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Assessment of Coastal Vulnerability to combined effects of Socio-Economical Factors and Erosion on Karnataka Coast with the aid of Integrated Remote Sensing and GIS Techniques

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Abstract: *The coastal zones are highly resourceful and dynamic. Last decade has been witness to the increased frequency of tropical cyclones and the devastating tsunami. These changing times has brought importance of assessing the vulnerability of the coast to natural hazards. Present study intends to develop Coastal Vulnerability Index (CVI) for the administrative units, known as talukas of Karnataka State. Four variables characterising the vulnerability of the coast were considered, which includes rate of shoreline change, low-lying area, population and road network. Data was assimilated using the techniques of remote sensing and GIS. A total of 298 km of shoreline was assessed in accordance with the talukas in the study. It was observed that 63 km of the shoreline of the study area is under very high vulnerable category and 77 km of shoreline is high vulnerable category while 100 km and 58 km of coast are of moderate and low vulnerable categories respectively.*

Keywords: *Coastal Vulnerability Index, Low-lying areas, GIS, DSAS, Erosion, Socio-economic variable*

1. Introduction

The large rise in the population and recent developmental activities has imparted pressures on coastal areas. In addition, change in global climate has increased the threat of accelerated sea-level rise, frequency of storm surges, severe waves, and tsunamis. IPCC [10] has estimated that 7 million people would be displaced from their homes in India for a rise of 1 m in sea-level. The direct impact of the sea-level rise on the coastal zones would be accelerated erosion and shoreline retreat [21]. Also, indirectly it might affect coastal groundwater aquifers with salt water intrusion, wetlands and estuaries with flooding and may threat coastal infrastructure [24]. Coast is not only threatened by the aggravated sea-level rise, but also by increased episodes of the storm surges and coastal flooding and tsunami. In this regard, quantifying the vulnerability of coastal sectors to the impact of the natural hazard is an important aspect of coastal zone management since measuring vulnerability is a key step towards effective risk reduction [3].

Vulnerability assessment is a complex process involving multiple dimensions of vulnerability, including physical geological as well as socio-economical factors. Vulnerability of a coast is better determined if one has information on the physical and ecological coastal features, human occupation, population, and past and present shoreline trends [11]. Several coastal vulnerability assessment methods were developed such as inundation maps, common methodology [10], computer aided models etc., for coastal management. Coastal Vulnerability Index (CVI) developed by Thieler and Hammar-Klose [33] is one of the universally accepted indices for calculating the vulnerability due to coastal erosion and sea-level rise.

The majority of the earlier studies derived CVI for different coastal environments on using basic information on coastal geomorphology, rate of sea level rise, past shoreline evolution, coastal slope, mean tidal range, and mean wave height. And acknowledged that inclusion of demographic and economic variables may result in a useful and more comprehensive index [14]. Subsequent studies have included socio economic variables in their assessments [11, 14, 18]. The studies have also suggested that vulnerability assessment is to be carried out at regional scale since the important local variations in vulnerability are shrouded by simplifications at the national scale [19].

Researchers adopted techniques of remote sensing and Geographic Information System (GIS) to assemble, assess and display data about various vulnerability variables and to calculate CVI [24, 9, 13]. The advantage of repetitive coverage and synoptic view of the ‘Area of interest’ from various earth observation satellites have assisted in generation of databases on various aspects of the coastal and marine environment [22].

Indian subcontinent has a coastline of 5,400 km and around 250 million people live within 50 km of thecoastline of India [9]. In spite of the various policies and regulatory frameworks, India's coastal and marine ecosystems are under threat due to multiple stresses [30]. December 2004 tsunami has

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brought the importance for scientific study of the natural hazards and coastal processes of the Indian coast [13]. Vulnerabilities associated with the various coastal states of India are being studied in recent times using afore mentioned approaches [9, 6, 11, 21, 29, 18, 13, 12, 14].

