International Journal of Remote Sensing & Geoscience (IJRSG)
www.ijrsg.com

COASTAL VULNERABILITY ASSESSMENT FOR NORTH EAST COAST OF ANDHRA PRADESH, INDIA.

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Abstract

Coastal areas of Andhra Pradesh in the north eastern part of India are mostly vulnerable for accelerated erosion hazards. Along the 200 km of coastline most of the coastal areas, towns and industries are threatened by reoccurring of storms, flood events and sever coastal erosion. The east coast of India is mostly affected by tropical cyclones originating from northern and southern Bay of Bengal, where 1-2 tropical cyclones form every year along the coast. Recently two tropical cyclones that formed in the Bay of Bengal are Hudhud (October 13, 2014) and Phylin (October 11, 2013) has caused devastating impact on the eastern coast. With this study, it is an attempt to develop to develop a coastal vulnerability index (CVI) for the Andhra Pradesh using eight relative risk variables. Most of these parameter are dynamic in nature and requires different data from different sources. The base data is from remote sensing satellites, for others it is taken from long-term in situ measurements and from numerical models. Zones of vulnerability to coastal, natural hazards of different magnitude (high, medium and low) are identified and shown on map. In this study, tsunami run-up has been considered as an additional physical process parameter to calculate the CVI. In earlier studies, tidal range are assumed to include both permanent and episodic inundation hazards.

Introduction

Coastal zones have changed significantly during the 20th century, due to increase of population, urbanization and other development activities. The coastal area and its inhabitants are at risk and more vulnerable to storm events, flooding due to significant rise in sea level. Millions of people will be affected to coastal erosion and flooding incidence due to projected sea level rise. In India about 25% of the human population live within 50 km of the coast. The Indian coastal regions are under significant threat of tsunamis and tropical cyclones. The increasing of sea level were lead to beach recession where 70 % of the sandy beaches have been a likely retreating in the past century (Nayak 2005). The east coast of India had also experienced the rising tendency of the sea level not in an equal precipitation, but it varies differently throughout the coastal areas. However increasing coastal population, recent observed cyclones and storm surges and climate change-induced sea level acceleration stressed the importance of the scientific studies on coastal vulnerability and the collect appropriate information for government decision makers, community residents (Kumar and Kunte 2012). This work aims to describe natural hazards impacts, in order to identify, assess of risk of the coastal zone based on remote sensing and GIS technology.

Study Area

Andhra Pradesh is situated between the Eastern Ghats to its west and the Bay of Bengal to its east (Fig. 1), bordering on the north with the state of Orissa and Vizianagaram district and East Godavari district to the south. The city coordinates lies between 17°41′18″N latitude, and 83°13′07″E longitude. Its periphery consists of plains along the coast line and hills of the Eastern Ghats which is surrounded it on North and the West. This region is also called the Agency Division. It occupies an area of approximately 11,161 km. The state has a coastline of 974 km, the second longest among all the states of India after Gujarat.

