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Geospatial Analysis of Coastal Geomorphological Vulnerability along Southern Tamilnadu Coast

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1. Introduction

Coastal vulnerability is defined as the occurrence of a phenomenon, which has the potential for causing damage to or loss of buildings under natural ecosystems and the other infrastructure man-made. The assessment of the coastal erosion hazard and mitigation is an estimation of a coastal area susceptible to erosion, based on a number of factors such as shoreline changes, geology, geomorphology, rate of sea level rise, waves and current pattern, human impact on coast etc. Many researchers have successfully investigated long-term shoreline changes and morphological changes in the coastal landforms based on remote sensing and GIS techniques (Meijerink 1971; Nayak and Sahai 1985; Prabhakar Rao et. Al. 1985; Shaikh et.al. 1989; Vinodkumar et. al. 1994; Capobiance et. al. 1999; Loveson et.al. 1990; Chandrasekar et. al. 2000, 2000a, 2000b, 2002a ; Amaro et. al. 2002 a,b; Vital 2003a, Vital et. al. 2003b; Rajamanikam 2006). The relationship of the heavy minerals and shoreline changes along Nile delta, Egypt has been well explained by Frithy and Komar 1993; Frithy and Khafugy (1991); Fishawi and Ohdr (1989); Lofty and frithy (1993). They have been described the correlation between the rates of shoreline erosion to the heavy mineral groups and grain sizes of the beach sediment. Hasham and white (2002) have studied the impact of shoreline changes in Nile delta using the combination of remote sensing data nearshore bathymetric surveys, heavy minerals and grain size.

The present study is aimed to investigate the coastal vulnerability based on four parameters namely; 1) Land use/ Land cover changes, 2) Shoreline changes over the years, 3) Rate of erosion and accretion, 4) Sediment transport during pre-monsoon, monsoon, post-monsoon seasons using remote sensing and GIS techniques.

II. Geology

The south Indian coast especially Tamilnadu coast is made up of granulite facies of charnockites. Ramachandran et. al. (1986), Narayanasamy and Lakshmi (1990) have investigated the western part of Tirunelveli granitoid of non-garnetifeous mica, hornblende gneisses and mixed gneisses associated with migmatites. The crystalline limestones in Tamilnadu are probably the oldest one in the world. These deposits are noticed in Vaippar catchment area of Tuticorin district. The presence of crystalline limestone and calcgranulites are observed with granular quartzite, garnetiferous gneiss and migmatite. Gopal and Jacob (1995) have collected and identified several plant fossils belonging to felicals ginkgoales and coniferales from Sivaganga belts (Northern part of Kallar). The study area composed of Gondwana formations are found to overlain by loose sand and laterites. It is exposed in

Tuticorin and Ramanathapuram districts and are confined to the coastal plains and flood plains of Vaippar river.

III. Materials and Methods

3.1. Study area

The present study area lies between Kallar and Vembar lies in the Gulf of Mannar, Tamilnadu with in the latitudes of 8°55″ to 9°5″ N and longitudes of 78°10″ to 78°20″ E. It is bounded by Gulf of Mannar in the east, Surangudi in the west, Vembar river in the north and Kallar river in the south. The extend of total area is about 136.54 km^2 (figure 1). The study area attracts various wetland features like creek, coastal sand dune, and mangrove ecosystem. Extensive beach sand dunes enriched with deposits of black sand (IImenite, garnet, rutile and zircon) are seen. The area forms four major types of geomorphic units such as buried pediment, flood plain, valley fill and lateritic upland.