Coast of Karnataka has a length of 298 km and a population of 4.3 million (National Institute of Disaster Management, India). The coast is under direct threat originating from Arabian Sea. The high density of population along the coastline of Karnataka has made the population highly vulnerable to the natural hazards. Also, important infrastructure such as rail and road networks close to coast are constantly threatened due to the erosion caused by giant sea waves especially in times of storm surges and cyclones.

From the survey of literature it was noticed that previously only Hegde and Reju[8] and Dwarakish et al., [6] had assessed the vulnerability for the smaller parts of southern Karnataka coast considering mostly the physical variables. Appelquist and Balstrøm[15] had developed the concept of Coastal Hazard Wheel (CHW) framework excluding socio economic variables. Except for Hegde and Reju [9], where in population was considered in assessment, studies lack socio-economical variables for the vulnerability assessment. Present study attempts to assess vulnerability of coastal Karnataka with the aid of geospatial techniques for erosion and socio economic variables: population and road network.

2. Study Area

The Karnataka coast extends between Longitude 74°5'22.09" E and 74°51'53.75" E and Latitude 14°53'36.53" N and 12°45'02" N. The length of coast is about 298 km. The coastal stretch is a part of 3 districts of Karnataka state, namely, Udupi, Dakshina Kannada and Uttara Kannada. The coast is bound between Western Ghats on the east and the Arabian Sea on the west. Areas near the river mouths along the study area suffer permanent erosion due to natural shifting and migration of the river mouths [28]. The tides are of mixed semidiurnal type and its range increases towards the north of the state [25]. Significant wave height, during the monsoon has been assessed to be greater than 3 m [26] and is normally less than 1.5 m during the rest of the year. Deep-water waves approach the coast from south-western and north-western directions [26].

The northern part of the study area is geologically composed of Precambrian crystalline gneiss, schist and granite rocks, fronted by a narrow coastal plain of alluvial or Tertiary deposits. In locations where the rock extends to the coastline, coastal cliffs and rocky shores are formed. The coastline has drowned river valleys, estuaries and many small inlets, which is a typical submergence characteristic [22]. The southern part of study area has extensive straight beaches and estuaries with low estuarine islands and mangroves.

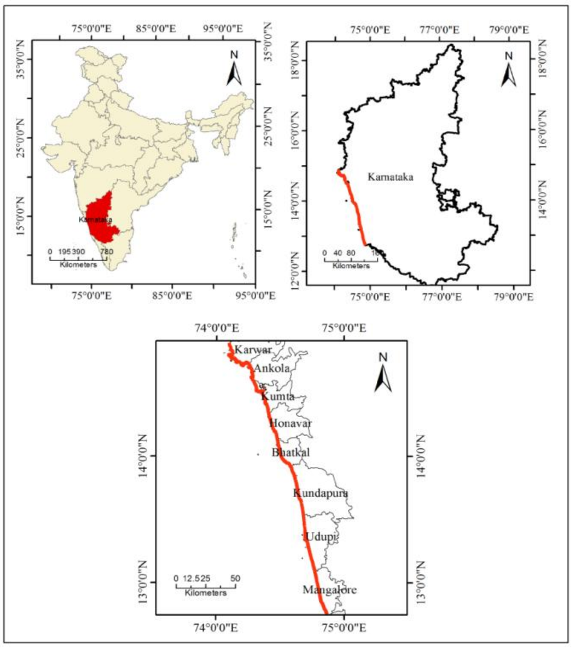

Figure 1: *Study Area*

3. Methodology

Present study focuses on the vulnerability of the Karnataka coast to four factors: Shoreline change (erosion or accretion), low-lying coastal areas, road networks and population. Since the coastal processes and the activities along the coast are very dynamic, a grid template of 1.5 × 1.5 km was prepared using ArcGIS 9.3 package to represent them. It was assumed that the processes remained constant with in this bound region.

