UDC 551.46(267)

P.S. Mujabar * and N. Chandrasekar **

Beach Topography and Morphodynamics along the Southern Coastal Tamil of India by Using Beach Profile Analysis

Beaches are highly dynamic in nature. Several tons of sediment are redistributing each day due to the action of waves, winds and currents. The profiles of beaches, cliffs and other coastal landforms are often studied and analyzed in the coastal areas. The most common method for measuring beach topographic change is the beach profile. This manuscript deals with the topographical and morphological analysis of beaches along the southern coastal Tamil Nadu of India by using beach profile surveys. The beaches are surveyed by using a surveyor's level. The obtained data from the surveys are processed by using sophisticated software tools such as "Beach Morphology Analysis Package" (BMAP), an integrated set of computer analysis routines compiled by Coastal Engineering Research Center (CERC) at the U.S. Army Engineer Waterways Experiment Station. The temporal and spatial representations of beach profiles have been delivered and the morphological parameters such as beach width and slope have been analyzed.

The volumetric analysis of beach sediments and their annual and seasonal variations have been performed. Both cyclic (seasonal) and annual changes in the beach topography have been observed. The morphodynamic and volumetric analysis of beach profiles indicates that the beaches of Kanyakumari, Navaladi, and Ovari have experienced more annual loss of sediments and they poses severe beach erosion. The beaches of Tuticorin-south, Periathalai, Kayalpattinam and Tiruchendur have experienced more accretion. The dynamic changes in the beach topography may also interact and modify the other coastal landforms. The wave climate along the coast has also influenced the sediment dynamics of beaches. The present study implies that proper beach filling and nourishment projects should be made along the study area to save it from coastal erosion.

Keywords: geomorphology, coastal erosion, sediment transport, shoreline change.

1. Introduction

Beaches are one of the important coastal landform and most studied feature of coastal morphology. Beach topography is a result of complex interaction between natural coastal processes and anthropogenic activities. The topographical beach profile gives the surface shape, trend, slope and volume of sediments. These cross sections through coastlines can give a good idea about the changes that can occur over time at one point on the coast, either in the shape of a beach or a cliff, or in its size and volume. Guillen et al. (1999) and Cooper et al. (2000) reported that beach profiles are an important tool for elucidating long-term trends, such as erosion and accretion, and for predicting the future evolution of coastal landforms. The profile is useful for environmental management and planning authorities who need such information when planning new development, but rarely have the resources themselves to collect the data (Cambers and Ghina, 2005).

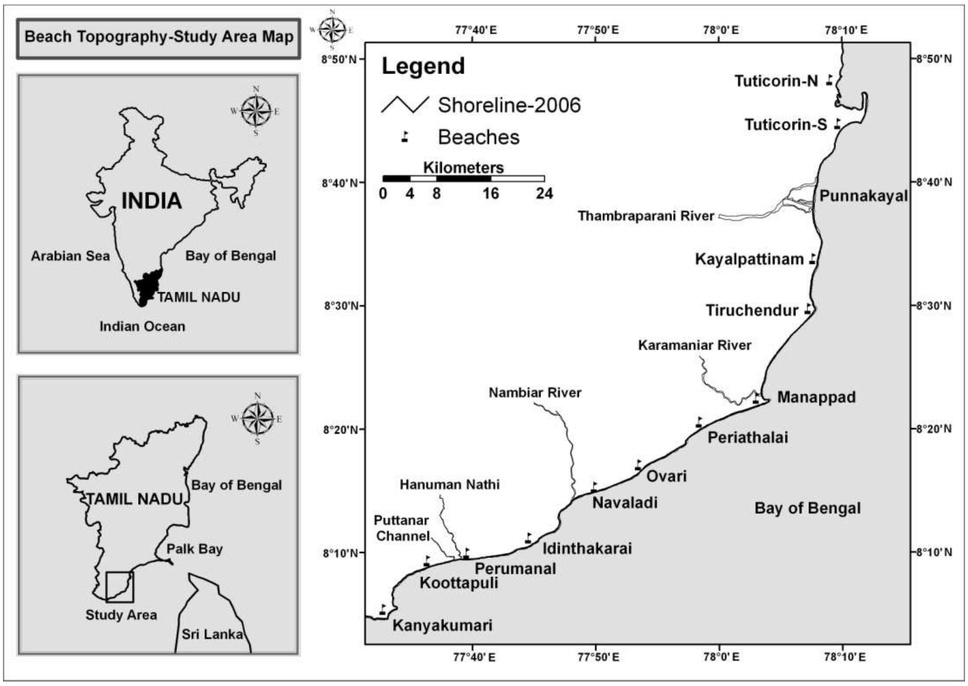
Coastal morphology is the result of combined action of hydrodynamic, geologic and climatologic processes. The beach morphology can be regarded as a sensitive indicator for the ongoing coastal dynamic processes of a particular coastline (Wright and Short, 1983; Hardisty, 1994). By monitoring the spatial and morphological changes of a beach over time, a good estimate of the rate and direction of coastal changes can be obtained (Dean, 1983; Brunsden, 2001). Krause (2004) states that the beach morphology of coasts undergoes perpetual and rapid changes. Generally, the influencing natural forces can be subdivided into long-term processes, which shape the coastal morphology on large spatial scales in the order of kilometers or more and short-term processes. More recently, anthropogenic effects may also influence substantially the shape of the coastline.

The present study intends to analyze the topographical and morphological changes along the southern coastal Tamil Nadu of India. Hydrodynamic and morphologic changes have been frequently observed after the Dec.-2004 tsunami along this area (Mujabar et al., 2006). The beach profile survey has been performed by using a surveyor's level or transit as represented by Parson (1997). The beach profiles obtained from the surveys are processed by using advanced computing tools like "Beach Morphology Analysis Package" (BMAP) and "THE BEACH" (Chandrasekar and Sheik Mujabar, 2010). The temporal and spatial representations of beach profiles have been delivered and the morphological parameters such as cross-shore beach width and slope have been estimated and analyzed. The volumetric analysis of beach sediments and their annual and seasonal variations have been performed. The shoreline change, erosion and accretion made along the beaches have also been predicted and discussed.

2. Geographical Setting

The study area is located along the southern coast of Tamil Nadu state, India (Fig. 1). The southwest coastline borders the Bay of Bengal whereas Indian Ocean borders the south coastline. The study area extends over a distance of 150 km. Moderate to high wave energy condition prevails along the study area, and the Ovari coastal zone is an enriched zone of placer mineral deposits (Angusamy and Rajamanickam, 2000). The wave energy is high, and during the rainy season pebbles have been deposited in some beaches. Waves approach the coast in the SE, NW directions, with wave periods varying from 5 sec to 15 sec. The drainage pattern along the study area is controlled by the Thambraparani River and minor rivers such as Karamaniar, Nambiyar and Hanuman Nadhi. Sea cliffs are along the Kanyakumari coast, which project towards the Indian Ocean forming promontory. Most of the beaches are sandy whereas Kanyakumari and Idinthakarai beaches are rocky in nature.

The study area includes mining sites, saltpans, estuaries, aquatic ponds, fishing harbor and development projects. Most of the beaches are habitually devoid of dunes. The coast along Kanyakumari has been affected by severe coastal erosion. Beach nourishment structures have been installed in the recent past along the coast of Kanyakumari and Koottapuli. Seawall and groins have been constructed along the coasts. Breakwater was constructed long ago in the fishing harbor (Chinna Muttom beach), just north of Kanyakumari. An ancient fort is at Vattakottai nearer to Kanyakumari which extends further beyond the surf zone. Vattakottai and Kanyakumari beaches are tourism centers of Tamil Nadu state. Sand mining is actively pursued along the coast of Idinthakarai, Navaladi, Ovari and Periathalai.



F i g. 1. Study Area Map

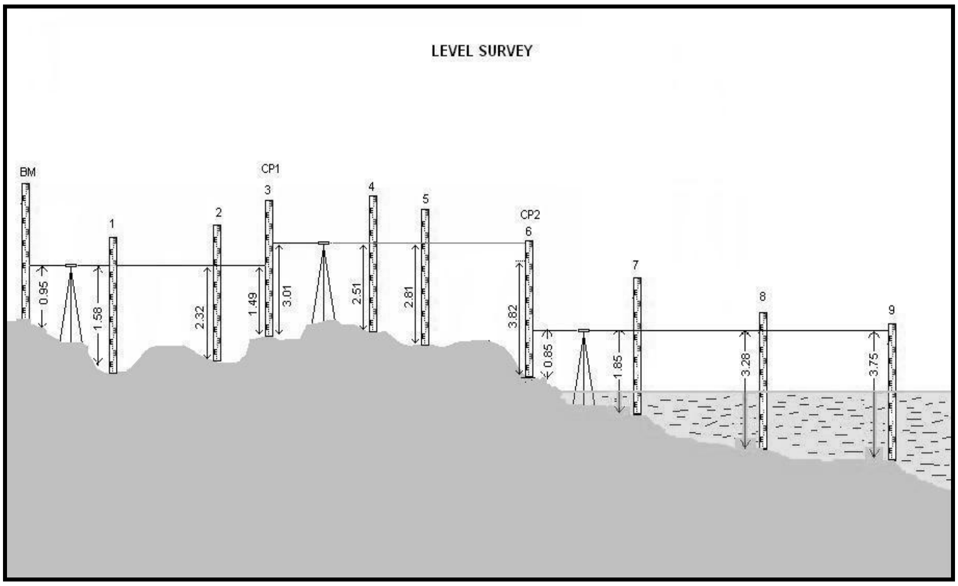
The coastal landforms along the study area have been greatly influenced by natural coastal processes and anthropogenic activities (Mujabar and Chandrasekar, 2011a, b). Mujabar et al. (2007) analyzed the morphological parameters of beaches along the south Tamil Nadu coast after the tsunami. They state that almost all the beaches were eroded by the tsunami waves. The mid tide and low tide zones of the beaches were more eroded than the berm and high tide zone. The beach width and the total cross-sectional area of all the beaches were reduced. The mean beach slope and the trend of the beaches were also affected by the tsunami. They also predicted that beach slope and width were also modified due to the change in the beach sediment volume and redistribution within the beach units. The coastal geology and geomorphology along the southern coastal Tamil Nadu play a vital role in modifying the shorelines. Mujabar and Chandrasekar (2011c) state that various coastal landform features such as headland and bays, beaches, mud flats, estuaries, sand dunes along the study area have been involved in the shoreline changes. They also state that the coasts with sand mining, have high longshore sediment transport rate and it may lead to severe erosion and accretion along the coast.

