

Shoreline change analysis of Vedaranyam coast, Tamil Nadu, India

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Abstract The coastal zone is one of the nation's greatest environmental and economic assets. The present research aims at studying the shoreline changes along Vedaranyam coast using conventional and modern techniques including field sampling, remote sensing, and geographical information system (GIS). The study area was divided into three zones. Dynamic Land/Sea polygon analysis was performed to obtain the shore line changes at different time periods between 1930 and 2005. From the multirate shoreline maps, the rate of shoreline change was computed using linear regression rate and end point rate. Further, the shoreline was classified into eroding, accreting, and stable regions through GIS analysis. The eroding, accreting, and stable coastal stretch along Vedaranyam is observed as 18 %, 80.5 %, and 1.5 %, respectively. Net shoreline movement is seaward, i.e., the coast is progressive with an average rate of 5 m/year. A maximum shoreline displacement of 1.3 km towards the sea is observed near Point Calimere. During the Asian Tsunami 2004, the eastern part of the study area showed high erosion. Sediment transport paths derived from the grain size analysis of beach sediments collected during different seasons help to identify the major sediment source and sinks. Point Calimere acts as the major sink for sediments whereas

Agastiyampalli and Kodiakkarai are found to be the major sources for the sediment supply along the Vedaranyam coast. Shoreline change study from field and satellite data using GIS analysis confirms that Vedaranyam coast is accreting in nature.

Keywords Accretion · Erosion · Shoreline change · Tsunami 2004 · Vedaranyam coast

Abbreviations

EPR	End point rate
LRR	Linear regression rate
GIS	Geographical information system
STM	Sediment trend matrix
GPS	Global positioning system
GCP	Ground control points
DSAS	Digital Shoreline Analysis System
ASTM	American Society of Testing and Materials

Introduction

A shoreline is a historically, ecologically, and economically significant coastal feature demanding extensive research. Shoreline is a dynamic geo-feature defining the extent of land and sea. An idealized definition of shoreline is that it coincides with the physical interface of land and water (Dolan et al. 1991). Shorelines are constantly undergoing a wide range of changes in shape due to natural coastal processes as well as human

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intervention. Shoreline change is considered one of the most dynamic processes in coastal area (Bagli and Soille 2003; Sunarto 2004; Mills et al. 2005; Marfai et al. 2008). Being active and dynamic, it undergoes erosion or accretion from time to time, and accordingly, it acquires stability or a shifting nature. The International Geographic Data Committee recognizes shorelines as one of the 27 most important features to be mapped and monitored (Li et al. 2002; Nguyen et al. 2008). Accurate demarcation and monitoring of shoreline changes are necessary for understanding and deciphering the coastal processes operating in an area (Chand and Acharya 2010). Coastal changes are attracting more focus since they are important environmental indicators that directly affect the coastal economic development and land management (Welch et al. 1992; Stokkom et al. 1993). The changes in shoreline configuration are highly related to the intensity of sediment transport in time and space. Sediment transport is in turn closely connected with nearshore hydrodynamics, dominated by wave–current interactions. For this reason, understanding the mechanisms of sediment transport, forced by the combined action of waves and currents, is an important topic in the research of coastal processes. Long-term monitoring of shoreline by traditional methods is time consuming, requires manpower, and is not economical. In contrast, the synoptic coverage provided by the satellites offers great advantages in shoreline monitoring. Historical data available in the form of maps cannot provide a quantitative estimate of the sediment transport or erosion and accretion, but can indicate the position of the shoreline at that time. However, the remote sensing data as well as the data from field observation from the recent past and the present can provide these details. The combination of the conventional and modern techniques can be satisfactorily used to assess the shoreline changes.

Study area

Vedaranyam is an ecologically important region situated on the southeast coast of India. It is a marine–coastal wetland with a wide diversity of habitats and ecological features including inter-tidal salt marshes, forested wetlands, mangroves, and brackish to saline lagoons. Point Calimere Wild life and Birds sanctuary form the major refuge for migratory and resident birds. About a 50-km coastal stretch of Vedaranyam with an extent of 10°10′–10°30′ N latitude to 79°40′–79°55′ E longitude has been

considered as the study area (Fig. 1). Near Point Calimere, there is a wide belt of swamps and creeks separated from the shoreline by a barrier of about 25-km long known as the Great Vedaranyam salt swamp which is the largest swamp in Tamilnadu. Salt pans are located along this swamp.

Bundles of beach ridges with intervening swales have developed in between Tirutturaiipoondi in the northwest and Kodiakkarai in the southeast to a breadth of approximately 55–58 km. In the outermost part of such beach ridge swale complex, 90–100-km-long Vedaranyam backwater is found. The occurrences of beach ridge swales indicate that the sea might have been in Tirutturaiipoondi area in recent years and gradually receded up to Kodiakkarai, the present-day seashore, thereby leaving the beach ridges and swales. Ramasamy and Ravikumar (2002) identified that off-shore sand bars/shoals which are enveloping the present-day Kodiakkarai shoreline have been built up to a distance of approximately 22 km inside the sea between Kodiakkarai in the northwest and Jaffna Peninsula in the southeast, while the distance between both is 30 km. Palk Bay is one of the five major permanent sediment sinks of India. This sediment load is said to cause a sea depth reduction of 1 cm/year.

