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Assessment and Analysis of Coastal Vulnerability to Sea level rise of Nagapattinam- Vedaranniyam coast using Geospatial Technology

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Abstract : Coastal zones currently have the highest concentration of population, industries and many major cities. The ongoing rapid expansions of economic and industrial activities along the coast the coastal zone indicate that this trend will accelerate in the near future. But at the same time one of the major areas of concern for coastal zone administrators and planners had been the determination of physical responses of the coastal zone to anticipate Sea level rise, Flooding and Storm surges. As, prediction of shoreline retreat and land loss rates are very critical to the planning of future Coastal zone management strategies, assessing the destruction and carrying out rehabilitation measures. The aim of this study is in assessing the coastal vulnerability for Nagapattinam- Vedaranniyam coast since the area is affected more due to Tsunami and different cyclones using Remote Sensing and GIS tools. Six various terrain and physical parameters such as Geomorphology, Land use/Land cover, coastal slope, Offshore bathymetry, shoreline change (1970-2015), mean Tidal height has been considered to calculate the Coastal Vulnerability Index(CVI) based on USGS classification and they show significant variations all along the coastal tract. Based on the CVI values calculated for the study area the coast is classified as five classes of vulnerability viz., very low, low, moderate, high, very high. Strong concept of GIS is used for over lying of individual layers and getting the integrated vulnerability map. The present study can be used as important tool for disaster management due to sea level rise for future development.
Keywords : Sea Level Rise; Coastal Vulnerability; GIS; Climate Change.

1. Introduction:

Sea level rise could have significant long-term impacts on the coastal area especially in areas classified as highly vulnerable. Such impacts include the distribution of ground water salinity and erosion of the narrow and low-lying coastal areas.Global sea level has risen approximately 18 Cm (7.1 inches) in the past century climate models predict an additional rise of 48 Cm by 2100, which is more than double the rate of rise for the 20^{th} Century. Predicted accelerated global sea level-rise has generated a need in coastal geology to determine the likely response of a coast line sea level rise.

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The primary challenge is predicting the Shore line response to sea level-rise is quantifying the important variables that contribute to coastal evolution in a given area. In this study the CVI (coastal vulnerability index) method is used to identify the vulnerable zones. This technique uses different ranges of vulnerability (low to very high) to describe a coast's susceptibility to physical change as sea level rises. The vulnerability index determined here focuses on six variables that strongly influence coastal evolution.(i.e.) Geomorphology, Historical shore line change rate ,Regional coastal slope ,Relative sea level change ,Mean significant wave height, Mean tidal range. These variables can be divided into two groups; they are Geologic variables, Physical process variables.

1.1 Geologic variables : The geologic variables are geomorphology, historic shore line change and coastal slope.

1.2 Physical process variables *:* The physical process variable includes significant wave height, tidal range and sea level change.

All of which contribute to the inundation hazards of a particular section of coast line overtime scales from hours to centuries. A relatively simple ranking system (tables) allows the six variables to be in- corporated into an equation that produces a coastal vulnerability index (CVI). The CVI can be used by scientists and researchers to evaluate the likelihood that physical change may occur along a shore line as sea level continuous to raise.

2. Study area:

Nagapattinam is situated in the middle of the Cauvery delta, a lowland area below sea level in parts and extending far inland. The area has been vulnerable to coastal flooding due to the gentle slope of coastal land. Nagapattinam District lies on the shores of the Bay of Bengal between North Latitude 10^{o}10'N and 11^{0}20'N East Longitude 79^{o}15' E and 79^{o}50'E. The stretch consists of a narrow region of sandy beach along the coast in the delta region of the Cauvery River. There are Salt pans as well as permanent Vedaranyam swamp region with mangrove forest. The base map is prepared from Survey of India topo sheets. The Base map is given below in Fig 1.