3. Methodology

The term “beach profile” refers to the cross-sectional trace of a beach perpendicular to the high tide shoreline and extends from the backshore cliff or dune to the inner continental shelf or depth of closure, a location where waves and currents do not transport sediment to and from the beach. Measuring beach profiles is an ideal activity for the analysis of beach morphology, landform dynamics, developmental projects and environmental assessments etc.

The beach profile survey is the process of making simple datasets with successive elevation and distance from a reference starting point towards the off-shore. Several techniques are available to perform the beach profile survey. Beach profile survey can be easily performed using stack and horizon method of La Fond and Rao (1954). Emery (1961) described a simple and rapid method to measure the beach profiles, henceforth called the Emery-method, which has been used in numerous studies throughout the world, such as Mexico, USA, Ecuador and Australia (Short and Trembanis, 2004). The first modern studies of profiles were motivated to understand its shape and variability in support of amphibious operations during World War II, when personnel and supply boats had to cross beach profile from off-shore to the dry beach (Bascom, 1980).

In the present work, the beaches along the southern coastal Tamil Nadu have been surveyed by using level and staff method (Fig. 2) as represented by Parson (1997). This method is very simple, accurate and easy to perform. Even with the latest development of survey techniques, the simple survey methods using Emery-poles or surveyor's level are still widely used by many researchers. The cost for these simple conventional survey methods is much less when compared with other surveys. When working in tropical developing countries, many methods which are based on high-technology equipment are not easily accessible. Due to lack of funding or access to such type of equipment, the climatic conditions (*e.g.*, high temperature and air humidity) and scarce resources for the maintenance may constitute limiting factors on the long-lasting employment of respective devices for beach profile monitoring purposes (Krause, 2004).



F i g. 2. Beach Profile Survey Using Surveyor's Level

Ramanujam et al. (1996) used surveyor's level (transit) and staff to measure the beach profiles at more than 48 profile sites along the coast from Tiruchendur to Vaippar. Chauhan (1997) used rod and transit method to measure the morphology of beaches along the coast of Machilipatnam, India. Vijayam et al. (1960) used the stack and horizon method to analyze the beach profiles of Vizhapatiinam coast. Vasudav et al. (1986) also used the same method to measure the beach profiles for analysing the seasonal changes of beaches along the coast of Vizhapatinum, India. Jayakumar et al. (2004) used the surveyor's level method to measure the profiles for analyzing the beach dynamics along the coast of Goa, India. Rajamanickam (2006) also used surveyor's level method to measure the profiles for beach placer study along the south Tamil Nadu coast. Chandrasekar et al. (2006) used surveyor's level method to analyze the morphology of beaches along the south Tamil Nadu coast. They used the beach profile data to classify and analyze the Dec.-2004 tsunami hazard along the Kanyakumari coast.

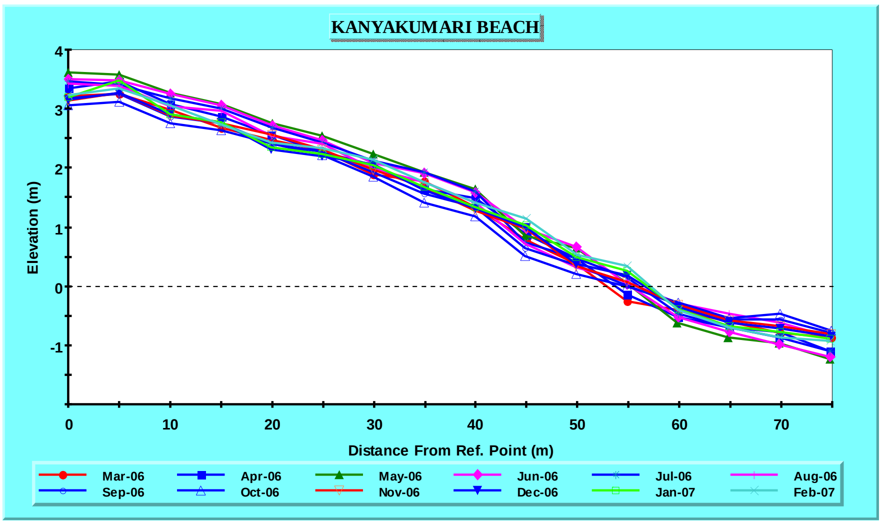
The coastal geomorphologies of the selected beaches are noted and the survey has been performed on the beaches for a period of two years (from Mar.-2006 to Feb.-2008). A straight narrow transect of length about 500 m was selected for the profile leveling. Leveling was started from a reference point on the berm area of beaches. The elevation of the reference point was obtained by leveling from a benchmark whose elevation from the mean sea level was known. The profile leveling was performed perpendicular to the direction of the coast, with an interval every 5m from the reference point to a point seaward of the low tide zone of the beach. A compass and a GPS receiver have also been used to spot the exact location for repeated measurements of the beach profile survey. The obtained beach profile survey data has been processed and is used to trace the profile of beaches. The data has also been used to estimate the beach width, slope and sediment volume of beaches.

In the present study, littoral environmental observations (LEO) were also carried out at the beaches along the study area. The breaking wave height (H_b) is measured by basic scientific method illustrated by Bascom (1980) in his seminal work on wave research. The wave breaking angle (α_b) with respect to the coastline is measured by using a surveyor's magnetic compass and the breaker depth (d_b) is also calculated by using a graduated pole.

4. Results and Discussions

4.1. Spatial and Temporal Representation of Profiles

Beach topographic analysis with short-term and long-term change in different spatial and temporal scales in the coastal dynamic environment is crucial for sustainable coastal management. A study of number of profiles from different points can produce information about the transportation of sediment along a coast, or how one area differs from another. The numerical profile data can be analyzed statistically or it can be plotted as a graph to give a physical representation of the shape of a coastline. Ying Li et al. (2005) states that the beach profiles have been observed to change over a range of spatial and temporal scales; however techniques for quantifying this variability have not been fully established.

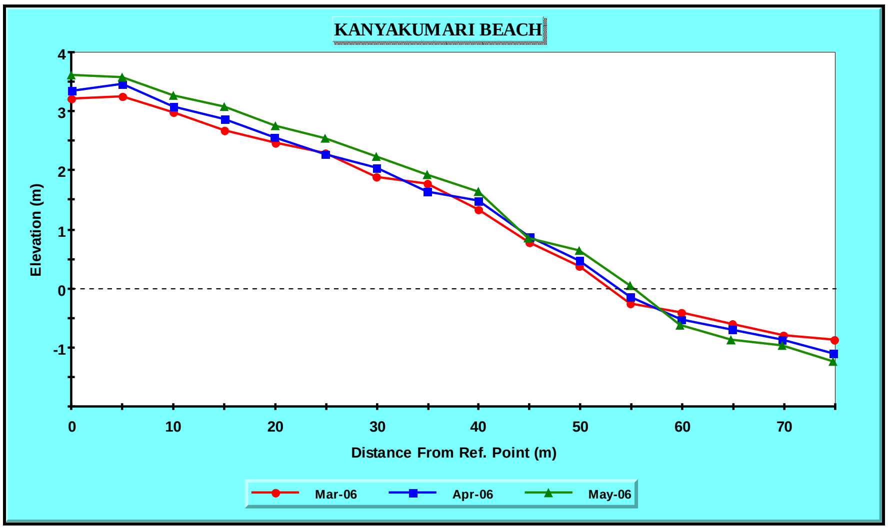


F i g. 3. Profiles of Kanyakumari Beach

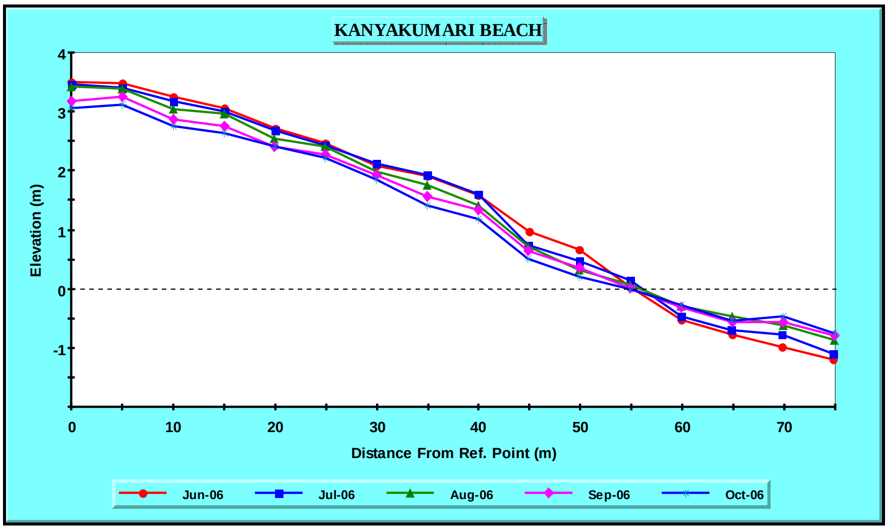
Beach erosion may be a short-term process (order from hours to seasons) that reflects adjustment to wave energy changes, or a longer-term one (order of years) that reflects an increasingly deficient beach sediment budget and shoreline changes. Clinton et al. (1975) also state that the seasonal changes in beach profiles constitute an important aspect of the variability of the coastal environment. The spatial and temporal representations of profiles obtained from all the 12 beaches along the study area have been drawn and the profile of Kanyakumari beach is shown in Fig. 3. The variations of beach profile on both annual and seasonal environment of the coasts have been analyzed. The beach profiles collected from the beaches have been used to study the beach dynamics, coastal erosion and shoreline change in both spatial and temporal scales. Mujabar and Chandrasekar (2011c) also state that coastal erosion and the dynamics of landforms along the study area are highly influenced by the various parameters such as coastal processes, interruption of sediment supply, geomorphology, tectonic activities, climate patterns and anthropogenic activities.

