Coastal Vulnerability Assessment along Kerala Coast using Remote Sensing and GIS

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Abstract— **Coastal vulnerability assessment is done mostly on the basis of vulnerability indices which has been developed as a rapid and consistent method for characterizing the relative vulnerability of different coasts. The main objective of this study is to present an Analytic Hierarchy Process (AHP) based Coastal Vulnerability Index (CVI) taking both Physical Vulnerability Index (PVI) and Social Vulnerability Index (SVI) into consideration. The study also investigates the shoreline changes using multi temporal satellite images. Geographical Information System (GIS) and remote sensing based study helped in the preparation of coastal vulnerability map and thereby to assess the impact along the Kerala coast.**

Keywords—coastal vulnerability index; physical vulnerability index; social vulnerability index; Analytic Hierarchy Process

I. INTRODUCTION

Kerala is situated along the southwest coast of India and has long sea shore of 590 km that includes sandy beaches, mud banks, rocky cliffs, lagoons, estuaries and barrier islands. Kerala has the highest concentration of people living in the coastal belt. Thus the major issues related to the coastal erosion, degradation of coastal vegetation, coastal resource management and intense economic activities in Kerala warrants special attention.

One of the coastal problems to be considered in Kerala is mainly coastal erosion. About 80% of the entire coastline of Kerala is affected by long term coastal erosion and part of the coastline of Kerala is affected by erosion and accretion in monsoon months. Natural factors that cause erosion in Kerala are heavy rainfall, loose sandy sea shore, destruction of mud deposits in the sea, and heavy discharge of water devoid of alluvium.

The assessment of coastal vulnerability is done mostly on the basis of vulnerability indices. One of the most initial attempts to formulize a Coastal Vulnerability Index (CVI) particularly for sea-level rise was developed by Gornitz and Kanciruk (1989) for the United States. There are attempts to calculate CVI of various coasts by taking only physical parameters [2] [3]. However, a major inadequacy in case of most vulnerability assessments is that they focus only on the physical characteristics of vulnerability. In majority of these studies the CVI is expressed as the square root of the product of the ranking factors divided by the number of parameters considered. Analytic Hierarchy Process (AHP) based CVI assessment considering both Physical Vulnerability Index (PVI) and Social Vulnerability Index (SVI) had also been developed [7] [8].

The present study involves in the computation of CVI using AHP taking into account PVI and SVI .The study also demonstrates the use of multi resolution and multi temporal satellite images of Landsat and LISS III to demarcate shoreline positions for the years 1973, 1990, 2000 and 2008. The methodology was applied to coastal districts of Kerala state to prepare the vulnerability map and classify the vulnerable regions. The details pertaining to the methodology used, analysis of the problem and the results of the study are discussed in the subsequent sections.

II. METHODOLOGY

The detailed methodology adopted for the study is shown in Fig.1. The detailed aspects are described in the following steps.

A. Coastal Vulnerability Index

The computation coastal vulnerability index involves in the estimation of physical vulnerability index and social vulnerability index. The weights for PVI and SVI were then calculated using the AHP which is discussed subsequently. CVI was further computed using the calculated indices to understand the relative vulnerability of the study area.

The present study considered nine variables that can be classified into two groups: 1) physical variables and 2) social variables. The physical variables include tidal range, significant wave height, sea level rise, shoreline change rate, slope and elevation. The social variables include population density, land use and road network. These parameters were derived from GIS analysis, remote sensing data and field data pertaining to the study area under consideration. The schematic diagram showing the methodology used in the study is shown in Fig.1 with the coastal vulnerability subdivided into two components namely physical

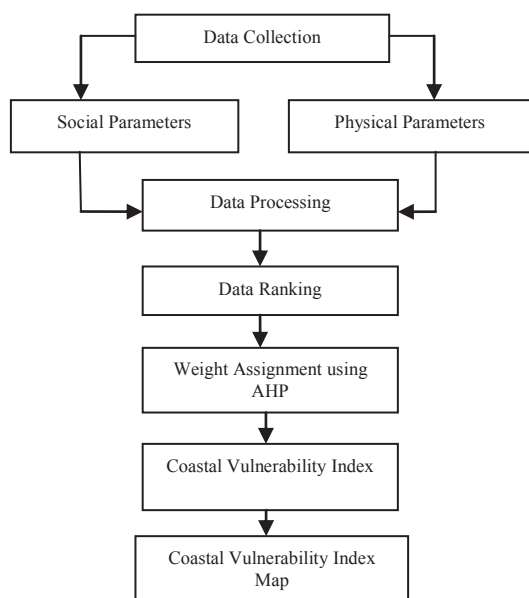vulnerability and social vulnerability along with the associated variables used for their computation.