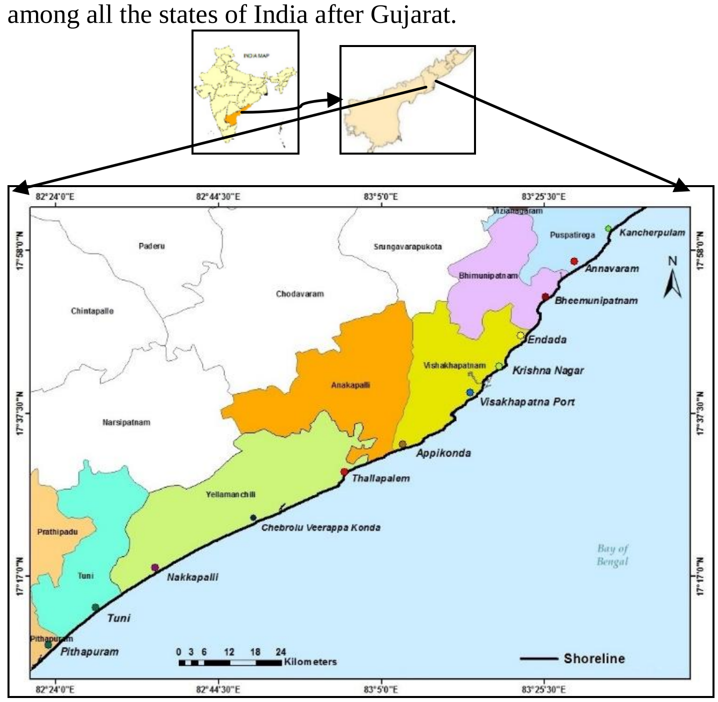

Figure 1. Study area map

Materials and Method

Vulnerability can be defined as an internal risk factor of the subject or system that is exposed to a hazard and corresponds to its intrinsic predisposition to be affected, or to be susceptible to damage. Risk is the potential loss to the exposed subject or system resulting from the convolution of hazard and vulnerability. Using the basic information like coastal geomorphology, rate of sea-level change, past shoreline evolution, and other factors will be used for estimating the CVI. The method of computing the CVI in the present study is similar to that used in Pendleton, Thieler, and Jeffress (2005): Thieler (2000); and Thieler and Hammar-Klose (1999). In addition to the six parameter the present study uses an additional geologic and physical process variable i.e. Coastal regional elevation and Tsunami run-up. The eight relative risk variable used are Shoreline change rate, Sea level change rate, Coastal slope Mean significant wave height, Tidal range, Coastal regional elevation, Coastal geomorphology and Tsunami run-up.
Most of these parameters are dynamic and require a huge amount of data from different source and then processed it for analyzing. They are derived from remote sensing, GIS and numerical model data. Data sets used in the present study for deriving each of these parameters presented in Table 1.

Table 1: Data used for the study

Data	Year	Source	Resolution
Landsat MSS Landsat TM Landsat ETM Landsat OLI/TIRS	1973 1988 2002 2014, 2015	USGS	60 m 30 m 30 m 30 m
Bathymetry	-	GEBCO	1 minute
CARTOSAT	2014	NRSC	30 m
IRS P6 (LISS 3)	2012	NRSC	23.5 m
Seal level change rate	2013-2015	GLOSS	-
Tidal range	2014	WX-Tide	-
Significant wave height	2015	INCOIS	-
Tsunami run-up	-	INCOIS	-

Shoreline Change Rate

Coastal shoreline are subjected to change due to coastal processes, which are controlled by wave characteristics and the near-shore circulation, sediment characteristics, beach form. From the coastal vulnerability point of view accretion will be considered as less vulnerable whereas erosion will be considered as more vulnerable because of the loss of private property and natural habitats such as beaches, dunes and marshes. It also reduce the distance between population and ocean.
Landsat MSS, TM and ETM images were downloaded from USGS for the year 1973, 1988, 2002, 2014 and 2015. The data has been projected to the Universal Transverse Mercator (UTM) projection system with WGS-84 datum. The shoreline was digitized using ArcMap. The shoreline was extracted using the near-infrared band, since it is the most suitable for the demarcation of the land-water boundary. The digitized shoreline will be in vector format and it is used as an input to the Digital Shoreline Analysis (DSAS) to calculate the rate of shoreline change. The inputs for this tools are shoreline in vector format, date of each vector layer and transects distance. The rate of shoreline change is calculated for the study area and risk ratings are assigned.

Sea-Level Change Rate

Sea level rises due to the climatic change which will be threat for environment and societies. Changes in mean sea-level as measured by coastal tide gauges which are called relative sea level change (Church and Gregory, 2001). Global warming is predicted to cause significant rise in the sea, due to melting of ice and thermal expansion of sea water. Global Sea-level Observing System (GLOSS) tide gauge data was the primary source of information for sea level trend. For the study area, tide gauge data recorded from Paradip, Visakhapatnam and Chennai for the period of 2013-2015 is used. The rate of sea level change is calculated using the interpolation technique for the study area and risk ratings are assigned.

