and periods are shown in table 4. As indicated earlier, based on the wave height data obtained through wave refraction patterns, the areas dominated by higher wave height (>1.1 m) has obviously higher energy condition whereas in the other areas with low wave height (< 0.05 m) and areas with moderately high wave height (0.9-1.0 m), the energy conditions are low to moderate. The area-wise results (north to south) are presented below.

Pirwadi (BP 8): The Pirwadi beach is about 1.3 km in length and semi-arcuate in shape and trends in a NNW-SSE direction. This beach is bounded on the north by Achara River mouth and a promontory at Aadwadi (Fig. 1). The wave dynamics in the area are of a mixed type with high wave energy from SW and W directions and moderately high wave energy from the NW direction (Table 4). This beach shows limited sediment displacement during pre- and post-monsoons and depicts 43% of erosion during monsoon. In the pre-monsoon season, the area shows about 7% accretion.

The gradient of the beach varies from 1:10 during to monsoon to 1:34 during pre-monsoon. The sediments in the area are moderately sorted fine sands with mesokurtic nature, both in the foreshore and backshore. In the foreshore the sands are coarsely skewed, while in the backshore the skewness is nearly symmetrical.

Hirlewadi (BP 7): The beach is nearly straight with a NNW-SSE orientation and extends for approximately 2 km. The beach width is about 140 m of which about 100 m is foreshore and the rest constitutes the backshore area. The wave energy conditions in the area for all the pre-dominant waves – SW, NW and W – are high (Table 4). The area shows accretion up to 42% during pre-monsoon season and up to 22% in the post-monsoon period (Table 3). Surprisingly, inspite of a high energy condition, the area shows nearly 4% of accretion even during the monsoon. The gradient in the area changes from season to season i.e., 1:15 (pre-monsoon) to 1:58 (post-monsoon) (Table 2) while in the monsoon both foreshore and backshore areas have nearly similar gradient (1:20). The sediments in the beach are represented by well sorted fine sand with leptokurtic kurtosis. In the foreshore the sediments are strongly coarse skewed while in the backshore they are nearly symmetrically skewed. Such examples are observed in many places along California, North Carolina, Maryland and Egypt [Inman and Jenkins, 2003].

Bagwadi (BP 6): Bagwadi is a semi-arcuate beach of about 2.2 km long and trends in a NNW-SSE direction. The beach shows a minor undulation south of BP 6 (Fig. 1). The area in this zone is slightly more arcuate compared to that to the north. The volumetric variations in the sediments in the area show accretion during pre- and also during post-monsoon. The level of accretion is nearly 20% during pre-monsoon and 17% during post-monsoon. Unlike the other areas, this area also shows removal (erosion) of the sediments to the tune of 48% during monsoon. The wave energy conditions in the area for all the three directional waves i.e., SW, NW and W show predominance of moderate to high conditions (Table 4). The gradient in the area shows variations from (1:11) pre-monsoon to (1:26) monsoon (Table 2).

The sediments in the area are moderately well sorted fine sands in the foreshore, and well sorted fine sands in the backshore with mesokurtic kurtosis. The foreshore sediments are coarsely skewed due to removal of finer fraction whereas in the backshore these are symmetrically skewed.

Tondavali (BP 5, 4 and 3): The Tondavali beach is about 3.4 km in length and extends from Upper to Lower Tondavali (Fig. 1). The configuration of the beach changes from N to S. In the north, it shows a nearly straight beach at profiles BP 5 and BP 4, while at BP 3 and the area between BP 5 and 4, it is semi-arcuate in nature. The gradient is variable and ranges from 1:4 to 1:23 in the entire area (Table 2). The accumulation and erosional trend shows that at BP 5 accretion of sediment ranges, both in the pre- and post-monsoon, to around 5% while at BP 3 up to 10% accretion is noticed during pre-monsoon and up to 57% in the post-monsoon. In both the cases erosion prevails during monsoon, at BP 3 erosion is to