Fig.1.Flowchart of methodology adopted for CVI

B. Data Ranking

The values of variable were assigned a vulnerability ranking based on value ranges from vulnerability point of view. Each variable was ranked from 1 to 4 representing very low, low, high and very high respectively. In other words, a value of 1 represents the lowest risk and 4 represent the highest risk. The database includes both quantitative and qualitative information. Thus, numerical variables are assigned a risk ranking based on data value ranges, while the non-numerical landuse variable is ranked according to the relative resistance of a given landform to vulnerability.

C. Weight assigning using analytic hierarchy process (AHP)

Analytic Hierarchy Process (AHP) developed by Saaty (1977) is a widely used multi-criteria decision making method aiming to derive relative priorities in multi -level hierarchic structures and to assign weights to these elements quantitatively. In the first step, pair-wise comparisons were carried out for all factors to be considered, and the matrix was completed by using scores based on their relative importance. The normalized matrix was formed by dividing each of the columns by the corresponding sum. As the last step, the average values of each row were computed and these were used as weights in the objective hierarchy for calculating the SVI and PVI. Having a comparison matrix a priority vector was computed which is the normalized eigen vector of the matrix. The consistency property of matrices was also checked to ensure that the weights given were consistent. For this, Consistency Index (CI) and Consistency Ratio (CR) given by Saaty (1977) are calculated as in (1) and (2):

$$CI = (\lambda_{max} - n)/(n-1) \tag{1}$$

$$CR = CI/RI \tag{2}$$

Where λ_{max} is largest or principal value of the matrix, n is the order of the matrix and RI is the Random Index.

RI is defined as the average of the resulting consistency index that depends on the order of the matrix given by Saaty. The values for RI for different order of the matrix are given in Table 1.

TABLE 1: RI VALUES FOR DIFFERENT ORDER OF THE MATRIX

N	2	3	4	5	6	7	8
RI	0	0.52	0.59	1.12	1.24	1.32	1.41

D. Coastal vulnerability assessment

Coastal Vulnerability Index was calculated using following procedure [4]. The weights derived using AHP were used for calculating the PVI and SVI using (3) and (4).

$$SVI = w_1X_1 + w_2X_2 + w_3X_3 \tag{3}$$

$$PVI = w_1X_1 + w_2X_2 + w_3X_3 + w_4X_4 + w_5X_5 + w_6X_6 \tag{4}$$

Where W_i is the weight value of ith (i=1,2….) social or physical variables, and X_i is the vulnerability score of ith variable.

Coastal Vulnerability Index was calculated as the average of SVI and PV using (5).

$$CVI = (SVI + PVI)/2 \tag{5}$$

The above equation had been used considering that both physical and social variables have equal contribution in coastal vulnerability. The values of each index for coastal zones were obtained by multiplying the vulnerability rank values by the corresponding weightage factors of the respective variables. These were processed in the ArcGIS environment. CVI values for the different segments of the coastline were further classified into low (lesser than 25th percentile), medium (between 25th–50th percentile) and high vulnerable (greater than 50th percentile) classes.

III. ANALYSIS OF THE PROBLEM

The methodology discussed in the above section was applied to calculate CVI along Kerala coast.

A. Study area

Kerala has a long coastal line of 590 km with nine coastal districts. These districts can be divided into south zone, central zone and north zone based on the availability of data. The South zone includes the southern districts of Thiruvananthapuram, Kollam, and Alappuzha with a length

of about 197 km. The Central zone consists of the districts namely Ernakulam,Thrissur and Malappuram with a length of 170 km. The districts like Kozhikode, Kannur and Kasargod form the North zone with a length of 223 km.