3.1. Shore line change rate

Shoreline is in continuous transformation due to coastal processes in control of beach morphodynamics. The shoreline change rate is one of the most common measurements used to indicate the dynamics and the hazards of the coast [27]. Determining the shore line change rate requires details of shoreline positions over a period of time. Satellite imagery and maps of are very useful data sources to reconstruct coastline change [5] in temporal and spatial scales.

Shoreline of the study area for the years 1972, 1991, 1998, 2000, 2006, 2012 and 2014 were extracted from ortho-rectified satellite images of Landsat MSS, ETM+ and OLI-TIRS sensors. Near infrared band data was spliced to create a binary data image with a clear separation between land and water classes. These binary images were processed using ERDAS Imagine 9.2 and ArcMap 9.3 to obtain shorelines of the study area in vector data format. Table 1 details the image accusation date, resolution, sensor and data type of satellite data used in the present study.

***Table 1:** List of satellite imagery acquisition date, sensor and resolution*

Acquisition date	Resolution	Sensor	Data Type
04-01-1972	60	MSS	Geotiff
03-01-1991	60	TM	Geotiff
17-03-1998	60	TM	Geotiff
08-01-2000	30	ETM+	Geotiff
11-02-2006	30	ETM+	Geotiff
15-03-2012	30	ETM+	Geotiff
13-03-2014	30	OLI-TIRS	Geotiff

The shorelines in the vector data format were used as the input to the Digital Shoreline Analysis System (DSAS), which uses GIS to compute rate-of change statistics for multiple historic shoreline positions [33]. Linear Regression Rate (LRR) method of shoreline change rate estimation provided by DSAS was used in present study. LRR is a well established method for computing long-term rates of shoreline change [4] as it uses all available cross over points to find overall rate of change. Transects at 100 m were cast perpendicular to the baseline. The rate of shoreline change for a grid cell is average rate of all transects present in that particular cell. From the coastal vulnerability point of view, coasts subjected to accretion are considered as less vulnerable areas as they move towards the ocean and result in the addition of land areas, whereas areas of coastal erosion are considered to be more vulnerable because of the resultant loss of individual and public property as well as important natural habitats. It also reduces distance between coastal population and ocean, thereby increasing the risk of exposure of population to coastal hazards.

3.2. Elevation

Extent of habitual land under threat due to future sea-level rise can be identified and estimated by detail analysis of the coastal regional elevation. Coastal elevation data is also important for determining sea level rise impacts to the human built environment [1]. Few of the earlier studies have used coastal slope instead of regional elevation [21, 9, 29, 18]. Present study has considered the amount of low-lying areas as the variable rather than regional elevation. The areas with elevation below 5 m from mean sea level were considered as the low lying area. These are subjected to flooding in an event storm surge and inundation in case of sea-level rise. From the coastal vulnerability point of view, coastal regions having higher amount of low-lying area will be considered as highly vulnerable while lesser amount of low-lying area considered as less vulnerable.

3.3. Road Networks

Accessibility for a stretch of coast is primary factor in designing a mitigation strategy. But, the road networks providing the accessibility, is a vulnerable factor because cost of protection, replacement or relocating them are very high [20]. So, increase in total length of road in each cell increases the vulnerability of the cell. In the present study, the total length of road in each cell is considered to be road density in that cell. Road density in each grid cell was estimated using the open source data of OpenStreetMap (OSM) database for the year 2014, Landsat satellite image and Google earth of 2014. Road density in the study is the quantity of road in km within each grid.

3.4. Population

Population has been usually considered to be a negative impact [20]. But, it has also been argued that it reduces vulnerability as people tend to have coastal protection structures for protecting their properties against inbound coastal hazards. In the present study, presence of human population is considered to increase the vulnerability of the study region. Worldpop project provides high resolution, contemporary data on human population distributions for south East Asian countries in raster data format. These data sets have been prepared using the fully documented, transparent and peer-reviewed methods outlined by Gaughan et al., [7], Linard et al., [16], Linard et al., [17] and Tatem et al., [31] to produce easily upgradable maps with open access and operational application.