the level of 58% while at BP 5 it is only about 8%. Compared to these two locations, the central profile in this area (BP 4) shows erosional trends in all the three seasons. Here the quantum of erosion varies from about 8% in pre-monsoon to 139% during the monsoon. During monsoon season the waves reach up to the frontal dune area in the backshore and removes sediments rich in heavy minerals from the dune area (Fig. 3 a, b). In addition to this, formation of temporary berms is also noticed in this area just around location BP 3 (Fig. 3d). This feature has resulted due to the deposition of the material that slumped from the frontal dune (Fig. 3 a, b) and also by addition of eroded material that are brought to the area by littoral currents from the adjacent location BP 4. Similar observations were also made of the beaches in Australia (Short, 1979a; 1979b; Wright et al. 1982c; 1981). The sediments in the foreshore area are moderately sorted, strongly coarse skewed fine sand with mesokurtic kurtosis, while in the backshore the sediments are moderately well sorted nearly symmetrically fine sands with platykurtic kurtosis.

Talashil (BP 2 and 1): The Talashil beach has a semi-arcuate configuration and the coast line is about 3.6 km in length and trends NNW-SSE. The gradients in the foreshore and backshore show seasonal variations (Table 2). The sediments in the foreshore are moderately well sorted, finely skewed, mesokurtic fine sand whereas in the backshore they are well sorted coarsely skewed, mesokurtic fine sand. The sediments in the area show an erosional trend at both the locations for the pre-monsoon and monsoon seasons with a very minor percentage of accumulation (2.54%) during post-monsoon (Table 3). The wave climate in the area for SW wave is moderate to high and for West and North West wave, it is high. The sediment accumulation is 0.4% at BP 2 and around 2% at BP 1 (Table 3).

Discussions

Each of the physiographic feature in the study area has defined morphodynamic characters depending upon beach geometry, nearshore topographic features, sediment texture, depositional and erosional processes, oceanographic (wave, currents) processes and beach response to different conditions (Khoshnavan, 2007).

The observed erosion at Pirwadi is probably caused due to high energy conditions from SW waves (Table 3) prevailing during monsoon. This higher erosion during the monsoon could be attributed to gradient variations of the beach (Table 2) due to which the monsoonal waves encroach the area even up to the backshore.

The variation in the textural parameters is probably due to the contrast in the morphodynamics in the area. The effects of which are seen in the variation of skewness where the coarse skewed nature of the sediment in the foreshore can be accounted by the removal of the finer fraction due to high energy waves approaching from SW and W. Although the limits of this shore faces can not be clearly defined, the observed effects are perhaps related due to the contrast in the dynamics as also present along the coast of South Brazil (Gruber, 2003).

The similarity in the gradient at Hirlewadi is probably due to the action of high energy waves from all the three prevalent wave directions (SW, NW, W) resulting in their encroachment upto the fore dune area (Fig. 3a). These waves remove sand from the dune which is brought back to the foreshore by the retreating strong monsoonal currents. The slumping of sand rich in heavy minerals from the dune-cut area is clearly seen (Fig. 3b). In addition to this, some contribution of the sediments from the adjacent northern area of Pirwadi can not be ruled out as during monsoon the eroded material from the northern area enters in the surf zone and is transported southwards by the longshore currents. These currents move faster during the monsoon season and spread the material along the beaches and decrease the shore to sea-ward transport which results in sediment accretion. The strongly coarse skewed nature of the sediment in the foreshore attests to this type of sediment movement.

The changes in the gradient at Bagwadi (BP 6) appear to have resulted due to the combined effect of the waves, their retreating strong currents and the observed ephemeral monsoonal streams. These streams flow in an E-W direction across the beach (Fig. 3c) and are fed by the monsoonal hinterland run-off water. This water is accumulated in the depressions or low lying areas between the dune ridges forming a runnel-like feature parallel to the beach. These streams remove sediments from the upper reaches / backshore areas and deposit the same in the mid-tide to low-tide region. Such erosion and accretion alters the observed gradient, and also results in redistribution of heavy minerals from backshore to foreshore zone.