The study area selected is the enclosed are with 2 km buffer from the shoreline position for the three zones. The study area is shown in Fig.2.
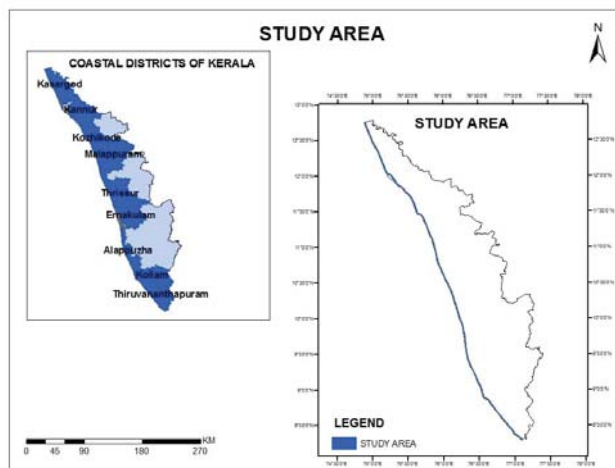

Figure 2: Study Area

B. Data used

The data used in the study include (i) satellite data for deriving the landuse, shoreline change (ii) recorded data of waves and tides (iii) estimated data of sea level rise, population intensity from population census data, slope and elevation derived from DEM of area, road network from the Google Earth images. The sources of data for different social and physical parameters are given in Table 2.

C. Computation of physical and social parameters

The physical and social factors together include nine variables. The study area selected for the assessment of coastal vulnerability is a 2 km buffer area from the shoreline

Population density for the panchayats in the 2 km study area was calculated using the population data of 2011. The population density values were obtained by dividing population of the coastal panchayats by the area of the panchayats. A population density map was prepared in the Arc-GIS environment where the individual polygons represent the various coastal panchayats. Landuse map was prepared from Landsat image of 2014 using supervised classification technique in ERDAS Imagine software. The following classes of land use were examined namely built-up, water body, wetlands or barren land, and agriculture. The classification of the road network had been done by making buffers of 250m, 500m, 1 km and 2 km shoreline created from Google Earth.

Shuttle Radar Topography Mission (SRTM) Digital Elevation Model had been used to generate the coastal slope and elevation. In order to determine the actual coastline position, images were classified using unsupervised technique and two classes (land, water) had been taken to demarcate the land water interface. The pixels representing the shoreline had been converted into vector layer to get the actual coastline [1].The vectorized shorelines for the years 1973,1990,2000 and 2008 were used to calculate the shoreline change rate using DSAS tool of Arc-GIS. The offshore transects were laid at an interval of every 1 km along the coastline. The DSAS tool calculated change statistics using EPR method which are useful in understanding the shoreline trends from a temporal perspective. End-point rate calculations are simply the rates determined based on the changes in position between oldest and most recent shorelines in a given dataset.

TABLE 2. DETAILS OF DATA AND SOURCES

Data	Data Summary	Source
Population Density	Census Data,2011	Economics and Statistics Department
Landuse Map	LANDSAT Image	USGS Site [http://earthexplorer.usgs.gov]
Road Network	Road	Google Earth
Slope	SRTM DEM	USGS Site [http://earthexplorer.usgs.gov]
Elevation	SRTM Data	USGS Site [http://earthexplorer.usgs.gov]
Sea Level Rise	Tide Guage Data	Global Sea Level Observing System(GLOSS)
Shoreline Change Rate	Satellite Images, Digital Shoreline Analysis System	USGS Site [http://earthexplorer.usgs.gov]
Tidal Range	Tide Tables	Harbour Engineering Department,Govt. of Kerala

The tide gauge data set of GLOSS was used as the primary source of information for sea level trend in the study area. Tide gauge data recorded in Cochin station during the period from 1950 to 2007 was used for the present study. The sea level rise for Cochin station was assumed to be same for all three zones. Significant wave heights were reproduced from reports[1][4][5].Tidal range values were obtained from the tide tables.

D. Data ranking

In case of social factor like , high population density was given high ranking. Built up class was considered as highly vulnerable in the case of landuse. It was considered that the proximity of a particular section of the road to the shoreline makes it more vulnerable.

A gently sloping coast where any rise in sea level would inundate large extents of land qualify for higher ranking. coastal regions having high elevation were considered as less vulnerable areas because they provide more resistance for inundation against the rising sea level, tsunami run-up, and storm surge. From the vulnerability point of view, high tidal range, high significant wave height value were given

more priority. In the case of shoreline change rate, erosion values were given higher ranking .The respective values and ranking assigned for each of the parameters belonging to social variables are described in Table 3. The classification for all social and physical factors for three zones was same. Table 4 shows the vulnerability ranking criteria for physical variables.

