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The Spatial Variability of Ridge and Runnel Beach Morphology Due to Beach Placer Mining along the Vembar – Kallar Coast, India

Przestrzenna zmienność morfologii plaży pod kątem grzbietów i strumieni spowodowana powstaniem kopalni złóż okruchowych wzdłuż Vembar – Wybrzeże Kallar w Indiach

Keywords: beach morphology, ridge & runnel, 3D model, sediments volume estimation
Słowa klucze: morfologia plaży, grzbiet i strumień, model 3D, określanie gęstości sedymentacji

1. INTRODUCTION

Morphological change along the beach face and littoral zone can be exceptionally complex due to dynamic nature of the physical process that force along and cross shore sediment transport. **Physical process along with local to regional morphology (tidal insets) and various anthropogenic factors can combine to create temporarily and spatially variable trends in morphological change.** Ridge and runnel beaches are a common feature in intertidal areas along the coastlines of India (Chakrabarti 2005). Although the term ridge and runnel beach has been applied to a variety of beach types in various hydrodynamic settings, true ridge and runnel in the study area is exposed to active coastal dynamics (Monica 1992). Moreover the aspect of ridge and runnel beach has received little attention in this morphological diversity due to beach placer mining. Sand beach ridges may be formed during storm waves and elevated water level events (Stapor 1982, Tanner and Stapor 1971 1972). They also emphasized the predominance of marine processes in the formation of beach. The study area has a low supply of sediment input. This starvation coupled with underlying geologic framework is resulting diverse beach and near shore morphology.

Ridge and runnel beaches are a common feature in intertidal areas along the coastlines. This type of longshore bars usually develops in environments with the following characteristics: 1) abundant fine to medium sand, 2) low beach gradient, 3) fetch limited wave climate and 4) high tidal range (Scott et al., 2011). **Classical sequences of ridge and runnel beach evolution with ridge accretion and/or onshore migration during low energy condition and destruction and/or offshore movement during high energy conditions** (Stepanian et al., 2001)**.** Erosion can affect the entire beach profile and this can result in a smooth featureless profile, or ridges can be partially eroded and described as "semi-permanent" features.

Shore normal beach profiles in the northern portion of Vaippar coast, Tamil Nadu (Fig. 1) showed a relatively simple bathymetric relief pattern with little variation. In contrasts, profile in the southern portion reveal a different relief pattern in the offshore due to the presence of corals, oyster bank and hard ground with an uneven surface. This geomorphic diversity in the area offers a good environment to examine beach profile to analyze the beach morphological change. The present paper is concerned to discuss the spatial and short term change of ridge and runnel beach morphology which is discussed based on the beach profiles data in the Vaippar coast, Tamil Nadu**.** Chandrasekar, et al., (2001) and Chandrasekar (2007)

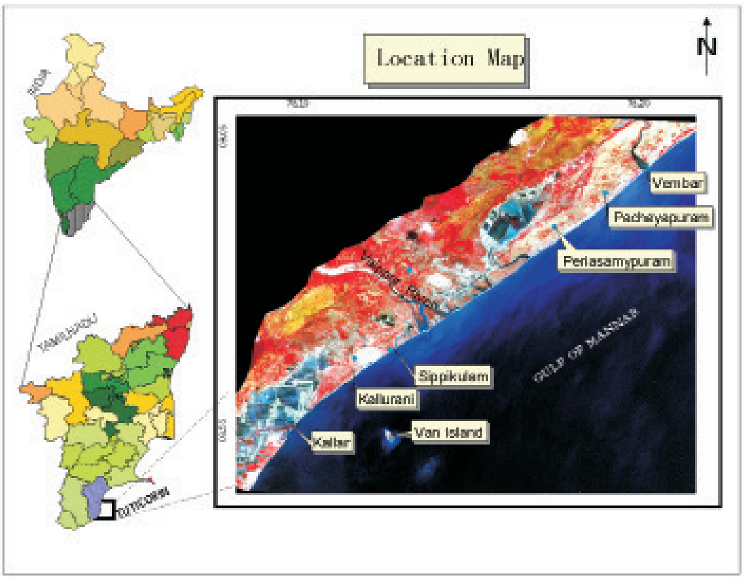


Figure 1. Location of the study area

Table 1. Beach Sand level variation along the study area during the year 2000 to 2006

