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Inlet Behaviour Induced Changes in the Beach-Dune complex at Valvati, Maharashtra, India

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Abstract

*The present paper examines the inlet behaviour, in terms of the shifts in the inlet location over a span of last eight years (2002-2010), and its impact on the adjacent beach-dune complex. Valvati tidal inlet is observed to exhibit a strong instability in its location and is characterized by seasonal shifts in the ebb channel across the beach with a history of inlet migration over years. The zone of inlet shifts was demarcated and profiles were superimposed for four periods in order to understand the erosion/fill of the beach-dune complex. The Beach-dune complex in the north was found to be more stable and recorded less of variations whereas, the southern section of this complex (closer to the inlet) exhibited maximum variations. These variations were in terms of lowering of the dune crest and erosion on either side as well as formation of an extensive berm. A definite shifting pattern in the inlet location was observed to have direct impact on the lower section of the dune complex. Lowering and recession of the dune complex exhibited changes in the tidal prism at Valvati. The depth at the inlet throat reduced considerably by 2010 (1.24m) as against the 2008 (3m) condition. 2010 condition exhibited a tidal prism of 1.1 * 106 m^3 as against a tidal prism of 9.2 * 106 m^3 in 2008. A strong cyclicity, in terms of the inlet shifts, along with the inlet behavior induced changes in the adjacent beach-dune complex is thus ascertained for this region.*

Keywords: *Inlet, ebb channel, beach-dune, inlet migration, tidal prism*

Introduction

Tidal inlets are the prevalent morphologic features along the coastline that serve as extremely important conduits for the exchange of water and sediments between bays, lagoons or estuaries and the sea (Moslow and Gingerich 1995). They are the most dynamic features along the coast. Complex temporal and spatial interactions of waves, tides, longshore currents and sedimentary structures are observed along the inlets. Though a classical image of an inlet is that of a breach across a barrier island, inlets are certainly not restricted to barrier environments only. Inlets can be cut through unconsolidated shoals or emergent barriers as well as through clay, rock or organic reef (Price, 1968).

There is no simple restrictive definition of an inlet; based on the geologic literature and on regional terminology, almost any opening in the coast, ranging from a few meters to several kilometers wide, can be termed as an inlet (Morang and Parson, 2002). Inlets are important economically as well as ecologically. Because they interrupt the uniformity and continuity of coastal processes and sediment transport, tidal inlets exert a tremendous influence on shoreline erosion/deposition trends, sediment budgets, and migration history (Moslow and Gingerich, 1995). Many tidal inlets are either ephemeral in nature or are associated with rapid large-scale morphologic changes. Thus, the behaviour of the inlets can have extremely significant environmental, social and economic impacts. Similarly, inlets can have significant effects on adjacent shores by interrupting the longshore transport and trapping onshore-offshore moving sand Saleh et al. (2005).

Many tidal inlets naturally migrate alongshore in the direction of net longshore drift. The rate and mechanism of inlet migration vary depending on several factors including wave climate, tidal range, depth of the main channel, nature of the substrate into which the channel is incised, sediment supply, and rate of the longshore transport (Moslow and Gingerich, 1995). Inlets often tend to have a considerable influence on shoreline behavior along adjacent shorelines (Hayes, 1979; Rice and Leatherman, 1983; Bruun, 1996; Galgano, 1998). The dominant role of inlets in controlling the cyclic nature of barrier island morphodynamics was well established by modeling inlet behavior in meso and micro-tidal conditions by Hayes in 1975 and subsequently in 1979. Dean and Walton (1975) suggested that tidal inlets represent the largest sediment sink along the coast, and are believed to be responsible for much of the beach erosion in Florida.

Inlet dynamics can give rise to remarkable alterations of adjacent beaches over time. Nummendal et al. (1977), FitzGerald et al. (1978), Anders et al. (1990), Dean (1991), Dean and Work (1993), Bruun (1996), Mehta (1996) and FitzGerald (1996) suggest that tidal inlets are responsible for most of the beach erosion along U.S. East Coast barrier islands. Galgano (1998) demonstrated that 70% of the barrier beaches along the mid-Atlantic coast are influenced by inlet activity.

A comparison of six inlets by Galgano (2009) along the U.S. Northeast coast demonstrates a consistent pattern of change. According to Galgano (2009) the arc of erosion is a mobile planform feature and its spatial behavior is time dependent. However, this study was restricted to the stabilized inlets. Foster (1991), Cleary (2002) and Galgano, F.A., (2008) had suggested the effects of inlet shifts on the nearshore environment. Hoque et al. (2009) observed that the Karambunai (Sabah, Malaysia) beach is subject to substantial erosional and exhibits updrift erosion due to the inlet dynamics.

Valvati Tidal Inlet

Numerous tidal inlets are observed along the Konkan Coast of Maharashtra. In most of the cases the tidal channels are observed to have developed shoals at various locations leading to common problems like: Channel migration, Navigational problems, updrift beach erosion and barrier breaching. Valvati tidal inlet channel like other inlets also faces the shoaling problem. Valvati tidal inlet has a migratory history which can be traced through the available records such as, Survey of India (SOI) Toposheets of 1925, 1965 and Aerial photograph of 1975 (Wakhare, 2004). However the tidal inlet appeared to have stabilized at the southernmost end of the Beach by 1998 and continued to be located there till October-November 2003. This inlet was characterized by a relatively small, minimum inlet width with a mean value of approximately 21.28 m (varying for different periods under study from 2002 – 2004 between 20 to 120 m). No historic bathymetric surveys exist for the inlet and the adjacent region. Surveys by Wakhare (2002) indicated that the ebb channel thalweg reached a depth of 0.4 m below mean sea level and the tidal prism of 3.1 * 105 m^3 was calculated following the methods given by Escoffier (1940, 1977), Kuelegan and Hall (1950), Kuelegan (1967), King (1974) and Jarret (1976).

