COASTAL VULNERABILITY ASSESSMENT ALONG MAHARASHTRA WEST COAST OF INDIA USING GEOSPATIAL TECHNIQUE

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ABSTRACT
The zones of coastal part of Maharashtra is spanning in the west central part of Indian peninsula, are potentially vulnerable to accelerated erosion hazard. Along the 720km of coastal Maharashtra, most of the areas, including tourist resorts, hotel, fishing villages, towns, are already threatened by recurring storm flood events and severe coastal erosion. The coastal regions of Maharashtra are threatened to tsunami and cyclones. The present study is therefore an attempt to develop Coastal Vulnerability Index (CVI) for the maritime state of Maharashtra using eight risk variables, using remote sensing and GIS techniques. Most of these parameters are dynamic in nature and require a large amount of data from different source. The base data for some of the parameters is from remotely sensed data and for others it is either from long term in-situ measurements or from numerical models. Vulnerability is identified and shown on a map. CVI map prepared for Maharashtra coast in this study can be used by the state and district administration involved in the disaster mitigation and management plan.

KEYWORDS: CVI, Coastal zone, Sea level, Risk, hazards.

1. INTRODUCTION

The coastal Maharashtra has changed significantly during the 20thcentury, due to the tremendous growth of population, urbanization and other developmental activities. The coastal zones and its habitants are at risk and more vulnerable to storm events, flooding, tsunami, due to significant rise in sea level. According to estimation 40% of world population living in coastal zones. In India around 25% of population of India live within 50km of the coast (http://www.un.org). The west coast of India had also experienced the rising tendency of sea level, but it varies throughout the coastal division. Cyclone Phyan which passed in 20 years along Mumbai and Konkan coast claimed lives and caused massive damage to property of coastal districts of Ratnagiri, Raigad, Sindhudurg, Thane, and Palghar in Maharashtra. The depression in Arabian Sea gave way to a low pressure zone causing heavy rain accompanied by gusty winds. The increasing coastal population, recent observed cyclone, flood and the climate changed-induced sea level acceleration stressed the importance of scientific studies on coastal ratings vulnerability and collect appropriate information for Government decision makers and management authorities. The main aim of this work is to describe natural hazards impacts, in order to assess the risk of coastal zone based on remote sensing and GIS technology.

There are several institutes and individuals working on the coastal vulnerability and sea level studies. International Panel on Climate Change (IPCC) an international initiative working on the assessment and projections of the climate change across the globe. Numerous works outside India were also conducted on the coastal vulnerability assessment (Gorlitz et al., 1994; Pethick and Crooks, 2000; Thieler, 2000; Thieler and Hammer-Klose, 2000a; Thieler and Hammer-Klose, 2000b; Pendleton et al., 2005). The following some of the similar work carried out for Indian coast has been listed.

The present study was an attempt to estimate the integrated CVI assessment along the Maharashtra coast usingeight input parameters. The advantage of the geospatial tools and data were extensively made use in the current study for the CVI assessment.

2. STUDY AREA

Maharashtra is situated between Gujarat to the north-west and Goa to the south-west and the Arabian Sea is bordering to the west. Maharashtra is a state in the western region of India and is the third-largest state by area. The city coordinates lie in between latitude 19° 39' 47.8080" N, and longitude75° 18' 1.0548" E. The state has a coastline of 720km and area 307,713km2 .Maharashtra state has 36 districts in which 6 districts lies along the coastline. Some of the major hazards of recent past in Maharashtra are cyclonePhyan, July 2005 cyclonephyan which passed along the coastline of Mumbai and Konkan coast claimed lives and caused damage to massive property of coastal districts of Ratnagiri, Raigad, Thane, Mumbai and Sindhdurg. Coastal geomorphology of maharashtra state is separated as beach, patches, spit, and habitation, vegetation, mangroves. The entire area of the state forms a “Peninsular Shield” which is composed of rocks. Along the coast from Ratnagiri to Mumbai and further north in Thane district there exist a series of long hot springs arranged almost in linear fashion which suggest that they are situated on a line of fracture. The climate of the state is tropical. The coastal areas receive heavy monsoon rain. The population of the coastal part of Maharashtra are for Thane (11,060,148), Mumbai suburban (9,332,481), Mumbai city (3,085,411), Raigad (2,635,394), Ratnagiri (1,615,065), Sindhdurg (849,651).