	Erosion Rate (m^3/month)					
MONTH	**VMB**	**PAM**	**PEM**	**KAM**	**SPM**	**KAI**
NOV-2000	5.922	7.730	7.470	7.510	8.610	6.950
DEC-2000	6.523	8.660	7.600	9.400	7.120	8.270
JAN-2001	6.110	8.240	7.000	8.730	9.200	6.621
FEB-2001	5.500	9.800	6.940	8.010	7.146	6.410
MAR-2001	5.257	9.240	6.810	6.350	8.960	4.460
APR-2001	7.480	9.960	5.910	8.250	9.030	4.200
MAY-2001	4.880	8.130	6.240	5.970	7.290	4.153
JUNE-2001	7.240	9.100	5.410	5.820	7.170	4.670
JULY-2001	7.080	8.400	8.750	6.900	8.330	4.612
AUG-2001	5.930	7.950	6.410	5.800	7.860	7.500
SEP-2001	6.250	6.760	5.250	6.120	8.140	4.730
OCT-2001	5.430	6.780	4.500	4.880	8.450	4.850
Pre Monsoon (2003)	5.470	8.060	6.190	6.250	8.430	5.720
Pre Monsoon (2006)	7.810	8.800	5.660	7.590	6.700	6.310

VMB-Vembar; **PAM**-Pachayapuram; **PEM**-Periyasamypuram; **KAM**-Kalaignanapuram; **SPM**-Sippikulam; **KAI**-Kallurani

proposed that unsystematic garnet sand mining affected the beach morphology especially the littoral zone along the coast between Periyathalai and Navaladi, Tamil Nadu. Along the coast between Thiruchendur and Kanyakumari, large quantities of garnet deposits are being exploited (Photo 2). In order to understand the impact of garnet mineral extraction, beach profiling was carried out to know the morphological variation of these beaches in the mining area. The mining of beach sand has disturbed the stability of beaches (Photo 1). The beach profile deviates from the actual profile in the extraction area. The profile is smooth in the non-mining area whereas the mining area represents the formation of ridges and runnels. Saravanan and Chandrasekar 2010 delineated the grain size variation and depositional environment condition along the southern eastern beaches in Tamil Nadu.

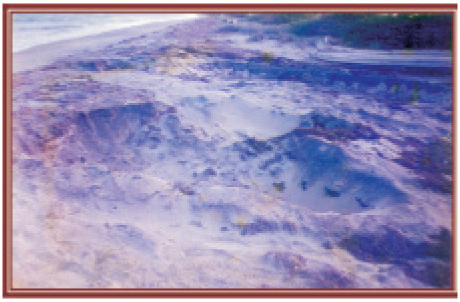


Photo 1. Sand mining near Vembar-Kallar Coast

Figure 31. Sand mining near Palmetto Point.

Figure 32. Ongoing sand mining near Palmetto Point.

Photo 2. Garnet placer enrichment along the Vembar-Kallar Coast

2. STUDY AREA

The study area is located in the coastal tract of Tamilnadu state, South India. The coastal stretch between Kallar and Vembar extends over a distance of about 24 km. The area lies between 8^0 45’ to 8^0 55’N and 78^0 10’ to 78^0 19’E (Fig. 1). The entire coast has been identified as zone of erosion. Medium to high wave energy condition prevail along the study area (Angusamy et al., 1998). The area is chiefly underlain by Precambrian gneisses, charnockites, granites and overlain by Quaternary sediments. Geomorphologically, the coastal stretch can be classified as a shoreline of emergence. Beach ridges are scattered along the study area (Loveson et al, 1996; Chandrasekar et al., 2000). The major geomorphological features like mudflats, sand dunes, islands, deltaic plain, beach rocks, beach ridges, etc. were demarcated from Linear Imaging Self-scanning Sensor (LISS) III and Panchromatic (PAN) merged data of Kallar and Vembar coast by Chandrasekar et al., (2000). The drainage pattern of the area is mainly controlled and influenced by the rivers like Vembar, Vaippar and Kallar which traverse through the formations of khondalite, leptynite and charnockite (Angusamy and Rajamanickam, 2000). The study area is endowed with workable deposits of placer minerals like garnet, ilmenite, etc (Angusamy and Rajamanickam 2000; Chandrasekar et al., 2002, Cherian 2003). It has been inferred that these minerals have been derived mostly from the khondalites (Udayaganesan et al., 1998). In general, the study area is witnessing several coastal developments of natural anthropogenic activities including salt pan, coastal aquaculture and major harbour activities and also serves as a promising resource of various heavy mineral deposits (Chandrasekar et al., 2010).