Taking in to consideration the inlet behavior it was thought to assess the impact of inlet shifts on the adjacent shoreline: the beach – dune complex in particular. Thus the aim of the present study is to understand the changes brought in the beach-dune complex, as induced by the tidal inlet shifting, under the natural processes. In order to fulfill this aim the objectives set were: i. To assess the temporal variations in the beach-dune plan form. ii. To examine the changes in the position of inlet and iii. To investigate spatio-temporal variations in the beach-dune complex Visa-Vis inlet position and its impact on the tidal prism.

Study Area

The study area, forms a small stretch of western coast of Maharashtra (fig.1). It represents the mouth portion of Valvati stream. The present study is mainly concentrated on the southern portion of Valvati-Aravi beach, the dune complex behind the beach and the tidal inlet interconnecting the beach and the bay. This area lies between 72^0 59' 40" East to 73^0 0' 10" East Longitude and 18^0 4' 10" North to 18^0 5' 4" North latitude. The present area under consideration forms the low lying area (along with the beach and the dune environment) of the basin lying between the Kondvil and the Shrivardhan headlands. Aravi and Valvati villages are located on a fossilized / lithified dune (aeolinite). The study area covers the southern beach, the dune complex and the tidal inlet proper. The morphological set up of the study area is represented in Fig. 2.

