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ORIGINAL PAPER

# Assessing coastal landscape vulnerability using geospatial techniques along Vizianagaram–Srikakulam coast of Andhra Pradesh, India

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## Abstract
Vizianagaram–Srikakulam coastal shoreline consisting of beaches, mangrove swamps, tidal channel and mudflats is one of the vulnerable coasts in Andhra Pradesh, India. Five site-specific parameters, namely rate of geomorphology, coastal elevation, coastal slope, shoreline change and mean significant wave height, were chosen for constructing coastal vulnerability index and assessing coastal landscape vulnerability. The findings revealed a shift of 2.5 km in shoreline towards the land surface because of constant erosion and that of 1.82 km towards the sea due to accretion during 1997–2017. The rate of high erosion was found in zones IV and V, and high accretion was found in zones II and III. Coastal vulnerability index analysis revealed constant erosion along shoreline and sea level rise in the study area. Most of the coast in zone V has recorded very high vulnerability due to erosion, high slope, significant wave height and sea level rise. Erosion and accretion, significant wave height, sea level rise and slope are attributed to high vulnerability in zones III and IV. Zone II recorded moderate vulnerability. Relatively lower slope, mean sea wave height and sea level rise have made this zone moderately vulnerable. Very low vulnerability was found in zone I, and low vulnerability was recorded in zone II. Accretion, low slope and low sea level rise were found to be causative factors of lower vulnerability. Thus, zones III, IV and V should be accorded higher priorities for coastal management. The findings can be helpful in coastal land planning and management and preparing emergency plans of the coastal ecosystems.

**Keywords** Coastal vulnerability index · Shoreline change · Erosion and accretion · Geospatial techniques

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## 1 Introduction

Climate change induced coastal vulnerability is on increase and thus requires urgent attention of scientific community and policy makers (Hinkel and Klein 2009). United Nations Conference on Environment and Development (1992) advocated assessing coastal vulnerability arising out from various events and stressed developing integrated coastal zone management (ICZM). Coastal processes assume greater significance for assessing coastal vulnerability, its mitigation and adaptation strategies. Numerous researches have assessed coastal vulnerability as a response to climate change and sea level rise (Nicholls and Hoozemans 1996; Bijlsma 1997; Hinkel and Klein 2009; Vinet et al. 2011). Coastal vulnerability has always been assessed in the context of susceptibility and adaptive capacity. Susceptibility generally includes potentiality of a system, while resilience is the system stability which is determined by the impact of sea level rise (Klein and Nicholls 1999). Rising sea level has been found to be an important reason for the occurrence of floods and storms in coastal areas, thus increasing vulnerability among coastal inhabitants (Rao and Sivakumar 2003; Unnikrishnan and Shankar 2007). Climate change and sea level rise have caused erosion and inundation in coastal areas leading to the increase in coastal susceptibility. Human impacts are found equally responsible for decreasing functionality of coastal areas and resultant degradation. Thus, sometimes losses of this environmental degradation exceed the benefits arising out from these productive areas (Bijlsma et al. 1996).

Coastal areas involve complex processes, and therefore, physical indicators have figured dominance among coastal hazard researches for addressing coastal vulnerability. Magnitude and intensity of these processes are determined by physical parameters as these govern the terrain characteristics. Thus, physical parameters are of paramount significance for coastal vulnerability assessment. A change in shoreline is associated with erosional activities along the coast and thus has been used as a parameter to assess coastal vulnerability (Zhang et al. 2001; Kana 2003; Felsenstein and Lichter 2014; Codjoe and Afuduo 2015; Shah 2015; Box et al. 2016). Mitigation of coastal vulnerability requires monitoring of changes in shorelines due to erosion (Kana 2003). Therefore, evaluation of site-specific physical indicators such as sea level rise, bathymetry, slope, elevation and impact of tides and waves is essential to understand the nature of coastal vulnerability. Regional characteristics of coastal areas play an important role in coastal vulnerability assessment. Several scholars have suggested understanding of regional characteristics of the coastal areas through field survey to examine vulnerability (Belperio et al. 2001; Terti et al. 2015; Karagiorgos et al. 2016). A comprehensive method for assessing regional characteristics involving extensive field surveys was suggested by Bryan et al. (2001) for examining coastal vulnerability to sea level rise. Engineering methods, high-spatial-resolution data and field surveys have also been used in the earlier literature. Moreover, geospatial techniques have become prominent in assessing coastal vulnerability using high-resolution satellite data and modelling the coastal characteristics. High-resolution topographic data help in examining finer details of the coastal areas. GIS-based modelling approach is compatible to examine regional coastal vulnerability assessment (Belperio et al. 2001). Geography and other allied disciplines (territorial planning, physical, environmental management, etc.) provide healthy support to disaster approaches. Maps provide spatial delineation of natural phenomena, hazardous sites and vulnerable areas. Advancement in computer science, remote sensing and GIS has led to effective identification and analysis of vulnerable areas. These analyses are often found beneficial for decision makers in strategic policy formulation (Kumar et al. 2010).