The changes in the frontal dune at Bagwadi is perhaps due to action of rain, wind and waves that erode the sediments and nourishes the adjacent beach during high energy events like monsoon as also reported along Australia and South Brazil (Luciana et al. 2003; Wright et al. 1984).

The overall wave energy condition at Tondavali between profiles BP 5 and BP 3 is moderate to high for the three predominant wave directions (SW, NW and W). In addition to the wave energy condition and the nature of gradient, the other factor which account for the erosional trends is the

presence of rip currents occurring around profile BP 4 (Fig. 1). These rip currents probably erode the sediments from the foreshore region under moderate to high wave conditions and results in heavy erosion at BP 4. The finer sediment texture (mean size 1.80-2.18 avg. 1.99) in this zone is also responsible for intense erosion, since beaches with finer sediments are less stable and prone to erosion than those with coarse sediments (Khoshnavan, 2007).

During the monsoon season, the waves at Talashil reach upto backshore area and affect the frontal dune exposing the heavy mineral stratification and the gradient gets smoothed by deposition of the slumped material from the dune cut as well as the berm. In addition, another significant erosional activity in this area is due to the combined effect of flooding of river Gad and erosion of the foreshore area by heavy monsoonal waves. This occurs in the area south of BP 1 (Fig. 3e, f) and results in the distribution of heavy minerals from backshore to foreshore zone.

As indicated above, another plume of rip currents (Fig. 1) is responsible for the observed erosion at BP 2. In addition, the Tondavali area around profile BP 3 shows 57% sediment accretion in the post-monsoon season and 10% accretion in the pre-monsoon season (Table 3). Such an accretion could result as the location BP 3 lies between two plumes of rip currents. Some of the sediments from BP 4 probably are transported to BP 3 by the littoral or tidal currents accounting for accretion at BP 3. Similarly, minor accretion at BP 1 resulted due to the sediments eroded from BP 2 and transported further south by littoral current. In addition to this the contributions of sediments from Gad River to the areas of BP 1 can not be ruled out.

To summarise the above findings out of all these 5 areas

- (i) Tondavali and Talashil beaches show erosion resulting due to the presence of rip currents, wave dynamics and variation in the coastal configuration within the area. The presence of rip currents especially at BP 4 which show high erosion and seasonal changes in the beach gradient is noteworthy.
- (ii) Areas north of Tondavali i.e. Bagwadi and Pirwadi also show erosion but to a lesser extent as a result of the presence of epehermal monsoonal stream at Bagwadi and also due to wave dynamics and seasonal changes in the beach gradient.
- (iii) The area of Hirlewadi depicts depositional trends throughout the year that resulted by the action of littoral currents that transport the sediment from north to south.

Implication of the study

The study area is known for its substantial accumulation of placer minerals like ilmenite, magnetite and chromite (Gujar 2010). The possible exploitation of these minerals in future may create natural crises related to severe erosion, modifications of the coastal configuration, possible local changes in the sea level and of the ecosystem.

These factors would affect the human settlement and the proposed tourism projects along the coastal belt. Along the Tondavali at profile location BP 4 where the rip currents are observed the high erosion is noticed in all the three season (range 8-140 %, Table 3). In addition to sediment erosion these rip currents, especially during the tidal cycles with longer wave period when they would have higher velocities, also pose danger for beachgoers and weak or non-swimmers. Furthermore, in view of the observed erosion along the more vulnerable areas, in the order of decreasing erosion, like Tondavali, Talashil and Pirwadi beaches (Table 3) which have a more or less a similar coastal configuration (semi-arcuate to straight) and the foreshore regions showing seasonal changes in the beach gradient (Table 2), it may be pragmatic to construct a sea wall to reflect and dissipate the wave energy and thus avoid or reduce beach erosion (Brunn and Nayak, 1980). The design of the sea wall could be finalised after a proper assessment of cost to benefit ratio which may be in accordance with the facilities and developments that would be created along the coastal strip. However, a reinforced concrete wall along with locally available rocks could be used to construct a curved sea wall and with the placement of tetrapods at the base to provide additional protection to the toe of the sea wall. Such a wall would help to prevent the wave over-topping the wall and also would reduce the wave energy and reflect the waves back to the sea. For the areas that are less vulnerable to erosion i.e. Bagwadi, a low cost bulkhead or sand bags or geotextiles could be used to minimise beach erosion. Geotextiles covering completely the slope area of the beach could either be water tight or porous to allow the water to percolate during the breaking of the waves.