4.2. Dynamics of Beach Topography

Beaches are loose accumulations of sand, gravel, or a mixture of the two that bound an estimated 30% of the world's coasts (Bird, 1996). Because they consist of more or less loosely packed non-cohesive sediments, beaches act as buffers that absorb, reflect, and dissipate energy delivered to the shore by waves. By doing so, they shelter areas behind the beach, especially during storms, from wave attack and flooding (Edward, 2005). The present study indicates that the topographical and morphological changes of beach profiles are mainly oriented with coastal geology, shore configuration and seasonal oscillation prevailing along the study area. The topographical representation of different beaches reveals that the profiles are higher during March, 2008 and the profile rises further from March to May. During April or May, the profile of almost all beaches attains maximum level.



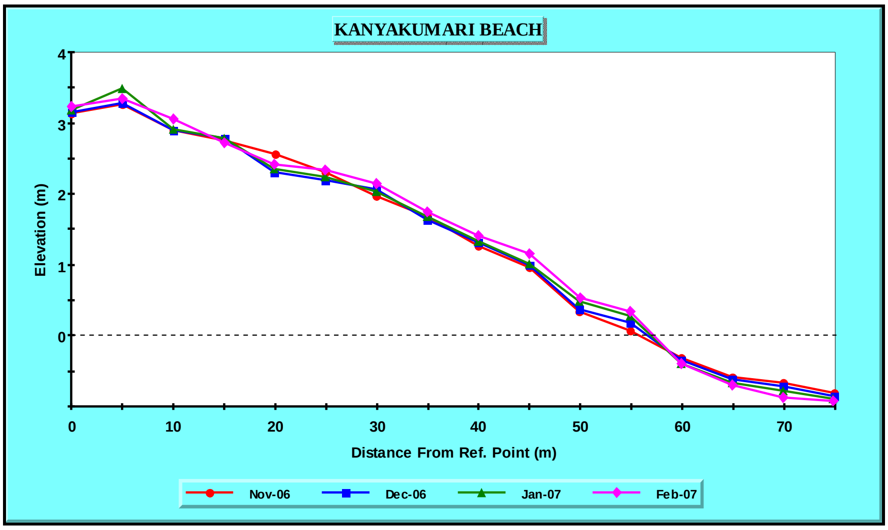
F i g. 4. Pre-Monsoon Profiles of Kanyakumari Beach



F i g. 5. Beach Profiles during Monsoon in Kanyakumari

The low energy littoral currents and waves prevail along the area during the summer deposit sediment on the beach berm and dune, thereby raising the beach profile. From the month of June, the profiles start to lower due to the increase in wave energy due to the SW monsoon. The lowering of profiles still continues up to the month of September (NE monsoon period, winter). Many researches (Clinton et al., 1975; Basterretxea et al., 2004) pertain the seasonal migration of the sand, with sediment transport towards the beach in summer, resulting steep beach face and a high berm at the end of summer. On sandy beaches short-term changes involving erosion are commonly a part of a so called morphodynamic cycle of adjustment of the beach profile to seasonal or non-seasonal changes in wave energy (Short, 1999). The short-term seasonal changes commonly correspond to the classic winter profile flattened by storms and the summer profile that accretes under fair weather conditions.

The profile of Kanyakumari beach during the different periods such as pre-monsoon, monsoon (SW & NE) and the post-monsoon are shown in Figs. 4, 5 and 6. The profiles in almost all the beaches during the months of March, April and May (pre-monsoon and summer) imply that the beaches have experienced accretion. The lift in profile level is more along the backshore due to more deposition of sediments. During this period well developed berms have been observed in the high tide region of beaches. It is also noticed that the profile along the foreshore experiences a lowering in most beaches which indicates the landward movement of sediments; however accretion have been noticed along the foreshore of Navaladi, Ovari and Periathalai beaches. More sediment deposits have been noticed in Ovari. Chandrasekar et al. (2001) insist that the change on foreshore of these beaches is closely linked to the formation and movement of garnet concentration in the near shore.



F i g. 6. Post-Monsoon Profiles of Kanyakumari Beach

The SW monsoon mostly starts from the month of June along the study area. The increased wave condition during the monsoon lowers the level of profile and causes beach erosion along the coast. More amounts of sediments have been removed from the berm and high tide region of beaches. The change in beach profile indicates the movement of sediments from the back and near-shore towards the off-shore. The profile also specifies the formation of off-shore sand bars along the near-shore and off-shore. Crest and troughs have been observed along the profile of beaches. The high waves during the monsoon break near the shoreline when the low waves result in an increased run-up on the beach foreshore (Battjes, 1974). The changes in the wave climate transport the sediments towards the sea. Reddy et al. (2000) imply that the sediments eroded from the beak shore are deposited to form longshore sand bars. The low wave climate during the NE monsoon leads to some accretion of sediments over the SW profile of beaches. After the NE monsoon, the beaches slowly retain the initial state and the beach experiences net loss or gain of sediment.

4.3. Beach Morphology and Morphodynamics

4.3.1. Beach Morphology

(a) Beach Width. The beach width is defined as the horizontal dimension of beach measured at right angles to the shoreline from the line of extreme low water inland to the landward limit of a beach. It is also defined as the distance between dune crest and shoreline position at high tide. It is an important parameter measuring the "health" of a beach. Understanding how beach width changes over varying timescales is vital for future shoreline management planning, for example, planning beach nourishment or seawall construction, defining hazard setbacks, identifying "hot spots" (locations of enhanced erosion) and the threat they pose to human structures and/or recreational activities. The cross-sectional beach width during each month of all the beaches have been calculated from the beach profile survey data. The seasonal and annual variation in the beach widths of all beaches are given in Tables 1 and 2. The study implies that the width of different beaches along the study area undergoes dynamic changes in both spatial and temporal scales which have been controlled by both natural and human induced activities particularly beach sand mining.

Table 1

Seasonal Changes in Beach Width

Beach Name	Beach Width (m)					
	During Mar.-2006 to Feb.-2007			During Mar.-2007 to Feb.-2008		
	Pre-Monsoon	During Monsoon	Post-Monsoon	Pre-Monsoon	During Monsoon	Post-Monsoon
Kanyakumari	57.3	54.2	50.5	51.9	48.8	50.5
Koottapuli	58.5	53.0	58.0	54.2	56.5	58.0
Perumanal	89.0	86.5	81.6	81.6	81.6	81.6
Idinthakarai	59.9	56.8	57.4	60.1	53.9	57.4
Navaladi	72.7	69.3	67.9	69.4	66.2	67.9
Ovari	56.4	45.2	52.0	48.8	46.1	52.0
Periathalai	131	130	133	137	131	133
Manappad	77.6	75.9	75.6	76.5	74.6	75.6
Tiruchendur	57.1	52.1	54.5	55.8	51.9	54.5
Kayalpattinam	96.6	97.0	99.4	101	93.4	99.4
Tuticorin-south	108	104	112	114	108	112
Tuticorin-north	48.3	48.2	48.7	44.5	43.4	48.7

T a b l e 2

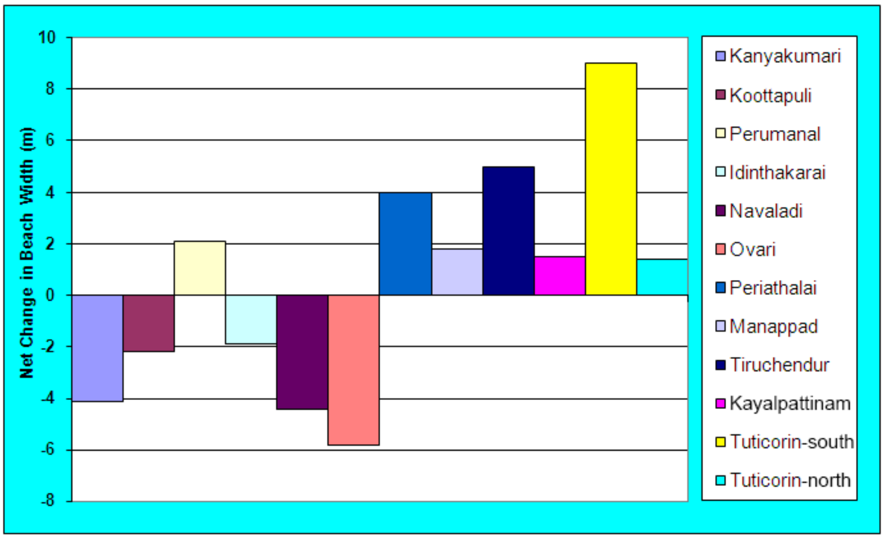
Annual Changes in Beach Width

Beach Name	Beach Width (m)			Annual Change in Beach Width (m)		
	Mar.-06	Mar.-07	Feb.-08	2006-07	2007-08	Net
Kanyakumari	56.9	55.3	52.8	-1.60	-2.50	-4.1
Koottapuli	53.2	51.7	51.0	-1.50	-0.70	-2.2
Perumanal	86.6	91.1	88.7	4.50	-2.40	2.1
Idinthakarai	57.4	56.2	55.5	-1.20	-0.70	-1.9
Navaladi	71.9	69.5	67.5	-2.40	-2.00	-4.4
Ovari	58.7	56.4	52.9	-2.30	-3.50	-5.8
Periathalai	128	130.5	132	2.50	1.50	4.0
Manappad	76.7	78.8	78.5	2.10	-0.30	1.8
Tiruchendur	54.6	56.9	59.6	2.30	2.70	5.0
Kayalpattinam	98.5	99.4	100	0.90	0.60	1.5
Tuticorin-south	109	113	118	4.00	5.00	9.0
Tuticorin-north	47.9	48.5	49.3	0.60	0.80	1.4