A plethora of methods have been developed by scholars to examine hazards in coastal areas. Appelquist and Balstrøm (2014) developed a GIS-based method, namely Coastal Hazard Wheel (CHW), to assess the coastal hazard of the rocky coast in the Djibouti state. CHW aims to minimize the gaps between earlier and recent methodologies in coastal hazard vulnerability assessment comprising dynamic physical parameters. This GIS-based method uses geo-data to address the large-scale coastal characteristics. Recently, holistic approaches have proved to be productive in addressing overall vulnerability of coastal areas. GIS-based multi-criteria decision analysis method (MCDA) with coastal vulnerability index provides holistic coastal vulnerability assessment resulting from erosion; anthropogenic activities and global climate change (Maanan et al. 2018). Gaki-Papanastassiou et al. (2010) assessed vulnerability of coast using coastal vulnerability index. Shoreline accretion and erosion have been monitored using aerial photographs of the coastal stretch since the last 50 years. Shoreline changes have been considered significant and most widely adopted approach in identifying vulnerable coast. Burningham and French (2017) addressed shoreline changes and its impact on coastal areas using cluster-based segmentation method. This method proved to be beneficial in addressing regional shoreline changes and identifying vulnerability of coast in response to floods and cyclones.

Coastal vulnerability index (CVI) is one of the important methods for assessing coastal vulnerability worldwide as it combines both susceptibility and coping capacity of the coastal communities (Gornitz et al. 1994, 1997; Fekete 2009; Chakraborty et al. 2005; Grothmann and Reusswig 2006). Coastal vulnerability assessment can provide reliable information about damages and estimation of degree of vulnerability along coastal areas. Di Paola et al. (2014) evaluated coastal vulnerability assessment (CVA) using three parameters such as beach retreat (which is a measure of potential erosion), beach erosion rate (calculated according to the shoreline positions in different periods) and run-up distance (coastal inundation).

Indian coasts are experiencing threats due to global climate change and sea level rise. Rapid urbanization and tourism concentrated in coastal areas are the cause of their deterioration (Alves et al. 2013; Dawson et al. 2011; Jonkman 2005; Merz et al. 2013). India is having a coastal stretch of 7500 km and has diverse marine ecosystems. Coasts are subjected to changes due to dynamic physical processes, and reducing vulnerability requires constant monitoring (Rani et al. 2015; Müller et al. 2011). The regions lying along Indian coastline are under great threats of tropical cyclones, tsunamis and floods causing great loss to human life and destruction of property (Sindhu and Unnikrishnan 2012). Bay of Bengal and Arabian Sea are the home of coastal hazards where 1 m increase in sea level may affect socio-economic conditions and displace millions of coastal inhabitants (IPCC 2001). Geomorphological aspects such as coastal slope, changes along shoreline, wave height and mean tide range are instrumental in assessing coastal vulnerability (Hegde and Reju 2007; Diakakis et al. 2012; Felsenstein and Lichter 2014; Fuchs et al. 2007). Dissipative beaches and waves are dominating factors leading to morphological changes (Gujar et al. 2011). Therefore, evaluation of physical traits of coastal system is necessary to assess coastal behaviour in response to changes in relative shoreline and sensitivity of rising sea level (Hammar-Klose and Thieler 2001; Fuchs et al. 2012; Kappes et al. 2012a).

Chipurupalle, Narsannapeta and Srikakulam *talukas* of Srikakulam district are vulnerable to various disasters including tsunamis, storm surges and tropical cyclones. These successive coastal disasters are leading to increasing coastal vulnerability due to rapid increase in population and have consequent setbacks to economy of these *talukas*. Floods and cyclones are common phenomena along the coast due to northerly winds during October to November. Alluvial plains, bays, tidal mudflows, lagoons, creeks and marshes are the major physiographic features found along Andhra Pradesh coast. These dynamic landforms are facing constant change due to erosion and rising sea level.

Therefore, reliable information system and monitoring is essential for safeguarding rapidly increasing population of coastal regions. The major aim of this study is to construct CVI and prepare a map for examining the potential impact of shoreline changes along Vizianagaram–Srikakulam shoreline using geospatial techniques.

## 2 Material and methodology

### 2.1 Study area

The study area lies between 18°5′45″N to 18°25′30″N latitudes and 83°41′39″E to 84°12′46″E longitudes. It covers a coastal stretch of 70 kms from Vizianagaram to Srikakulam including three *talukas* (administrative sub-divisions of the district) of Srikakulam district, namely Chipurupalle, Srikakulam and Narsannapeta (Fig. 1). Most of the Indian rivers flowing across the east bring large quantities of sediments which is suitable for agriculture. *Vamsadhara* and *Nagavali* are the two important rivers flow through low-lying areas causing high sediment deposition and erosion along the coast. *Nagavali* river which is also known as *Langulya* is an important river of Southern Odisha