Furthermore, the areas where rip currents are active i.e., the area between BP4 and BP2 along lower Tondavali (Fig. 1) there is a need to demarcate areas for protection of beachgoers, swimmers and water sports activities. In addition, artificial nurturing of the beaches is another measure to restore and maintain the equilibrium of the sand budget. This can be achieved by depositing the unwanted portion of the sand back into place after removal of the heavy minerals. Such a process would also help to maintain the sand budget and to a certain extent restore the biological community. During the environmental

impact assessment study, similar experiments along the Kalbadevi beach which is ~100 km north from the present study area have shown the success of such a venture (Fernandes et al. 2007; Sivadas et al. 2005).

Hence, taking into account the sensitivity of the study area any developmental activity such as placer mining, mineral industry, tourism or any other progress must be carefully considered. This would require detailed investigations encompassing a comprehensive study of environmental impact analysis, risk assessment, seasonal sediment budgeting etc.

Conclusions

The results of the seasonal beach profiling from Pirwadi to Talashil in Maharashtra, indicate that though this region is a continuous stretch of beach of 12.5 km long, but seasonal variations in the configuration and in the gradient of the beaches have been noted at different locations. Similarly, the wave energy conditions also vary from moderately high to high and this coupled with variable coast line configurations, slope of the beaches along with littoral and rip currents are responsible for the observed erosional (more vulnerable areas are Tondavali, Talashil and Pirwadi and less vulnerable area of Bagwadi) and depositional trends (at Hirlewadi). Protective measures such as reinforced concrete sea wall with tetrapods at the toe of the wall in the more vulnerable areas and geotextiles in less vulnerable areas are suggested. These factors would significantly influence the spatial and temporal variations in heavy mineral accumulation in the study area.

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Fig. 3. Photographic evidences of morphological variations along the study area.

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(b) Dune cut at Hirlewadi with slumped heavy mineral rich sediments.

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(f) Flooding of river Gad in the backshore area of Talashil.

Fig. 4. Seasonal beach profiles of the study area (north to south, BP 8 to BP 1). The zero line represents the mean sea level

Table 1

Area & Profile No	Position		Coastline Configuration, trend and length (km)	Nature of the beach sediments	Vertical Control (m) above M.S.L.
	Latitudes	Longitudes			
Pirwadi (BP-8)	16°11'46.97"	73°26'15.50"	Semi-arcuate, NNW-SSE, 1.21	Moderately well sorted fine sand	+3.964
Hirlewadi (BP-7)	16°10'47.11"	73°26'31.16"	Straight, NNW-SSE, 2.0	Well sorted fine sand	+3.375
Bagwadi (BP-6)	16°09'33.79"	73°26'53.18"	Semi-arcuate, NNW-SSE, 2.2	Moderately to well sorted fine sand	+3.644
Tondavali (BP-5)	16°08'56.07"	73°27'03.20"	Semi-arcuate, NNW-SSE, 3.3	Moderately well sorted fine sand	+4.632
Tondavali (BP-4)	16°07'40.80"	73°27'19.76"			+3.865
Tondavali (BP-3)	16°06'49.89"	73°26'30.67"			+4.790
Talashil (BP-2)	16°06'09.93"	73°27'32.32"	Semi-arcuate, NNW-SSE, 3.5	Moderately well sorted to well sorted fine sand	+4.627
Talashil (BP-1)	16°05'52.81"	73°27'39.70"			+5.665