The profiles are characterized by a large seasonal and annual variation in the incident wave height and beaches exhibit a distinct change in beach morphology. However the morphological changes are better explained by seasonal reversals in the littoral drift direction and by the variations in the incident wave energy conditions. Masselink and Pattiaratchi (2001) state that the seasonal change in beach morphology is traditionally ascribed to a variation in the incident wave energy level with calm conditions in summer resulting in wide beaches with pronounced subaerial berms and energetic conditions in winter causing narrow beaches with nearshore bar morphology. It is observed that the beaches of Kanyakumari, Koottapuli, Idinthakarai, Navaladi and Ovari have experienced a reduction of beach width during the study period while the other beaches have experienced an increase in beach width. This indicates the spatial variation of erosion and accretion along the different beaches.

During the period of March to May the widths of beaches are in increasing trend, and they reach a maximum value in April–May. The berm area is also larger during these months. After this period, the increase in wave climate due to the SW monsoon lowers the profile and reduces the beach width considerably. In majority of the beaches the beach width attains minimum values during August or September. These seasonal oscillations of beach morphology have been extensively studied by many researchers (Chandramohan et al., 1993; Chauhan, 1997; Kasinatha Pandian and Dharanirajan, 2007; Clinton et al., 1975). From September onwards, the beach width slightly increases from its minimum level. It is due to comparatively low wave energy and reversal trend in the direction of sediment transport prevailing during the NE monsoon. Chauhan (1997) states that the littoral currents were moderate to strong during the SW monsoon, variable during the NE monsoon, and weak during non-monsoon period. The direction of these currents also varies during the SW and the NE monsoons. Beach eroded during the SW monsoon, but despite the prevalent moderate-high wave regime, and moderate-strong littoral currents, the beach profiles of the NE monsoon had accretion over the profiles of the SW monsoon. Chauhan (1997) also says that the beach profiles of the NE monsoon had accretion over the profiles of the SW monsoon. During the NE monsoon the influence of littoral currents and waves is comparatively lower than that of the SW monsoon and the widths of most beaches are in increasing trend. But severe storms may also attack the shoreline during this period and the storm-generated waves that cut away the berm cause an off-shore sediment motion and bar formation.

During December–March the beach profiles are gradually raised and attain maximum level during April or May. The net change in beach widths along different beaches has been represented in Fig. 7. The study indicates that the beaches of Kanyakumari, Koottapuli, Idinthakarai, Navaladi and Ovari are eroding considerably and the beaches of Periathalai, Manappad, Kayalpattinam, Tiruchendur and Tuticorin-south have been present in accretion trend. It has been noted that the width of beaches along the intensive mining sites have been considerably decreased (Table 2) which leads to more erosion along the coast.



F i g. 7. Net Change in Beach Width

(b) Beach Slope. The beach slopes of all beaches have been measured from the beach profile data. The seasonal and annual variations in beach slopes are given in Tables 3 and 4. Zinn (1969) states that the slope of a beach is the angle formed by the intersection of plane of the beach with the horizontal plane of the sea-water surface. He also states that beach slope influences the width of beaches. During non-monsoon the slopes are larger almost in all beaches due to the accumulation of sediment along the berm and high tide zones. The reduction of beach slope during monsoon indicates the removal of sediment from the berm and dune to the offshore. After the monsoon the beach slope increases again. No significant annual changes in beach slopes have been noticed.

Table 3

Seasonal Changes in Beach Slope

Beach Name	Beach Slope (degree)					
	During Mar.-2006 to Feb.-2007			During Mar.-2007 to Feb.-2008		
	Pre-Monsoon	During Monsoon	Post-Monsoon	Pre-Monsoon	During Monsoon	Post-Monsoon
Kanyakumari	4.07	3.47	3.77	4.02	4.20	3.86
Koottapuli	5.63	4.69	4.82	5.18	4.25	4.35
Perumanal	3.73	2.83	3.00	3.69	3.25	3.20
Idinthakarai	4.35	4.31	4.51	4.47	4.25	4.39
Navaladi	3.10	2.85	2.88	3.35	3.31	3.26
Ovari	3.45	3.41	3.53	3.77	3.48	3.44
Periathalai	2.27	2.26	2.07	2.43	2.29	2.34
Manappad	3.59	3.42	3.43	3.57	3.37	3.31
Tiruchendur	3.47	3.48	3.57	3.97	4.18	3.87
Kayalpattinam	2.71	2.34	2.47	2.60	2.40	2.58
Tuticorin-south	2.72	2.31	2.47	2.30	2.18	2.27
Tuticorin-north	3.27	3.37	3.30	3.61	3.85	3.61

Table 4

Annual Changes in Beach Slope

Beach Name	Beach Slope (degree)			Annual Changes in Beach Slope (degree)		
	Mar.-06	Mar.-07	Feb.-08	2006-07	2007-08	Net
Kanyakumari	3.69	3.66	3.70	-0.03	0.04	0.01
Koottapuli	4.75	4.57	4.91	-0.18	0.34	0.16
Perumanal	3.13	3.49	3.24	0.36	-0.25	0.11
Idinthakarai	4.34	4.56	4.58	0.22	0.02	0.24
Navaladi	3.04	3.26	3.26	0.22	0.00	0.22
Ovari	3.42	3.45	3.42	0.03	-0.03	0.00
Periathalai	2.12	2.26	2.38	0.14	0.12	0.26
Manappad	3.47	3.62	3.45	0.15	-0.17	-0.02
Tiruchendur	3.38	3.77	4.08	0.39	0.31	0.70
Kayalpattinam	2.63	2.63	2.65	0.00	0.02	0.02
Tuticorin-south	2.56	2.23	2.29	-0.33	0.06	-0.27
Tuticorin-north	3.06	3.18	3.59	0.12	0.41	0.53

4.3.2. Morphodynamics and Volumetric Analysis

The morphodynamics of beach refers to the interaction and adjustment of seafloor topography and fluid hydrodynamic processes. The hydrodynamic processes including those of waves, tides and wind-induced currents respond instantaneously and lead to the morphological change and redistribution of sediment. The seafloor morphologies and sequences of change of dynamics are involved in modifying cross-shore and longshore sediment transport.

As sediment takes a finite time to move, there is a lag in the morphological response to hydrodynamic forcing. Sediment can therefore be considered to be a time-dependent coupling mechanism. Since the boundary conditions of hydrodynamic forcing change regularly, this may mean that the beach never attains equilibrium. Dean and Dalrymple (2004) state that beach profiles vary with time, both seasonally as the wave climate changes and over the long-term, in response to the pressures of erosion or accretion. Beach profiles measured at the same location over time can provide details about the behavior of the beach. The behavior of the entire beach can be examined in terms of shoreline recession and volumetric sand loss by the continuous profile measurements along the beach; moreover, an overall sand budget (sources and sinks of sand) can also be determined.

Interpretation of beach response to coastal processes can be done with geometric and volumetric comparison of beach profile sets (U.S. Army Corps of Engineers, 2002). Dean and Dalrymple (2004) also state that the convenient use of beach profiles is the determination of volumetric change of a beach, $\Delta V_{s.}$ The volumetric calculation of profiles provide a time history of the volume of beach, and by determining the volume differences between surveys the erosion or accretion of the beach can be assessed as a function of time. There are no common standards for quantifying rates of beach change (Moore, 2000) and for determining high tide shoreline position (Galgano et al., 1998; Douglas and Crowell, 2000). Beach erosion is generally quantified through some statistical treatment of retreat rates and volumetric losses (*e.g.,* Leatherman, 1983). Sa-Pires et al. (2004) state that the variations of beach sediment volume have been widely used to quantify the changes and to understand the beach response to coastal processes. For any geometric and volumetric calculations an arbitrary vertical datum is needed. The definition of the vertical datum above which is determined the beach volume is not consensual and different authors have adopted different values.

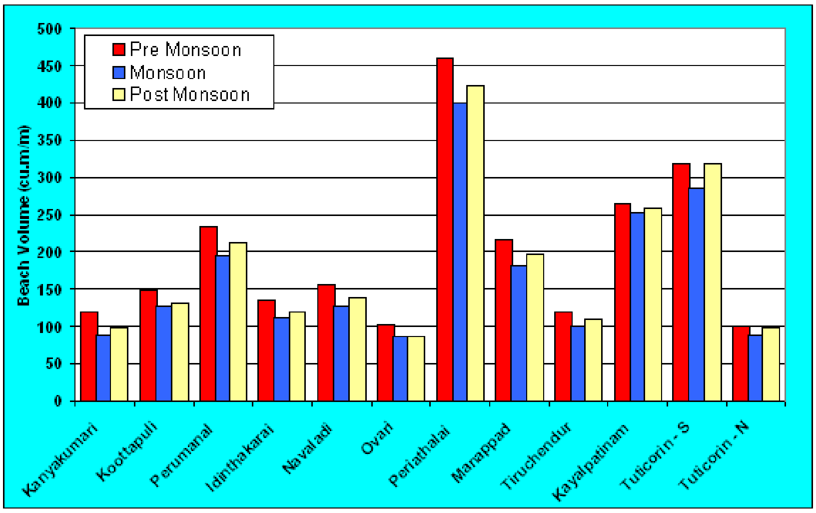
In the present work the Mean Sea Level (MSL) has been considered as the reference vertical datum for performing geometric and volumetric analysis of beach profiles. Sa-Pires et al. (2004) analyzed the standard deviation of relative volume variation for different datum. They observed that beach volume variability is higher for levels across the MSL. For each profile at a given time, the area of sand above the arbitrary datum, from the baseline to the off-shore limit of the profile, is determined. For all profiles of the survey the volume of sand in the beach above the arbitrary datum is obtained by the areas of the profiles along the beach which provides the beach sediment volume per unit length of beach.