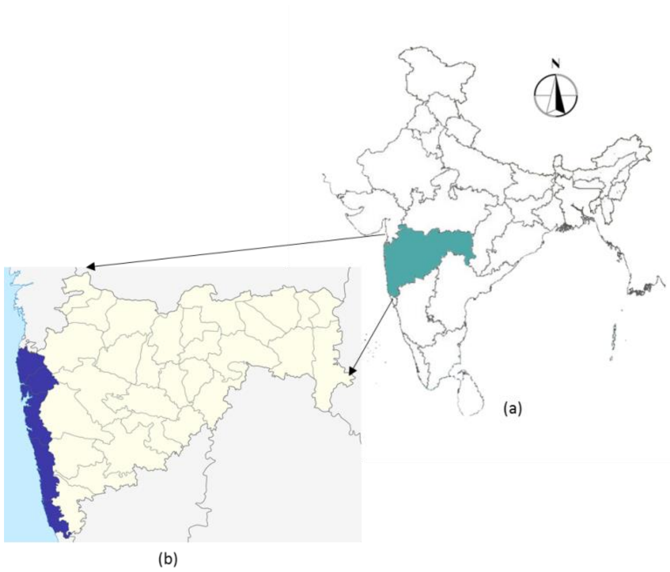

Figure.1 (a) Location of Study Area (b) Study Area

3. DATA USED

Most of these parameters are dynamic and require a huge amount of data from different sources and then proceed it for analysing. They are derived from remote sensing, GIS and numerical model data. Data sets used in the present study for deriving each parameter are presented in table1.

Table1: Data used for this work

Data	Year	Source	Resolution	ParameterDerived
Landsat MSS Landsat TM Landsat ETM Landsat OLI/TIRS	1973 1988 2010 2017	USGS (https://www.usgs.gov/)	60m 30m 30m 30m	Shoreline change rate
Cartosat	2014	NRSC (https://www.nrsc.gov.in/)	1minute	Elevation
GEBCO	NA		2 min	Slope
IRS P6 (LISS 3)	2012	NRSC	23.5m	Geomorphology
Monthly mean Sea level data	2013-2015	GLOSS		Sea level Change
Astronomical tide	2014	WX-Tide		tidal range
Significant wave height	2015	INCOIS (Mike-21 Simulated)	0.25 degree	SWH
Population Density	hhttps://maharashtra.gov.in/	-	-	Population Density

4. METHODOLOGY

This work was carried out using the various input data derived from remotely sensedmodelled and census data. Generation of individual parameters using these dataset is being elaborated in the following sections. The scheme of the method employed in the current study is provided as flow-chart (Figure 2)