The beach in the study area is partially urbanized coast and is faced by the group of offshore islands. The harbor development and beach sand mining has resulted rapid erosion in the south as a result of drift perturbation. The northern beach is largely protected by barrier islands (Fig. 1). But the dune front shows pronounced erosion due to scrapping of black sands in the area. The comparison of beach profile with adjacent segments shows that the beach is most dynamic. The beach profile is most responsive to daily weather, wave, wind and mining conditions showing more exaggerated changes in stability, erosion and accretions. The mining of beach induce intensive sediment movement from one to other as storms alternate with calm periods. The volume of sediment in the fore shore of the coast is very much affected due to unregulated mining. On the other hand, the distributions of sediment in lines of ridges and runnel slope fluctuate considerably. Ridge and runnel morphology becomes pronounced where the beach is free from beach sand mining (Photo 1).

3. MATERIALS AND METHODS

3.1. Beach profile survey

The beach profile measurements were taken following the stack and horizon method by Lafond and Rao (1954) which was later modified by Emery (1961). The leveling above mean sea level (MSL) and below sea level data are adjusted to MSL datum using fixed benchmark of known elevation, located behind the beach during the lowest-low water level period so that maximum length of the beach section was exposed. The beach profile survey starts from the reference point (usually near the coastline) and covers backshore, intertidal zone and finishes near the inner breaker zone. The beach profile survey was carried out by using Total Station with RTK GPS. Figure 2. shows a schematic run of a beach profile and its segments. Using ranging poles and an Abney level, the slope of each profile segment is recorded (for example, $slope_1$ for profile segment A-B). Ground distance along each profile segment is also recorded (for example, distance d_1 for segment A-B). The beach width and cross-sectional area parameters are computed as given in Figure 2. The study covered a beach at a distance of approximately 50 km. The elevation of the area where points were collected along transect ranged from approximately 8m (dry beach) to -10m (into the water). The beach profiles were carried out for a period from 2000 to 2006 to analyze the spatial and short term variable of beach morphology **Fig. 3a to d**.

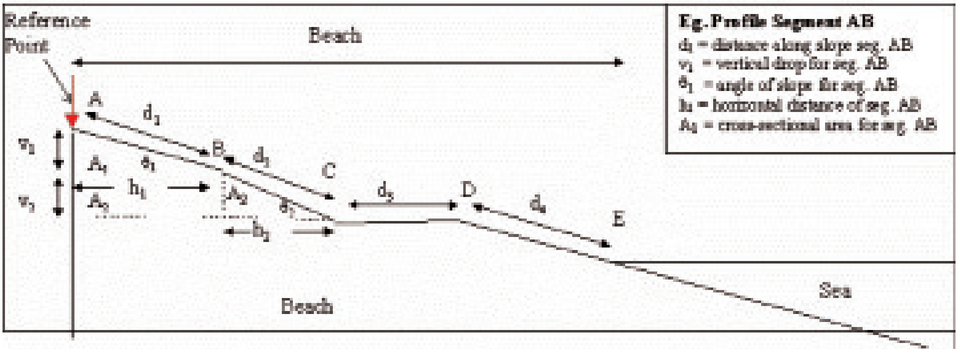
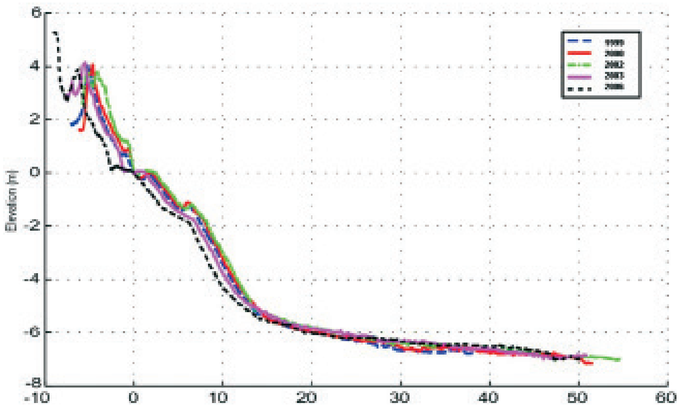