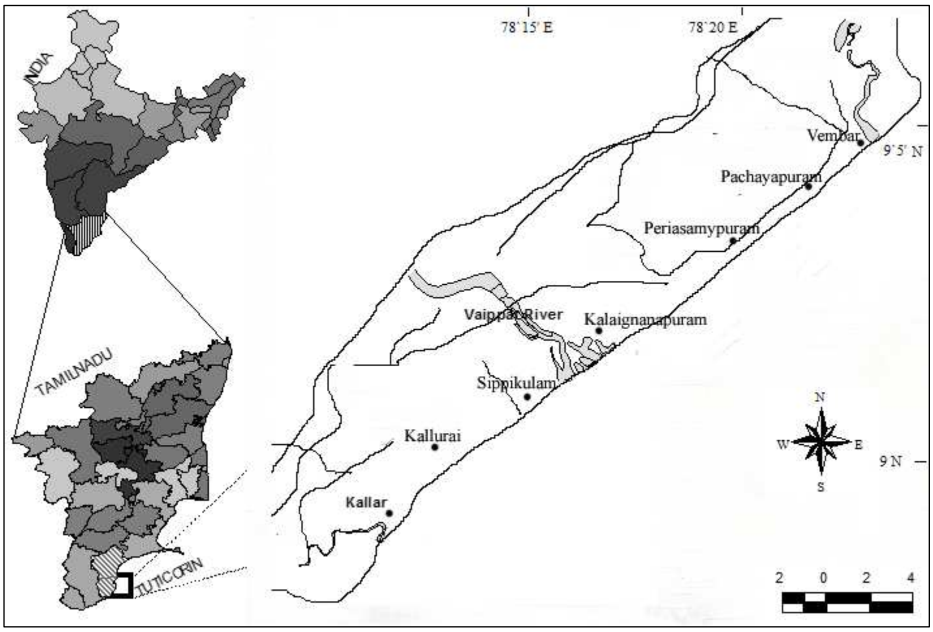


Figure 1. Location map of the study area

3.2. Satellite Data

The digital products of multispectral satellite images of Landsat MSS, Landsat ETM+ along with high resolution IRS-1D PAN data and Toposheet (N0. 58, L/1, L/5 and K4 at 1:25000 scale) are selected for coastal vulnerability analysis. The detailed characteristics of these imageries are described in Table 1.

Table 1. Spatial and spectral characteristics of Multispectral and PAN imageries

S. No	Sensor	Path / Row	Spectral resolution	Spatial resolution	Producer	Acquisition date
1	Landsat-MSS	143/054	4	79m X 57m	Earthsat	1979-01-08
2	IRS-1D PAN	101/67	1	5.8m	NRSA	2001-08-01
3	IRS-LISS III	101/67	4	23.5m	NRSA	2001-08-11
4	Landsat ETM+	143/054	8	Band 1-5, 7 : 30m Band 6 : 60m Band 8(PAN): 15m	USGS	2006-01-21

3.3. Field Data

Beach sampling station is kept at an interval of 3.8km, but for the places with the lack of approach like river confluence, saltpan and swale where the interval is maintained to be wider or narrower. Each profile is done by proper positioning, using Garmin Map handheld GPS system. . The accuracy obtained, as shown by the receiver, is between 3 and 6 m. Further beach profile is prepared by visual observation and the stretch of the beach, the distance between the sampling points, i.e., from low tide to berm is measured accurately by a metallic tape.

3.4. Vulnerability Parameters Estimation

3.4.1. Landuse/ landcover change detection

The coastal landuse / landcover change map between Kallar and Vembar coast has been prepared based on three categories namely, classification, segmentation and change detection. To resize the Landsat MSS image by a factor of 2 to create 30 m data that matches the Landsat ETM+ data. For classification, we considered the statistical, textural and tonal parameters to extract feature values from landsat TM imagery. The feature set contains 10 classes which include river, tanks, swale, saltpan, salt affected land with scrub, mangroves, mudflat, beach ridges, vegetation and settlements. Feature sets are classified using Support vector machine classifier with adjustable learning parameters. Classified results help us to partitioning coastal landforms because class intensities are homogeneous. Many techniques are available for segmentation process but in our paper, we have used split and merge techniques proposed by Tanimoto et. al. (1977). At the end, change detection can be achieved by geo-reference based subtraction of various periods of segmented landuse/ landform classes.