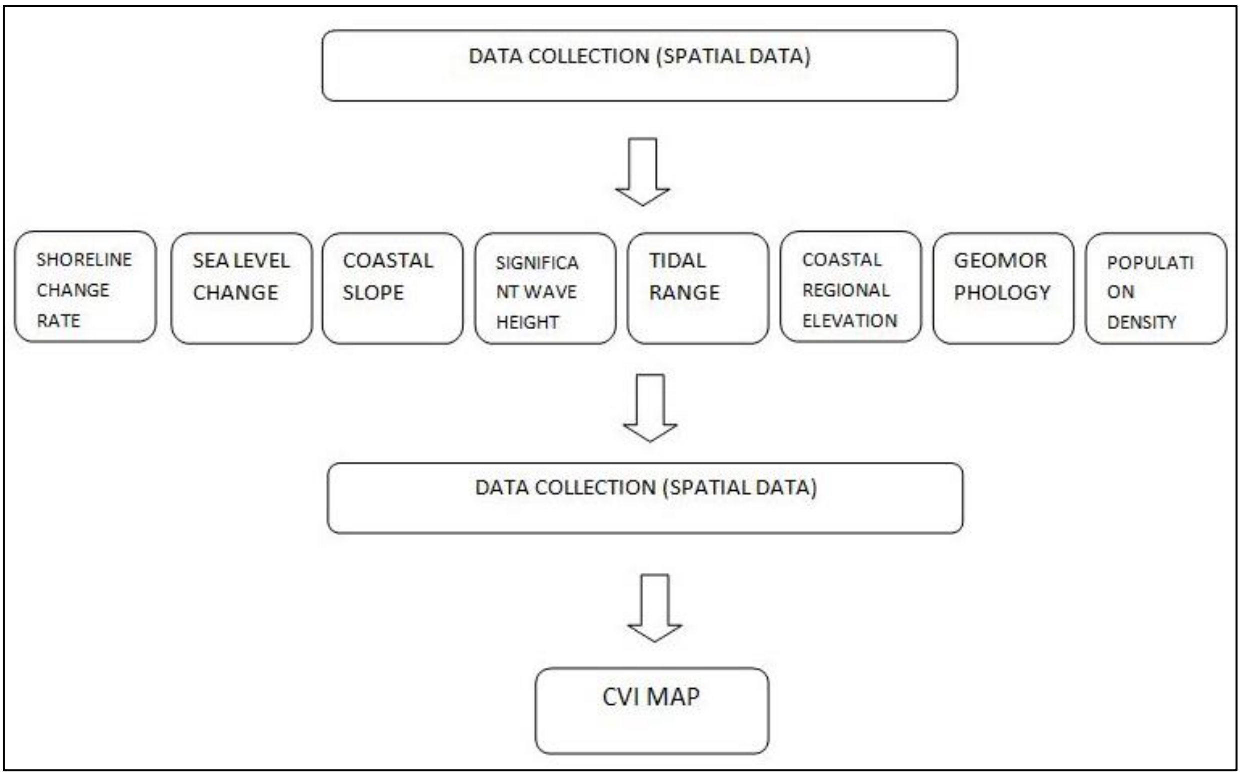

Figure 2. Flow-chart showing the methodology of present work.

4.1. Preparation of input parameters

Shoreline change rate: Coastal shorelines 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 loss of private property and natural habitats such as beaches, dunes and marshes. It also reduces the distance between population and ocean.

Sea level change rate: Sea level behaviour is such an important for tracking climate change. Sea level bounces up and down slightly from year to year. Changes in the 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 primary source of information for sea-level trend. For the study area, the tide gauge data recorded from Paradip.

Coastal Slope: Slope or gradient of a line is a number that describes both the direction and the steepness of line. Coastal slope (steepness or flatness of the coastal region) is linked to the susceptibility of a coast to inundation by flooding (Theiler, 2000). General Bathymetric Chart of the Oceans (GEBCO) data of one-minute grid resolution coastal topography and bathymetry has been used to get the regional slope of the coastal area. The slope values in degrees are calculated using the Environmental Information System software package. The slope is calculated for the entire study area, and risk ratings are assigned.

Tidal Range: The tidal range is the vertical difference between the high and low tide. Tides are the rise and fall of sea level caused by the combined effect of the gravitational force of the moon and the sun. Coastal areas having high tidal range will be considered as highly vulnerable and low tidal range as low vulnerable. In this study, tidal data is predicted from WX-Tide software for the year 2014 and maximum amplitude of tide are calculated, and risk ratings are assigned.

Coastal Regional Elevation: Regional elevation may be defined as the average elevation of a particular area above mean sea level. In the present study, Shuttle Radar Topography mission (SRTM) data are used to derive the coastal regional elevation. The 90-m resolution SRTM raster data are resample to 1 km and risk rates are assigned to the entire coastline based on the elevation values

Coastal Geomorphology: Geomorphology can be defined as the study of landforms and landscapes. Geomorphology includes endogenic processes volcanism, tectonics, flooding, cyclones, tsunami, erosion, transportation and deposition. Coastal geomorphology provides a basic understanding of the coastal geomorphology environment. To extract the coastal geomorphology IRS P6 LISS-3 data have been used and it is overlaid on DTM.

Significant Wave Height: Significant wave height can be defined as the mean wave (trough to crest) of the highest third of the waves. These waves are used as an alternative to wave energy and are 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 material is a function of wave height. The wave energy increases with increase in 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.

Population Density: Not only the number of people, but also the lifestyle, consumption patterns, and regions people inhabit and use directly affect the environment. The relationship between population growth and environmental degradation may appear to be the straight forward. More people demand more resources and generate more waste. Fishing, harvesting, the destruction of mangroves, and the pollution, sedimentation from human activities all can affected the coastal environment. The average population density in coastal areas is about 80 persons per square kilometre, twice the world's average population density.