The primary objective of the present study is to understand the shoreline behavior of Vedaranyam which has a unique morphology due its inverted “L” shaped geometry. This is suggestive of the fact that this formation has been achieved over a long period of influence of the inter-tidal forces acting on the coast as well as the wave action of Bay Bengal and the Palk Strait. The present study focused on assessing the shoreline changes under normal and extreme (tsunami) coastal conditions and understanding the sediment transport mechanisms prevailing along the coast.

Monitoring of shoreline changes

Remote sensing data has been used to detect shoreline changes (Frihy et al. 1998; Shaghude et al. 2003; Kuleli 2005; Vanderstraete et al. 2006; Ekercin 2007; Bayram et al. 2008; Sesli et al. 2008). Siddiqui and Maajid (2004) evaluated a multi-temporal principal component analysis on LANDSAT Multispectral Scanner and TM data to evaluate coastal changes between 1973 and 1998 in Pakistan. Rajamanickam et al. (2004) studied the short-term shoreline changes and its possible causes in

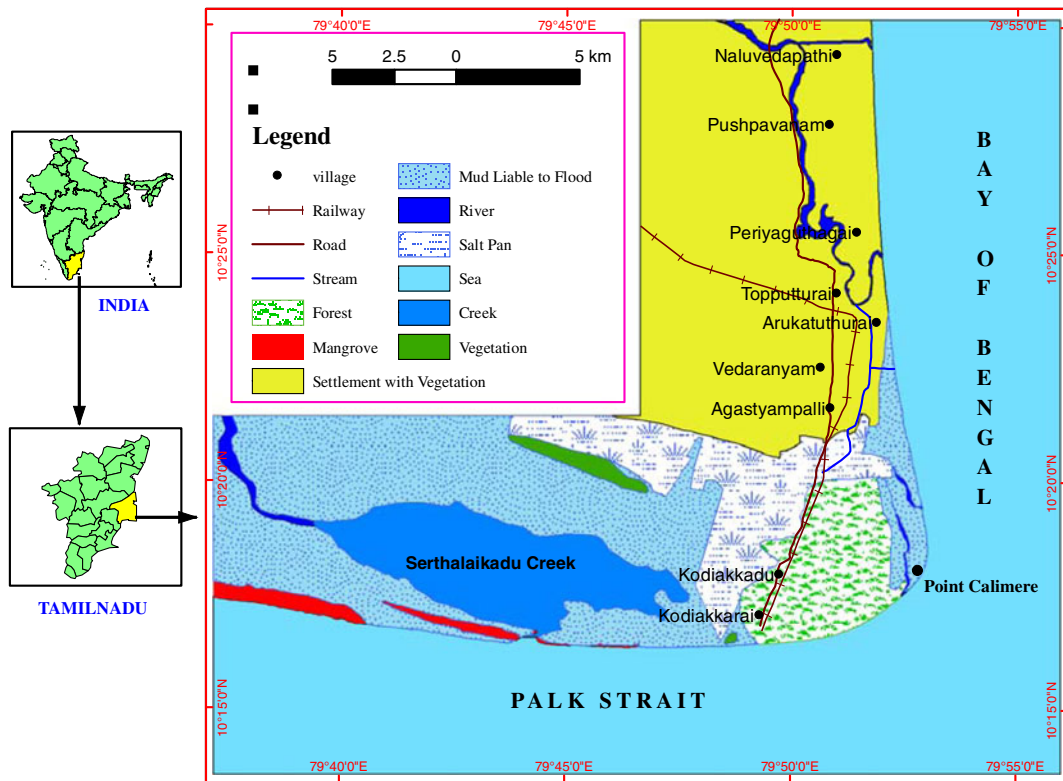


Fig. 1 Study area

and around the Kallar and Vaippar coast using remote sensing and GIS techniques. Remotely sensed data can provide valuable preliminary estimates of change, and is a unique tool for research and monitoring coastal areas and deltaic environments (Ciavola et al. 1999; Yang et al. 1999; Wu 2007; Kuleli 2010). Integration of the latest techniques of remote sensing with geographical information system (GIS) has been proven to be an extremely useful approach for the shoreline changes studies due to synoptic and repetitive data coverage, high resolution, multispectral database, and its cost effectiveness in comparison to conventional techniques (Chand and Acharya 2010).

Grain size distribution has been widely used to infer transport and depositional process (Folk and Ward 1957). McLaren (1981) presented Sediment Trend Matrix (STM) which utilizes a statistical analysis of grain size parameters viz., mean, sorting, and skewness. Gao and Collins (1992) re-examined the basic assumption of McLaren model and concluded that though the two cases stated above are predominant, the presence of other cases can cause a high level of distortion while using the one-dimensional model. Lucio et al. (2002)

proposed a new statistical approach to establish the sediment transport direction along a one-dimensional profile with the help of grain size distribution. Weber et al. (2003) used grain size parameters to infer sediment transport energy and to distinguish different environments along the 300-km-long transport path from the delta platform to lower Bengal fan. Crowell et al. (1993) preferred the linear regression statistic for calculating long-term rate of shoreline change.