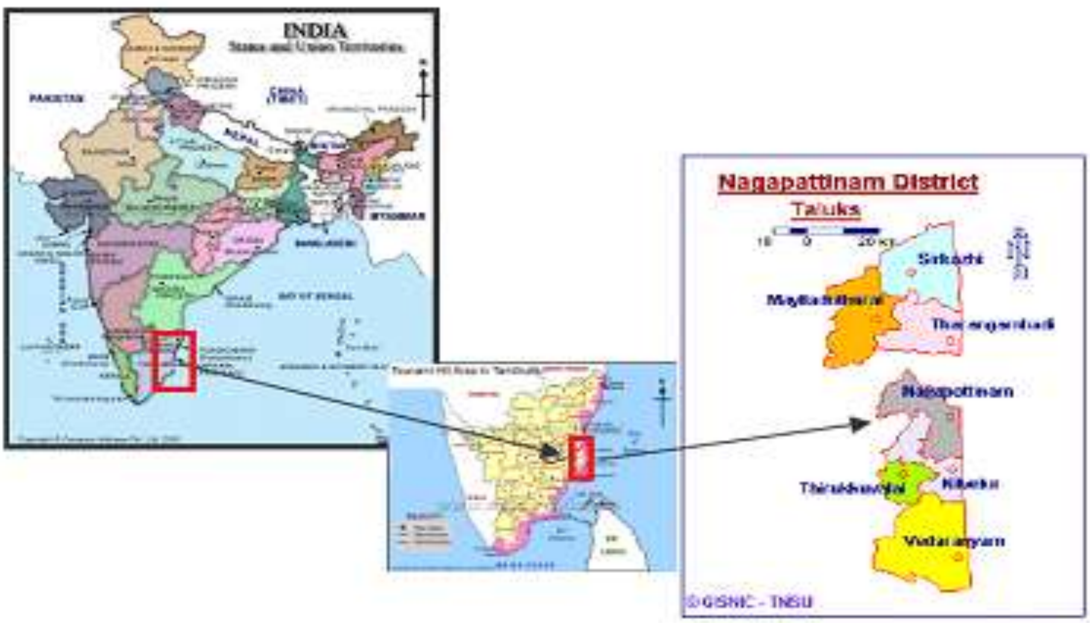


Fig 1.Nagapattinam- Vedaranniyam sector

3. Need for the Study

The state of Tamil Nadu has a 1000km long low gradient coast which stands severely exposed to various natural calamities like storms, coastal flooding etc. The onslaught of destructive tsunami waves

(Dec.2004) along Tamil Nadu coast has forced the coastal zone planners to realize that serious studies are urgently needed to forecast the potential damage and identify vulnerable areas along the coast.

The area selected for the present study (Fig.1) is among the most vulnerable areas of the Tamil Nadu coast and it has been historically prone for flooding and storm surges. During the onslaught of Tsunami in 2004 this area had experienced maximum damage with heavy loss of human life. Hence, it has been selected.

Nagapattinam is situated in the middle of the Cauvery delta, a lowland area below sea level in parts and extending far inland. The area has been vulnerable to sea level rise due to the gentle slope of coastal land.

4. Objective of The Present Study

- To bring out a holistic model on the coastal vulnerability of Nagapattinam – Vedharanniyam coast due to accelerated sea level rise.
- Create a detailed coastal geomorphology map for N-V coast.
- Identification of highly vulnerable zones with respect to sea level rise.
- Categorization of the study area in to different zones based on its vulnerability.
- Suggesting a suitable remedial and management plans.

3. Methodology:

The objective of the study is to identify the vulnerable zones of Nagapattinam – Vedaranniyam part of Tamil Nadu Coast. Conventional methods require extensive and intensive field survey, and preliminary investigation on various geological parameters. This is a time consuming exercise involving more workforce, energy and cost. The change in the proposals, if any, suggested would require the repetition of the exercise, which would take considerable time. This could be avoided, if Geographical Information System is utilized in identifying the site.

The state of the art, Remote Sensing technique, uses satellite imageries and aerial photographs for obtaining the ground information. Remote Sensing gives a synoptic view about the whole area under consideration. Delineation of topographical features can be done using satellite imageries. Various topographical themes obtained from imageries can be integrated and analyzed by using Geographical Information System software.