Figure 2. The beach slope and cross sectional area of beach

3.2. Geospatial analysis

To create thematic map of beach profile we were able to utilize mean annual beach change rate information. GIS software used in the present study is ArcGIS. The base map was prepared, and the coastal boundary and drainage features were extracted from Survey of India topomaps on 1:50,000 scale. This traced map was scanned and imported into ARCINFO. These features were digitized through online digitization. The digitized datasets were converted to Universal Transverse Mercator (UTM) projection, and exported to Arcview shape file. A position on the earth is given by the datum WGS-84 and UTM zone number 44 with easting and northing coordinate pair in that zone. Since the UTM projection system is a well established reference system, there are many practical advantages in applying it to our national cadastral mapping. No less than 100 countries in the world have accepted this projection, as they must be finding it very satisfactory for both mapping and rectangular referencing.



X axis 1cm-10m, y axis 1cm=2m

Figure 3a. Vembar

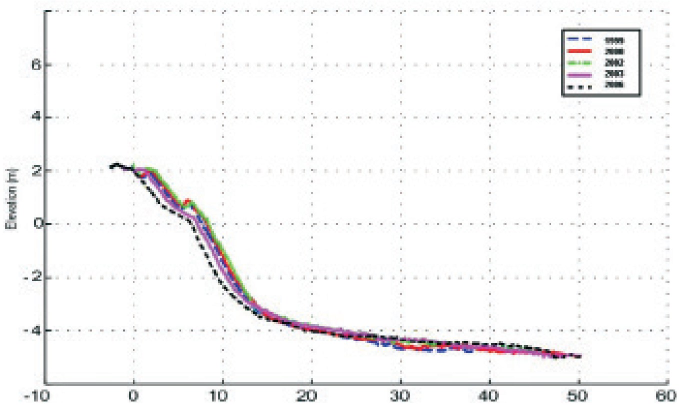


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Figure 3b. Periyasamypuram

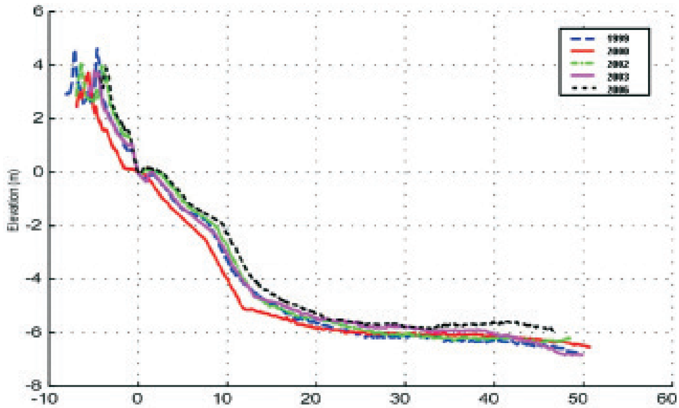

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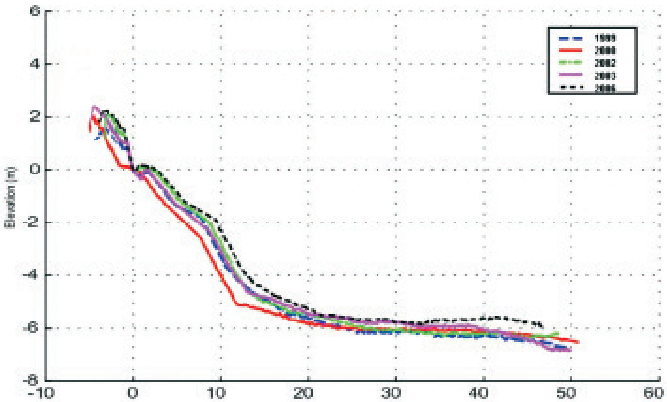
Figure 3c. Kallurani



X axis 1cm-10m, y axis 1cm=2m

Figure 3d.