4.2. Calculation of CVI

CVI is determined by combining the relative risk variable to create a single indicator. The coastal stretches of Maharashtra are classified as low, medium, and high risk based on their vulnerability to the eight relative risk variables under study. Each of the eight input relative risk variable and then assigned appropriate risk classes 1, 2, 3, 4 and 5 based on its ability to cause very low, low, medium, high, very high damage respectively for a particular area of coastline. The risk ratings are assigned for all the above variable. Once the risk ratings are assigned for all the variables, the CVI is calculated by the square root of the ranked variable divided by the total number of the variables (Pendleton, Thieler, and Jeffress, 2005).

$cvi = \sqrt[2]{(a \times b \times c \times d \times e \times f \times g \times h) \div 8}$------------------- (1)

Where,

a =Shoreline change rate (m/y), b= Sea level change rate (mm/y), c= Coastal slope

d= Significant wave height (m), e= Tidal range (m), f= Coastal regional elevation (m),

g= Coastal geomorphology, h= Population (NO/SQ.KM)

Data collection is carried out by various sources. Risk classes is assigned for each parameter and coastal vulnerability index is calculated using the formula and then CVI map is generated.

Table 2: Risk ratings assigned for different parameters

Parameter	Length Of Risk Ratings				
	1	2	3	4	5
	Very Low	Low	Medium	High	Very High
Shoreline Change Rate(m/y)	>2	-2to2	-2 to -5	-5 to -10	<-10
Coastal Slope	>2	1 to 2	0.2 -1.0	0.10-0.2	0.0 - 0.1
Elevation(m)	>10	5 - 10	2 -5	1-2	<1
Geomorphology	Barrier island Cliffs	Barrier land Dense marsh vegetation Mangroves	Open land Lagoon Gully land Vacant land	Bay Creek Estuary Mudflats Spit Tidal flat	Habitation, Vegetation Built-up land Beach
Sea level change rate(mm/y)	-	0.0-0.5	0.5-1	1-2	2-1
Mean significant wave height(m)	-	-	1.35 – 1.5	1.5 -1.7	-
Tidal range(m)	-	2-4	4-6	6-8	8-12
Population Den(NO/SQ.KM)	≤200	200-300	300-500	500-1000	≥1000

5. RESULTS

The CVI assessment was carried out using the eight input parameters derived from geospatial methods.

5.1. Distribution of the risk classes of the input parameters

The input parameters derived using the geospatial technique were assigned the risk rates. The individual parameters risk classes are shown the large variability and distribution along the Maharashtra coast.

Shoreline Change Rate: The present study reveals that coastline near Virar in the north is a high risk area. The coastline about 180km north-south and east-west 64km of Ratnagiri is a low risk and very low risk area respectively. The coastline from the end of the border of Gujarat and in between Thane is also low risk area

Sea Level Change Rate: The present study revealed that about 250km coastline of Thane district, has a very high risk rating. Starting from the border of thane to the Mumbai city, the coastline fell into high risk ratings. The coastline of Raigad district fell into low risk ratings. The coastline of Ratnagiri district is very low risk ratings. The coastline of Sindhurgar district is also low risk area.

Coastal Slope: The present study revealed that most of the study area has a medium risk rating. The coastline stretching from thane to Mumbai city is having very high risk ratings. The coastline stretching from the end of Raigad district to the Ratnagiri district is have low risk ratings.

Significant Wave Height: The present study revealed that the mean significant height ranges between 1.35-1.5m is medium risk vulnerable area. The mean significant height ranging from 1.5-1.7m is high risk vulnerable area. From the border of Gujarat to the border of Raigad the coastline has medium risk vulnerable ratings. The rest of the coastline has high risk vulnerable ratings.

Tidal Range: The present study shows that the coastline of Dahanu has a high risk rating. The coastline stretching from end of dahanu to the raigad has a medium risk of ratings and the rest of the coastline is having low risk ratings.

Coastal Regional Elevation: The present study revealed that the most of the part of coastline has a very high risk ratings having elevation less than 1 m. Some of the initial part of Maharashtra coastline is medium and low risk vulnerable areas.

Geomorphology: The present study shows that the study area consisting of sandy beach, habitation, vegetation, built-up land etc. have very high risk ratings. Most of the coastline is having very high risk ratings; very less of the coastline near Ratnagiri has a very low risk rating.