Coastal Slope

The coastal slope is defined as the change of the altitude to the horizontal distance between any two points on the coast. Coastal slope (steepness or flatness of the coastal region) is linked to the susceptibility of a coast to inundation by flooding (Thieler, 2000). Coastal slope is an important parameter in deciding the degree to which coastal land is at risk of flooding from storm surges and during tsunami (Klein, Reese and Sterr, 2000). Locations having gentle land slope, will have great penetration of seawater as compared to fewer slopes, and resulting in land loss. The coastal areas having gentle slope will be considered as highly vulnerable areas and areas having steep slope will considered as low vulnerability.
General Bathymetric Chart of Oceans (GEBCO) data of one-minute grid resolution, which gives the coastal topography have been used to get the regional slope of the coastal areas. GEBCO data are useful in deriving the coastal slope values

on both land and in the ocean. The slope values is calculated in degrees for the study area and risk ratings are assigned.

Tidal Range

Tidal range is the vertical difference between the high and low tide. It is forced by the gravitational force of the moon and the sun. Tidal range is related to both permanent and episodic inundation. Coastal areas having high tidal range, will be considered as highly vulnerable and low tidal range as low vulnerable. In the present study, tide data is predicted from the WX-Tide software for the year 2014 and maximum amplitude of the tide are calculated, and risk ratings are assigned.

Coastal Regional Elevation

It is referred to as the average elevation of a particular area above mean sea level. Coastal regional elevation study help us to understand, which area is threatened by future sea level rise. The coastal elevation are also used to estimate the land potentially available for wetland migration in response to sea level rise and the sea level rise impacts to the human built environment (Anderson *et al*, 2005). Coastal region having high elevation will be considered as less vulnerable and region having low elevation will be considered as high vulnerable. In the present study CARTOSAT data are used to derive coastal regional elevation. The 30-m resolution raster data are resampled to 500m and risk rates are assigned based on the elevation values.

Coastal Geomorphology

Geomorphology is defined as the study of landforms and landscapes. Geomorphology includes endogenic processes-volcanism, tectonics, flooding, cyclones, tsunami, erosion, transportation and deposition. The processes responsible for this are alluvial and fluvial, glacial, Aeolian and coastal. Rising sea level will bring about the redistribution of coastal landforms comprising subtidal bed-forms, intertidal flats, salt marshes, sand dunes, cliffs and coastal lowlands (Pethick and crooks, 2000). Coastal geomorphology provides a basic understanding of the coastal environment. To extract the coastal geomorphology IRS P6 LISS-3 data have been used and it is overlaid on DTM. The coastal geomorphic classes were extracted based on the visual interpretation and within the zone of 500m from the coast. Using the topographic information from the DTM, cliff areas are identified and classified. The study area consist of sandy beaches, cliffs, pediment & Pedi plain, spits. These geomorphic classes were assigned the risk ratings as high vulnerable (sandy beaches, spits), medium vulnerable (Moderately dissected hills), and low vulnerable (Highly dissected hills, spits).

Significant Wave Height

Significant wave height is used as an alternative to wave energy and is important in studying the vulnerability of shorelines. Wave energy increases as the square root of the wave height, thus the ability to mobilize and transport beach or coastal materials is a function of wave height. The wave energy increases with increase in the wave height, which results in loss of land area due to increased erosion and inundation along shore, so those coastal areas of high wave height are considered as more vulnerable coast sand areas of low wave height as less vulnerable coasts.

Tsunami Arrival Height

Tsunamis results in generation of waves of different periods and height. These wave parameters depend on earthquake source parameters, bathymetry, beach profile, coastal land topography and presence of coastal structure. These surges cause flooding of sea water into the land as much as 1 km or even more, resulting in loss of property and human life.

The Tsunami model has been used, which takes the seismic deformation and bathymetry as input to predict the run-up heights and travel times of a tsunami wave for different parts of the coastline (kumar *et al*, 2010). The run –up heights will be given as input for interpolation technique. Based on the run-up values, risk rating will be assigned for the entire study area.

Calculation of CVI

The CVI is determined by combining the relative risk variable to create a single indicator. Each of the eight input relative risk variable are then assigned appropriate risk classes 1, 2 and 3 based on its ability to cause low, medium and high damage respectively for a particular area of coastline. The risk ratings are assigned for each variable is given in Table 2. Once the coastline is assigned a risk value for each variable, the CVI is calculated by the square root of the product of the ranked variable divided by the total number of variables (Pendleton, Thieler, and Jeffress, 2005).The CVI is represented by the Equation (1).