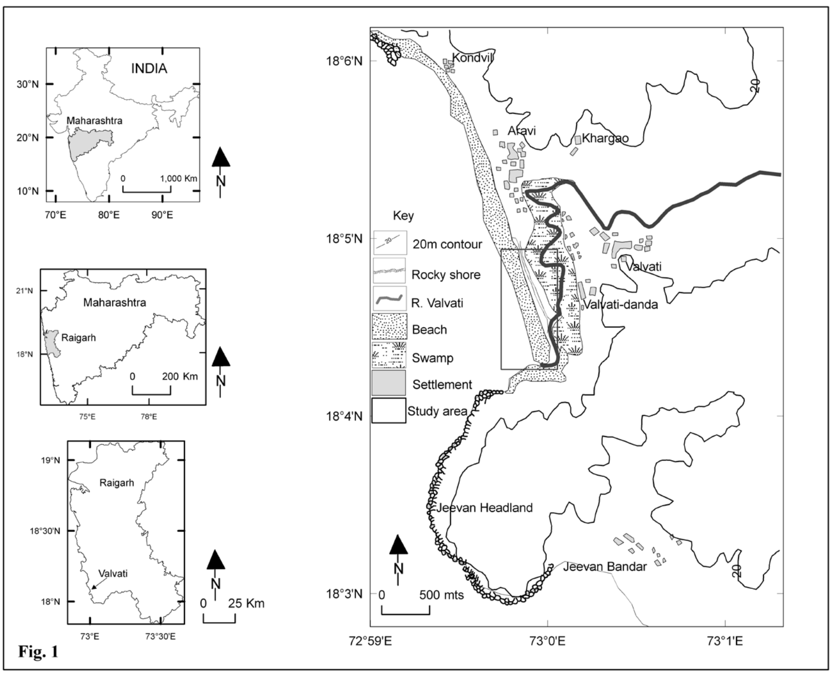

Fig.1 : Location of the study area

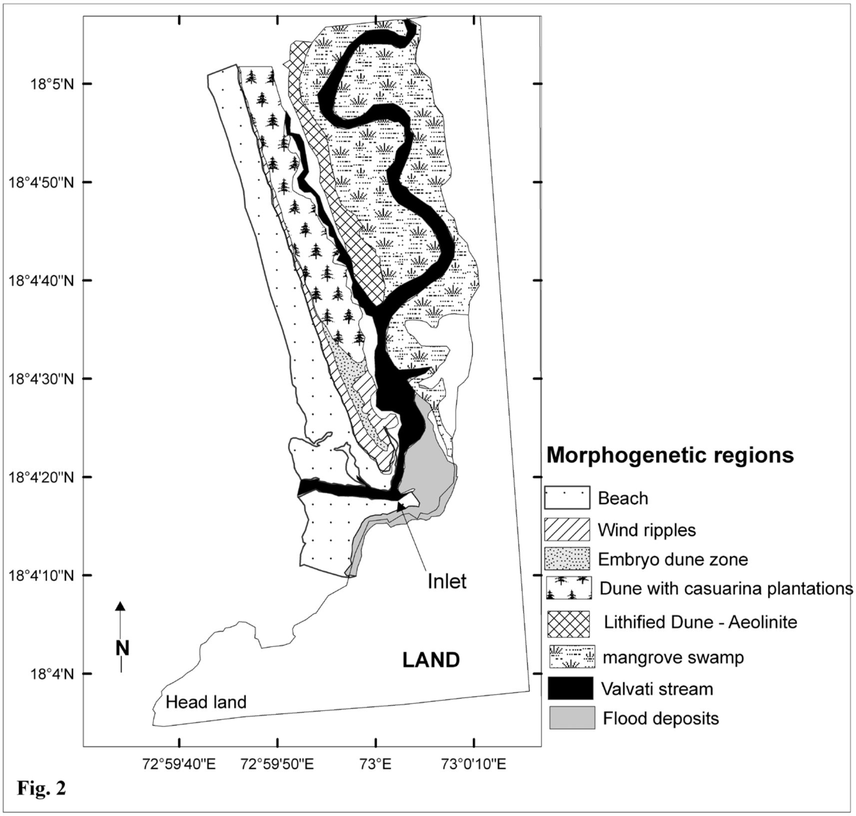

Fig. 2 : Morphological Set-up of the study area

The beach forms one of the major zones of the system. The entire stretch of the beach from Kondvil to the Creek mouth, south of Aravi is about 4 km. The beach is marked with the presence of dune. The dunal range, from the southern point to an extent of 1.5 km, is covered with Casuarina plantation, there after it has exposed dunes. Just behind the dune a small tidal channel fed only by the marine water bifurcates from the main channel. Western bank of it is of the dune and eastern is lithified dune (aeolinite). The exposed portion of the aeolinite is rather static and runs for a length of almost 800 to 900 meters parallel to the present dune and the beach. It separates the smaller tidal channel from the main channel. The main channel, which has its source in the neighbouring coastal hill ranges, travels a distance of around 10.5 km before it drains in to the Arabian Sea. A very small tract of it forms a part of the tidal basin wherein extensive mangroves are observed to have come up. Valvati tidal inlet was selected for the present study as it is characterized by inlet shifts in a natural set-up. This phenomenon is recorded in the past by Wakhare (2002 and 2004).

Methodology

The primary data was generated through field survey. Certain secondary data was collected which was necessary in order to make comparisons and come to the conclusion related to the set aim.

Field Work Component

The fieldwork involved terrestrial surveys to determine the spatial aspects of the forms as well as detailed documentation of the landscape scenario observed in the region. The surveys have been carried out with the Dumpy Level, theodolite and a hand held GPS, whereas for documentation, 'still and video' photography of the region was carried out. The terrestrial surveys were conducted in pre-monsoon season.

The field component was divided into three parts: i. Identification of Bench mark. ii. Beach-Dune and Inlet Plan mapping, and iii. Beach-Dune profiling.

Identification of Bench mark: Before the initiation of the mapping component, it was necessary to identify a reference point, preferably a known point that would serve as a bench mark for the entire survey work. Since certain data was borrowed from surveys carried out earlier (Wakhare, 2002 and 2004) the same location which was considered and marked as bench mark for the earlier studies was again located and marked as the reference point for the present work. The height of this point was recorded as 6m in the earlier studies and the same was maintained in the present study. Thus, all the readings were later on reduced to the scale based on the height of the bench mark as 6m.

Plan mapping: This was done basically using the hand held GPS. The GPS was calibrated and the accuracy level was noted down. Since this is a lower end GPS the heights given by it are not reliable. Thus GPS was used only for locating the points on the ground and not for deducing the elevation values. The entire segment of the Beach, from the portion where the exposed dune starts, up to the tidal channel mouth was traced initially. Similarly the southern beach portion was also mapped. Thus, for the beach portion low tide line, high tide line and the berm line were mapped extensively. Sea ward and land ward dune edges were also mapped using the GPS. Details of the inlet and the channel across the beach were also mapped. This helped in preparation of the plan map and a geomorphic map of the study area.

Beach-Dune profiling: The third component of field work comprised of beach-dune profiling. For this Dumpy level along with GPS was used. At the low tide level 13 -15 pegs were raised with an average spacing of 50-80 m. the geographical locations of these pegs were ascertained with the GPS. These pegs helped in defining the profile line that would be followed during the beach-dune profiling. For profile survey the initial point (bench mark) was taken as the first back sight and the successive readings were taken with the dumpy level. In all ten profiles were generated for the area under consideration.

Analysis and representation of data: The data collected/generated was further put through simple technical analysis in order to derive the necessary variables, which were used for further analysis. Using the conventional methods for deriving the reduced levels, elevation values were obtained for all the profiles. The Beach-Dune profiles were then plotted using the Microsoft Excel Software. The locations of the points surveyed on the beach-dune complex were also plotted manually and then subjected to further analysis in Arc GIS 9.2.

Change detection: In order to bring out the shifts in the location of inlets, the maps prepared were superimposed for the successive years and the net change in the location was analysed. Similarly the changes in the dune extent were also measured by overlay technique in Arc GIS 9.2.

Results and Discussion

Shifts in the Valvati tidal inlet location (Fig.3)

Previous studies carried out by Wakhare (2004) from 1997 to 2002 indicated that the inlet had stabilized and did not exhibit any shifting tendency. The maximum velocity and equilibrium velocity versus inlet cross sectional area plots attempted then, confirmed that the inlet location to be stable. However Wakhare year in her concluding remarks raised some concerns about shoaling of the inlet and possibility of inlet shift in the near future.

During a monsoon storm in 2003 it was noticed that the ebb channel breached the northern bar and the inlet position shifted northward of its previous location (fig.3). The shift in the inlet was around 180m north. As can be seen from the Fig. 3 the inlet repositioned itself where previously the natural casuarina vegetation existed in 2002. The channel across the beach became straight and the down drift bar got attached to the left bank of the ebb channel. As a result of the inlet shift the dune portion suffered from heavy erosion especially at the southern tip along with the sea ward and land ward dune faces. Due to this breach, in 2004 a portion of the natural vegetation that got detached from the northern bar became a part of the southern bar (plate 1b).