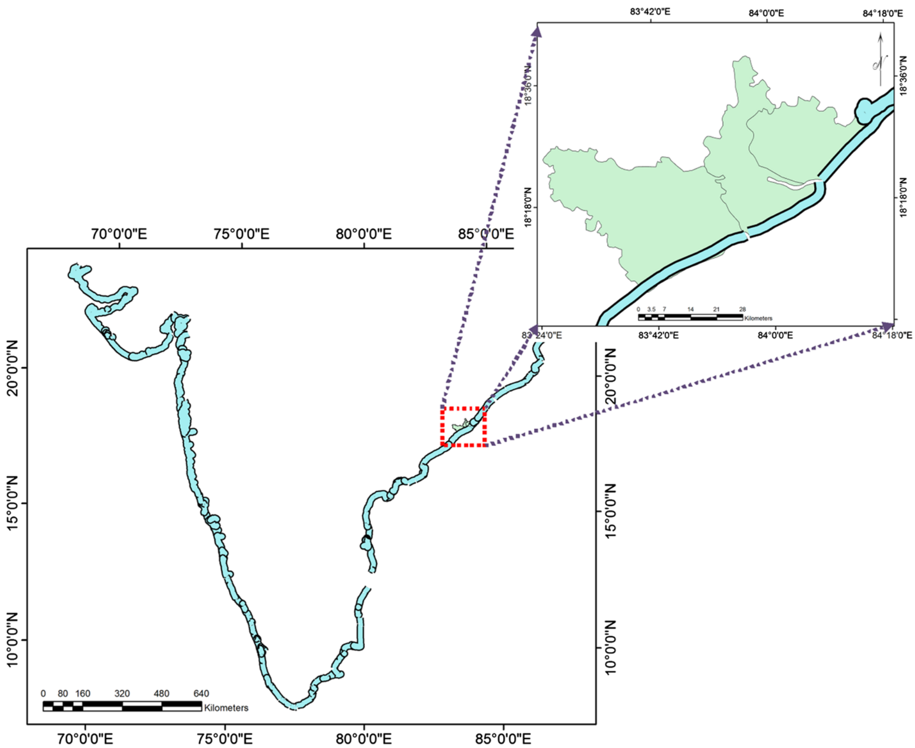


**Fig. 1** Location of study area

region affecting Srikakulam *taluka*. The density of population in Narsannapeta, Srikakulam and Chipurupalle is 5100, 7000 and 22,000 persons/km$^2$, respectively. The study area enjoys highly humid climate. North-east monsoon creates low pressure causing heavy rainfall and provides favourable conditions for the occurrence of tropical cyclones. Alluvial plains, tidal mudflows, mangrove swamps and lagoons are the prominent characteristic features of this coastal landscape. These landforms are dynamic due to sea level rise and coastal erosion. Tides, wind, waves, currents and storms are the major forces on the coast. The results of these interactions on the shoreline and near shore seabed are called coastal processes. Fishing and agriculture are the two major economic activities in the study area. These activities are affected badly by the undulations in slope, geomorphology, regional elevation and rate of shoreline changes.

### 2.2 Database and method

Sources of data used for assessing coastal landscape vulnerability and their specifications are presented in Table 1. CVI model was prepared to determine coastal vulnerability index by integrating weights of five physio-geological parameters, namely (a) rate of accretion and shoreline erosion, (b) mean sea level rise, (c) coastal slope, (d) geomorphology and (e) mean sea wave height and tidal range. Shoreline was digitized using Google Earth Pro 2007 and 2017 and was verified with LANDSAT 8 Satellite image. Shoreline of 1997 was digitized using NIR band of LANDSAT 5 TM (30 m resolution) for the study area. Changes in shoreline were assessed with the help of vector digitized layers and was utilized as inputs for digital shoreline analysis system (USGS 2005). Landsat 5 Thematic mapper (TM) and Landsat 8 operational land imager (OLI) of 30 m resolution for February 1997 and 2017 were used to delineate the shoreline for assessing erosion and accretion (Fig. 2). The extracted shoreline for both years intersected to demarcate and identify the displaced area (Table 2). Bathymetry and suspended sediment concentration were considered to assign weightage for each area according to the amount of erosion and accretion. Study area has dynamic coastal relief, and slope was extracted from ASTER digital elevation model (Fig. 3). Bathymetry chart was produced from shuttle radar topography mission (SRTM) 30 PLUS (900 m) data for mapping the depth of ocean at 10 m interval. Sea level data derived from Permanent Service for Mean Sea Level (PSMSL) portal found helpful in

**Table 1** Data sources and their specification

| Parameters | Data type | Sources of data | Details about data | Period |
|---|---|---|---|---|
| Rate of shoreline change | Spatial | LANDSAT TM (path and row-140/47), ETM image (141/47,140/48) | USGS satellite image (30 m resolution) | 1997, 2007, 2017 |
| Coastal elevation | Spatial | SRTM DEM | 30 m resolution | 2017 |
| Bathymetry | Spatial | SRTM DEM and DGH for bathymetry | 30 m resolution | 2017 |
| Sea level rise | Conventional | PSMSL | Monthly sea level | 1997–2017 |
| Significant wave height | Conventional | ECMWF | Pre- and post-monsoon | 2017 |