Population Density: The present study shows that from the border of Gujarat to the thane district, the coastline has a high risk. The coastline stretching from border of thane to Mumbai city has very high risk ratings. The coastline extending from Mumbai to the Raigad district has medium risk ratings, the coastline of Ratnagiri has low risk ratings and there are very low risk ratings for Sindhurgarh district.

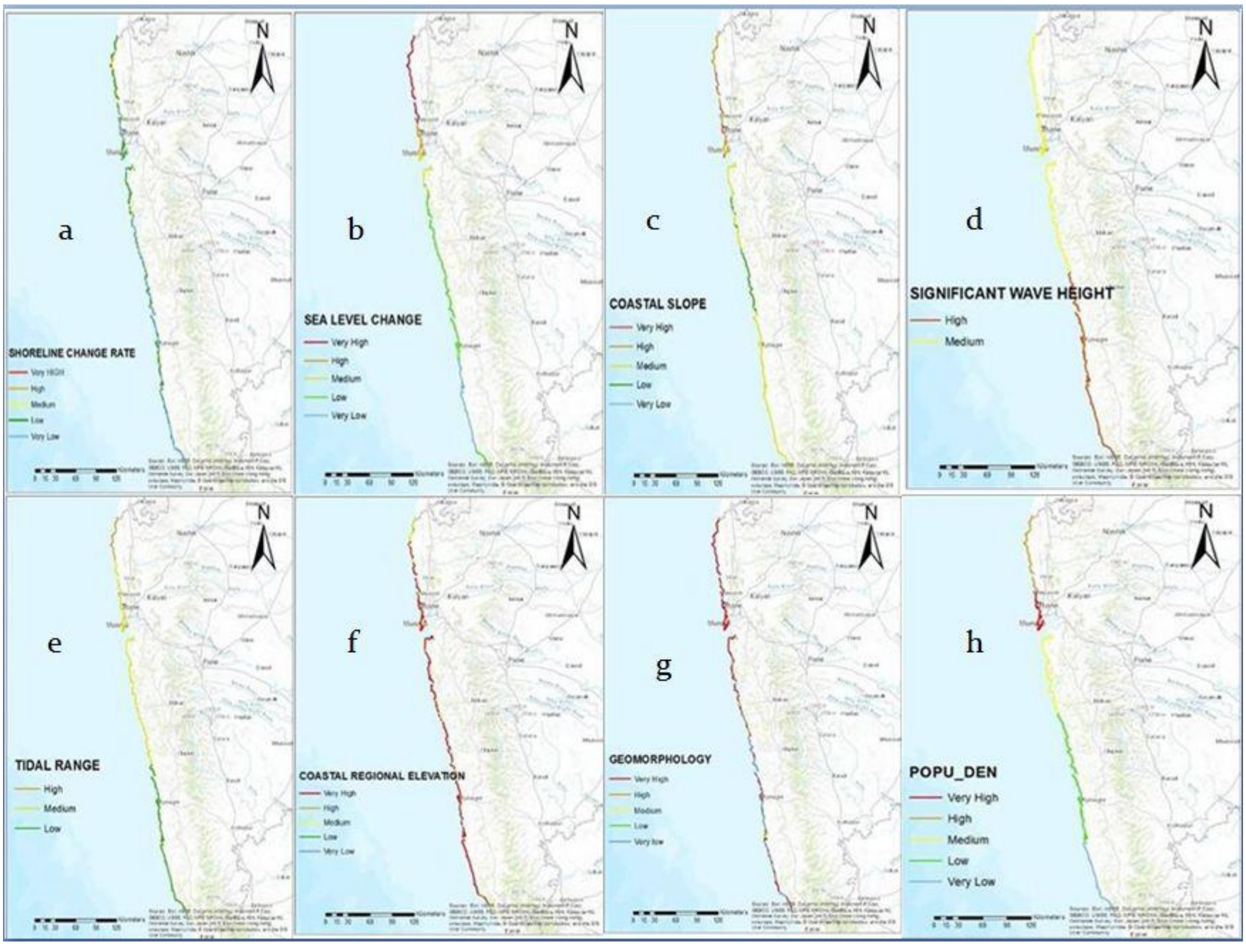

Figure.2 The maps showing the input parameters: (a)Shoreline change rate; (b) Sea level change(c) coastal slope (d) Significant wave height (e) Tidal range(f) Coastal regional elevation(g)Geomorphology (h) Population density, generated for estimating CVI.