3.4.2. Coastline changes

Coastline can be extracted from a single band image, since the reflectance of water is nearly equal to zero in reflective infrared bands, and reflectance of absolute majority of landcovers which is greater than water. This can be achieved by histogram thresholding on band 4 of resized Landsat MSS (1979) and Landsat ETM+ (2006) imageries. Band 4 exhibits a strong contrast between land and water features due to the high degree of absorption of near-infrared energy by water and strong reflectance of near-infrared by vegetation and natural features in this range. With this method water and land can be separated directly. Water pixels are then assigned to one and land pixels to zero. Therefore, a binary image has been obtained. Finally, edge extraction can be achieved from these binary images using sobal filters.

3.4.3. Rate of erosion and accretion

The erosion and accretion rate has been calculated using beach profile data obtained from PAN and multispectral imageries. The difference in water depth over the period gives change in water volume for the period. Reduction or increase in water volume implies accretion or erosion. Finally, total erosion and accretion volume of shoreline has been calculated using Toposheet and multispectral imageries.

3.4.4. Sediment Budget

The volume of sediment transferred to a shoreline depends on the balance between the volume of sediment available and capacity of net onshore and alongshore sediment transport system. The bathymetry is one of the main factors for controlling the sediment transport. In the present study, 3D bathymetric contour model of the study area has been created from the hydrographic chart, surveyed in 1967. The beach profile sediment volume has been calculated using beach profile data obtained from satellite imageries. The beach sediment volume computations are calculated using Arcview 9.2 database through an extension developed by U.S. Army corps called Profile Extractor 6.0 version.

IV. Results and Discussion

4.1. Results on vulnerability parameters

4.1.1.Coastal Landuse/ Landcover changes

Landuse/ landform change detection has been done by classification, segmentation and change detection methods. SVM classifier gives 93.2% of accuracy in both 1979 and 2006 imageries. Classified imageries were segmented by split and merge techniques. Finally pixel difference between both imageries have been calculated. The distributions of different landuse and landcover types in 1979 to 2006 have shown the presence of positive changes (+) in settlements, saltpan, salt affected land with scrub, swale and mudflats. Similarly, the negative changes (-) are observed in river, vegetation, mangroves, tanks and beach ridges.