Materials and methods

For the present study, the shoreline data from historical maps, topographic sheets, field survey, and satellite data covering the Vedaranyam coast had been collected between 1930 and 2005 (Table 1). Beach sediments were collected from six stations along the coast on full-moon day during different seasons between December 2003 and May 2005. As there were two full-moon days occurring in July 2004, beach samples were collected on both days and represented by July-I and July-II. Sampling stations were fixed approximately at 5-km

Table 1 List of spatial data products used

S. no.	Period	Type of data	Sensor
1	1930	Toposheet	–
2	1970	Toposheet	–
3	January 1991	Landsat-5	Thematic Mapper (TM)
4	November 1999	Landsat-7	Enhanced Thematic Mapper+ (ETM)
5	July 2002	IRS-1D	LISS III and PAN merged
6	February 2004	GPS survey	–
7	December 2004	IRS-P6	LISS III
8	January 2005	IRS-P6	LISS III

GPS global positioning system, IRS Indian Remote Sensing satellite, LISS linear imaging and self-scanning sensor, PAN panchromatic sensor

interval viz., Arukatuthurai (P1), Agasthiyampalli (P2, P3), Point Calimere (P4), Kodiakkarai (P5), and Serthalaikaadu creek (P6). Using Leica GS5+ Global Positioning System (GPS), the stations were identified and samples were collected between the berm and plunging zone. About 250 g of unconsolidated sand was collected in a polythene cover using a scoop at each sampling location and brought to the laboratory for grain size analysis. Sediments could not be collected during some period due to rough weather and inaccessibility to the coast.

The research aimed at delineating erosion and accretion zones, identification of horizontal displacement and computation of rate of shoreline change. Consequently, two kinds of GIS analyses were performed, viz., Dynamic Land/Sea polygon analysis and analysis of rate of shoreline change. Vedaranyam coast has an “L” shape with different coastal environments; hence, the study area was split into three zones approximately equal in length as zone I, III, and II viz., Palk Strait, Bay of Bengal, and their mixing zone, respectively, for better understanding of the shoreline behavior. A field survey was conducted to collect ground control points (GCP) using Leica GS5+ GPS over the study area. Second-order polynomial transformation model was used to georeference the digital images to GCS-WGS-1984 co-ordinate system using GCPs. After geometric correction was applied to all the spatial data, they were projected to GCS-UTM-Zone 44 co-ordinate system and imported to GIS for shoreline mapping. Shoreline from 1930 and 1970 toposheets and from near-infrared bands of satellite data were digitized. Shoreline in 2004 was tracked using GPS and converted to a shape file. ArcGIS 9.0 was used to generate the polyline themes and their attributes. A common buffer area was created with the same extent of shorelines and stored as a polygon theme. The shoreline themes were overlaid with the buffer

theme individually. Each had two polygons, one being Land and the other being the Sea.

A vector-based transect analysis was carried out to calculate the horizontal displacement and the rate of shoreline change was performed using Digital Shoreline Analysis System (DSAS) developed by United States Geological Survey. It was carried out in four steps: (1) shoreline preparation, (2) baseline creation, (3) transect generation, and (4) computation of rate of shoreline change. Shorelines from 1930 to 2004 were stored in a geodatabase with UTM co-ordinate system. The shoreline of 2005 was excluded from the calculation of the rate of shoreline change since it was collected immediately after the tsunami. Shape and relative location of the reference line (baseline) for generating transects to the shorelines directly impacts the rate calculations in DSAS (Thieler 2005). Landward baseline by manual digitization with similar shape of the shorelines and 503 transects, each with a length of 2.5 km at 100-m intervals, were generated. While creating transects, their intersection points with different shorelines were noted. End point rate (EPR) and linear regression rate (LRR) were considered for the computation of rate of shoreline changes. EPR was calculated by dividing the distance of horizontal shoreline movement by the time elapsed between the earliest and latest measurements. LRR was determined by fitting a least squares regression line to all the comparable shore points of different periods for a particular transect. The positive EPR and LRR values represent the shoreline movement towards sea (i.e., rate of accretion) and negative values indicate towards sea (i.e., rate of erosion).

The collected beach samples were oven-dried to remove the moisture content. From each of the dried samples, 100 g was taken for grain size analysis. The samples

Table 2 Shore area changes

Time step	Period	Zone I		Zone II		Zone III		Entire study area	
		E	A	E	A	E	A	E	A
1	1930–1970	0.009	2.937	0.008	7.790	0.412	2.053	0.430	12.783
2	1970–1991	1.325	5.770	0.588	2.432	0.002	2.581	1.916	10.783
3	1991–1999	1.865	0.130	0.774	0.321	0.545	0.189	3.180	0.640
4	1999–2002	0.296	0.068	0.674	0.044	0.652	0.001	1.620	0.112
5	2002–2004	0.009	0.604	0.034	0.460	Nil	0.631	0.042	0.170
6	2004–2005	0.130	0.181	1.125	0.086	0.476	0.001	1.731	0.268

E erosion, *A* accretion values (km²)

were run through American Society of Testing and Materials (ASTM) sieves from +18 to +400 mesh sizes at 0.5Φ interval in a Ro-Tap sieve shaker for 20 min. The sediment retained on each sieve was carefully removed and weighed and the statistical parameters viz., mean, sorting, skewness, and kurtosis were computed.