Figure 3a-d. Beach profile shows Ridge and runnel morphology along the study region

In addition to the above quoted advantages, modern satellite based geodetic measurement techniques like Global Positioning System etc; provide directly the coordinates in UTM projection devoiding the user of the hustles of conversion from one coordinate system to another. In the area of digital mapping, most of the GIS software today also handles the cartographic data in an UTM projection with the possibility of converting the coordinates from one projection system to another.

4. RESULTS & DISCUSSION

Results presented here illustrate spatial change of ridge and runnel beach morphology in the Vaippar coast from 2000 to 2006. The analysis shows significant spatial variability within 50 km study area.

The dune front was linked to the beach by a gently sloping beach terrace. This terrace lacked bed forms and was fronted by a sleep slope down to the uppermost runnel. The south west wind direction (oblique wave with a 45^{o} angle to the beach) trapped very little sand in the ridge crest while a significant amount of sand was trapped on the lower part of the ridges slope. The ridge and runnel morphology shows small long shore variability due to mining activities remnants. Spatial variability in this short term ridge and runnel morphology is in the rapid transition from erosion to accretions in Patchaiyapuram and Vembar prompt further inquiry. This zone where the erosion to accretion takes place coincides almost exactly with the toe of dune complex. These dunes of Vaippar have been severely scrapped and are probably contributing to the local sediment budget of Patchaiyapuram.

The tremendous change in Kallar section provides resulting from mining in the dune shows that sediment eroded from the zone has deposited in the profiles of Kallar to vembar. The several beach profiles suggested that differences in ridge location and height on the intertidal profile reflect the coastal dynamics. For the majority of the analyzed profiles the volume of beach (material) sediment has fluctuated from year to year by 5 to 10 m^3/m. These fluctuations are due to littoral current and waves. The beach ridges are formed at the limit of swash run up (Hesp 1999).

In the field ridges are barely discernable, typically being only 0.5 to 1.0 m high above the gentle undulating dune fields or low lying swampy plains lying sea wards. Beach ridges tend to have similar spacing to fore dunes where progradation is slow or storms and high water levels are common. Ridges are typically parallel to the coast. The maximum height point was retained as that representing ridge crest position. The procedure of the identification of a crest when the ridge usually appeared to be a flat surface on the profile as its central point was applied. Ridge and runnel are best expressed where the beach is completely devoid of coastal structures or terraces. The beach sediments are characterized throughout by fine to medium grain size sands being well to very well sorted (Saravanan and Chandrasekar (2010). The sand tends to be coarser and less well sorted on the upper beach. The ridges consist of coarser sediments than runnel. The ridge and runnel shows small longshore variability. The changes are best expressed when associated with mining activities remnants. Short term profile mobility is variable alongshore and is essentially limited to the mid beach ridges and runnels. The sand inputs are rapidly recycled to the foredune where developing embryo dunes are consistently observed. Monthly erosion rate prevailing along the study area is shown in Table 1. The erosion rate at Vembar beach ranges from 7.81 m^3 to 5.25 m^3 with maximum during monsoon and minimum during March. The maximum erosion rate of 9.8 m^3 and minimum of 7.73 m^3 has been recorded in the beach of Pachayapuram. The erosion rate ranges between 5.41 m^3 and 8.75 m^3 in the beach of Periyasamypuram. In Kalaignanapuram, the erosion rate varies from 5.80 m^3 to 9.40 m^3. With the maximum erosion rate of 9.2 m^3 and minimum of 6.7 m^3, Sippikulam behaves as an erosional coast without having any significant accretion. In Kallurani, the rate of erosion varies between 4.15 m^3 to 8.27 m^3 (Table 2). Rates of change are highest during rare severe storm events (Baskaran 2004). This has been proved by the present study as the beach which experienced low erosion in one period suddenly endures heavy erosion in the next season and vice-versa due to the local fluctuation in yearly monsoon.