(a) Seasonal Changes. The sediment volumes above the reference datum in all beaches have been computed from beach profile survey data. The seasonal beach sediment volume and their changes are given in Table 5 and represented in Fig. 8. The volumetric analysis implies that the sediment volume along the different beaches undergoes typical seasonal changes due to the hydrological conditions.

Table 5

Seasonal Changes in Beach Sediment Volume

Beach Name	Beach Sediment Volume (cu.m/m)					
	During Mar.-2006 to Feb.-2007			During Mar.-2007 to Feb.-2008		
	Pre-Monsoon	During Monsoon	Post-Monsoon	Pre-Monsoon	During Monsoon	Post-Monsoon
Kanyakumari	122	105	110	119	89	97
Koottapuli	143	128	134	148	127	132
Perumanal	232	194	203	235	196	214
Idinthakarai	132	121	125	135	113	121
Navaladi	164	132	145	157	127	138
Ovari	103	82	92	102	87	87
Periathalai	411	390	404	459	399	424
Manappad	224	194	214	216	181	197
Tiruchendur	116	92	103	121	100	109
Kayalpattinam	265	237	257	265	252	259
Tuticorin-south	306	275	304	320	286	320
Tuticorin-north	101	88	96	100	89	98



F i g. 8. Seasonal Variation of Sediment Volume

During the period March–May the volume of sediment in beaches is bigger almost on all beaches. The low wave energy prevailing along the study area during this summer period enhances the trapping of sediments across the beaches. From June onwards the sediment volume decreases by reason of changes in the wave climate due to the SW monsoon. The sediment from the berm and high tide zone of the beaches is eroded and transported due to the littoral currents. The change in beach profile shows the movement of sediment from berm to the off-shore and it also indicates the development of small bars along the low tide region and off-shore of the coasts. In addition to the changes in the beach morphology, the sediment volume undergoes rapid decreases on beaches. The reduction of sediment volume continues up to October. From November onwards the beaches start to regain the sediments. The comparatively low wave climate of the NE monsoon to the SW monsoon enhanced the slight increase in sediment volume during the period of October and November. After the end of December it has been noticed that the beaches regain more amount of sediment due to the landward movement of the off-shore sediment. Well developed berms have been noticed on some beaches due to the movement of the off-shore sand bar towards the berm.

The present study implies that there is a spatial and temporal variation of beach sediment volume with respect to the seasonal wave parameters along the beaches. It also indicates the cyclic changes in the beach morphology and morphodynamics. The seasonal changes in beach profiles constitute an important aspect of the variability of the coastal environment (Clinton et al., 1975). It has been understood since the late 1940's that with few exceptions the sand level on the exposed portion of a beach is higher towards the end of summer than at any other time of the year. Clinton et al. (1975) state that the winter storm waves overtop the summer berm and erode the backshore, their action thus reducing the width of the exposed beach. The winter beach is typified by a gently sloping beach face that in places extends shoreward to the toe of the sea cliff. Heinze (2001) states that the changes in beaches are significantly different with respect to physiography, incident wave energy and direction, available sediment supply, tendency to erode or accrete and level of development. Nordstrom (1992) implies that the cycles of change in beach profile configuration and sediment volume may be associated with changes in the relative energy levels of winter and summer wave climates.

The present study also implies that there are more changes during the SW monsoon than during the NE monsoon due to the difference in the wave climate during these monsoons. The beaches are highly responding to the SW monsoon than the NE monsoon due to the high wave conditions. Sajeev and Sankaranarayanan (1996) estimated the changes in beach sediment volume along the Calicut beaches of Kerala, India. They estimated a change of volume of 10 cu.m/m during the SW monsoon and 5 cu.m/m during the NE monsoon. Bhat et al. (2003) estimated the seasonal changes of beach sediment volume along the coast of Maharastra, India. They also observed more changes in sediment volume during the SW monsoon.

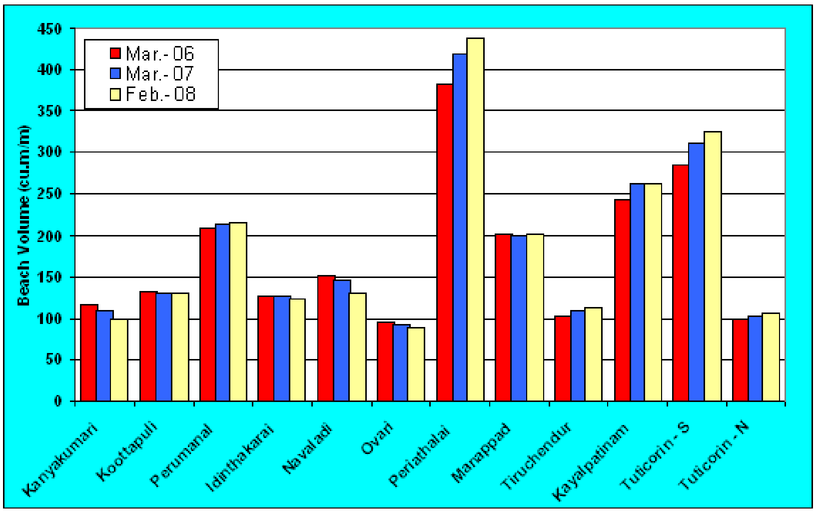
Chauhan (1997) has made extensive works in morphology of beaches along the east coast of India. He states that the SW and the NE monsoons and non-monsoon periods, the average wave energy flux (P) is 1.35, 0.66 and 0.4 kW/m. He inferred that during the NE monsoon the sediments accumulate and depositional environment prevails on the beaches along central east coast of India. He also states that the relatively high wave and current regime during the NE monsoon does not produce any erosions' effect on the beach, and the area has accretionary tendency. High input of the fluvial sediments and their deposition on the beach due to fluctuations in the wave energy flux, from the turbid water plumes during this monsoon, appears to be the contributing process.

(b) Annual Changes. The annual beach sediment volume and changes for all beaches along the study area are shown in Table 6. Fig. 9 shows the annual variations of the sediment volume in different beaches. During the period 2006-08, the beaches of Kanyakumari, Koottapuli, Navaladi, Ovari and Manappad have experienced a reduction of sediment volume while the remaining beaches have gained sediment. The Kanyakumari, Navaladi and Ovari beaches have experienced more loss of sediment (6, 5, 4 cu.m/m respectively). The beaches of Manappad and Koottapuli have very low sediment losses. The Idinthakarai beach has no net loss or gain. The beaches of Periathalai, Tuticorin, Kayalpattinam, Tiruchendur, Perumanal and Tuticorin-south have gained sediments. The beaches of Periathalai, Tuticorin-south and Kayalpattinam experienced more gain of sediment during this period. The Periathalai beach has gained sediment of volume 29 cu.m/m and the Tuticorin-south has gained 27 cu.m/m of sediment. The construction of breakwater (Groin) at the Periathalai has enhanced the trapping of sediment along the coast. During monsoon large amount of sediments from the Thambraparani River is discharged along the Punnakayal coast and transported by littoral currents and waves. The bay nature of Tuticorin-south beach has effectively enhanced the trapping of more amount of sediments which are depositing along the coast.

Table 6

Annual Changes in Beach Sediment Volume

Beach Name	Beach Sediment Volume(cu.m/m)			Annual Changes in Volume (cu.m/m)		
	Mar.-06	Mar.-07	Feb.-08	2006-07	2007-08	Net
Kanyakumari	116	110	98	-6	-12	-18
Koottapuli	132	130	131	-2	1	-1
Perumanal	208	214	216	6	2	8
Idinthakarai	128	128	123	0	-5	-5
Navaladi	151	146	130	-5	-16	-21
Ovari	96	92	88	-4	-4	-8
Periathalai	383	412	424	29	12	41
Manappad	203	200	202	-3	2	-1
Tiruchendur	102	110	113	8	3	11
Kayalpattinam	243	262	263	19	1	20
Tuticorin-south	284	311	335	27	24	51
Tuticorin-north	100	103	105	3	2	5



F i g. 9. Annual Variation of Sediment Volume

During the period 2007-08 the same trend is observed almost on all the beaches. But the beaches of Kanyakumari and Navaladi have experienced more loss of sediment than that of during 2006-07. The Kanyakumari beach has experienced a loss of 12 cu.m/m of sand and the Navaladi beach has lost 16 cu.m/m of sand. Idinthakarai has experienced a sand loss of 5 cu.m/m of sand while it gained sediment during 2006-07. The Koottapuli beach has gained sediment during 2007-08 while it lost sediment during 2006-07. The beaches of Perumanal, Periathalai, Tiruchendur, Kayalpattinam, Tuticorin-south and Tuticorin-north have experienced gain of sediments. But the amounts of deposition of sediment on these beaches are decreased than that of during the period 2006-07.