Table 2

Area / Profile		Gradient			
			Pre-monsoon (March –April 2005)	Monsoon (August 2005)	Post-Monsoon (October 2004)
Pirwadi	BP 8	A	1 : 18	1 : 10	1 : 26
		B	1 : 23	1 : 10	1 : 34
Hirlewadi	BP 7	A	1 : 15	1 : 23	1 : 58
		B	1 : 38	1 : 20	1 : 22
Bagwadi	BP 6	A	1 : 11	1 : 20	1 : 20
		B	1 : 22	1 : 26	1 : 13
Tondavali	BP 5	A	1 : 22	1 : 22	1 : 12
		B	1 : 11	1 : 11	1 : 11
	BP 4	A	1 : 16	1 : 17	1 : 15
		B	1 : 14	1 : 50	1 : 10
	BP 3	A	1 : 23	1 : 14	1 : 50
		B	1 : 50	1 : 40	1 : 80
Talashil	BP 2	A	1 : 13	1 : 20	1 : 90
		B	1 : 10	1 : 13	1 : 16
	BP 1	A	1 : 70	1 : 15	1 : 60
		B	1 : 50	1 : 60	1 : 12.5

Table 3

Location	Profile Name	October 2004 (Base Profile) (Volume)	March 2005	August 2005	December 2005	Width of beach (meters)	Pre-monsoon (From Oct. 2004 to March 2005)	Monsoon (From Oct.2004 to August 2005)	Post-Monsoon (From October 2004 to December 2005)	Remarks
			← in cubic meters →							
Pirwadi	BP 8	138.069	138.023	45.044	93.259	80	+7.06%	-43.61%	-18.12%	Erosion
Hirlewadi	BP 7	86.308	123.064	89.774	109.089	75	+42.59%	+4.02%	+22.78%	Deposition
Bagwadi	BP 6	80.456	97.328	41.453	94.853	60	+20.97%	-48.48%	+17.89%	Erosion
Tondavali	BP 5	183.316	193.120	168.203	190.994	65	+5.35%	-8.24%	+4.19%	No deposition nor erosion
Tondavali	BP 4	225.124	206.592	-88.929	-08.689	100	-8.23%	-139.5%	-103.8%	Heavy erosion
Tondavali	BP 3	107.563	119.278	44.998	169.482	60	+10.89%	-58.17%	+57.56%	Little deposition
Talashil	BP 2	149.720	134.774	138.675	150.342	70	-9.98%	-7.38%	+0.41%	Erosion
Talashil	BP 1	239.428	231.943	192.186	245.503	75	-0.03 %	-19.73%	+2.54%	Erosion

Table 4

Area	South West Waves					North West Waves					West Waves					Remarks
	Wave Period (in seconds)					Wave Period (in seconds)					Wave Period (in seconds)					
	6	8	10	12	14	6	8	10	12	14	6	8	10	12	14	
Pirwadi	M	MH	H	H	H	M	MH	MH-H	H	H	M	MH	H	H	H	H = South West MH = North West H = West
Hirlewadi	M-MH	MH-M	H	H	H	MH	MH-H	H	H	H	MH	MH-H	H	H	H	H = South West H = North West H = West
Bagwadi	M	MH	MH-H	H	H	M	MH	MH	H	H	M	M	MH-H	H	H	MH = South West MH = North West MH = West
Tondavali	M	M-MH	MH-H	H	H	M-MH	M-MH	MH-H	H	H	M	M	MH-H	H	H	MH = South West MH = North West MH = West
Talashil	M	M-MH	MH-H	H	H	MH	MH-H	H	H	H	M-MH	MH-H	H	H	H	MH = South West H = North West H = West