4. Materials and methods

4.1 Data Used

The SOI Toposheets that served as the base map was also used to delineate contours of ground elevation. SOI Toposheets No:58N9 ,58N10, 58N11, 58N13, 58N14, 58N15 at a scale of 1:50000. Visible and NIR data from space platforms such as IRS P4 and P6 provided rapid assessment of disaster affected area.

4.2 Methods

ENVI and GIS environment was used to extract information, classify and overlay spatial information. Change detection using IRS P4 and P6 data involved preprocessing, classification and application of the change detection techniques. Analysis can be divided into the following groups:

4.2.1 Image Preprocessing using ENVI software

Georeferencing and geometric correction for all images was carried. All images were registered to the topographic maps using the UTM WGS-84. Map to image registration for the IRS P4 image was done using valid ground control points (GCPs) and a second order polynomial transformation. Image to image registration was also carried for the IRS P6 image using 125 GCPs along the coastal area of Nagapattinum - Vedaranium. RMS was equal to 2 m. These images was very useful in investigating the coastal ecosystem/landscape change over the entire study area.

4.2.2Change Analysis*:*

Change detection technique involved the use of satellite images to categorize primary changes in land use/cover between the different periods of image acquisition. Due to unavailability of accurate information on the status of erosion/accretion over the coastline, the change detection technique was used to outline only the area of changes, with a general overview on the type of potential changes

Coastline changes due to the temporal variations were carried by delineating the shoreline limits form the multiple images. Infrared bands are well-known for their ability to highly differentiate water bodies from their land surrounding. A threshold is determined from the analysis of the histogram of each image to separate land from water. Coastline was converted from line to equidistant points of 100 m, then, using the near tool in ArcGIS to calculate distance between coastlines. The result shows the change assessment which is the rate of erosion and/or accretion in meters.

4.2.3 Sea Level Rise Scenarios:

The determination of relative sea level change variable is derived from the change in annual mean water elevation over time as measured at tide gauge stations along the coast. This variable inherently includes both ecstatic sea level rises due to isostatic and tectonic adjustments of the land surface. Tide-gauge records suggest an average sea level rise is 3mm/yr. Variations in sea levels are natural responses to climate change, geoidal variations, movements of the sea floor, and other earth processes.According to the climate change scenario results, the projected range values of sea level rise for the year 2100 were between 32 and 5.6 mm with a maximum of 9.5 mm and a mean of 6.0 mm. Because of the relatively broad range of results, indicating variable trends, projections used in this study are considered as the general projections of the average sea level rise in the Northern-Eastern part of the Mediterranean. Other scenarios also took into consideration seasonal variability. The projections used in this study are considered as the projected values for sea level rise scenarios for the year 2100. The projected values were obtained by multiplying the estimated trend in mm/yr by the number of years from present. For example, to calculate the increase in 2100 for a scenario of 0.06 mm/yr based on the shoreline delineation of 2000 multiply 0.6 by 100, the expected increase is 6mm. The highest scenario is chosen as the upper limit of accelerated sea level rise and the lowest scenario as the lower limit. According to the different scenario results, the projected sea level rises average was 0.6 m with a maximum projection of 5-7.5 m.

4.3 Generation of Thematic Maps

4.3.1 Geomorphology:

The Geomorphology variables express the relative erodibility of different land form types and landscapes, including the description, classification, origin, development and history of planetary surfaces. It is used to identify the regularities among landforms and what processes lead to patterns. In this study, Land sat pan sharpened FCC (band 4, 3 and 2 combination) image has been used to generate geomorphology map (Fig.2). The various coastal geomorphic features identified in the study area are beach ridge, creek, deep pediment, deltaic plain, dissected uplands, estuarine, flood plain, inter tidal flat, mangrove swamp, mud flat, pediplain, river, salt flat, Supratidal flat, swale, undissected uplands, valley, tanks.