Results and discussion

Identification of erosion/accretion regimes

Dynamic Sea/Land polygon analysis provides zone-wise shore area changes during different time periods from 1930 to 2005 as shown in Table 2. Also, the dynamic shore area, i.e., the area under maximum shoreline oscillations, between 1930 and 2005 is identified as 25 km². In the initial time steps 1 and 2, i.e., 1930–1970 and 1970–1991, all the three zones are dominated by accretion with high accretion observed in zone II and zone I, respectively. In the subsequent time steps 3 and 4, erosion predominates in zone I in 1991–1999 and almost equally eroded areas are observed in zone II and zone III during 1999–2002. From 2002 to 2004, all the three zones are dominated by accretion. The analysis shows the area of accretion decreases up to the recent past when compared to the initial period, i.e., 1930. The shoreline of Vedaranyam was affected by Asian tsunami on December 26, 2004. Jayakumar et al. (2005) reported that the tsunami inundation along the Vedaranyam–Nagore coastal stretch was high because of the low-lying areas. Within 1 month, i.e., between December 2004 and January 2005, zone II and zone III showed high erosion. The overall rate of accretion and erosion is 0.27 km² and 1.73 km², respectively.

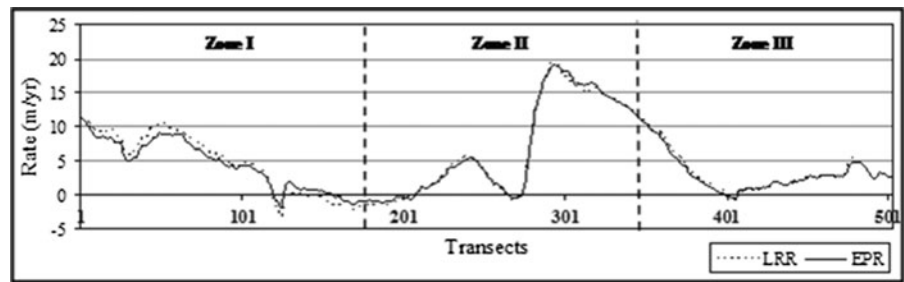
Rate of shoreline change

Zone-wise variations in EPR and LRR for 1930–2004 along the Vedaranyam are given in Table 3 and Figs. 2 and 3. From Table 3, it is clear that the average LRR is positive for all the zones. The overall average shows that the Vedaranyam coast is accreting at the rate of 5 m/year between 1930 and 2004. Comparison of minimum and maximum values of LRR shows relatively high erosion and accretion occurring in zone I and zone II, respectively. Further, the shoreline is classified into erosion, accretion, or stable region using the LRR values as shown in Fig. 3. In the total coastal stretch, 18 %, 80.5 %, and 1.5 % coastal lengths are found to be under erosion, accretion, and stable, respectively. Comparatively higher LRR for zone II and higher percentage of accreting shoreline of the study area confirms the progressing nature of the coastline. Maximum EPR occurs between 1930 and 1999 in zone II with the seaward displacement of 1.3 km whereas the minimum EPR occurs between 1970 and 1999 in zone I with the landward displacement of 55 m. From Table 3, it is clear that average EPR is positive for all the zones with an overall average of 4.92 m/year. This also proves that

Table 3 Statistics of LRR and EPR

Rate (m/year)	Zone I		Zone II		Zone III	
	LRR	EPR	LRR	EPR	LRR	EPR
Average	4.98	4.79	6.0	6.2	3.94	3.82
Minimum	-3.21	-1.87	-2.15	-1.41	-0.53	-0.83
Maximum	11.41	11.38	19.56	19.2	13.28	13.42

Fig. 2 Variation of LRR and EPR along the shoreline



the Vedaranyam shoreline is progressing towards the sea with an average rate of 5 m/year.

Sediment transport processes

The mean, sorting, and skewness values obtained from grain size analysis were used to decipher the sediment transport path based on the McLaren “rules of

transport”. Between December 2003 and May 2005, monthly variations in sediment transport processes are assessed from STM (Figs. 4 and 5), and the major source and sink locations for each period are identified (Table 4 and Fig. 6) along Vedaranyam coast. P3 (Point Calimere) is observed to be the major sink while P2 (Agastiyampalli) and P5 (Kodiakkarai) are identified as major sources for sediment supply. This