During 2006-07 the Periathalai beach gained a sand of volume 29 cu.m/m but it is considerably decreased to 12 cu.m/m during 2007-08. Similarly the Tuticorin-south beach has gained a sand of volume 27 cu.m/m but it is considerably decreased to 24 cu.m/m during 2007-08. The gains of sediment of other beaches are also reduced during this period due to the changes in hydrological and littoral sediment transport. The reduction of sediment volume has also indicated the lack of sediment supply along beaches. Edward (2005) implies that the net loss of beach sediment results in durable changes in beach morphology as the beach seeks to adjust the situation of sediment deficit. On any sandy or gravelly beach profile short-term morphodynamic changes may be embedded in longer-term changes involving net sediments gains or losses, the latter being synonymous with overall beach erosion throughout the profile and leads to shoreline changes.

4.4. Wave Breaking Height and Breaking Angle

The wave climate along the study area is generally characterized by a small, short period wind-driven waves. The monthly wise RMS wave breaking height during the period from Mar.-2006 to Feb.-2008 measured on different beaches along the study area are given in Tables 7 and 8. The corresponding wave breaking angles are also given in Tables 9 and 10. Unlike the majority of coasts of the world, the east coast of India experiences two phases of stormy conditions. They are the SW monsoon (June–September) and the NE monsoon (October–December) (Chauhan, 1997). From January to March low wave conditions prevail along the study area. During March and April the wave environment begins to modify and attain to moderate conditions. During June and July the coastal area is under the influence of the SW monsoon and high wave energy environment prevails along the study area during August to September moderate wave climate exists. From October onwards the coast is under the influence of the NE monsoon. Even though the wave climate during the NE monsoon is comparatively lower than that of the SW monsoon, moderate storms may be developed in the Bay of Bengal. After December the wave energy starts to decrease. The wave height mostly increases during March–June and mostly decreases during December–March along the study area. The wave breaking heights are bigger during the monsoon periods on all the coasts.

Table 7

Wave Breaking Height (H_{brms}) Measured on Beaches during 2006-07

Beach Name	RMS Wave Breaking Height from Mar.-2006 to Feb.-2007 (m)											
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Kanyakumari	0.38	0.40	0.42	0.81	0.69	0.59	0.40	0.68	0.51	0.52	0.42	0.41
Koottapuli	0.32	0.30	0.28	0.69	0.38	0.32	0.33	0.58	0.52	0.43	0.32	0.30
Perumanal	0.35	0.36	0.34	0.78	0.62	0.61	0.48	0.69	0.59	0.50	0.41	0.38
Idinthakarai	0.31	0.32	0.33	0.62	0.65	0.42	0.31	0.57	0.53	0.55	0.42	0.41
Navaladi	0.62	0.60	0.52	0.89	1.05	0.82	0.71	0.92	0.81	0.61	0.60	0.59
Ovari	0.57	0.52	0.53	0.95	0.75	0.71	0.64	0.84	0.74	0.68	0.61	0.52
Periathalai	0.52	0.50	0.55	1.12	0.94	0.85	0.62	0.95	0.87	0.62	0.58	0.53
Manappad	0.38	0.42	0.45	0.75	0.69	0.52	0.51	0.72	0.61	0.48	0.45	0.41
Tiruchendur	0.41	0.38	0.35	0.68	0.61	0.51	0.42	0.61	0.52	0.43	0.38	0.36
Kayalpattinam	0.32	0.31	0.34	0.65	0.52	0.47	0.43	0.57	0.52	0.48	0.41	0.34
Tuticorin-south	0.35	0.32	0.33	0.70	0.62	0.52	0.48	0.52	0.55	0.48	0.32	0.25
Tuticorin-north	0.32	0.28	0.27	0.69	0.58	0.52	0.51	0.65	0.42	0.38	0.35	0.33

T a b l e 8

Wave Breaking Height (H_{brms}) Measured on Beaches during 2007-08

Beach Name	RMS Wave Breaking Height from Mar.-2007 to Feb.-2008 (m)											
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Kanyakumari	0.42	0.41	0.48	0.79	0.81	0.65	0.49	0.68	0.59	0.53	0.48	0.39
Koottapuli	0.30	0.32	0.33	0.59	0.45	0.36	0.31	0.58	0.49	0.38	0.31	0.30
Perumanal	0.35	0.31	0.30	0.35	0.34	0.32	0.32	0.48	0.52	0.52	0.47	0.36
Idinthakarai	0.36	0.32	0.32	0.35	0.37	0.37	0.38	0.45	0.55	0.61	0.49	0.42
Navaladi	0.68	0.67	0.69	1.22	1.25	0.95	0.67	0.92	0.89	0.68	0.62	0.60
Ovari	0.60	0.58	0.59	0.98	1.15	0.80	0.65	0.81	0.72	0.64	0.58	0.54
Periathalai	0.41	0.48	0.45	0.85	0.82	0.71	0.51	0.83	0.76	0.58	0.52	0.54
Manappad	0.45	0.46	0.42	0.78	0.65	0.61	0.52	0.76	0.65	0.53	0.49	0.48
Tiruchendur	0.34	0.32	0.35	0.78	0.69	0.61	0.43	0.52	0.51	0.47	0.43	0.40
Kayalpattinam	0.31	0.30	0.32	0.69	0.68	0.58	0.52	0.68	0.61	0.52	0.41	0.36
Tuticorin-south	0.28	0.25	0.27	0.72	0.69	0.54	0.52	0.48	0.51	0.42	0.31	0.27
Tuticorin-north	0.31	0.32	0.33	0.67	0.53	0.54	0.41	0.59	0.37	0.35	0.33	0.32

T a b l e 9

Wave Breaking Angle (α_b) Measured on Beaches during 2006-07

Beach Name	Wave Breaking Angle from Mar.-2006 to Feb.-2007 (degree)											
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Kanyakumari	75	73	43	8	8	9	7	164	165	169	164	161
Koottapuli	76	68	38	3	5	4	3	95	174	172	169	119
Perumanal	79	61	43	15	9	12	8	162	175	176	173	82
Idinthakarai	91	75	82	13	14	7	9	88	176	173	175	98
Navaladi	49	45	45	10	3	3	4	175	173	167	165	161
Ovari	68	47	49	8	7	12	7	171	175	171	165	171
Periathalai	103	58	45	5	6	6	13	171	169	118	155	135
Manappad	79	80	55	31	7	9	11	99	167	162	155	158
Tiruchendur	79	65	49	8	7	12	25	41	119	135	125	164
Kayalpattinam	72	75	58	38	31	7	12	158	167	172	173	105
Tuticorin-south	42	41	47	45	43	39	28	135	145	151	135	116
Tuticorin-north	60	68	65	8	18	7	12	98	132	142	165	125

Table 10

Wave Breaking Angle (α_b) Measured on Beaches during 2007-08

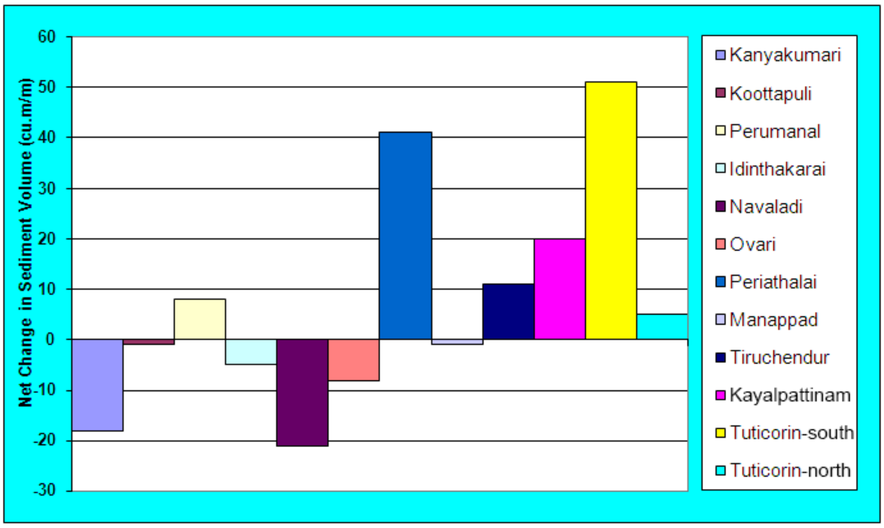
Beach Name	Wave Breaking Angle from Mar.-2007 to Feb.-2008 (degree)											
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Kanyakumari	69	49	48	9	9	12	135	171	162	170	125	98
Koottapuli	74	52	42	31	41	42	25	137	171	161	115	125
Perumanal	74	63	51	31	15	19	12	98	98	175	95	99
Idinthakarai	78	61	48	29	17	45	24	110	95	177	95	173
Navaladi	81	87	4	7	5	12	32	173	171	105	105	101
Ovari	48	43	48	10	5	9	13	95	168	162	112	104
Periathalai	103	99	75	15	11	14	21	96	169	152	125	148
Manappad	80	72	42	24	7	8	13	88	135	97	134	121
Tiruchendur	74	65	31	12	12	7	38	92	141	105	125	138
Kayalpattinam	109	62	65	25	25	8	14	163	161	115	162	108
Tuticorin-south	45	46	55	33	24	10	26	85	132	128	135	148
Tuticorin-north	48	75	75	13	23	13	28	100	128	115	145	142

During the period 2006-07 the maximum wave breaking wave height (1.12 m) is noted in Periathalai and the minimum (0.25 m) is recorded on Tuticorin-south coast. The wave-breaking heights in Navaladi, Ovari and Periathalai are bigger than that of the other coasts. These coasts have high breaking wave heights with plunging breakers during the monsoon. Kanyakumari, Manappad and Idinthakarai have moderate wave climate. The coasts of Tuticorin-south, Tuticorin-north, and Kayalpattinam have low wave climate. During the period 2007-08 the maximum wave breaking wave height (1.25 m) is noted in Navaladi and the minimum (0.25 m) is recorded on Tuticorin-south coast. The wave-breaking heights in Navaladi and Ovari are bigger than that of the other coasts. The wave climate on the Periathalai coast is comparatively reduced than that of during 2006-07. The coasts of Tuticorin-south, Tuticorin-north, and Kayalpattinam have low wave climates. During March to May the wave breaking angle mostly ranges from 50–100 deg. From June onwards wave breaks in northern direction. During this period the wave breaks almost parallel to the shoreline with small breaking angles. The wave breaking angles are less than 45 deg. to the coast in most of the beaches and coasts. This is due to the influence of the SW monsoon. From October onwards there is a rapid change in the direction of wave breaking angle. During this NE monsoon period the wave breaks at greater angles with the coastline and from January onwards it gradually decreases.