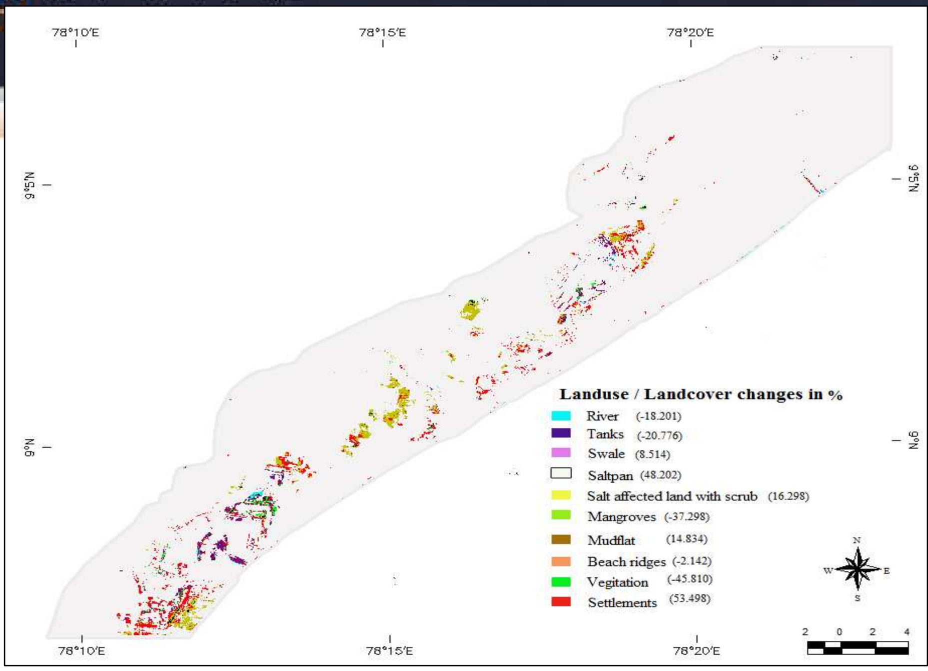


Figure 2. Landuse/ Landform change map

4.1.2. Coastline changes

During the period from 1979 to 2006, the higher rate of coastline length difference is noticed at kalaignanpuram. Its coastline length is measured to be of about 94.50m. Likewise the lower rate of coastline length difference is noticed at periasamypuram zone (23.04m). Table 1 demonstrate shoreline length difference along the study area.

Table 1. Coastline length difference between 1979 to 2006

Year	Stations (coastline length difference in meters)					
	Kallar	Kallurani	Sippikulam	Kalaignanapuram	Periasamypuram	Vembar
1979-2006	82.43	134.04	68.65	94.50	23.04	81.89

4.1.3. Profile Elevation Model

The Profile Elevation Model (PEM) has to be calculated by the elevation difference between the time invariant ground based data and Triangulated Irregular Network (TIN). The corrected 30 m resolution PEMs are used to extract the minimum (core) and maximum (envelope) elevations for each cell over the entire coastal zone. Resulting PEMs are then used to derive standard measures of coastal change as well as novel type of maps, characterizing coastal dynamics and vulnerability in the study area.

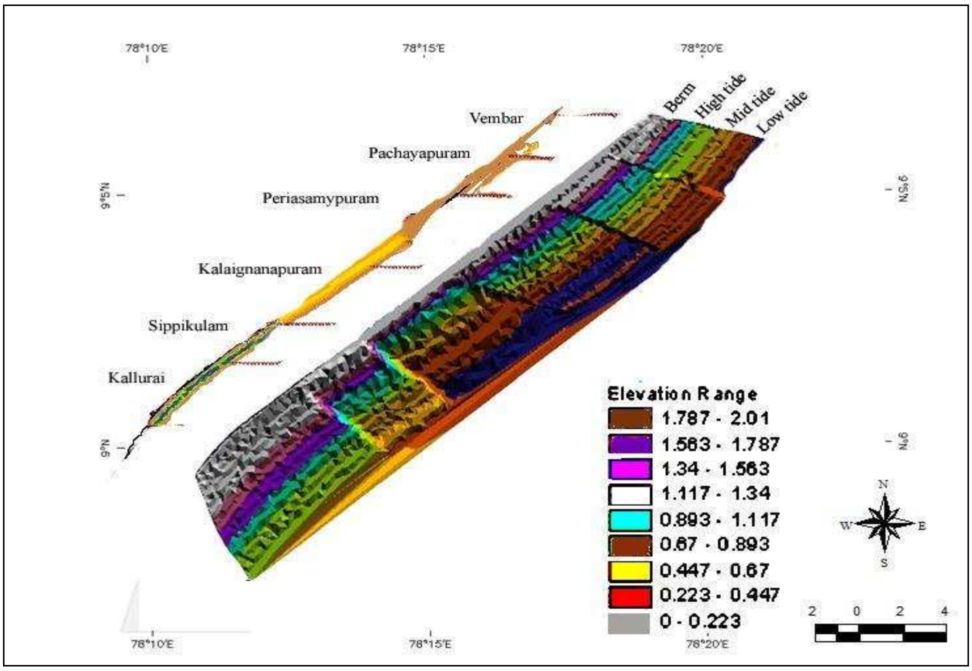


Figure 3. Digital Elevation Model of the study area in 2002

The beach profile differences of the study area between 2000 and 2002 are visualized via Triangulated Irregular Network (TIN) data structure. The generated yearly beach profile elevational TIN surfaces are shown in figure 4. The coastal area is generally eroded in summer and most deposition occurred in winter. Through an observation of TIN surface (Fig.4), yearly changes are follows. Most of the dune areas have experienced more than 3m erosion and dune areas have moved towards the west (retreated). The foreshore slope is seen to have been eroded as well as the nearshore is extended to the foreshore by 6m. Most of the deposition occurred in dune and berm areas. The analyzed results have demonstrated that the coastline of Kallar and Vembar area is very complex and dynamic.