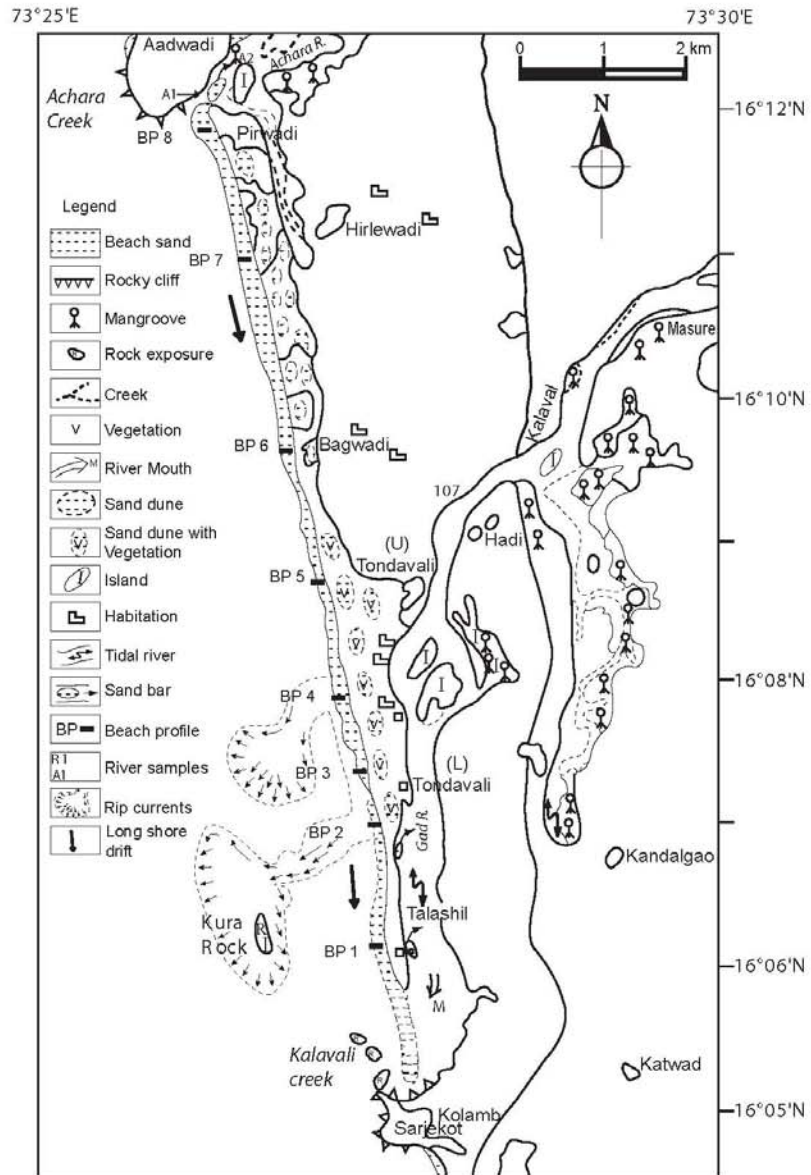


Fig. 1

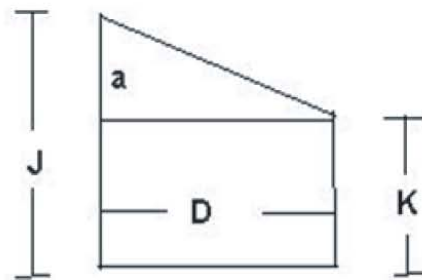
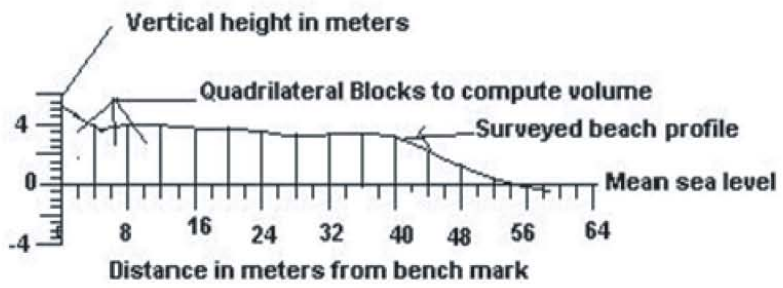