4.3.2 Shore line change rate:

Ortho-rectified IRS P4 and P6 images covering the study area were used. The data have been projected to the Universal Transverse Mercator (UTM) projection system with WGS-84 datum. The shorelines (Fig.3) of different years were digitized using Arc GIS 9.3. The near infrared band that is most suitable for the demarcation of the land–water boundary has been used to extract the shoreline. The digitized shoreline for the different periods in the vector format was used as the input to the Digital Shoreline Analysis System (DSAS) to calculate the rate of shoreline change. The inputs required for this tool are shoreline in the vector format, date of each vector layer, and transect distance. The rate of shoreline change is calculated for the entire study area, and risk ratings are assigned. The length of observation is 4270m. The net erosion has been worked out to be 1.19 Acers and the rate of erosion is 0.11m/year. The length of the side is 2900m. The acceleration is 0.29m/year. But the site is liable for erosion. Shore line change rates within the Nagapattinam- Vedaranniyam were all classified as moderate vulnerability.

4.3.3 Regional coastal slope:

Slope is used to describe the measurement of the steepness, incline, gradient, or grade of a straight line. For the present study the slope map (Fig.4) has been generated using the contour level of this area...

The Coastal slope is calculated using the formula,

Slope = (Distance between Shoreline and Contour/ Contour Interval)*100

The determination of regional coastal slope is an indication of the relative vulnerability inundation and the potential rapidly of shore line retreat because low sloping coastal regions should retreat faster than the steeper regions. Regional coastal slope of Nagapattinam - Vedaranniyam area fall in moderate, high and very high vulnerability.

4.4.4 Relative sea level change:

The determination of relative sea level change variable is derived from the change in annual mean water elevation over time as measured at tide gauge stations along the coast. This variable inherently includes both ecstatic sea level rises due to isostatic and tectonic adjustments of the land surface. Sea level change map (Fig 5) was generated using Arc GIS software .This map indicates sea level change of the Nagapattinum-Vedaranium coastal area.

4.4.5 Mean significant wave height:

The wave period is the time interval between two consecutive wave crests. The wave velocity (celerity) equals the wave length divided by the wave period. Sea reports give the significant wave height. This is calculated from the height of all the waves during a 20 minute period. The significant wave height is the average height of the highest third of these waves. The term came into use when trying to relate the height of waves reported by observers on ships to those measured by oceanographic instruments. It was found that the wave height reported by a skilled observer was equal to the average height of the highest third of the measured waves.Wave height map was generated using Arc map (Fig 6) and significant wave heights along the Nagapattinam – Vedaranniyam coast 1.5m (moderate vulnerable).

4.4.6 Mean tidal range

Tidal range is the vertical difference between the highest high tide and the lowest low tide. For the current study, coastal areas with high tidal range are considered as high vulnerable and low tidal range as low vulnerable. In the current study, predicted tide data (Fig.7) from WX Tide software is taken as the base data, and the maximum amplitudes of the tide in a year for the Indian coastal locations are calculated, and risk rates are assigned. Tidal range linked to both permanent and episodic inundation hazards. Tide range data were obtained from Indian tide tables. Where mean tide range is 0.475m (very high vulnerability)

5. Degree of Vulnerability

Coastal Vulnerability Index:

The prediction of coastal vulnerability is not straightforward. There is no standard methodology, and even the kinds of data required to make such predictions are the subject of much scientific debate. In order to develop a rational assessment of coastal vulnerability, relevant information is required. The compilation of this database is integral to mapping potential coastal changes due to sea-level rise. This database follows an earlier database developed by Gornitz et al. [11]. A comparable assessment of the sensitivity of the coast vulnerability to sea-level rise is presented by Shaw et al. [13]. Six physical variables are investigated. Their attribute are found in Table 2; they cover:

- Geomorphology;
- Coastal slope (percent);
- Rate of relative sea-level rise (mm/yr.);
- Shoreline erosion and accretion rates (m/yr.);
- Mean tidal range (m);

- Mean wave height (m).

The CVI allows the six variables to be related in a quantifiable manner that express the relatively vulnerable of the coast to physical changes due to future sea level rise. Once each section of coast line is assigned a vulnerability value for each specific data variable, the coastal vulnerability index (CVI) is calculated as the square root of the product of the ranked variables divided by the total number of variables;

$$CVI = \sqrt{\frac{(a*b*c*d*e*f*g)}{6}}$$

a- geomorphology, b- coastal slope, c- relative sea level rise, d- shoreline erosion/accretion rate, e- mean tide range, f- mean wave height.