3.5. Coastal Vulnerability Index

The procedure adopted in present study to calculate CVI is similar to that of Thieler and Hammer-Klose [24]; Parthasarathy and Natesan [2]. The methodology yields a classification of coast based on numerical data that cannot be equated directly with particular physical effects but identifies the most affected regions. Initially a database of the variables under consideration for the study area was built by compiling data from various sources. Each of the variables is assigned with a score or rank varying from 1-5 where in 1 signifies lowest contribution to coastal vulnerability and 5 signifies the highest contribution. Table 2 shows risk classes of the parameter for calculating CVI. After the assignment of risk value for each variable, depending upon its contribution to vulnerability, the CVI is calculated as the square root of the product of the ranked variables divided by the total number of variables given by the equation

$$CVI = \sqrt{\frac{a*b*c*d}{n}} \qquad (1)$$

Where, a = risk rating assigned to shoreline-change rate, b = risk rating assigned to elevation, c = risk rating assigned to population density, d = risk rating assigned road density and n= number of variables

4. Results and Discussion

4.1 Shoreline change rate

Shoreline Change Rate (SCR) was calculated for 42 years using Linier Regression Method. Also net shoreline movement was calculated. Table 3 shows the details of the LRR and Net Shoreline Movement (NSM) for the talukas of the study area positive values indicate accretion while negative values indicate erosion. Average accretion for complete study area was found to be 1.133 m year^{-1} and average erosion was 0.533 m year^{-1}. It was observed that Karwar, Honnavar, Kundapur and Udupi talukas witnessed accretion while other talukas were under erosion. Maximum and minimum LRR of 2.90 m year^{-1} and -2.00 m year^{-1} was noticed in Karwar because of the geomorphological settings of the area. Coastline of Karwar is characterized by open beaches as well as the rocky head lands. The shoreline had advanced towards sea by about 17.93 m in Karwar taluk, highest in the study area, followed by Udupi with 16.51 m, Honnavar with 8.54 m and Kundapur with 6.13 m. Bhatkal, Mangaluru, Kumta and Ankola had witnessed a recession of the shoreline by 4.40 m, 3.01 m, 1.77 m and 1.40 m respectively.

4.2 Elevation

Figure 2 shows the low-lying areas along the study grids. Table 4 details the total quantity low lying areas in each of the talukas. It can be noticed that Mangaluru, Udupi and Honnavar talukas have higher amount of low lying areas in comparison with other talukas. The least quantity of low elevation areas were found in Ankola taluk. The geomorphology of Ankola is characterized by rocky headlands and outcrops very close to coast. Also it was notice that the grid cells enclosing he river mouths also showed lesser values. These were verified and corrected by visual interpretation of the satellite images.

4.3 Road networks

Total length of roads in each grid cell was calculated using the GIS. The largest density of 14.62 km was found at southern part of Mangaluru while lowest was 0.14 km in northern part of Udupi. Table 4 details the amount of road networks in study grids in accordance with talukas. Increase in density indicates that the particular stretch is more accessible to human population there by increasing the tourist potential as well as increasing the mitigation measures of the stretch. Figure 3 shows distribution of Road density along the study grids.

4.4 Population

Distribution of population along the grids is shown in Figure 4. Highest population count was found in the grid cell of southern Mangaluru with a count of 7853. Lowest was 0 or no population habitation at rocky headland of Kumta taluka. It was observed that southern grid cells were more populated than the northern grid cells except at north Karwar. Population count in grid cell was higher for the cell which were close to or part of urbanized areas.