4.5. Beach Dynamics and Shoreline Changes

4.5.1. Beach Erosion and Accretion

The beach profile study indicates that the study area has experienced both erosion and accretion. The net change in sediment volume is represented in Fig. 10. The Kanyakumari zone has experienced erosion. In this zone the profile survey has been carried out in three stations namely Kanyakumari, Koottapuli and Perumanal. Erosion is severe on the Kanyakumari beach. The Koottapuli has also experienced erosion, but the Perumanal coast has an accretion trend. In the Ovari zone all the selected beaches except the Periathalai beach have experienced erosion, particularly the Navaladi coast has experienced more beach erosion. The Periathalai coast has experienced accretion. In the Tuticorin zone the profile survey has been carried out in three stations namely Manappad, Tiruchendur and the Kayalpattinam coast. All the beaches along this zone have experienced accretion. The present study also indicates that accretion is dominated in the Tuticorin zone. The Tuticorin-south beach has experienced more accretion due to the bay and concave nature of shoreline.



F i g. 10. Net Change in Sediment Volume

Beach erosion may be a short-term (order of hours to seasons) process that reflects adjustment to wave energy changes, or a longer-term (order of years) one that reflects an increasingly deficient beach sediment budget. On sandy beaches short-term changes involving erosion are commonly a part of a so called morphodynamic cycle of adjustment of the beach profile to seasonal or non-seasonal changes in wave energy (Short, 1999). Seasonal changes commonly correspond to the classic winter profile flattened by storms and the summer profile that accretes under fair weather conditions. The loss of beach sand usually corresponds to a gain of sand in the near-shore area, and *vice versa*. Beach sand can also be lost to the coastal features such as sand dunes, estuaries, and submarine canyons.

4.5.2. Shoreline Change along Beaches

Beach profiles measured at the same location over a period can provide details about the behavior of the beach. By taking a series of profiles along a beach and then repeating the profile measurements at later times, the behavior of the entire beach can be examined in terms of shoreline recession and volumetric sand loss. The concept of an equilibrium profile which is the average beach response to the natural forcing makes it possible to determine several beach responses to changes in forcing. Dean and Dalrymple (2004) analyzed the inter-relation between the shoreline changes and beach profiles. They state that the beach profile can be utilized to predict the shoreline changes.

The changes in the horizontal distance between the fixed reference point on the berm to the intersections of the beach profile with the vertical datum (Δy) is a key factor to identify the shoreline changes. The profiles can be concerned with changes in the shoreline position Δy, which can represent either a shoreline advancement ($\Delta y > 0$) or a recession ($\Delta y < 0$). The shoreline changes during the period 2008-10 and the rates of changes (Δy) along the different beaches are obtained from the beach profile data and shown in Table 11.

Table 11

Shoreline Change along Beaches

Coastal Zone	Beach Name	Shoreline Change (m)	Rate of Shoreline Change (m/year)
Kanyakumari	Kanyakumari	-4.10	-2.05
	Koottapuli	-2.20	-1.10
	Perumanal	2.10	1.05
	Idinthakarai	-1.90	-0.95
Ovari	Navaladi	-4.40	-2.20
	Ovari	-5.80	-2.90
	Periathalai	4.00	2.00
Tiruchendur	Manappad	1.80	0.90
	Tiruchendur	5.00	2.50
	Kayalpattinam	1.50	0.75
Tuticorin	Tuticorin-south	9.00	4.50
	Tuticorin-north	1.40	0.70

This study represents the advancement and retreat of shorelines, erosion and accretion made along the different beaches of the study area. It also represents that the shoreline along the Kanyakumari and Ovari coastal zone are retreating and that of Tiruchendur and Tuticorin zones are advancing. Shoreline change investigation along the coastal study area using remote sensing also indicated the coastal erosion along these coastal zones. Nayak (1992) identified Kanyakumari as one of the major erosion coasts in India. The tourism and construction of artificial barriers enhance the erosion along the Kanyakumari zone (Chauhan et al., 1996). Usha and Subramanian (1993) have reported that the coast near Ovari is exposed by severe erosion. But the Tiruchendur coast has experienced accretion. Sanil Kumar et al. (2006) also identified Tiruchendur as one of the prograding coasts along the Tamil Nadu coasts.

5. Conclusion

The study of beach profile emphasizes that the morphology of beaches along the study area undergoes dynamic changes in different spatial and temporal scales. Both cyclic (seasonal) and annual changes in the beach topography has been observed. The morphodynamic and volumetric analysis of beach profiles indicates that the beaches of Navaladi, Kanyakumari and Ovari have experienced more annual loss of sediments and they possess severe beach erosion. The beaches of Tuticorin-south, Periathalai, Kayalpattinam and Tiruchendur have experienced more accretion. The dynamic changes in the beach topography may also interact and modify the other coastal landforms. The beach erosion has received great attention from coastal scientists, government agencies, local authorities and beachfront owners, its perception and exact definition are controversial issues, mainly as a result of the diverse interests of the different parties involved in beaches and/or their management. A complete understanding of beach change throughout the coastal zone requires an active coastal management and profile modeling with clear definitions of beach processes and quantification of erosion rates.

Acknowledgement

The authors are thankful to Dr. Bhoop Singh, Director, NRDMS, Department of Science and Technology, New Delhi for his kind help in completing the work. The authors are also thankful to Department of Science and Technology, New Delhi for providing the financial assistance under NRDMS Scheme (ES/11/546/2000 and ES/11/936(5)/05).

REFERENCES

Angusamy, N. and Rajamanickam, G.V., 2000. Distribution of heavy minerals along the beaches from Mandapam to Kanyakumari, Tamilnadu. *Journal of the Geological Society of India*, 56(8), 199–211.

Bascom, W., 1980. Waves and Beaches: The Dynamics of the Ocean Surface, Revised and Updated Edition. Garden City: Anchor Books, New York, 366 p.

Basterretxea, G.A., Orila, X.A., Jordi, X.B., Lynetta, R.L.E., Liux, C.X.M., Duartc, X., and Tintore, J., 2004. Seasonal dynamics of a micro tidal pocket beach with Posidonia oceanic sea beds (Mallorca, Spain). *Journal of Coastal Research,* 20(4), 1155–1164.

Battjes, J.A., 1974. Computation of set-up, longshore current run-up and overlapping due to wind generated waves. Communication of Hydraulics, Rep. No. 74–2, Dept. of Civil Engg. Delft University of Technology, 244 p.

Bhat, M.S., Chavadi, V.C., and Hegde, V.S., 2003. Morphology and sediment movement in a monsoon influenced open beach at Gangavali, near Gokarn (central west coast of India). *Indian Journal of Marine Sciences*, 32(1), 31–36.

Bird, E.C.F., 1996. Beach Management. Chichester: John Wiley & Sons, 281 p.

Brunsden, D., 2001. A critical assessment of the sensitivity concept in geomorphology. *Catena*, 42, 99–123.

Cambers, G. and Ghina, F., 2005. Introduction to Sandwatch: An educational tool for sustainable development. Coastal Region and Small Island Papers, 19, UNESCO, Paris, 96 p.

Chandrasekar, N., Anil Cherian, Rajamanickam, M., and Rajamanickam, G.V., 2001. Influence of Garnet sand mining on beach sediment dynamics between the Periathalai and Navaladi coast, India. *Indian Journal Associations of Sedimentologists*, 20(2), 223–233.

Chandrasekar, N., Saravanan, S., Loveson Immanuel, J., and Rajamanickam, M., 2006. Classification of tsunami hazard along the southern coast of India: an initiative to safeguard the coastal environment from similar debacle. *Science of Tsunami Hazards*, 24(1), 3–23.

Chandrasekar, N. and Sheik Mujabar, P., 2010. Computer application on evaluating beach sediment erosion and accretion from profile survey data. *Computational Geosciences*, 14(4), 503–508.

Chandramohan, P., Sanil Kumar, V., and Nayak, B.U., 1993. Coastal processes along the shorefront of Chilka lake, east coast of India. *Indian Journal of Marine Sciences*, 22, 268–272.

Chauhan, P., Nayak, S., Ramesh, R., Krishnamoorthy, R., and Ramachandran, S., 1996. Remote sensing of suspended sediments along the Tamil Nadu Coastal waters. *J. Ind. Soc. Remote Sensing*, 24 (3), 105–114.

Chauhan, O.S., 1997. Climate induced changes in beach morphology and sediment dynamics, Machilipatnam. Second Indian National Conference on Harbour and Ocean Engineering (Inchoe-97) Tkiruvananthapuram, December 7–10, 1153–1162.

Clinton, D. Winant, Douglas, L. Inman, and Charles, E. Nordstrom, 1975. Description of seasonal beach changes using empirical eigenfunctions. *Journal of Geophysical Research*, 80(15), 1979–1986.

Cooper, N.J., Leggett, D.J., and Lowe, J.P., 2000. Beach-profile measurement, theory and analysis: Practical guidance and applied case studies. *Journal of the Chartered Institution of Water and Environmental Management*, 14, 79–88.

Dean, R.G., 1983. Beach Profiles. In: Herbich, J.B. (ed.), Handbook of Coastal and Ocean Engineering, Vol. 2: Offshore Structures, Marine Foundations, Sediment Processes, and Modeling, Houston: Gulf Publishing Company, 715–734.