The CVI is calculated based on the risk value assigned to input parameters using the field calculator of ESRI ArcMap software. The CVI value was generated for different segments of the coastline are categorized into CVI classes viz., low, medium and high vulnerable corresponding to <25th percentile, 25-50th percentile and > 50th percentile.

Table 2. Risk Ratings are assigned for different parameters

Variable	Risk Rating		
	Low(1)	Medium(2)	High(3)
Shoreline change rate (m/y)	> 0 (accretion)	≥ -10 and < 0 (erosion)	< -10 (severe erosion)
Coastal slope (degrees)	> 1.0	> 0.2 and ≤ 1.0	≥ 0 and ≤ 0.2
Coastal regional elevation (m)	> 6.0	> 3.0 and ≤ 6.0	> 0 and ≤ 3.0
Sea-level change rate (mm/y)	< = 0	> 0 and ≤ 1.0	> 1.0 and ≤ 2.0
Significant wave height (m)	-	1.4 - 2.1	-
Tidal range (m)	≤ 2.5	> 2.5 and ≤ 3.5	> 3.5
Geomorphology	Highly Dissected Hills	Moderately Dissected Hills	Sandy beaches, spits
Tsunami arrival height(m)	≥ 0 and ≤ 2.38	> 2.38 and ≤ 3.0	> 3.0

$$CVI = \sqrt{\frac{a*b*c*d*e*f*g*h}{8}} \qquad (1)$$

Where

a = Shoreline change rate (m/y)
b = Sea level change rate (mm/y)
c = Coastal slope (degrees)
d = Significant wave height (m)
e = Tidal range (m)
f = Coastal regional elevation (m)
g = Coastal geomorphology
h = Tsunami run-up (m)

Results

Shoreline Change Rate

The present study revealed that about 52 km of coastline has a high risk ratings, recording erosion rate of 10 m/y along the north coast of Bheemunipatnam, Central chebrolu veerappa konda and south of Tuni. About 93 km of coastline has a medium risk ratings with erosion rate between 0 and 10 m/y along the coast stretches, north of Endada, Krishna Nagar, and Visakhapatnam Port, central part of an Appikonda, Thallapalem, and southern part of Nakkapalli. About 35 km of coastline that recorded accretion along the northern coast of Kancherpulam and Annavaram has a low risk ratings (Fig. 2).

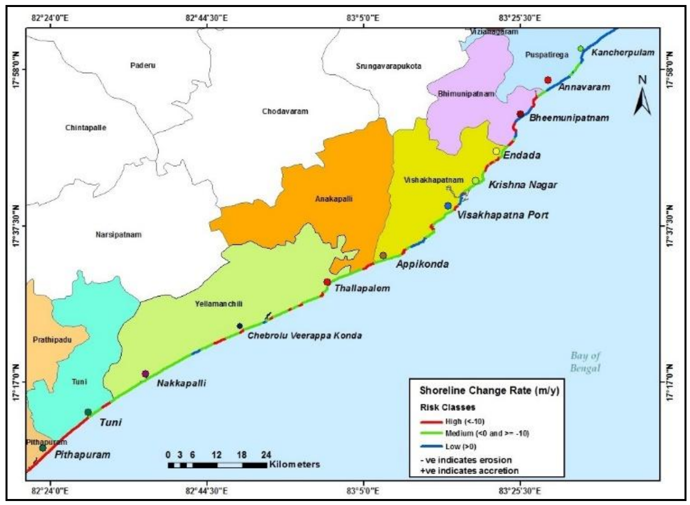

Figure 2. Risk classes for shoreline change rate

Sea-Level Change Rate

The present study shows that about 81 km of coastline has a high risk rating, recording sea-level change rates of more than 1.0 mm/y along the North coastal of Puspatirega, Bheemunipatnam and Visakhapatnam port. About 70 km of coastline has a medium risk ratings with sea level change rate between 0.1 and 1.0 mm/y along the coast of Yellamanchili district. Around 29 km of coastline has a low risk rating in the southern part of Tuni and Pithapuram district (Fig. 3).