Classification of each segment of coast in grid cell was carried out based on the Table 2 and CVI was calculated using the Equation (1). CVI values for study area range from 1.00 to 11.18. The mean CVI value is 3.85 while the mode and the median are 3.16 and 3.46 respectively. The standard deviation is 2.04. The 1st 2nd and 3rd quartiles are 2.23, 3.46 and 5 respectively. CVI values were divided into low, moderate, high, and very high-vulnerability categories based on the quartile ranges. CVI values below 2.23 were assigned to the low vulnerability category. Values from 2.34 to 3.35 were considered to be moderately vulnerable. Highly vulnerable values lie between 3.36 and 5. CVI values above 5 are classified as very high vulnerability. It was observed that 21% of coast was in very high vulnerable category and 26% was in high vulnerable category. Moderate and low vulnerability category coast were of 33.5% and 19.5% respectively. Table 5 details the statistical parameters of CVI for various talukas. Figure 5 shows the CVI for talukas of Karnataka.

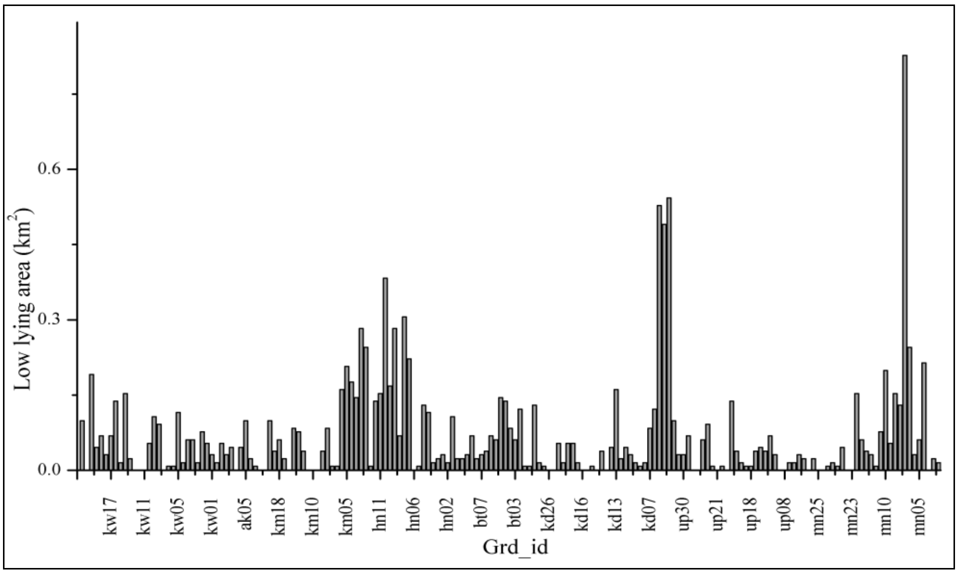

Figure 2: *Distribution of Low-lying areas along the grids*

Table 2: *Coastal Vulnerability Classes*

Parameter	Risk ranking				
	1	2	3	4	5
Shoreline change rate (m year^{-1})	≤ -0.399	-0.4 to -0.065	-0.066 to 0.067	0.068 to 0.537	> 0.538
Low lying areas (km^2)	≤ 0.007	0.008 to 0.022	0.023 to 0.030	0.031 to 0.110	>0.111
Road density(m)	>4793.094	3040.341 to 4793.093	2625.160 to 3040.341	1641.459 to 2625.159	≤ 1641.458
Population Density (person per grid)	≤ 33	34 to 52	53 to 65	66 to 284	>285

Table 3: *SCR statistics of talukas*

Taluka	No. of Transects	Net shoreline movement (m)	LRR(m year^{-1})		
			Min.	Max.	Average
Karwar	620	17.93	-2.00	2.90	0.44
Ankola	264	-1.40	-1.58	2.09	-0.02
Kumta	430	-1.77	-1.51	1.23	-0.08
Honnavar	272	8.53	-0.68	1.63	0.28
Bhatkal	319	-4.40	-1.71	0.70	-0.17
Kundapur	452	6.13	-0.62	0.90	0.13
Udupi	529	16.51	-0.68	1.06	0.20
Mangaluru	401	-3.01	-1.29	0.79	-0.26