Table 2. Yearly beach sand change rate (m^3 /year) at different location of the study area

Beach	Erosion Rate 2000-2001	Erosion Rate 2003	Erosion Rate 2006
VMB	-0.285	-1.16	- 0.788
PAM	-0.465	-0.41	- 0.893
PEM	-0.535	-1.07	-1.141
KAM	-0.94	-1.805	-2.264
SPM	-1.335	-1.635	-1.158
KAI	-0.295	-0.985	-0.817

VMB-Vembar; PAM-Pachayapuram; PEM-Periyasamypuram; KAM-Kalaignanapuram; SPM-Sippikulam; KAI-Kallurani

The annual erosion rate prevailing along the study area is shown in Table 2. During the year 2000, the erosion rate ranges from 0.28 m^3 to 1.33 m^3 with high rate at Sippikulam and low at Vembar. There are offshore islands situated near to the Sippikulam coastline (Fig. 1). They might have acted as a barrier to the northerly littoral drift direction of waves and so the beach had experienced higher erosion activity in all the seasons (Chandramohan, 1998; Chandrasekar et al., 1996). Maximum erosion occurred in the beach of Kalaignanapuram during 2001 with minimum erosion rate at Pachayapuram of 1.80 m^3 and 0.41 m^3 respectively. In the year 2002, Kalaignanapuram beach showed high erosion rate of 2.26 m^3 and Vembar beach had endured the minimal erosion rate of 0.78 m^3 (Table 2). Predominantly, accretion activity is higher than erosional activity in the beaches of Kallurani and Vembar due to the supply of sediments to the beach by the rivers Kallar and Vembar respectively during monsoon season. (Hanomgond and Chavadi 1993; Crickmore et al., 1990).

In order to quantify the beach morphology variability, we calculated volume and slope from 3D elevation models and then compared the Kallar and Vaippar surfaces **(Fig. 4a-c)**. The sediment volume changes on the high and low tide parts of the beach are positive or negative during the same period. It shows that cross shore sediment transport between the low tide and the high tide beach are weak. The contrasted grain size reflects the cross-shore movements (Van Lancker et al. 2004). Elevation change shows that much of the accretion (up to 2m) was concentrated in zones of Vembar and Patchiyapuram shows higher slopes due to deposition of sand. The sections of Vembar and Vaippar had lower slopes than the section of Kallar prior to mining. The slope became more prominent in these