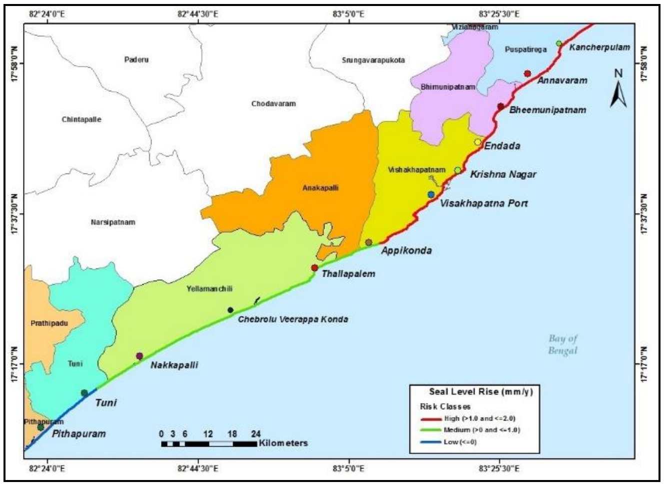

Figure 3. Risk classes for sea-level change rate

Coastal Slope

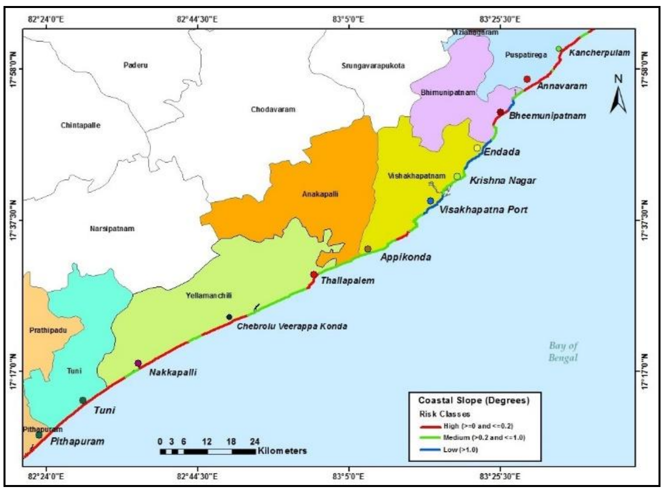

Figure 4. Risk classes for coastal slope

The present study shows that about 150 km of coastline has a high risk ratings, with coastal slope less than 0.2°, about 25 km of coastline has a medium risk ratings with a coastal slope between 0.2° and 1.0° and remaining 5 km of coastline has a slope more than 1.0° which are categorized under low risk ratings (Fig. 4).

Tidal Range

The present study shows that about 172 km of coastline has a medium risk rating with tidal range between 2.5 and 3.5 m along the coastal stretches of Puspatirega to Yellamanchili district. About 8 km of coastline has a low risk ratings with tide range of less than 2.5m along the coast of Tuni and Pithapuram district (Fig. 5).

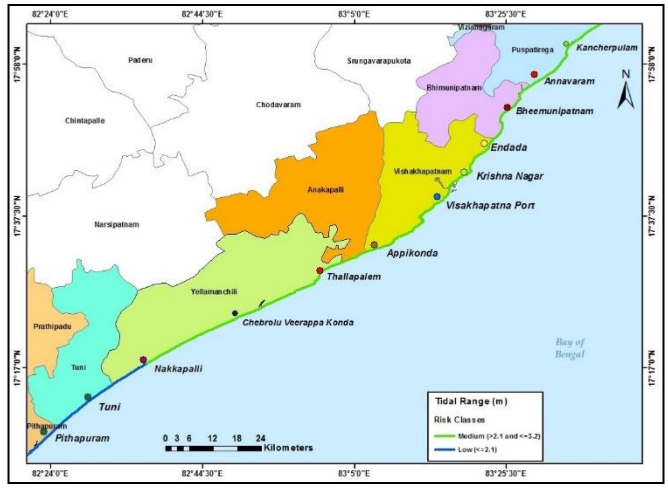

Figure 5. Risk classes for tidal range

Coastal Regional Elevation

The present study shows that 65 km of coastline has a high risk ratings, recording coastal elevation between 0 and 3m. About 35 km of coastline has a medium risk ratings recorded elevation between 3.0 and 6.0m. About 80 km of coastline has a low risk ratings recorded elevation more than 6.0 m (Fig. 6).