Fig.2

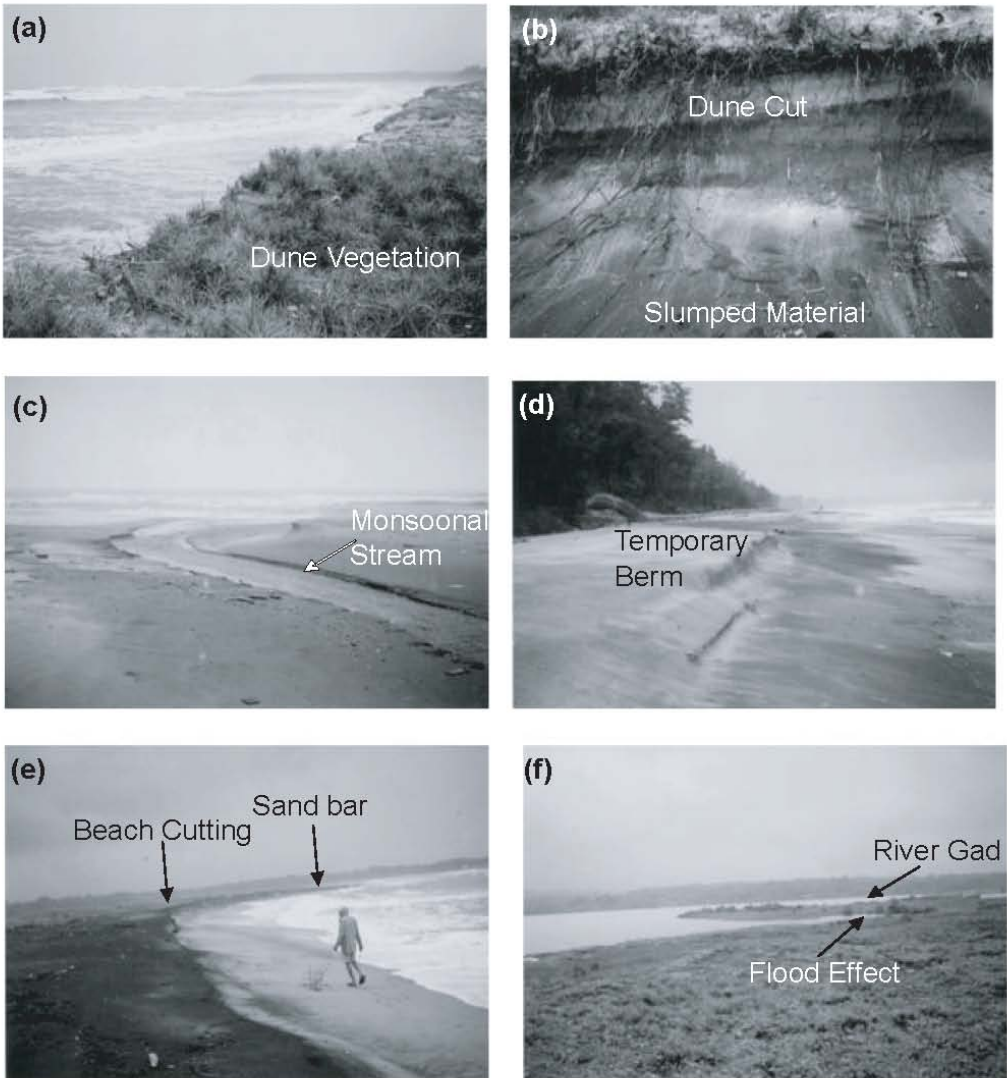
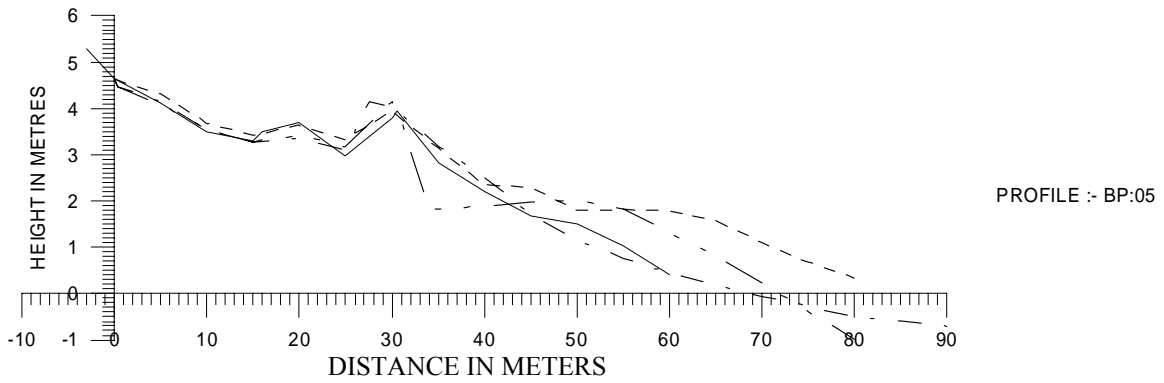
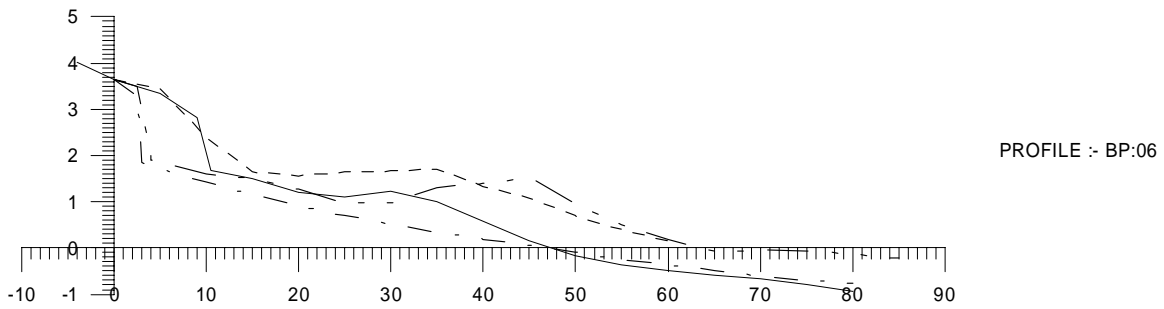
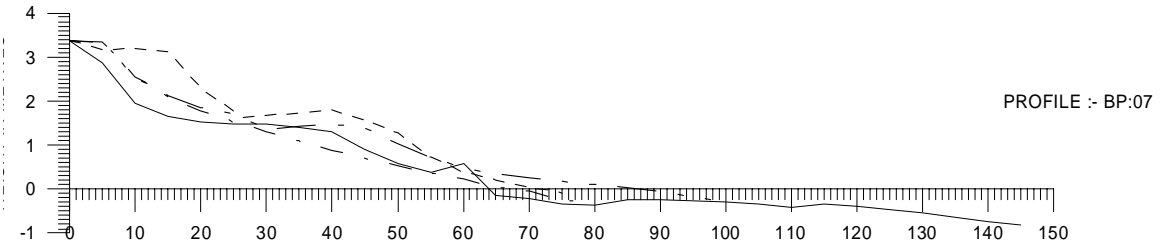