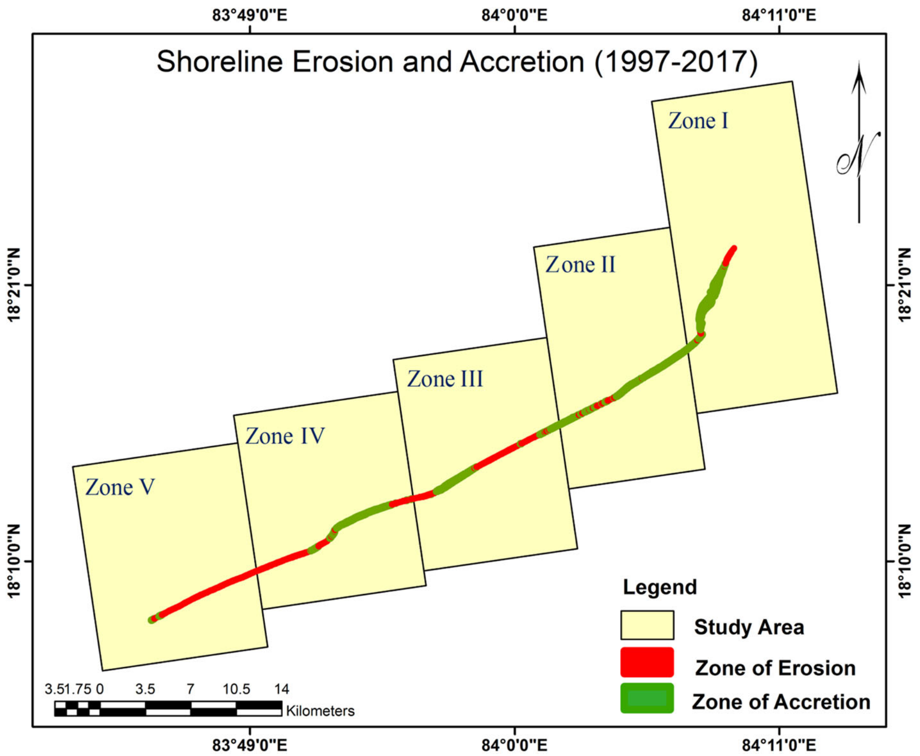


**Fig. 2** Identifying soil erosion and accretion

**Table 2** Rate of shoreline changes in different periods along the shoreline

| Grid no. | Zone | Latitude | Longitude | Change in shoreline (in metres) | | |
|---|---|---|---|---|---|---|
| | | | | (1997–2007) | (2007–2017) | (1997–2017) |
| 1 | I | 18.3751 | 84.1592 | − 436.43 | 679.84 | 162.35 |
| 2 | II | 18.3016 | 84.0725 | − 721.356 | 563.03 | 377.75 |
| 3 | III | 18.2378 | 83.9797 | 551.8034 | − 23.28 | 1027.42 |
| 4 | IV | 18.207 | 83.872 | − 628.212 | − 318.38 | 251.44 |
| 5 | V | 18.1696 | 83.7613 | − 360.225 | − 402.87 | − 634 |

providing average of every minute interval data from the nearby ten stations. Concentration of suspended sediments in the ocean (pre-monsoon and post-monsoon) was examined from red and near-infrared bands of Landsat 8 OLI (30 m) images for April (pre-monsoon) and September (post-monsoon) 2017. Red band and near-infrared bands are more sensitive to suspended particle matter. Near-infrared and red bands are efficient for mapping medium to high suspended solid matter in water as water gets totally absorbed in near-infrared bands. We utilized only red band to execute the model and to determine suspended particle matter (Eq. 1) following Pandey and Kunte (2016). Digital numbers of Landsat