Through primary and secondary data collection the values for each variable will be found out and each variable will be assigned a relative risk value based on the potential magnitude as shown below table 1 Reference Table (USGS Project)

Table.1. Ranking of Coastal Vulnerability Index (Reference Table from USGS

Variables	Very Low	Low	Moderate	High	Very High
Geomorphology	Rocky cliffed coasts, Fjords	Medium cliffs , Indented coasts	Low cliffs, Glacial drift, Alluvial plains	Cobble Beaches, Estuary, Lagoon	Barrier beaches , Sand beaches, Salt marsh, Mud flats, Mangrove, Coral reefs
Shoreline erosion/ Accretion(m/yr)	>2.0	1.0 – 2.0	-1.0 - +1.0	-2.0 - -1.0	<-2.0
Coastal slope (%)	>14.70	10.90 – 14.69	7.75 – 10.89	4.60 – 7.74	<4.59
Relative sea level change(mm/yr)	<1.18	1.8 – 2.5	2.5 – 3.0	3.0 - 3.4	>3.4
Mean wave height(m)	<1.1	1.1 – 2.0	2.01 – 2.25	2.26 – 2.6	>2.6
Mean tide range (m)	>6.0	4.0 – 6.0	2.0 – 4.0	1.0 – 2.0	<1.0

Vulnerability refers to areas vulnerable to the forecasted sea level rise. The criteria contributed in defining degree of vulnerability are SLR, CVI, geomorphology, land use/cover, and population etc. Based on these criteria coastal vulnerable areas are described below. Most vulnerable coastal areas are: Flat and low-lying coastal plain, Deltaic and estuaries coastal plain areas, Sandy shores characterized by gentle slopping beach. Through primary and secondary data collection the values for each variable will be found out and each variable will be assigned a relative risk value based on the potential magnitude as shown below table 1 to generate the vulnerability indexes for each parameter (Fig.8.) 500m grids were buffered out from the shoreline for our study area. Each grid is assigned different variables based on the various parametric features present within the grids. Vulnerability Index (CVI) is calculated based on USGS classification. From the above value the study area ranking is given below the table 2.

Table 2. Ranking of CVI for N-V coastal area

Variables	**Low**	**Moderate**	**High**
Geomorphology	Deltaic plains	Cobble Beaches, Estuary, Lagoon	Barrier beaches , Sand beaches, Salt marsh, Mud flats, Mangrove, Coral reefs
Shoreline erosion/ Accretion(m/yr)	NA	0.11	0.29
Coastal slope (%)	7.9	6.5	0.12
Relative sea level change(mm/yr)	2.5	NA	NA
Mean wave height(m)	1.245	NA	NA
Mean tide range (m)	NA	NA	0.475

6.Socio-Economic Impacts

The framework makes distinction between natural and socio-economic vulnerabilities. This sealevel vulnerability analysis shall provide important information in the management of the effects of different sea level rise scenarios.

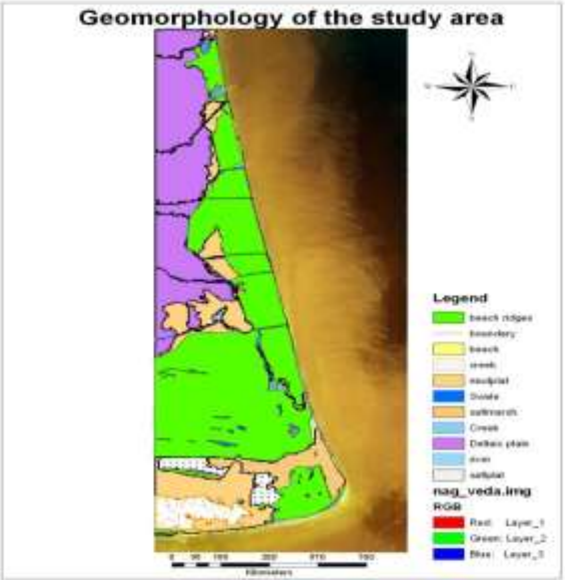
Consequently, several mitigation steps must be taken to reduce these impacts on the coastal region. First, in vulnerable areas monitoring gauges to monitor the rise continuously must be implemented. In addition, Nagapattinum- Vedaranium coastal areas must be analyses on a larger scale in order to get more accurate information. Finally, the most important decision is to clarify where the flood risk areas are. Therefore, future land use plans should take them into consideration and preserve them. Current sea level rise is after all not exaggerated; in fact the opposite case is more plausible. Observational data and changing conditions in such places as Greenland suggest if there's a real problem here it's underestimation of future sea level rise.