Dean, R.G. and Dalrymple, R.A., 2004. Coastal Processes with Engineering Applications, Cambridge University Press, 133–161.

Douglas, B.C. and Crowell, M., 2000. Long-term shoreline position prediction and error propagation. *Journal of Coastal Research*, 16(2), 145–152.

Edward, J. Anthony, 2005. Beach Erosion, Encyclopedia of Coastal Science. Edited by Maurice L. Schwartz, Published by Springer, The Netherlands.

Emery, K.O., 1961. A simple method of measuring beach profiles. *Limnology and Oceanography*, 6, 90–93.

Galgano, F.A., Douglas, B.C., and Leatherman, S.P., 1998. Trends and variability of shoreline position. *Journal of Coastal Research*, SI 26, 282–291.

Guillen, J., Stive, M.J.F., and Capobianco, M., 1999. Shoreline evolution of the Holland coast on a decadal scale. *Earth Surface Processes and Landforms*, 24, 517–536.

Hardisty, J., 1994. Beach and near shore sediment transport. In: Pey, K., Sediment Transport and Depositional Processes. Blackwell Scientific Publications, 219–255.

Heinze, H., 2001. Change in the active volume of sediment on developed and undeveloped beaches, southern Maine: Geological Society of America, Abstracts with Programs, 33, A2–A11.

Jayakumar, S., Raju, N.S.N., Gowthaman, R., 2004. Beach dynamics of an open coast on the west coast of India. 3rd Indian National Conference on Harbour & Ocean Engineering, NIO, Goa, 9–16.

Kasinatha Pandian, P. and Dharanirajan, K., 2007. Beach morphology and coastal protection along Ennore coast in the north of Chennai city, southeast India. *Indian Journal of Science and Technology*, 1(1), 1–7.

Krause, G., 2004. The Emery-method revisited-performance of an inexpensive method of measuring beach profiles and modifications. *Journal of Coastal Research*, 20(1), 340–346.

La Fond, E.C. and Rao, P.R., 1954. Beach erosion cycles near Waltair on the Bay of Bengal, Andhra Univ., India. Memoirs in Oceanography, 1, 63–77.

Leatherman, S.P., 1983. Shoreline mapping: a comparison of techniques. *Shore and Beach*, 51, 28–33.

Masselink, G. and Pattiaratchi, C.B., 2001. Seasonal changes in beach morphology along the sheltered coastline of Perth, Western Australia. *Marine Geology*, 172(3–4), 243–263.

Moore, L.J., 2000. Shoreline mapping techniques. *Journal of Coastal Research*, 16, 111–124.

Mujabar, P.S., Chandrasekar, N., Saravanan, P., Loveson, S., 2007. Impact of the 26th December 2004 tsunami along the coast between Kanyakumari and Ovari, Tamil Nadu, South India. *Shore and Beach*, 75(2), 22–29.

Mujabar, P.S. and Chandrasekar, N., 2011a. Shoreline change analysis along the coast between Kanyakumari and Tuticorin, India using remote sensing and GIS. *Arabian Journal of Geosciences*, DOI: 10.1007/s12517-011-0394-4.

Mujabar, P.S. and Chandrasekar, N., 2011b. A shoreline change analysis along the coast between Kanyakumari and Tuticorin, India using digital shoreline analysis system. *Geo-Spatial Information Science*, 14(4), 282–293.

Mujabar, P.S. and Chandrasekar, N., 2011c. Coastal erosion hazardous assessment for the southern coastal Tamil Nadu and implication for sustainable development. *Natural Hazards*, DOI: 10.1007/s11069-011-9962-x.

Mujabar, P.S., Chandrasekar, N., and Saravanan, S., 2006. Impact of the 26th December 2004 tsunami on beach morphology and sediment volume along the coast between Ovari and Kanyakumari Tamilnadu, South India. *Shore and Beach*, 75(2), 22–29.

Nayak, S., 1992. Coastal Environment. Scientific Note, Space Applications Centre, Ahmedabad. RSAM/SAC/COM/SN/ 11/92, 114 p.

Nordstrom, C.F., 1992. Estuarine beaches: an introduction to the physical and human factors, Elsevier Applied Science, London and New York, 1992. 16th Edi. 225 p.

Parson, L.E., 1997. Beach and Near-Shore Survey Technology. Coastal Engineering Technical Note, U.S. Army Engineers Waterways and Experiment Station, CETN II-38 (6/97). 10 p.

Rajamanickam, M., 2006. Remote sensing and GIS application on beach placer minerals evaluation along the coast between Kallar and Vembar. Ph.D., Thesis, Tamil University, Tanjore, 179 p.

Ramanujam, N., Radhakrishnan, V., Sabeen, H.M., and Mukesh, M.V., 1996. Morphodynamic state of beaches between Vaipar and Tiruchendur, Tamilnadu. *Journal of Geological Society of India*, 47, 741–746.

Reddy, D.R., Prasad, V.V.S., Reddy, K.S.N., Varma, D.D., and Malathi, V., 2000. Seasonal variation in beach morphology and grain size characteristics for the shore between Baruva and Vajarpukotturu. East Coast of India. *Journal of Indian Association for Sedimentologists*, 19(1&2), 47–58.

Sajeev, R. and Sankaranarayanan, V.N., 1996. Seasonal changes of the sediment size distribution and stability along the beaches of Kerala, southwest coast of India. *Indian Journal of Marine Sciences*, 25, 216–220.

Sanil Kumar, V., Pathak, K.C.P., Pednekar, P., Raju, N.S.N., and Gowthaman, R., 2006. Coastal processes along the Indian coastline. *Current Science*, 91(4), 530–536.

Sa-Pires, C., Taborda, R., Ferreira, O., and Dias, J.A., 2004. Beach volume changes: Vertical datum definition. *Journal of Coastal Research*, SI 39, 341–344.

Short, A.D. and Trembanis, A.C., 2004. Decadal scale patterns in beach oscillation and rotation Narrabeen Beach, Australia – Time series, PCA and wavelet analysis. *Journal of Coastal Research*, 20(2), 523–532.

Short, A.D., 1999. Beach and Shore Face Morphodynamics. Chichester: John Wiley & Sons, 379 p.

U.S. Army Corps of Engineers, 2002. Coastal Engineering Manual. Engineer Manual, 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C. (in 6 volumes).

Usha, N. and Subramanian, S.P., 1993. Seasonal shoreline oscillations of Tamil Nadu coast. *Current Sciences*, 65, 667–668.

Vasudav, K., Sastry, A.V.R., and Swamy, A.S.R., 1986. Seasonal changes in the Vizhakapattinam-Bhimunpattinam beach profiles. *Journal of Indian Association of Sedimentology*, 6, 17–24.

Vijayam, B.E., U. Aswathanarayaka and C. Mahadevan, M., 1960. Sand movement on the Waltair beach, Visakhapatnam, India. *Current Science*, 26, 145–150.

Wright, L.D. and Short, A., 1983. Morphodynamic variability of surf zones and beaches: A synthesis. *Marine Geology*, 56, 93–118.

Ying Li, Murray, L., and Dominic, R., 2005. Multi-scale variability of beach profiles at Duck: A wavelet analysis. *Coastal Engineering*, 52(12), 1133–1153.

Zinn, D.J., 1969. An inclinometer for measuring beach slopes. *Marine Biology*, 2, 132–134.

* National College of Engineering,
Maruthakulam, Tirunelveli,
India
E-mail: sheikmujabar@yahoo.com

Manuscript received 04.01.12
Revised 01.02.13

** Center for Geo-Technology,
Manonmaniam Sundaranar University, Tirunelveli,
India

АНОТАЦІЯ Аналіз профілів пляжів є найпоширенішим методом вивчення їх динаміки. Проведено топографічний та морфологічний аналіз пляжів уздовж південного берега Тамілнад (Індія) з використанням методів зйомки їх профілів. Отримані дані обробляються із застосуванням сучасних програмних засобів, зокрема "Beach Morphology Analysis Package" («Пакет для аналізу морфології пляжу»). Представлено динаміку просторових профілів пляжів, проаналізовано їх морфологічні параметри, такі, як ширина та уклон. Проведено морфологічний і гранулометричний аналіз наносів на пляжах та їх річної та сезонної динаміки. В результаті на пляжах Каньякумарі, Наваладі та Оварі виявлене значне зменшення наносів, тоді як на пляжах південного Тутікоріна, Періаталай, Кайалпатінам і Тіручендур зафіксовані більші об'єми наносів. За результатами досліджень рекомендується здійснювати контроль за природним підживленням пляжів для зберігання їх від берегової ерозії.

Ключові слова: геоморфологія, берегова ерозія, транспорт наносів, зміна берегової лінії.

АННОТАЦИЯ Анализ профилей пляжей является наиболее распространенным методом изучения их динамики. Проведен топографический и морфологический анализ пляжей вдоль южного берега Тамилнад (Индия) с использованием методов съемки их профилей. Полученные данные обрабатываются с применением современных программных средств, в частности "Beach Morphology Analysis Package" («Пакет для анализа морфологии пляжа»). Представлена динамика пространственных профилей пляжей, проанализированы их морфологические параметры, такие, как ширина и уклон. Проведен морфологический и гранулометрический анализ наносов на пляжах и их годовой и сезонной динамики. В результате на пляжах Каньякумари, Навалади и Овари обнаружено значительное уменьшение наносов, в то время как на пляжах южного Тутикорина, Периаталай, Кайалпатинам и Тиручендур зафиксированы бóльшие объемы наносов. По результатам исследований рекомендуется осуществлять контроль за естественной подпиткой пляжей для сохранения их от береговой эрозии.

Ключевые слова: геоморфология, береговая эрозия, транспорт наносов, изменение береговой линии.