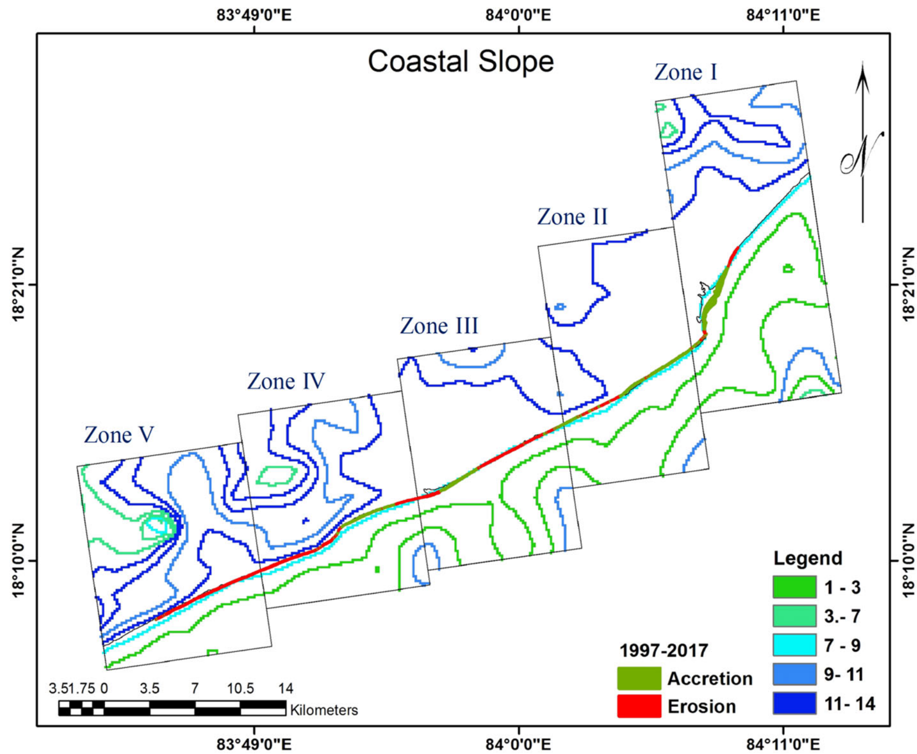


**Fig. 3** Determining coastal slope

OLI (30 m) were converted into reflectance for applying the model:

$$\mathrm{SPM} = \frac{A * \rho}{1 - \rho/c} \tag{1}$$

where $A$ = 327.84 g $m^{-3}$ and $C$ = 0.1708. In this way, the solid particles suspended near the shore have been examined, which gives the idea about transportation of suspended particle along the coast during pre-monsoon and post-monsoon.

Data derived from Permanent Service for Mean Sea Level (PSMSL) were used for assessing trends in sea level for the study area including adjoining areas hosted by Global Sea Level Observing System (GLOSS). Nearby tide gauze location Vishakhapatnam Sea and Paradip were also included in the study area. Change in sea level rate was estimated from 1997 to 2017 with the help of monthly mean tide gauze data collected from 14 tide gauge stations lying across the adjoining parts of the study area (Fig. 4). Data of sea level trend pertaining to tide gauge stations were interpolated by kriging interpolation technique, and the values along the coast were assigned the corresponding coastal segments using Arc GIS software. The coasts that recorded high sea level rise were assigned as high vulnerable and lower sea level rise assigned as low vulnerable.

Significant wave height was calculated using data derived from the European Centre for Medium-Range Weather Forecasts (ECMWF). It was calculated by using average of the one-third highest wave/12 h as average wave energy (Fig. 5). Geomorphology map of the study area was taken from Bhuvan thematic map service provider (Fig. 6). Map was

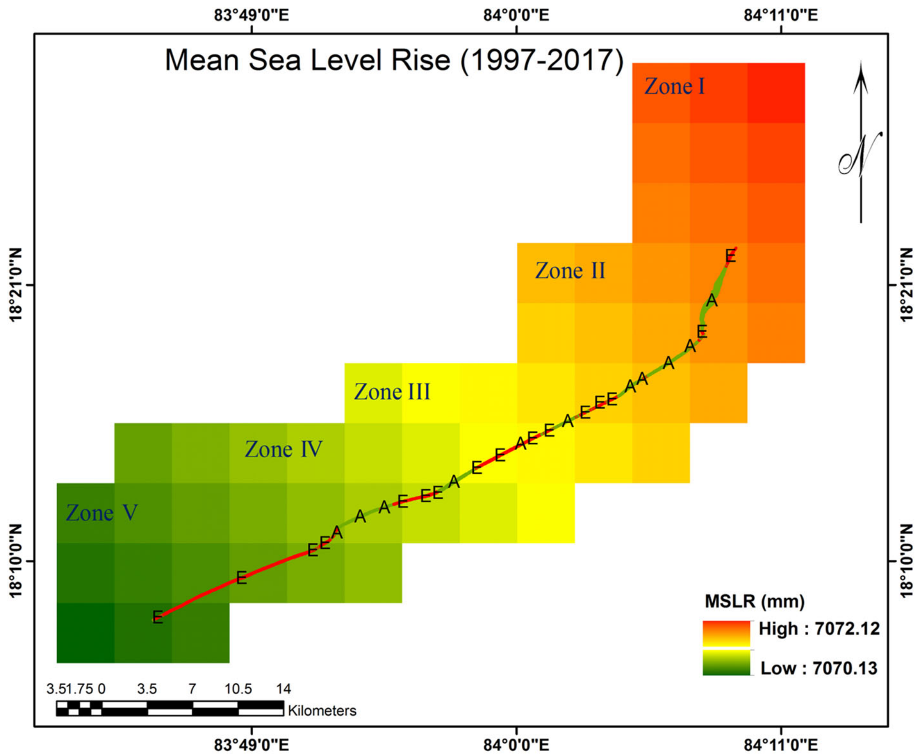


**Fig. 4** Assessing mean sea level rise

converted into vector data format. SRTM digital elevation model was used for preparing elevation map. Elevation points were extracted through intersection with shoreline. Regional elevation is an important consideration for projecting future sea level rise. Elevation classes are assigned according to vulnerability of the coastline; low elevation is considered very high vulnerable. Regional elevation also helps in identifying the sensitive flood areas and estimating area under further sea level rise.