Subsequent survey carried out in 2006 revealed the fact that the inlet was unable to scour its gorge and was not able to stabilize itself at the new location. This was evident from the fact that it again shifted 60m south west. This shift had a major impact on the dune portion which can be observed in the Fig. 3. The tip of the southernmost portion of the bar experienced heavy erosion and felling of the casuarina trees as the landward portion of the ebb channel took a sharp bend before moving on to the beach. The remnants of the natural vegetation which were seen in 2004 (plate 1b & c) got completely uprooted as the southern bar also lowered in its height. Most of the depressions were filled by this time though a conspicuous depression remained at the southern most portion of the study area. As it can be seen from the Fig.s 3 & 4, this depression also can be observed in 2008. The down drift bars mostly got attached to the land ward side.

In 2008 the inlet shifted almost 91m south of its 2006 location. The channel across the beach became straight and developed a number of depository features in the sea ward direction suggestive of the possible ebb delta formation. Depressions filled with mega ripples and superimposed current ripples on either side of the channel that moved across the beach indicated the flow conditions during this time. The northern bank of the inlet was near vertical that was subject to active bank erosion due to undercutting currents, while the southern bank was marked by the presence of boulders. The depression mentioned in the Fig.s 3 (that was also conspicuously present in the previous surveys) coincided with location of the ebb channel course of 2002.

The inlet position was noticed to have almost stabilized by 2010 as there was no shift observed in the inlet position from

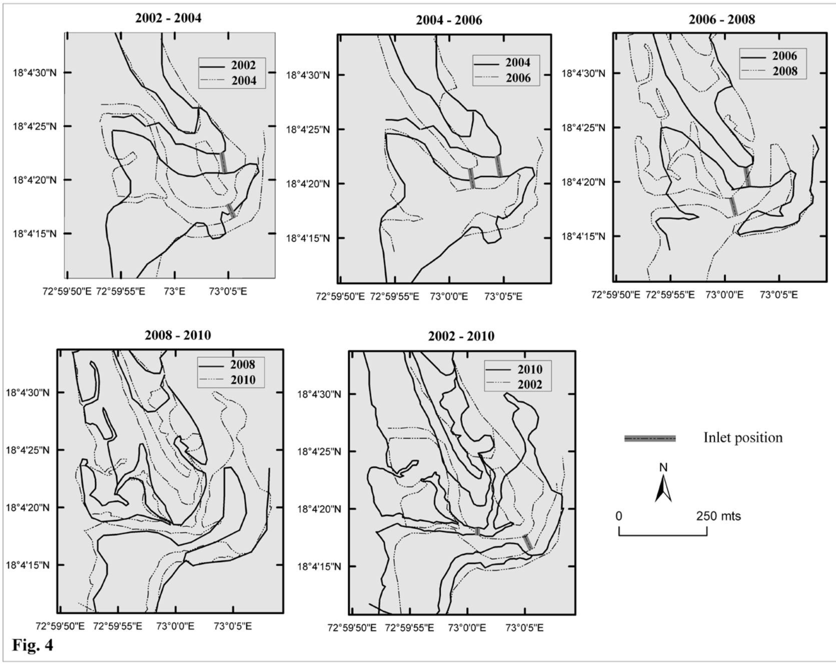

Fig. 4 : Comparative diagrams of the inlet shifts and related changes in the adjacent beach-dune complex (2002-2010)

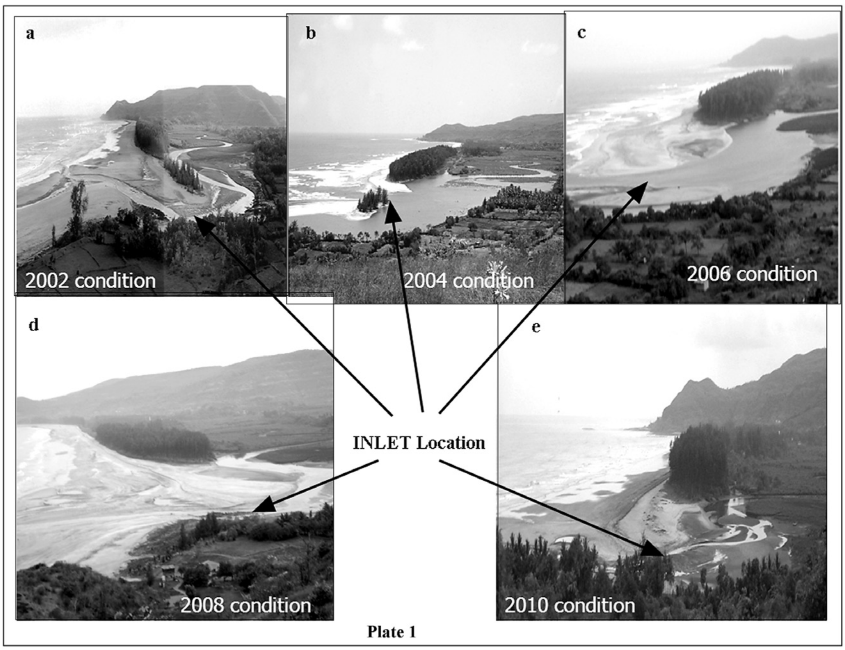

Plate 1 : Location of Valvati Inlet from 2002 to 2010

2008 to 2010. The inlet channel appeared to have silted as the depth was about 1.2m at throat as against 3.0 m in 2008. Extension in bay ward deposits was also noticed. Expansion and increase in height of the northern bar from the 2008 condition was quite evident from the profiles and the marking of high tide level which appeared to have shifted further south by 280 m. A narrow belt of embryo dunes with vegetation was developed by 2010 (plate 1e).