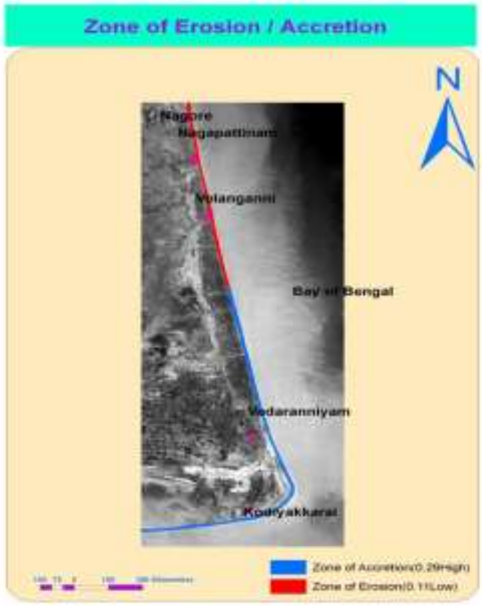
8. Result and Discussion:

For final weight all the individual layers are assigned and evaluated as each of the includes its importance from the first level. In the second phase their overlaid for getting the final vulnerable map. . According the weightage allotted the entire area is categorized into three classes (high, low, moderate) .Similarly the CVI of the same area is also calculated using the above formula. The value is 2.2669. The present study has brought out some unique information on the CV along the Nagapattinum-Vedaranium Coastal region. From the geospatial techniques, Remote Sensing and GIS has played a major role in the present study.

This study illustrate that GIS with its unique capabilities of building and efficiently handling large volumes of spatial database can aid decision makers make the right and reliable choice on the selection of vulnerable zone. The coastal vulnerable index (CVI) provides the relative potential of coastal change due to future sea level rise. As ranked in this study, geomorphology, regional coastal slope, and wave height are the most important variables in the determining the spatial variability of the CVI. Tidal range and sea level rise rate do not contribute to the spatial variability in the vulnerability index. We feel this approach best describes and vulnerability specific the Nagapattinam- Vedaranniyam sector.

9.Thematic Maps





Fig(2) Geomorphhology MapFig (3) Shoreline Change Map

Fig(4) Slope Map Fig:5 Sea levelchange Map

Fig:6 Wave Height Map

Fig:7 Tidal change Map

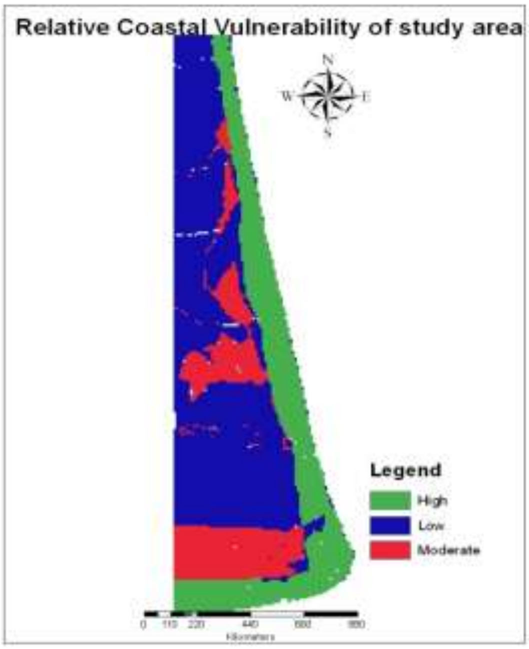


Fig:8 Vulnerability Map

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