Contours were digitized from bathymetric images obtained from SRTM DEM (30 m resolution) to measure the depth of coastline towards the open oceanic regions. Wave hydrodynamic bathymetric analysis is important for inundation modelling used for evaluating the effects of sea level rise. The analysis has been based on grids prepared by using satellite cell size metadata.

All physio-geological parameters (Eq. 2) were integrated to develop a comprehensive coastal vulnerability index (CVI). Algorithm of CVI can be represented as a product of square root of weighted variables divided by total variables (Pendleton et al. 2004):

$$\mathrm{CVI} = \sqrt{\frac{a \times b \times c \times d \times e}{5}} \tag{2}$$

where $a$ = rate of shoreline change, $b$ = coastal elevation, $c$ = coastal slope, $d$ = geomorphology, and $e$ = significant wave height and mean tide range.

Calculated weighted averages of individual parameters were combined to develop a composite index for the selected coastal *talukas* (Hahn et al. 2009).

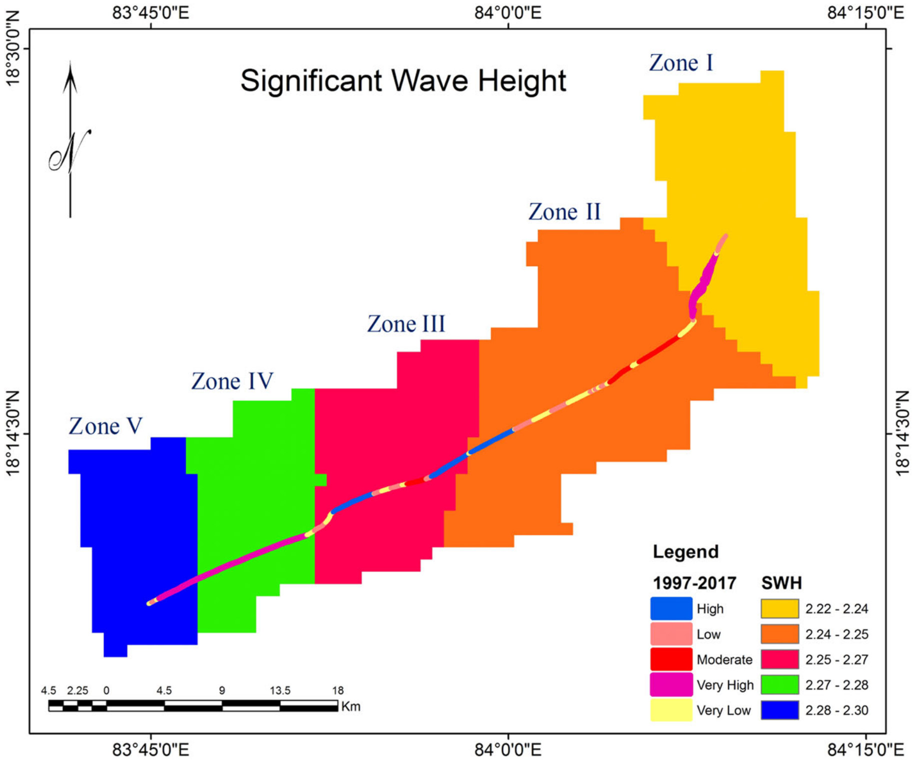


**Fig. 5** Estimating mean significant wave height

## 3 Results and discussion

A shift of 2.5 km was found in shoreline towards the land surface because of constant erosion and that of 1.82 km towards the sea due to accretion during 1997–2017. Data regarding shoreline changes were collected from five stations of study area (Table 2). The rate of high erosion in last 20 years has been found in zones IV and V, and high accretion was found in zones II and III (Fig. 7).

Erosion and accretion depend on the composition of landform materials. Bathymetry and suspended sediment concentration have been considered to assign weightage for each area according to the amount of erosion and accretion. Channel bars and terraces were found to be significant depositional land forms along river mouth. An area above 1.04 km was characterized by low vulnerability due to gentle slope and landform characteristics. Tidal marine flats were located adjacent to the beach at a distance of 1.5 km. Significant barrier dunes were observed in the middle portion of the shoreline. Low coastal slope or elevation showed high vulnerable area and vice versa. Most of the shoreline (76%) with >12% regional slope experienced very high vulnerability. Mean significant wave height was utilized as a substitute to wave energy leading to transportation of coastal sediments. This plays a major role in highlighting vulnerability of the coast. Rate of significant wave height which is below the average value 0.64 has been recorded along the coast of Srikurmam (Table 3). Area below − 0.83 km represents very high vulnerability and