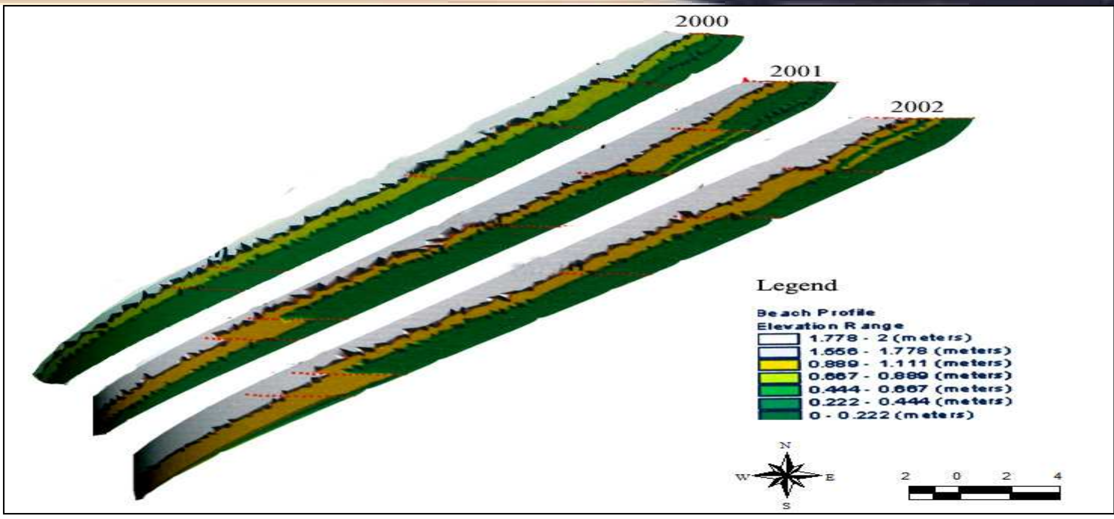


Figure 4. Beach profile difference of the study area between 2000 and 2002

4.1.4. Rate of erosion and accretion

During the period of 33 years, the erosion process is more dominant than accretion process. The total area lost due to erosion is 1137.43m^2, while the total area of accreted land has 863.74 m^2. The maximum erosion is occurring at Sippikulam, Kalaignanapuram and Periasamypuram zones. This may be due to mining of coastal resources like coral mining, beach sand mining and other dredging activities seen in the study area. Table 2 reported the erosion and accretion rate in the period between 1968 and 2001.

Table 2. Rate of erosion and accretion between 1968-2001

Phase	Stations (erosion and accretion rate in m^2 /Km/year)					
	Kallar	Kallurani	Sippikulam	Kalaignanapuram	Periasamypuram	Vembar
Erosion	170.32	32.65	234.63	254.45	244.54	200.84
Accretion	166.14	178.45	90.54	119.54	122.64	166.43
Net rate	-4.18	145.8	-144.09	-134.91	-121.9	-34.41

Positive (+) symbol indicates accretion, similarly negative (-) symbol indicates erosion.

4.1.5. Sediment Budget

Similarly, within a span of 33 years the shoreline brings a change in erosion of sediment by a volume of about 35127.58 m^3 and the total volume accretion is about 28302.94 m^3. The maximum volume rate of erosion is in sippikulam, kalaignanapuram periasamypuram and vembar zone. Similarly, maximum volume rate of accretion is in kallar and kallurani. Table 3 described the volume of sediment eroded, sediment accretion and net sediment volume in the duration from 1968 to 2001.