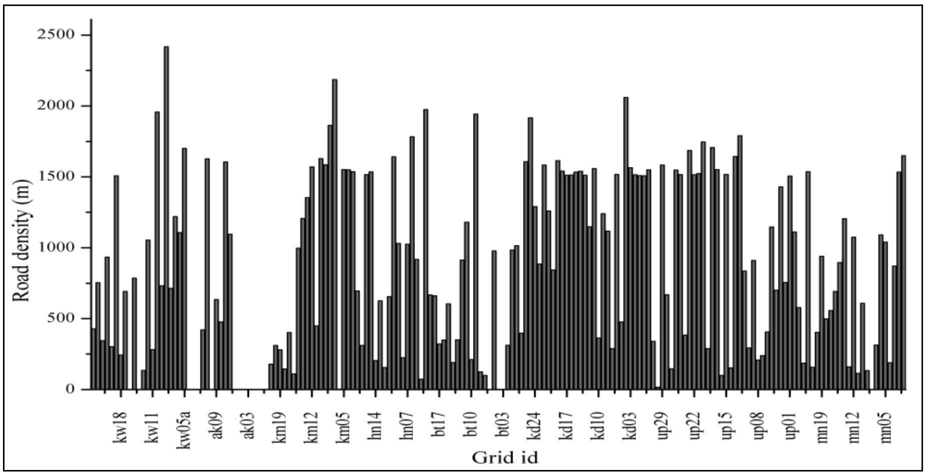

Figure 3: *Distribution of Road density along the grids*

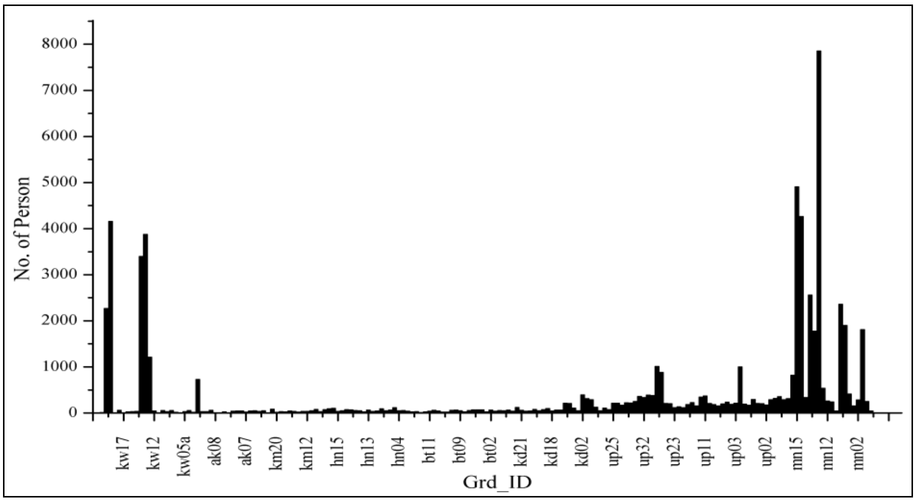

Figure 4: *Distribution of population along the grids*

Table 4: *Grid based variable quantities of talukas*

Taluka	Average Accretion rate (m year^{-1})	Average Erosion rate (m year^{-1})	Low lying area (km^2)	Road Network (km)	Population count (No of persons)
Karwar	1.072	0.302	1.400	76.249	16178
Ankola	0.308	0.419	0.451	4.324	287
Kumta	0.321	0.381	1.492	68.987	1124
Honnavar	1.532	0.283	2.418	40.975	785
Bhatkal	0.242	0.566	0.964	54.206	796
Kundapur	0.375	0.398	1.010	87.603	1626
Udupi	0.507	0.580	2.419	98.569	9437
Mangaluru	0.920	1.192	2.418	140.430	32822

5. Conclusions

Increase in the events of coastal hazards has highlighted the need of vulnerability assessments of coast to mitigate the threats involving these hazards. It is necessary to carry out a systematic vulnerability assessment to formulate suitable actions for protecting people and property. Present study evaluated the vulnerability of Karnataka coast to two physical and two socio-economical variables. The transformation of the Karnataka coastline for a period of 42 years was observed using Landsat satellite images. Average accretion for the study area was found to be 1.133 m year^{-1} and average erosion was about 0.533 m year^{-1}. Low-lying area which could be inundated were mapped and estimated by employing the remote sensing techniques. Aspects of socio-economical importance were also evaluated in the present study in the form of two variables road network and population.