Analyses of the surveyed maps indicate that the orientation and position of the ebb channel have changed repeatedly over time and have dictated much of the changes in the adjacent dune and beach complex in the past decade. In 1995 the channel was much to the north with a straight channel moving across the beach. It started shifting towards south and assumed its location due south in 1998, the shift was of about 72 m SE. Major shifts were not observed during 1998 to 2002. However, during this period the ebb channel across the beach did exhibit shifting tendency. It was this period when the Valvati tidal inlet was more or less stabilized and indicated the formation and stabilization of well developed ebb and flood delta.

Dramatic changes were recorded after 2002 in the direction and rate of movement of the inlet channel (Fig. 4). During the period 2002-2004 the inlet moved 180 m in the northern direction. In the next two years (2004-2006) the channel reversed its direction and moved 60m in the southwest direction. During the same period the remnant bar vegetation was uprooted completely. By 2008 the inlet shifted 91m in south west direction from its location in 2006. On the plan map it can be observed that the inlet position in 2008 and 2010 is much closer to that of the 2002 position and most of the bar that was eroded during the last six years has resurfaced. However there are considerable changes as far as the vertical extent of the bar is concerned. It can be clearly observed that the dune edge has receded from its position in 2002 by almost 261m (northward) by 2010. Inlet location has shifted N-W by 150 m and the tidal channel runs through a straight path in 2010 which appears to be the previous branch of the main channel of 2002 condition. The dune part along with its extended bar in 2002, which was eroded and showed maximum variations in terms of the inlet shifts, appears

Fig. 4 : Bar graph depicting shifts in the Valvati tidal inlet (mid-point) since 1995

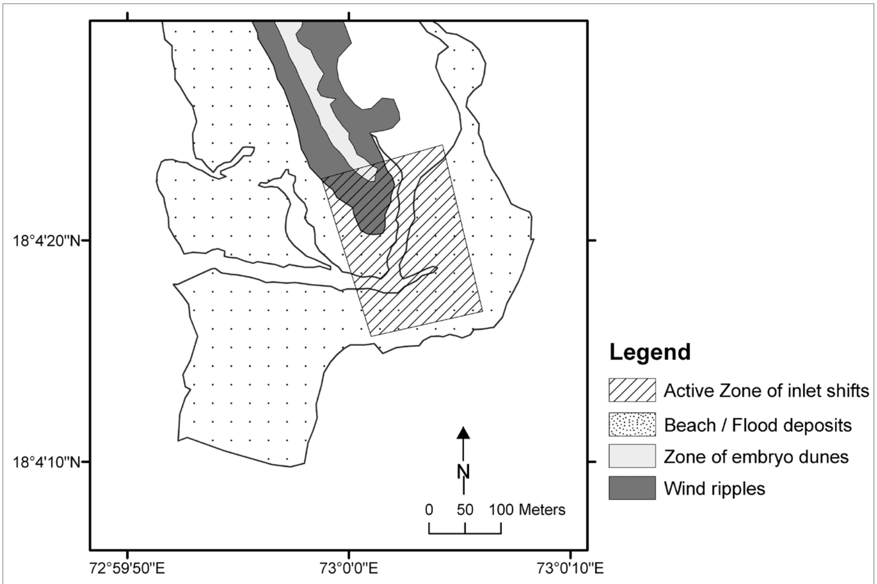

Fig. 5 : Active zone of inlet shifts

to have rebuild again by 2010. In all, a zone of 200m was demarcated as an active zone of inlet shifts (fig. 6).

The changes in terms of the vertical extent of the bar and the beach-dune complex also exhibit changes with respect to the inlet shifts. The changes in the beach-dune complex are recorded for the study period which can be directly attributed to the inlet shifts.

The Valvati Beach-Dune Complex

Valvati beach extends for 4.2 Km and is backed by the dune. The average width of the beach is approximately 120 m. at neap tide and around 140m during spring tide. However the width is not uniform throughout the beach length and the beach becomes narrower especially towards the north. The Dune complex is well established and has a good vegetation cover. A road cuts the continuity of the beach-dune profile in the northern region. Dune portion along the Aravi settlement and south of it has been stabilized by the plantation of casuarina trees in 1990.

For the present study the area south of Aravi settlement is taken in to consideration. Fig. 7 depicts the Dune and beach portion under consideration. The dune complex has an average width of 120m. It runs parallel to the beach for almost 940 m. The bar extends further from the dune edge to the inlet for another 400m. Thus altogether the study area is having a length of about 1340m. The beach in this part has an average width of about 100 to 120 m.

In order to understand the changes in the beach-dune complex due to the inlet shifts it was essential to bring out the vertical changes in the adjacent beach-dune portion. These variations are highlighted below.