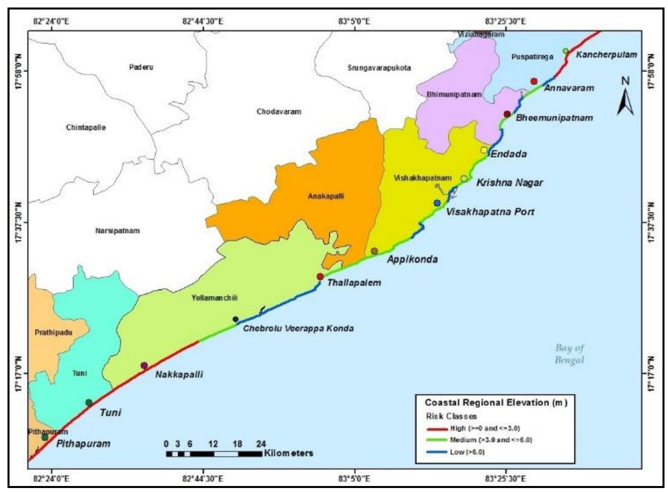

Figure 6. Risk classes for coastal regional elevation

Coastal Geomorphology

The present study shows that 155 km of study area consist of sandy beaches, spits and pediment & Pedi plain that have a high risk ratings. About 14 km of coastline have a medium risk ratings which consist of moderately dissected hills. About 11 km of coast having low risk ratings due to consists of highly structured dissected hills (Fig. 7).

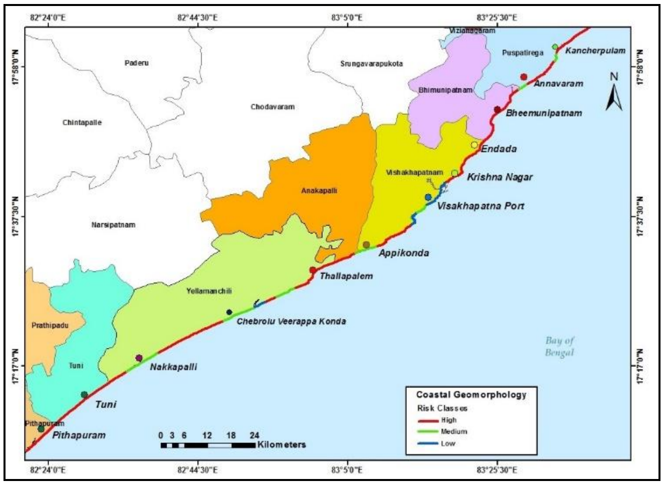

Figure 7. Risk classes for coastal geomorphology

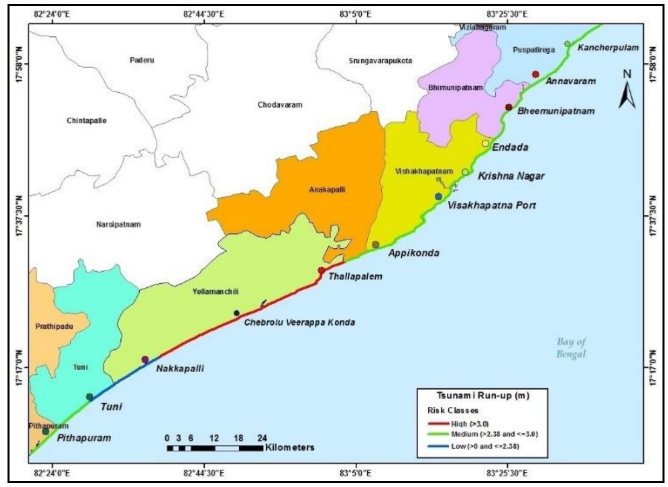

Figure 9. Risk classes for Tsunami run-up

Significant Wave Height

The present study revealed that the mean significant wave height ranges between 2.2 and 3.0 m. The entire coastline is in the medium vulnerability class (Fig. 8).