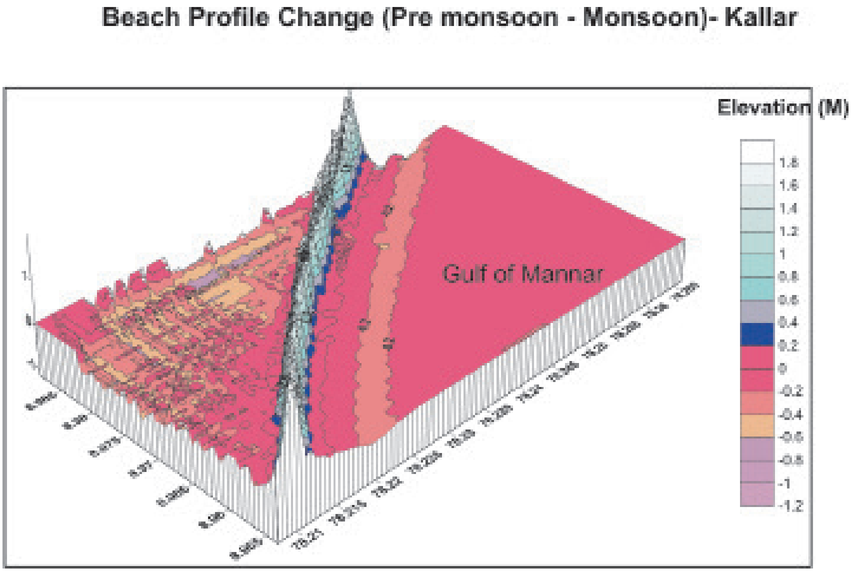


Figure 4a. Pre monsoon 2000

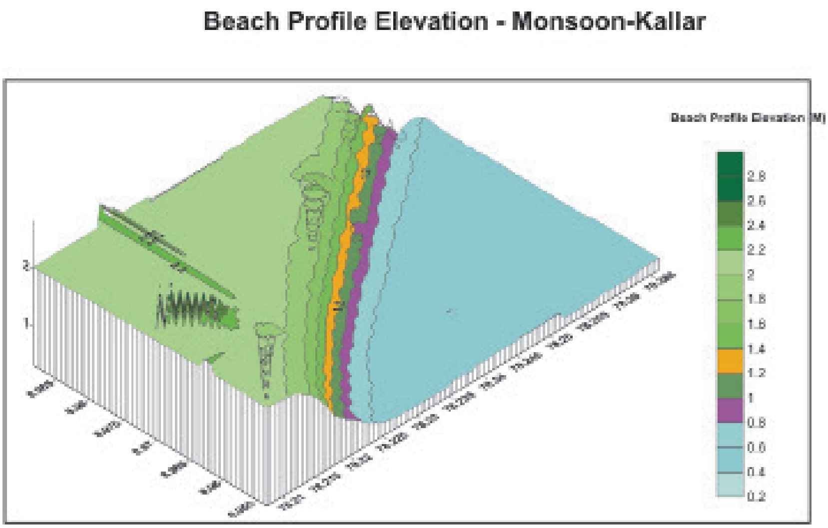


Figure 4b. Pre monsoon 2003

zones in the years of 2003–2006. The area of elevation change was determined for the different years from 2000 to 2006 (Fig. 4a to 4c). Fig. 4a indicates where significant gain of sand occurred anywhere between 1 and 10 feet or above. Fig. 4b indicates where none or little positive change occurred. Fig. 4c indicates where little negative change occurred that indicate where more significant erosion

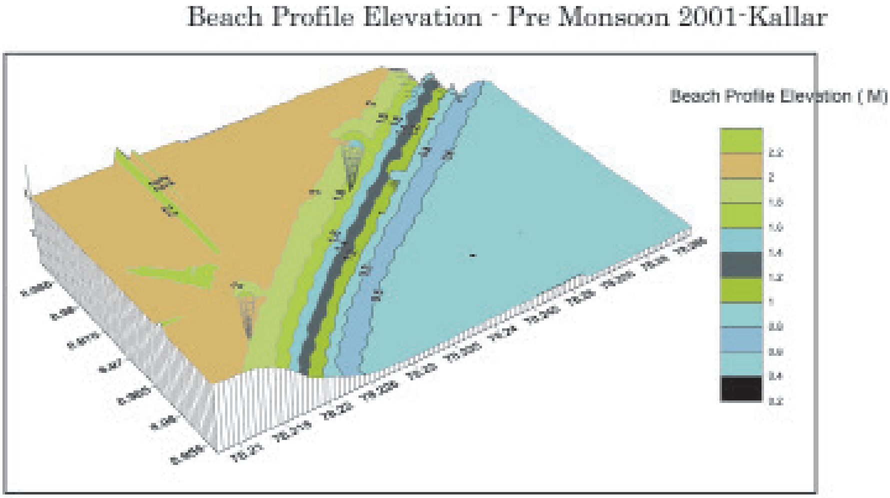


Figure 4c. Pre-monsoon 2006

Figure 4a-4c. 3D elevation models of Beach sand volume and slope of beach morphology along the study area

occurred between – 1 and – 5 feet loss of elevation. Figure 5a&b. shows comparative study between 2000 and 2006 that visually represents gained or lost of sand. The blue color (Fig. 5a) represents areas that gained material and the red color (Fig. 5b) represents areas that lost materials. Based on profile measurements the sediments volume changes are estimated from 2000 to 2006 are shown in Table 3. After analysis of cut/fill raster, the Table 3. shows the 1,05,96,310 cubic feet of sand that were lost due to mining between 2003 and 2006. From this study, we probably knew that the beach would have gained sand by the nourishment of beach after beach sand mining or dredging in the nearshore.

Table 3. Total Sediment volume change estimation along the study area (in cubic feet)

Year	2000 – 2001	2001 – 2003	2003 – 2006
Sum	35,35,927	54,66,192	1,05,96,310

CONCLUSION

This study has explained that the changes can be highly variable over relatively short distances and periods of time and that the speed at which a beach / dune mining is remarkably high capturing this fine scale variability in space and time on ridges & runnels which is crucial to the understanding of short and long term