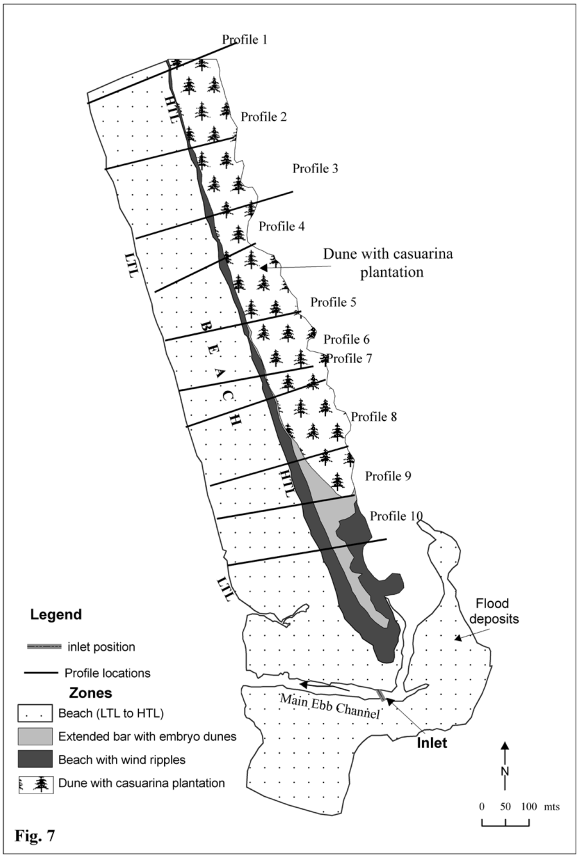

Fig. 6 : Location of the profiles for the beach-dune complex

Variations in the beach-dune profiles

Fig. 7 depicts the locations where the profiles were taken in 2010. Profiles for the previous years were also extracted, for the same locations, from the data generated earlier. Though it is expected that the major changes in the beach plan and profile form would be directly related to the wave energy, and the dune erosion to the major / minor storm conditions, the impact of the inlet behaviour on the adjacent beach- dune region cannot be neglected. Thus profiles for the region, that was thought to be much away from the inlet impact zone, were attempted along with the zones much closer to the inlet position. In all ten profiles were taken. The first and the third profile ran from the lithified dune segment (aeolinite) to the low tide line, while the rest of the profiles extended from the landward dune edge to the low tide line. Ninth profile marked the southernmost limit of the dune. Tenth profile was taken across beach to the bar top and up to the low tide line on the inner channel edge. No profiles were attempted from this location down south as this region was marked as the active zone wherein the inlet exhibited its shifts in the past ten years.

It can be clearly observed that the first profile does not depict any changes as far as the dune portion is concerned. In fact this was the narrowest portion of the dune with a width of 35m. Variations were observed in the inner creek and beach portions; however these cannot be directly attributed to the inlet shifts. Though variations in terms of dune face erosion on the sea ward as well as land ward side are conspicuous. A major deviation (from the 2002 profile through 2006 and up to 2010) is the development of a well established berm. This can be clearly observed in the third profile.

Fifth and sixth profile again follows the same trend that is outlined for the first four profiles. Again berm development is clearly seen. However, sixth profile shows the initiation of the lowering of the dune crest. Lowering of the dune crest, erosion of the sea ward dune face and development of the berm are well marked in the next two profiles. Dune crest lowering of 30 cms and 42 cm is recorded for the profiles seven and eight respectively. Dune face recession by 12m is observed for the profile eight.

Profile number nine is taken exactly at the tip of the dune and indicate overall low dune heights. Dune crest lowering is again observed in this case as well. It is the tenth profile which tends to exhibit maximum variations. This was the region where in 2002 the extended vegetation was marked. By 2008 the bar had lowered considerably (2.45m) and its crest shifted west ward. Beach also indicated overall erosion but accretion towards the low tide line.

A general aspect which can be induced from the beach-dune profiling is presented in the representative profiles from the upper, middle and lower sections of the beach-dune complex (fig. 8 a, b, & c). The upper zone does not exhibit any major variations which can be attributed to the inlet shifts. Though, berm formation is more conspicuous in this section that cannot be attributed to the inlet behaviour. Berm formation and the accretion at the lower end of the beach are indicative of the low energy conditions. This (2008) might be the period of recovery wherein the beach profile shows typical berm formation.

Generalized pattern for the middle section shows much variation in the beach zone along with the berm formation. This zone is not too close to the inlet shift zone, but the fact that the runnel, which at times has shown a tendency to get it self attached to the ebb channel across the beach, might be responsible for the dune face erosion cannot be ruled out.

The lowermost zone is closest to the inlet shift zone and exhibits maximum variations. The variations in terms of the lowering of the dune crest and the bar can directly be attributed to the inlet shifts in this case. As and when the inlet shifted in northward direction it obviously has initiated the erosion process for the beach-dune complex in the immediate neighbourhood. Same thing cannot be spelled out for the northern section. The ebb channel moving across the beach becomes more elongated and follows a curved path as and when the inlet resumes the southward position. The ebb channel moves in a meandering fashion and erodes most of its dune ward banks. This results in the dune face erosion. In case of Valvati, field observations in 2002 clearly indicated this mechanism. As the dune face erodes, the dune position at times may recede. In case of Valvati the erosion of the dune face resulted in uprooting of the casuarinas trees and dune face erosion.