Table 5: *Statistical parameters of CVI for talukas*

	Karwar	Ankola	Kumta	Honnavar	Bhatkal	Kundapur	Udupi	Mangaluru
Mean	3.714	3.539	3.103	3.966	3.874	3.928	4.727	3.535
Median	3.313	3.873	2.828	3.464	3.162	3.313	4.472	2.739
Mode	3.873	4.472	2.000	3.873	1.732	2.828	4.472	2.236
Max.	10.000	5.000	6.325	9.682	10.000	8.944	8.660	12.500
Min.	0.707	1.581	1.225	1.225	0.707	1.414	1.000	1.118
Std. Dev	2.143	1.215	1.358	2.223	2.865	1.754	1.952	2.267

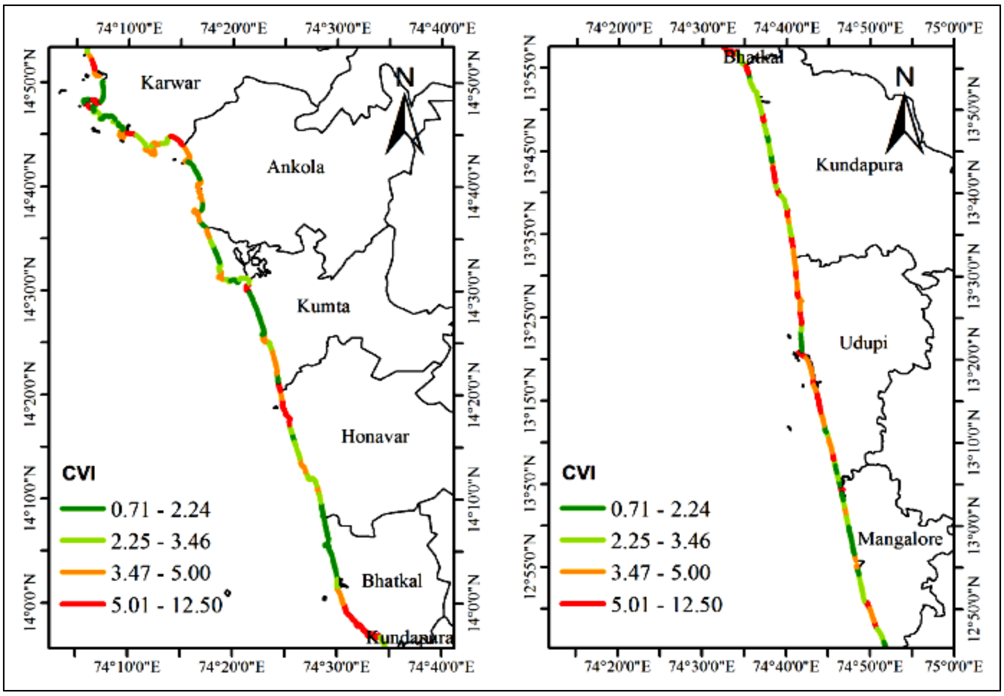

Figure 5: *CVI for talukas of Karnataka*

It was observed that 62.58 km of the shoreline of the study area was under very high vulnerable category and 77.48 km of shoreline is high vulnerable category while 99.83 km and 58.11 km of coast are of moderate and low vulnerable categories respectively.

The CVI developed in the present work provides an understanding about the vulnerability of the Karnataka coast to erosion, coastal flooding Study has summarised the vulnerabilities of fore mention variables based on the administrative units so as to facilitate prioritizing and policy framing support to authorities of affected coastal areas. More comprehensive study of coast can be carried out by including other physical, geological and socio-economical variables.

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