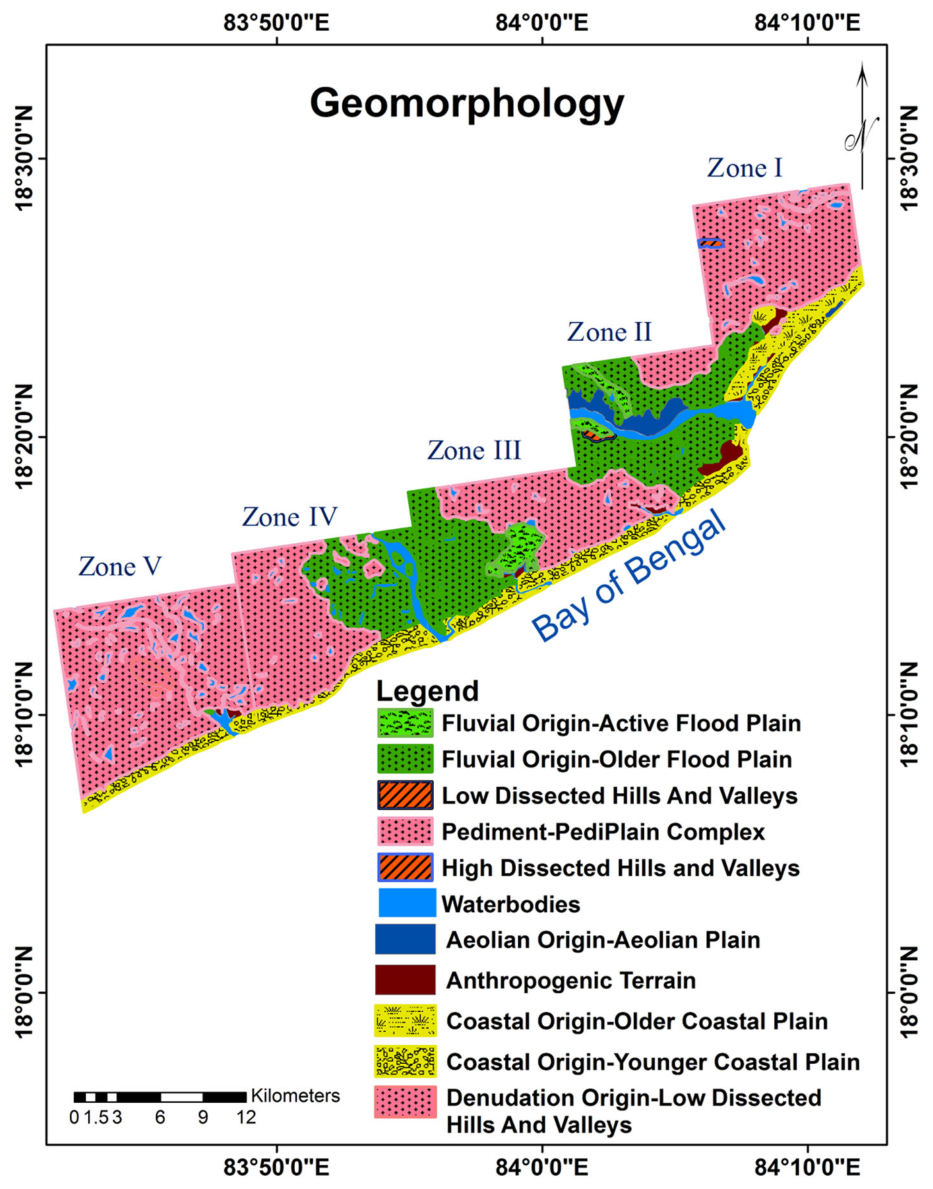


**Fig. 6** Map showing geomorphology

having mud flats, cliffs type of landform with high rate of significant wave height. The rate of erosion in Chipurupalle *taluka* is higher than the remaining part of the study area.

Vulnerability classification revealed Chipurupalle and Narsannapeta *talukas* are high and very high vulnerable. Moderate vulnerability was found in Srikurmam. Low vulnerability is recorded in Narsannapeta and Srikurmam *talukas* (zone IV and V). The highest wave height and the lowest wave height were found along the coast of Narsannapeta *taluka* and Chipurupalle *taluka*. Mean sea level rise was an average level for the surface of one or