Table 3. Sediment budget (1968-2001)

Stations	Erosion sediment volume (m^3/km/year)	Accretion sediment volume (m^3/km/year)	Net sediment volume (m^3/km/year)
Kallar	4839.64	4948.32	108.68
Kallurani	848.9	5159.7	4310.8
Sippikulam	7638.9	3316.2	-4322.7
Kalaignanapuram	5913.7	3888.04	-2025.66

This volume changes are attributed that the longshore sediment transport is higher in the northward direction as compared to southward direction in all locations (Chandrasekar et. al. 2000, 2001).

Similarly, we extracted seasonal changes of sediment volume based on spatial interpolation method. Satellite data goes some way to provide spatial data for every location. However, more often data are stratified, patchy or even random. The role of interpolation in GIS is to fill the gap between observed data points and construction of contours (Figure 5).

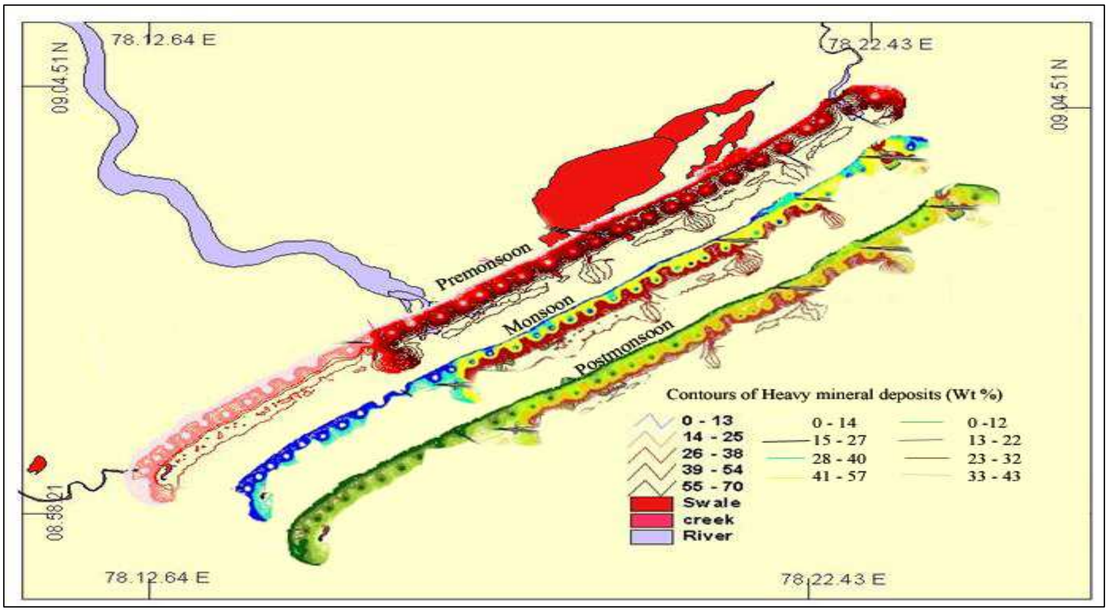


Figure 5. Contour map of seasonal changes of sediment volume

4.2. Modelling and Mapping of Coastal vulnerability

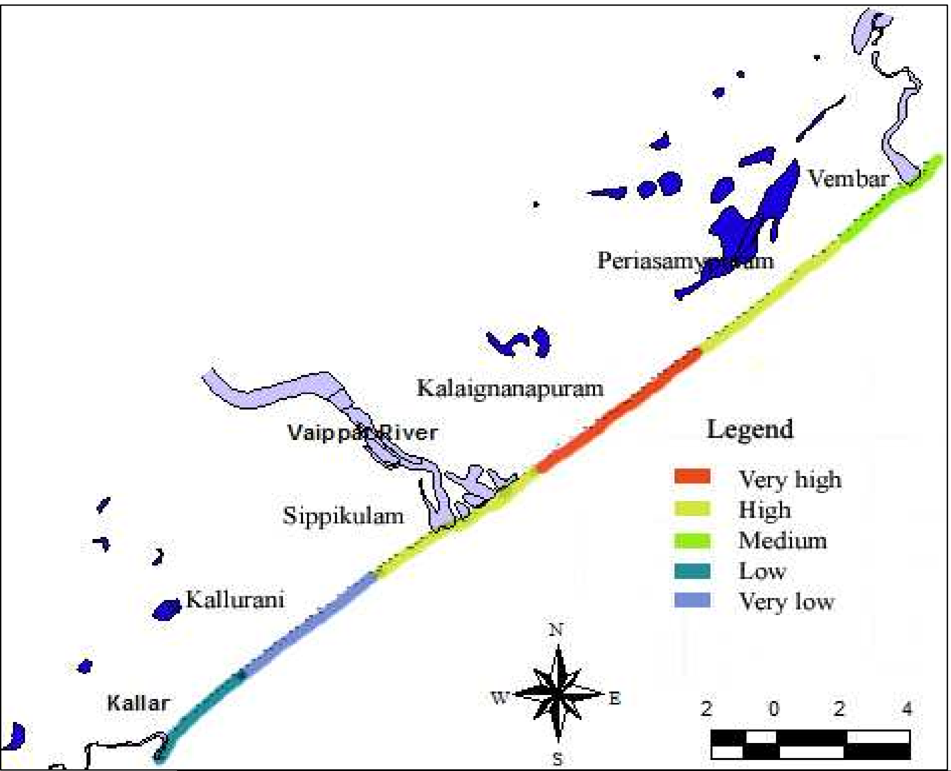
The coastal hazard mapping method is guided by Cambers, et. al., (2000) using mean annual and monthly beach change. In our work, coastal hazard map is prepared based on landuse/ landform changes, length of coastline changes, erosion and accretion rate and sediment transport. Based on these parameters, vulnerability has been categorised into five namely, very high, high, medium, low and very low. Table 4 described the assessment of vulnerability category.

Table 4. Classes of Coastal vulnerability

Parameters	Hazard category				
	Very high	High	Medium	Low	Very low
Land use/ Landform changes	Loss of vegetation (mangroves) and beach width. Increased settlements and saltpans. Changes in river mouth	Increased salt affected land with scrub	Loss of beach ridges	Variation in tanks and swales	Mangroves in shoreline region