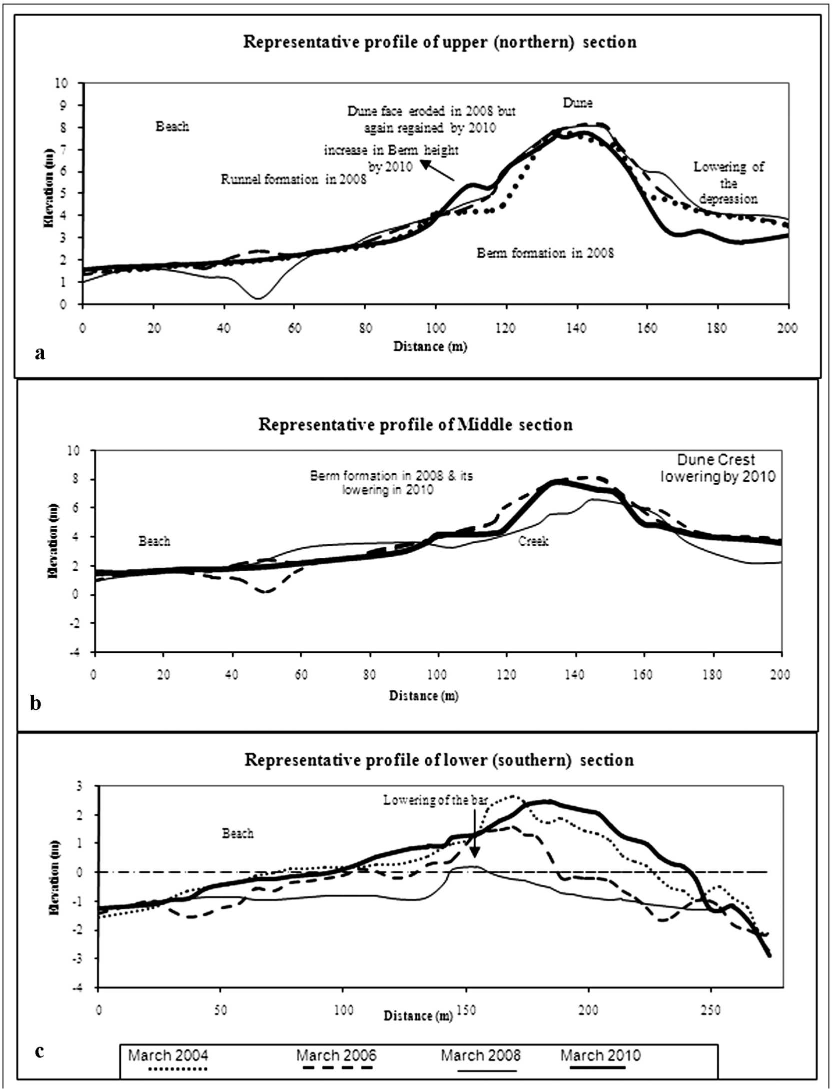

Fig. 7 : Representative profiles of the beach-dune complex

Conclusions

Valvati inlet has a shifting tendency and has exhibited its impact on the adjacent areas. The area specific conditions, which can be stated in the form of conclusions of the present study, are discussed below.

Shifts in the Tidal inlet location:

Overall, Valvati inlet shows a strong tendency of southward shift. This southward shift is also partly due to the presence of the northern barrier. Definite shifts were recorded for Valvati inlet location from 2002 to 2010. A total zone of around 200m is identified as the zone of inlet shifts (2002-2010) (fig. 6).

Recession of the Dune edge:

Dune edge has receded from its position in 2002 by 261m. Entire vegetation patch has disappeared by 2006. The dune edge erosion was accompanied by the dune lowering. Overall, dune face erosion and dune crest lowering was observed. Uprooting of the trees on the seaward face of the dune was a common scene in this area.

Impact of changes in the beach-dune complex on the tidal prism

Definite shifting nature of this tidal inlet has a direct impact on the dune complex which is quite evident from the profiles of the lower section. The lowering and recession of the dune complex increased the tidal inlet prism from 3.1 * 105 m3 in 2002 to 9.2 * 106 m3 in 2008. This has directly affected the low level farms at Khargaon village and the wells at Valvati danda village. The tidal prism computed was much less 1.1 * 106 m3 in 2010 with the inlet depth at throat being only 1.2 m below MSL. The inlet position appeared to be stabilized at the 2008 position along with narrowing and shallowing of the ebb channel.

Extension of the northern bar in southern direction along with the inlet throat shallowing and low tidal prism indicated that the net amount of water getting in to and out of the bay to have considerably gone down. Discussion with the local folks at Valvati, Aravi and Khargaon revealed the fact that the farms have remained safe from the sea water intrusion in these last one year.

The channel depth at the inlet proper and that of the main ebb channel has considerably reduced due to extensive shoaling effect. The channel is unable to scour its gorge and maintain the depth at the inlet. If further shoaling in the ebb channel continues it may lead to the partial or total closure of the inlet. In such a circumstance there is a probability of the inlet to shift its location in near future.

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References

Anders, F.J., Reed, D.W., and Meisburger, E.P., (1990): Shoreline Movements, Report 2, Tybee Island, Georgia to Cape Fear, North Carolina, 1851-1983. Technical Report CERC-83-1, U.S. Army Corps of Engineers Waterways Experimental Station, Vicksburg, Mississippi, 152 pp.

Bruun, P., (1996): The Development of Downdrift Erosion. Journal of Coastal Research, 11 (4): 1242-1257.

Bruun, P., (1996): The Development of Downdrift Erosion. Journal of Coastal Research, 11 (4): 1242-1257.

Cleary, W. J. (2002): Variations in inlet behaviour and shoreface sand resources: Factors controlling management decisions, Fig. Eight Island, NC, USA, Jour. Coastal Res., issue 26, pp. 148-163.

Dean, R.G., (1991): Impacts of Global Change: Engineering Solutions. In Our Changing Planet: Joining Forces for a Better Environment. Proceedings of

Symposium on the Commemoration of the 20th Anniversary of the Graduate College of Marine Studies, University of Delaware, Newark, Delaware, 13-17.