Table 4:Length wise Risk ratings for the parameters (km)

Parameters	Length of Coast falling under different risk classes of the input parameters				
	Very low	Low	Medium	High	Very High
Shoreline Change rate	304	310	43	13	7
Sea Level change	131	315	71	53	107
Coastal Slope	1	111	393	110	63
Significant Waveheight	-	-	363	314	-
Tidal range	-	275	344	59	-
Coastal regionalElevation	19	31	77	33	518
Coastal Geomorphology	217	27	13	40	381
Population	123	227	136	100	92

5.2. Coastal Vulnerability Index

The CVI analysis of states reveals that the upper part of Maharashtra coastline near Thane and Mumbai has a very high risk area. The rest of the area is having low risk ratings. The map representation of the spatial distribution of the CVI classes is shown below.

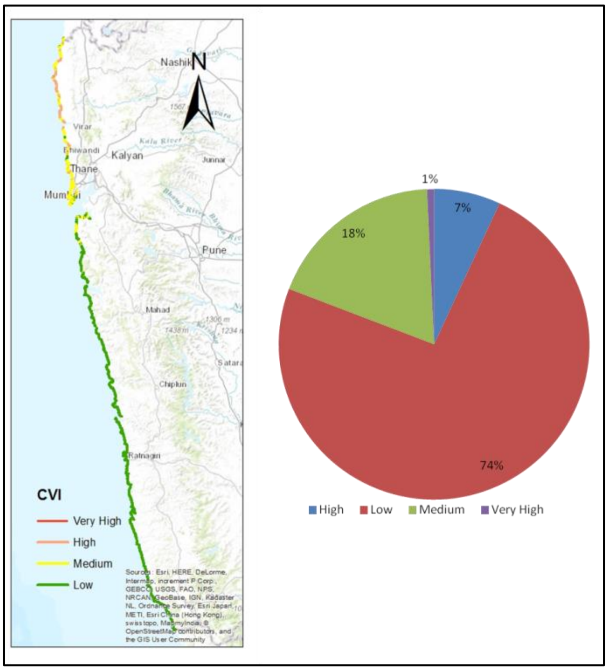

Figure.3. CVI map and the percentage of different vulnerable classes

6. DISCUSSIONS

The CVI presented in the study is similar to that used in Pendleton,Thieler and Jeffress (2005), Thieler (2000), and Thieler and Hammar- Klose (1999). This method is very effective in that it highlights coastal areas where the various effects of sea level rise may be the greatest. In addition to the six variables used by earlier researchers, the present study used two additional variables to represent the vulnerability more precisely, an additional geologic process variable coastal regional elevation and an additional variable population is used. The imperative for using these additional variables are discussed.

In the previous studies, coastal slope is used as one of the parameters for calculating the CVI, with low coastal slope representing high risk and vice versa. Such an assumption does not always hold. For instance, areas with low coastal slope falling in areas of high coastal regional elevation are not as vulnerable as similar areas falling in low coastal regional elevation. Such inconsistencies could be effectively addressed if coastal regional elevation is also considered as an additional parameter that represent the vertical level of the terrain. The reasons for environmental decline are complex, but population play a significant role. Today about 3 billion of the World population living in the coastline, live within 200 kilometres of the coastline. By 2025, that figure will be double. The high concentration of people in coastal region has produced economic benefits, including improved transportation links, urban development, revenue from tourism and food production. But the combining effects of booming population growth economic and technological development are threatening the ecosystems that provide the economic benefits. Unless the government and the users take action, population pressures and associated levels of economic activity, will further degrade the coastal habitats.

CONCLUSION

The present study proves the usefulness of remote sensing data, in situ observations, numerical modelling, and GIS analysis tools for coastal vulnerability studies. The coastal vulnerability maps generated using the techniques serves as a broad indicator of threats to people living in coastal zones. The methodology helps in characterizing the risk associated with coastal hazards and can be effectively used by the coastal managers and administrators for better future planning so as to mitigate the losses due to hazards as well as for prioritization of areas for evacuation during disasters.

7. ACKNOWLEDGEMENT

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