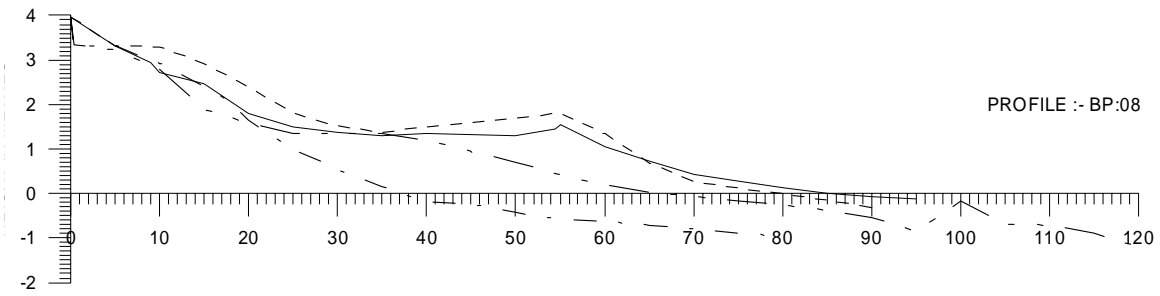


Fig. 3



OCT 2004: _____
 MAR. 2005: - - - - -
 AUG. 2005: — — — — —
 DEC. 2005: — — — — —

Fig.4