Dean, R.G., and Walton, T.L., (1975): Sediment Transport Processes in the Vicinity of Inlets with Special Reference to Sand Trapping. Estuarine Research, Volume 2, New York, New York: Academic Press, pp. 125-149

Dean, R.G., and Work, P.A., (1993): Interaction of Navigation Entrances with Adjacent Shorelines. Journal of Coastal Research, 18: 91-110.

Escoffier, F. F. (1940): The stability of tidal inlets, Shore and beach, Vol. 8, pp. 114 – 115.

Escoffier, F. F. (1977): Hydraulics and stability of tidal inlets, GITI Report 13, coastal engineering research center, U.S. Army engineer waterways experiment station, Vicksberg, MS

FitzGerald, D.M., (1996): Geomorphic Variability and Morphologic and Sedimentary Controls on Tidal Inlets. Journal of Coastal Research, 23: 47-71.

FitzGerald, D.M., Hubbard, D.K., and Nummendal, D., (1978): Shoreline Changes Associated with Tidal Inlets Along the South Carolina Coast. Proceedings, Coastal Zone 1978. American Society of Civil Engineers: 1973-1994.

Foster, E. R. (1991): Inlet behaviour and the effects on beach erosion in Lee county, Florida , Procc. 1991 National conference on Beach preservation technology, pub. The Florida Shore and Beach Preservation Asso., Tallahassee, Fl, 32301, pp 178-193.

Galgano, F.A., (1998): Geomorphic Analysis of Modes of Shoreline Behavior and the Influence of Tidal Inlets on Coastal Configuration, U.S. East Coast. Ph.D. Dissertation, University of Maryland, College Park, MD.

Galgano, F.A., (2008): Types and Causes of Beach Erosion Anomaly Areas in the U.S. East Coast Barrier Island System: Stabilized Tidal Inlets. Middle States Geographer, 40: 158-170.

Galgano, F.A., (2009): Beach Erosion Adjacent to Stabilized Microtidal Inlets Middle States Geographer, 2009, 42: 18-32

Hayes, M.O., (1975): Morphology of Sand Accumulation in Estuaries. Proceedings, 2nd International Estuarine Research Federation Conference, Myrtle Beach, SC: 3-22.

Hayes, M.O., (1979): Barrier Island Morphology as a Function of Tidal and Wave Regime. In Barrier Islands, ed. Leatherman, S.P., New York, NY: Academic Press, pp. 1-27.

Hoque, M. A., Ahad, B. G. and Saleh, E. (2009): Sediment Transport and morphodynamics of the tidal inlet and adjacent coastlines of Salut-Menkabong, Sabah, Malaysia, Journal of Coastal Research, Vol. 56, pp. 1360-1364

Jarrett, J. T. (1976): Tidal prism-inlet area relationships, CERC, GITI report 3, 32 pp

Keulegan, G. H. (1967): Tidal flows in entrances: water level fluctuations of basins in communication with the seas, Technical Bulletin no. 14, U.S. Army engineer waterways experiment Station, Committee on Tidal Hydraulics, Vicksburg, MS

Keulegan, G. H. and Hall. J. V. Jr (1950): A formula for the calculation of tidal discharge through an inlet, B.E.B bulletin, Vol. 4 no. 4.

King, D. B. (1974): The dynamics of inlets and bays Technical report-22, coastal and oceanographic engineering lab, University of Florida, Gaines Ville

Mehta, A.J., (1996): A Perspective on Process Related Research Needs for Sandy Inlets. Journal of Coastal Research, 23: 3-21.

Morang, A. and Parson, L (2002): Coastal morphodynamics, in, Morang, A. ed. Coastal engineering manual, Part IV, Coastal geology, Chapter IV-3, Engineering manual 1110-2-1100, U S Army Corps of Engineers, Washington, DC

Moslow, T. F. and Gingerich, K. J. (1995): Inlet Geomorphology and Geology, in Coastal Inlet Hydraulics and Sedimentation, Pub. E M, U. S. Army Corps of Engineers, Washington, D.C.

Nummendal, D., Oertel, G.F., Hubbard, D.K., and Hine, A.C., (1977): Tidal Inlet Variability - Cape Hatteras to Cape Canaveral. Coastal Sediments 1977, American Society of Civil Engineers, Charleston, SC: 543-562.

Price, W. A. (1968): "Tidal Inlets", The Encyclopedia of Geomorphology, Encyclopedia of Earth Sciences Series, Vol. III, R. W. Fairbridge, ed., Reinhold Book Corp, NY, pp 1152-1155.

Rice, T.E., and Leatherman, S.P., (1983): Barrier Island Dynamics: The Eastern Shore of Virginia. Southeastern Geology, 24 (3): 125-137.

Saleh, E., Haque, M. A., Saad, S. and Magupin, S. (2005): A study on shoreline and inlet changes of Salut-Megkabong Lagoon, Sabah, Malaysia using remote sensing images, Proc. Asian conference on remote sensing (Vietnam), in CD ROM.

Wakhare, A. S (2002): "Variations in the location and morphological characteristics of the ebb delta at Valvati – Aravi tidal inlet", Transactions, Institute of Indian Geographers, Vol 23, No. 1 & 2.

Wakhare, A. S. (2004): Beach and Creek Sedimentation Processes: A case from Valvati-Aravi area from West Coast, Maharashtra, Unpublished doctoral dissertation, University of Pune, Pune.

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