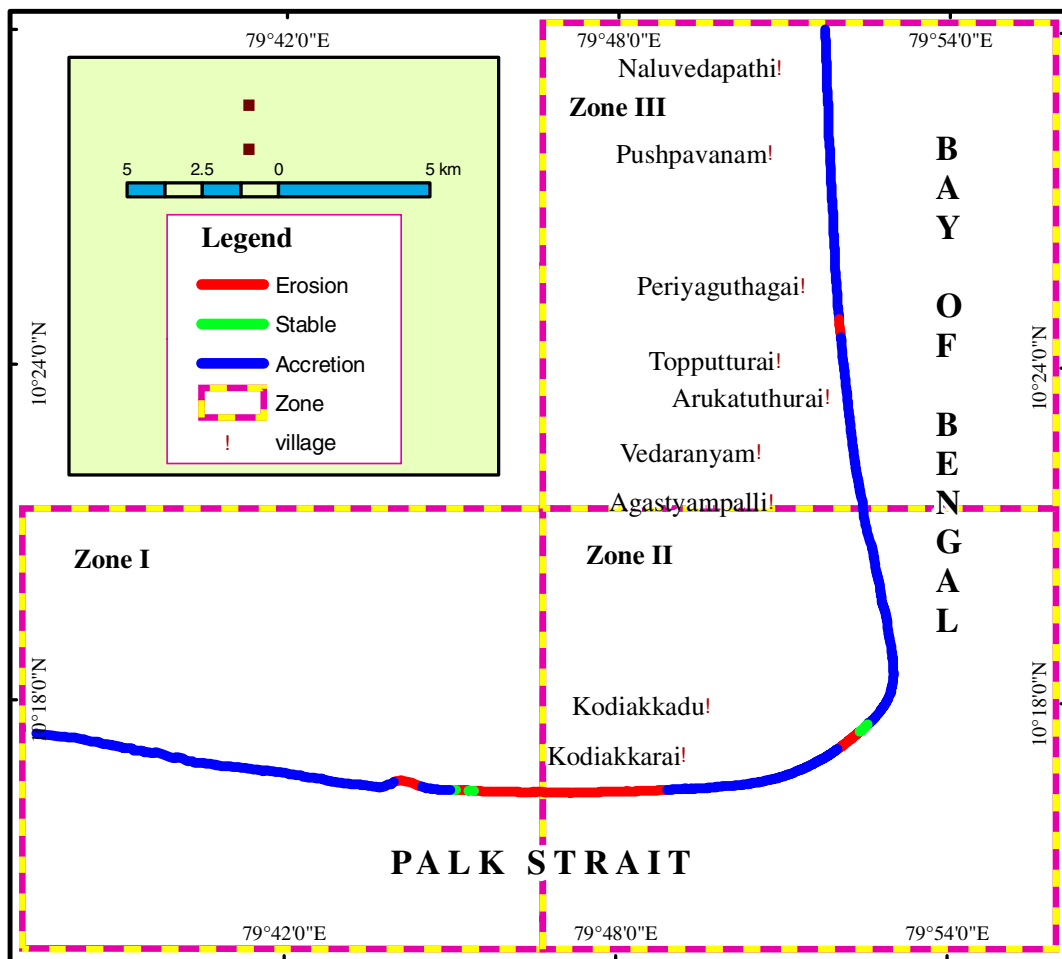


Fig. 3 Shoreline classification map

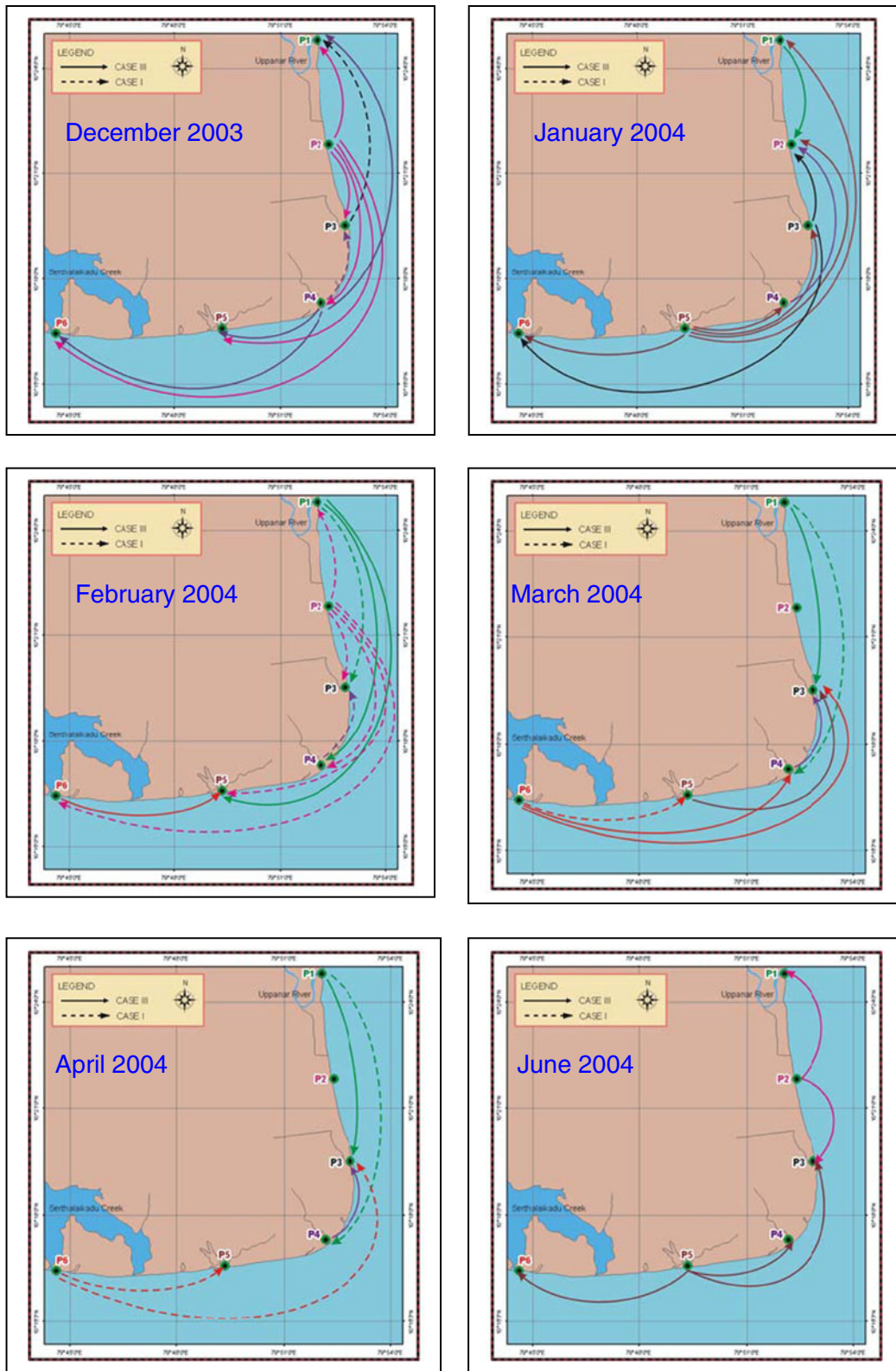


Fig. 4 Sediment trend between December 2003 and June 2004

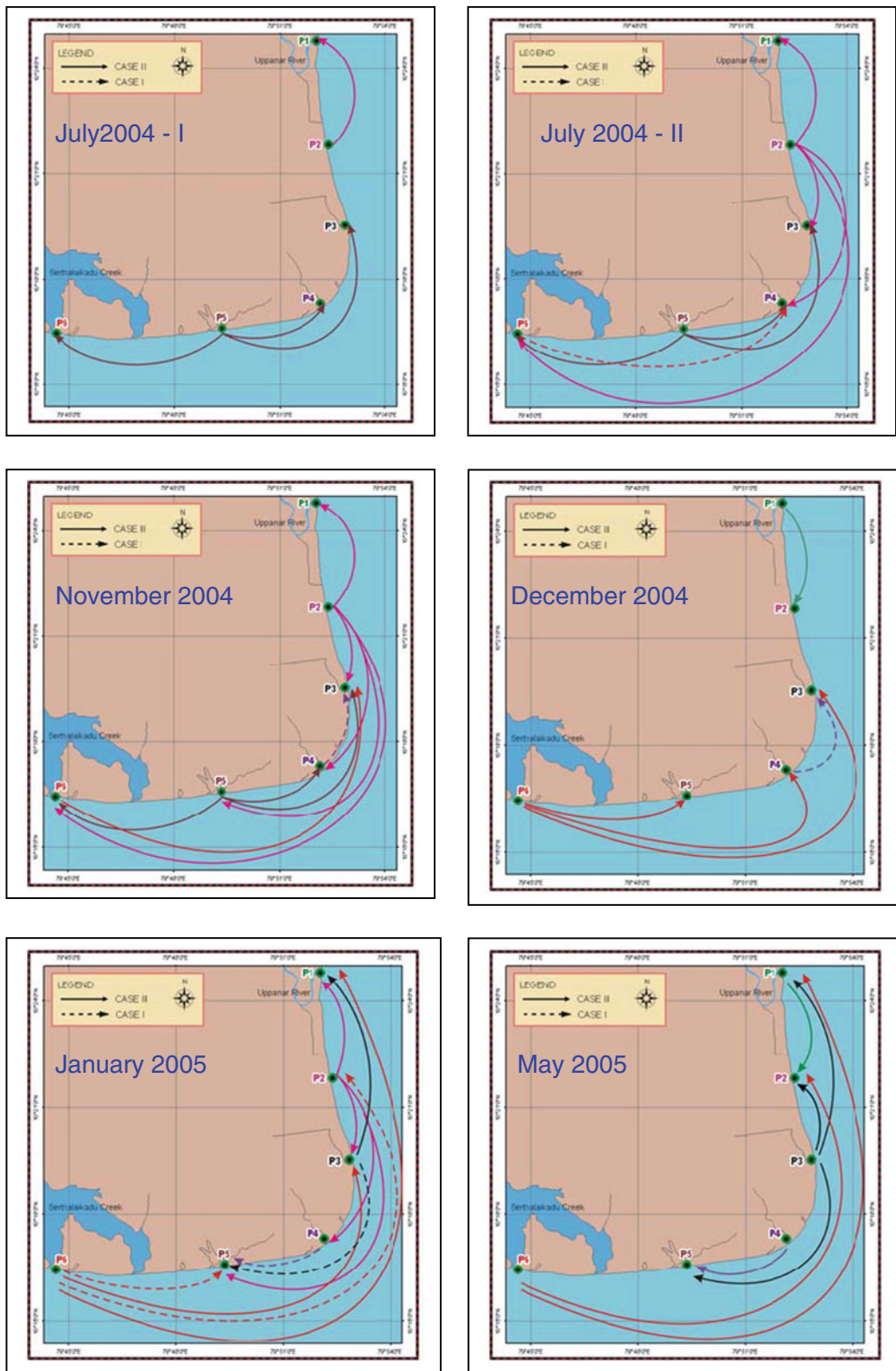


Fig. 5 Sediment trend between July 2004 and May 2005

Table 4 Source and sink locations

S. no.	Period	Major source	Major sink
1	December 2003	P2, P4	–
2	January 2004	P5	P2
3	February 2004	P2, P1	P5, P3
4	March 2004	P6, P1	P3, P4
5	April 2004	P1, P6	P3
6	June 2004	P5, P2	P3
7	July 2004—I	P5	–
8	July 2004—II	P2, P5	P4
9	November 2004	P2, P5	P3
10	December 2004	P6	P3
11	January 2005	P2, P6	P5, P1
12	May 2005	P3	P2

explains the coastal processes underlying the growth of the Point Calimere tip. Sediment movement shows variation for the two sets of samples collected in July 2004 indicating the dynamic behavior of the coast. The formation of Point Calimere projection is due to two constantly opposing wave directions such as northeast and southeast, with one set of waves predominant over the other. Further, the foreland formation is determined by the rate at which the stream delivers the sediment and the rate at which the wave can winnow and move the sediments in either direction away from the mouth. The coastline is consequently affected predominantly by waves from northeast. This is clearly reflected by the shape of the foreland which has veered