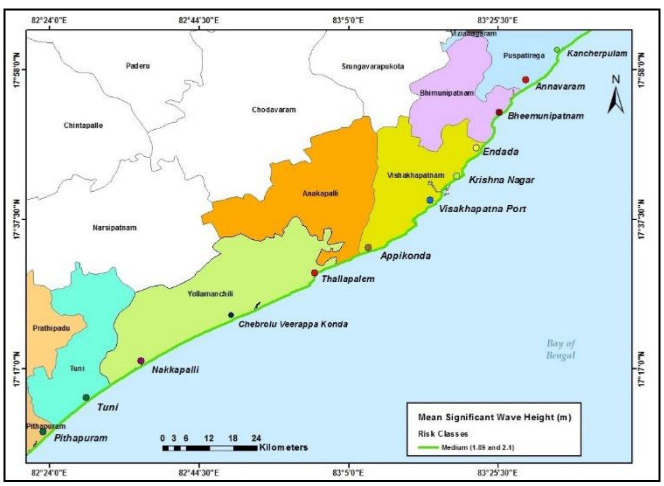

Figure 8: Risk classes for significant wave height

Tsunami Run-up

The present study shows that about 45 km of coastline having a high risk ratings ranges more than 3m. About 120 km of coastline have a medium risk ratings, recording tsunami run-up between 2.38 and 3.0 m. About 15 km of coastline have a low risk ratings recorded run-up between 0 and 2.38 m (Fig. 9).

Coastal Vulnerability Index (CVI)

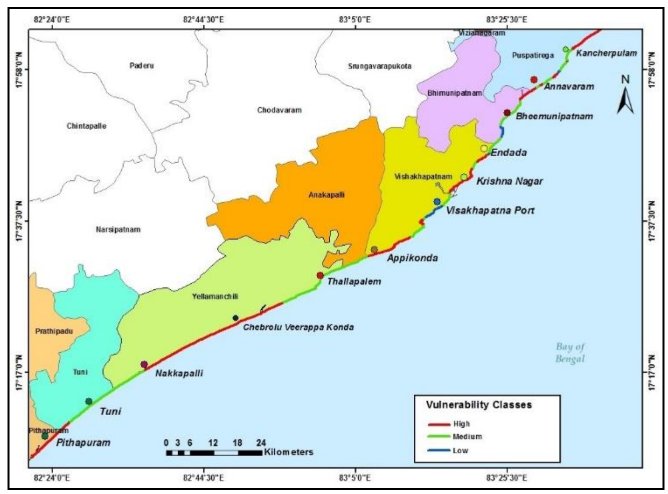

Figure 10. CVI classes along Andhra Pradesh coast

The coastal stretches of Andhra Pradesh are classified as low, medium, and high risk based on their vulnerability to the eight relative risk variables. The resultant CVI is calculated and the vulnerability zones along the shoreline are delineated on the map (Fig. 10). The CVI value along the study area of Andhra Pradesh coastline varied from 2 to 16. The 25th and 50th percentiles of CVI value are 4.0 and 8.0, respectively. Those parts of the coastline having CVI values ranging from 2.0 to 4.5 are considered to be low vulnerable, those ranging from 4.5 to 8.0 are considered to be medium vulnerable, and the remaining parts having CVI values of more than 8.0 are high vulnerable. Accordingly, about 90 km of the coastal stretch of Andhra Pradesh state, covering parts of Bheemunipatnam and Visakhapatnam is highly vulnerable. About 64 km of the coast of Andhra Pradesh having medium risk, covering the Nakkapalli and Kancherpulam and 26 km of the coast is under low risk covering the Thallapalem.

Conclusion

The present study conclusively proves the usefulness of remote sensing data, in situ observations, numerical modeling, and GIS analysis tools for coastal vulnerability studies. The coastal vulnerability maps produced using this technique serve as a broad indicator of threats to people living in coastal zones. This is an objective methodology to characterize the risk associated with coastal hazards and can be effectively used by coastal managers and administrators for better planning to mitigate the losses due to hazards as well as for prioritization of areas for evacuation during disasters.

Acknowledgments

I hereby acknowledge with deep sense of gratitude to the valuable guidance, encouragement and suggestions given by my guide Dr. T. Srinivasa Kumar Scientist – F, R.S Mahendra Scientist D, Dr. P.C. Mohanty Project Scientist B, Mr. Sachikanth Nanda who has been a constant source of inspiration throughout this work.

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Biography

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