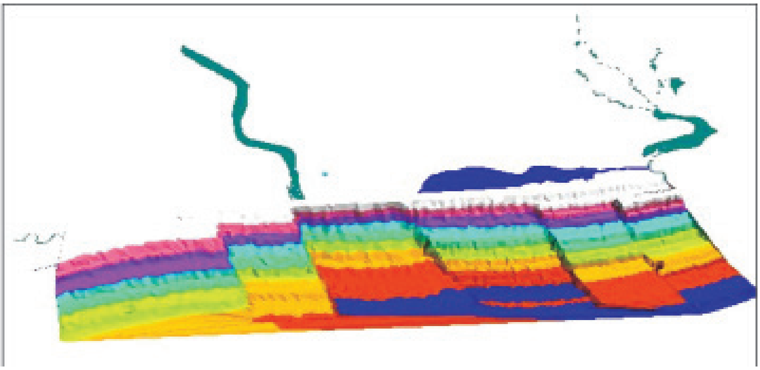


Figure 5a. Beach Profile TIN Surfaces-2000 (Vembar-Kallar Coast)

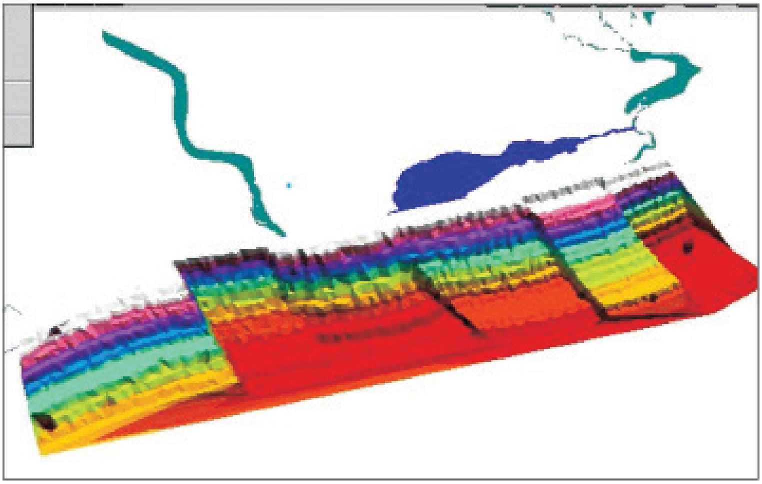


Figure 5b. Beach Profile TIN Surfaces-2006 (Vembar-Kallar Coast)

Figure 5a&b. Comparative study for the year of 2000 to 2006 sediment volume from profile measurements as Raster layer along the study area

trends in beach morphological changes. Beach profile is displaying a regular set of intertidal ridges or bars alternating with runnels. Strong swash over the back slopes of the ridges creates current ripples marks in dunes. Regular ridges and runnel form large scale stability. Grain size, the slope and height of the ridges vary between sections of the beach. Beach sand mining affected the ridge and runnel morphology. Short term profile changes are due to variation in wave energy, where the ridge and runnel morphology is prone. It is expected by 2011 that large volumetric change in sediment budget due to heavy mining that changes the beach morphology significantly will occur. Mobility of beach ridges and runnels consider the need to look at different field sites for mining activity.

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STRESZCZENIE

Celem tej pracy jest omówienie przestrzennych i krótkotrwałych zmian w morfologii plaży pod kątem grzbietów i strumieni na podstawie profili plaży w Vembar, na wybrzeżu Kallar, Tamil Nadu, Indie. Plaże składają się głównie z średniego do grubego piasku i ciężkich minerałów. Dla plaż charakterystyczne są grzbiety, strumienie i zagłębienia. Grzbiety i strumienie są niewielkie ze względu na prace kopalniane prowadzone w okolicy. Ustalono, że przestrzenne i tymczasowe zmiany w systemie grzbietów i strumieni są kontrolowane przez pianę morską/łamiące się fale. Zmiany objętości sedymentu wynikają z nieregulowanej aktywności kopalni. Erozja ma wpływ na profil wszystkich plaż, zwłaszcza strumieni. Strefy przyrostu znajdują się wyżej, to znaczy na najwyższych grzbietach i wałach plażowych. Krótkotrwałe zmiany wielkości plaży wyjaśniają zniekształcenie grzbietów i strumieni. Ma to związek z pobliską kopalnią. Zaobserwowano wzorzec wiatru wyżej plaży, gdzie warunki pozwalają na transport sedymentu piasku i jego ruch na grzbietach i strumieniach.