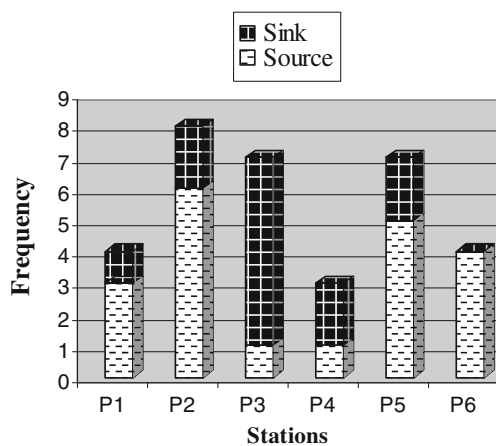


Fig. 6 Frequency of stations acting as sediment source/sink

windward. Sediment distribution at Vedaranyam during different seasons show that sediments move towards north during southwest monsoon and vice versa during northeast monsoon. The observations from recent satellite data agree with the longshore current direction perceived through conventional methods (Natesan 2004). The longshore currents from the Bay of Bengal in the north and the Gulf of Mannar in the south transport these sediments into the Palk Bay. The net quantum of littoral sediments entering into the Palk Bay from the Nagapatnam coast is $0.27 \times 10^6 \text{ m}^3$ (Sanil Kumar et al. 2002).

Conclusions

From the study on shoreline dynamics of Vedaranyam coast between 1930 and 2004, the dynamic shore area is found to be 25 km^2 . Area of accretion declines from 1930 to 2004 indicating the change in coastal dynamics of Vedaranyam. Eroding, accreting, and stable coastal stretches along Vedaranyam are observed as 18 %, 80.5 %, and 1.5 %, respectively. A maximum shoreline displacement of 1.3 km towards the sea is observed in zone II near Point Calimere. The overall accretion and erosion within a month after the tsunami is computed as 0.27 km^2 and 1.73 km^2 , respectively. Point Calimere acts as the major sink whereas Agastiyampalli and Kodiakkarai are found to be the major sources for the sediments along the Vedaranyam coast. The net shoreline movement is seaward, i.e., the coast is progressive with an average rate of 5 m/year. Shoreline change analysis from field and satellite data as well as GIS analysis confirms that Vedaranyam coast is accreting in nature. From the identification of sediment sources/sinks for Vedaranyam, the study provides the reason for the growth of Point Calimere tip. The results obtained from the study can be used to prepare a coastal zone management plan for Vedaranyam. Especially the progressing coast can be made use for beneficial purposes with due consideration given to preserve the coastal wetland at Vedaranyam.