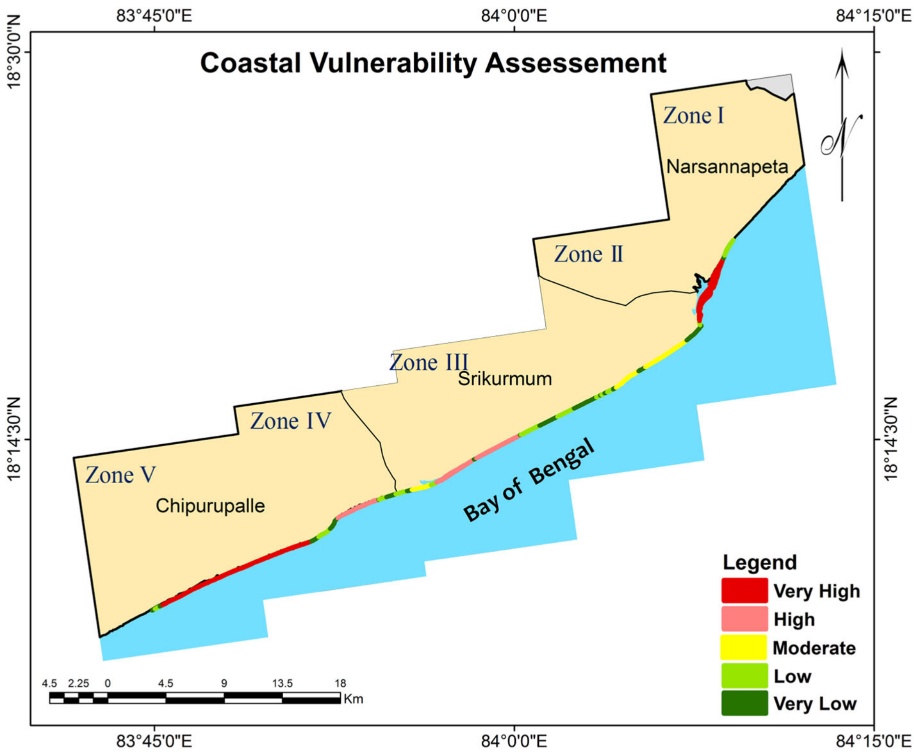


**Fig. 7** Coastal vulnerability assessment

**Table 3** Extent of coastal vulnerability and respective contributing factors

| Coastal vulnerability | Geomorphology | Coastal slope (%) | Shoreline erosion/ accretion (km) | Significant wave height (m) | Regional elevation (m) |
|---|---|---|---|---|---|
| Very low | Fluvial deposition/ beaches | < 3 | > (− 0.83) | < 0.64 | < (− 25) |
| Low | Embayed/ indented | 4.3165 | − 0.83 to (− 0.62) | 0.64–0.727 | − 25 to (− 5) |
| Moderate | Flood plains/ sand dunes | 4.3260 | − 0.62 to (− 0.4) | 0.727–0.814 | − 30 |
| High | Beaches | 4.3355 | − 0.41 to 1.04 | 0.814–0.901 | 25–50 |
| Very high | Mudflats and cliff | > 12 | < 1.05 | > 0.901 | > 50 |

more of earth ocean from which heights such as elevations may be measured. Very high vulnerability is recorded in upper region of study area (Narsannapeta *taluka*). Moderate vulnerability is recorded in middle region of study area (Chipurupalle *taluka*), and low vulnerability is recorded in Srikurmam. The highest sea level rise is recorded about

7072.12 mm along the coast, and lowest sea level rise is recorded in lower area of coastline with rate of 7070.20 mm.

CVI was calculated using long drawn value of shoreline changes, and vulnerability was classified into five categories, namely very high, high, moderate, low and very low. Erosion, accretion, coastal slope, wave height and sea level rise were found to be more influential factors for causing vulnerability along the shoreline. The results revealed that Voleti Atchanna Agrahagram in zone IV and Jeerupalem and Kollibhimavaram in zone flying in Chipurupalle *taluka* were very highly vulnerable. Zone V has higher erosion, while zone IV has recorded high accretion. Slope, mean sea wave height and sea level rise were also high in zones IV and V causing vulnerability along the shoreline. Rajarampuram in zone I and Kalingapatnam and Nandigram of zone II also recorded high coastal vulnerability mainly due to erosion and accretion. Balivada, China Thonangi, Perlavanipeta and Mogadalapadu in zone II recorded moderate vulnerability as impact of wave height found insignificant. Zone III has recorded low vulnerability, but the impact of erosion and accretion was also seen in this zone. Very low vulnerability is found in zone III and some parts of zone IV due to lower mean sea level rise. Korlam and Batchuvanipeta in zone II recorded low and very low vulnerability.

## 4 Conclusion

This article analyses various causes held responsible for coastal vulnerability in Vizianagaram–Srikakulam coastline in India. Exiguous understanding of coastal vulnerability has led to the realization about its impact assessment on people and their associated activities. Physio-geological variables, namely significant wave height, rising sea level, changes in shoreline, elevation of coast and bathymetry, were used for constructing coastal vulnerability index model. Findings of the model have revealed rising sea level and shoreline fluctuations are the major controlling factors for coastal vulnerability. CVI was used for detecting changes in shoreline and analysing spatial extent of vulnerability along coast of Chipurupalle, Srikakulam and Narsannapeta *talukas* of Srikakulam district. The total coastline of the study area was divided into five zones based on satellite cell size metadata. Zonal analysis using GIS helped in analysing more accurate vulnerability along the coast of the study area. Southern part of study area is highly dynamic due to meeting of rivers and recorded highest fluctuation in shoreline mainly due to erosion. The study demonstrated that zone V has been facing severe erosion by mean sea wave height and sea level rise. Coastal inhabitants are more vulnerable in zones IV and V, and fishing and agricultural activities in these zones are affected due to impact of erosion and shoreline changes. Zones I and II experienced very low and low vulnerability, respectively, and zone III recorded moderate vulnerability. Hence, zones III, IV and V require immediate attention and policy implication. Coastal vulnerability index analysis involving physio-geological variables can help in land use management and planning and resource conservation. It can also help in preparing emergency management plans for coastal hazards. However, socio-economic variables along with physical parameters can be more beneficial in further coastal vulnerability assessment.

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