Coastline changes (m)	Above 85	70 to 85	55 to 70	40 to 55	Below 40
Net rate of erosion and accretion (m^2/km/years)	Below -140	-140 to -100	-100 to -60	-60 to -20	Above -20
Net sediment volume (m^3/km/years)	Below -3000	-2000 to -3000	-1000 to 1000	1000 to 2000	Above 2000

After reclassifications and by giving equal weightage with the above reference (table 4), beach sand change rate per month has been calculated using (Table 5). Finally, vulnerability map is prepared based on beach sand changes using GIS techniques (Figure 6).

Table 5. Beach sand change rate per month



Beach sand change rate/ month				
Very high	High	Medium	Low	Very low
> -3	-2.01to-3.0	-1.01to -2.0	-0.1 to -1.0	0 to -0.1

Figure 6. Coastal vulnerability map

From the map (Fig. 6) we found that Kalaignanapuram is very high vulnerable zone, Periasamypuram and Sippikulam belongs to high vulnerable category. Vembar area is medium category. Kallar and Kallurani is very low category.

Conclusion

Applications of Remote sensing and GIS have provided new insights to the beach topography in the Gulf of Mannar. This has also provided a data analysis tools and methods to evaluate the geospatial patterns in short and long term change. In the studied location, a very small area is more stable particularly Kallar and Kallurani. Beach foredune is also retreating due to anthropogenic and geogenic processes. The rate of beach morphological changes are highly spatial and temporal and is influenced by intensive sand mining at the coast and coral mining in the barrier coral islands. The geospatial analysis illustrates the significance of landcover/ landuse including variation in shoreline position and sediment budget has characterised the Geomorphological vulnerability in the coastal region of Southern Tamilnadu coast.

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