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References

- Bagli, S., Soille, P., (2003). Morphological automatic extraction of Pan-European coastline from Landsat ETM+ images. *International Symposium on GIS and Computer Cartography for Coastal Zone Management*, October 2003, Genova.
- Bayram, B., Acar, U., Seker, D., & Ari, A. (2008). A novel algorithm for coastline fitting through a case study over the Bosphorus. *Journal of Coastal Research*, 24(4), 983–991.
- Chand, P., & Acharya, P. (2010). Shoreline change and sea level rise along coast of Bhitarkanika wildlife sanctuary, Orissa: an analytical approach of remote sensing and statistical techniques. *International Journal of Geomatics and Geosciences*, 1(3).
- Ciavola, P., Mantovani, F., Simeoni, U., & Tessari, U. (1999). Relation between dynamics and coastal changes in Albania: an assessment integrating satellite imagery with historical data. *International Journal of Remote Sensing*, 20(3), 561–584.
- Crowell, M., Leatherman, S. P., & Buckley, M. K. (1993). Shoreline change rate analysis: long term versus short term data. *Shore and Beach*, 61(2), 13–20.
- Dolan, R., Fenster, M. S., & Holme, S. J. (1991). Temporal analysis of shoreline recession and accretion. *Journal of Coastal Research*, 7(3), 723–744.
- Ekerchin, S. (2007). Coastline change assessment at the Aegean sea coasts in Turkey using multitemporal Landsat imagery. *Journal of Coastal Research*, 23(3), 691–698.
- Folk, R. L., & Ward, W. C. (1957). Brazos River bar: a study in the significance of grain size parameters. *Journal of Sedimentary Petrology*, 27(1), 3–26.
- Frihy, O. E., Dewidar, K. M., Nasr, S. M., & El Raey, M. M. (1998). Change detection of the northeastern Nile Delta of Egypt: shoreline changes, Spit evolution, margin changes of Manzala lagoon and its islands. *International Journal of Remote Sensing*, 19(10), 1901–1912.
- Gao, S., & Collins, M. (1992). Net sediment transport patterns inferred from grain-size trends, based upon definition of transport vector. *Sedimentary Geology*, 81, 47–60.
- Jayakumar, S., Ilangovan, D., Naik, K. A., Gowthaman, R., Tirodkar, G., Naik, G. N., Ganesan, P., ManiMurali, R., Michael, G. S., Raman, M. V., & Bhattacharya, G. C. (2005). Run-up and inundation limits along southeast coast of India during the 26 December 2004 Indian Ocean tsunami. *Current Science*, 88(11), 1741–1743.
- Kuleli, T. (2005). Change detection and assessment using multi temporal satellite image for North-East Mediterranean Coast. *GIS Development Weekly*, 1(5).
- Kuleli, T. (2010). Quantitative analysis of shoreline changes at the Mediterranean Coast in Turkey. *Environmental Monitoring and Assessment*, 167, 387–397.
- Li, R., Ma, R., & Di, K. (2002). Digital tide-coordinated shoreline. *Marine Geodesy*, 25(1), 27–36.
- Lucio, P. S., Gama, C., & Andrade, C. (2002). One-dimensional alternatives to determine sediment trend transport. Case study: Troia–Sines arcuate coast—Portugal. *Littoral*, 5, 391–396.
- Marfai, M. A., Almohammad, H., Dey, S., Susanto, B., & King, L. (2008). Coastal dynamic and shoreline mapping: multi-sources spatial data analysis in Semarang Indonesia. *Environmental Monitoring and Assessment*, 142, 297–308.
- McLaren, P. (1981). An interpretation of trends in grain size measures. *Journal of Sedimentary Petrology*, 51(2), 611–624.
- Mills, J. P., Buckley, S. J., Mitchell, H. L., Clarke, P. J., & Edwards, S. J. (2005). A geomatics data integration technique for coastal change monitoring. *Earth Surface Processes and Landforms*, 30, 651–664.
- Nguyen, T., Peterson, J., Gordon-Brown, L., Wheeler, P., (2008). Coastal changes predictive modelling: a fuzzy set approach. *World Academy of Science, Engineering and Technology*, 48.
- Ramasamy, S. M., & Ravikumar, R. (2002). GIS based visualization of land–ocean interactive phenomenon along Vedaranniyam coast, Tamilnadu, India. *Indian Society of Geomatics Newsletter*, 9(1–2), 72–77.
- Rajamanickam, M., Chandrasekar, N., Saravanan, S., (2004). GIS-based shoreline change detection between Kallar and Vembar Coast. *International Conference on Remote Sensing Archaeology, Beijing*
- Sanil Kumar, V., Anand, N. M., & Gowthaman, R. (2002). Variations in nearshore processes along Nagapattinam coast, India. *Current Science*, 82(11), 1381–1389.
- Sesli, F. A., Karshi, F., Colkesen, I., & Akyol, N. (2008). Monitoring the changing position of coastlines using aerial and satellite image data: an example from the eastern coast of Trabzon, Turkey. *Environmental Monitoring and Assessment*. doi:10.1007/s10661-008-0366-7.
- Shaghude, Y. W., Wannäs, K. O., & Lundén, B. (2003). Assessment of shoreline changes in the western side of Zanzibar channel using satellite remote sensing. *International Journal of Remote Sensing*, 24(23), 4953–4967.
- Siddiqui, M. N., & Maajid, S. (2004). Monitoring of geomorphological changes for planning reclamation work in coastal area of Karachi, Pakistan. *Advances in Space Research*, 33, 1200–1205.
- Stokkom, H., Stokman, G., & Hovenier, J. (1993). Quantitative use of passive optical remote sensing over coastal and inland water bodies. *International Journal of Remote Sensing*, 14, 541–563.
- Sunarto, S., (2004). *Geomorphologic changes in coastal area surround Muria Volcano*. Dissertation, Gadjah Mada University Yogyakarta (in Indonesian).
- Thieler, E.R., (2005). *Digital Shoreline Analysis System—user's guide, version 3.0*. U.S. Geological Survey Open-File Report No. 2005-1304, 1–28.
- Natesan, U. (2004). Role of satellites in monitoring sediment dynamics. *Current Science*, 86(8), 1068–1069.
- Vanderstraete, T., Goossens, R., & Ghabour, T. K. (2006). The use of multi-temporal Landsat images for the change detection of the coastal zone near Hurghada, Egypt. *International Journal of Remote Sensing*, 27(17), 3645–3655.

- Weber, M. E., Wiedicke-Honbach, M., Kudrass, H. R., & Erlenkeuser, H. (2003). Bengal fan sediment transport activity and response to climate forcing inferred from sediment physical properties. *Sedimentary Geology*, *155*, 361–381.
- Welch, R., Remillard, M., & Alberts, J. (1992). Integration of GPS, remote sensing, and GIS techniques for coastal resource management. *Journal of Photogrammetric Engineering and Remote Sensing*, *58*, 1571–1578.
- Wu, W. (2007). Coastline evolution monitoring and estimation—a case study in the region of Nouakchott, Mauritania. *International Journal of Remote Sensing*, *28*(24), 5461–5484.
- Yang, X., Damen, M. C. J., & Van Zuidam, R. A. (1999). Use of Thematic Mapper imagery with a geographic information system for geomorphologic mapping in a large deltaic lowland environment. *International Journal of Remote Sensing*, *20*(4), 659–681.