TABLE 3. VULNERABILITY RANKING CRITERIA FOR SOCIAL VARIABLES

Parameters	Coastal Vulnerability Ranking			
	Very low(1)	*Low (2)*	*High (3)*	*Very high (4)*
Population Density (pop/sq.km)	1000-1500	1500-2000	2000-2500	>2500
Landuse	Barren land/Wetland	Waterbody	Agriculture	Builtup
Road Network	2000 m	1000m	500m	250m

TABLE 4. VULNERABILITY RANKING CRITERIA FOR PHYSICAL VARIABLES

Parameters	Coastal Vulnerability Ranking			
	Very low(1)	*Low (2)*	*High (3)*	*Very high (4)*
Tidal Range(m)	0- 0.25	0.25-0.5	0.5-1	>1
Significant wave height(m)	<1	1-2	2-3	>3
Sea level rise(mm)	0-20	20-40	40-60	>60
Shoreline change rate(m/year)	> 5	0-5	-10 - 0	< -10
Elevation(m)	>15	10-15	5-10	< 5
Slope(degrees)	>18	12-18	6-12	0-6

E. Analytic Hierarchy Process

Computation of the weight value followed AHP using pairwise comparisons. In the construction of a pair-wise comparison matrix, each factor was rated against every other factor by assigning a relative dominant value between 1 and 9 to the cell concerned. The weight values were computed for social and physical variables separately giving importance to population density, slope and elevation. Consistency property of matrices was checked to ensure that the weights given were consistent. Generally, CR of the value of 0.10 or less is considered relevant. The weight values obtained are shown in the Table 5.

F. Coastal Vulnerability Index

SVI, PVI values were obtained by multiplying the vulnerability rank values by the corresponding weightage factors of respective variables.CVI value was calculated as per equation (5) considering that both physical and social factors have equal contribution in coastal vulnerability.

TABLE 5. WEIGHTS OBTAINED FROM AHP PROCESS

Social and Physical Parameters	Weight values
Population Density	0.75
Landuse	0.19
Road Network	0.06
Slope	0.46
Elevation	0.24
Shoreline Change Rate	0.14
Sea Level Rise	0.08
Significant Wave Height	0.05
Tidal Range	0.03

IV. RESULTS AND DISCUSSION

Shoreline change detection was made by analyzing multi temporal satellite images. Social vulnerability Index, Physical Vulnerability Index and Coastal Vulnerability values were calculated and respective maps were prepared.

A. Shoreline mapping

Shoreline in the study area was never been constant and shows a continuous changing pattern. Shoreline change rate assessment revealed that the some sections of the beach in

each of the zones are subjected to erosion, while some other stretches are subjected to accretion. Shoreline change rate values for three zones are tabulated in Table 6. A negative sign signifies landward movement or erosion and positive sign signifies seaward movement or accretion.

From the table, it can be seen that the range of values of shoreline rate is -21.7 to 10.22 m/year with a mean rate of -8.03 m/year for South zone.   Poovar to Kovalam regions of Thiruvananthapuram district, parts of Kollam port are regions of higher erosion. High accretion is seen in places near Azheekal fishing harbour.

TABLE 6. SHORELINE CHANGE RATE VALUES FOR EACH ZONE

Zone	Shoreline change rate values(m/year)
South zone	-21.7 – 10.22
Central zone	-18.13 – 4.99
North zone	-18.16 – 8.43

In the case of central zone, rate of shoreline change is in the range -11.13 to 4.99 m/year with a mean value of -2.19 m/year. In this zone high erosion is seen near Fort Kochi and Vypin area, while high accretion zones are seen at Ponnani and Vakkad regions. Similarly the rate of shoreline change in the north zone ranges from -18.16 to 8.43 m/year with a mean rate value of -2.87 m/year. The high rate of erosion is seen at Azheekal beach areas and high rate of accretion is seen from Muzhappilangadi beach regions to Dharmadam regions.

B.   Erosion and Accretion Statistics

The shoreline change was analyzed for the year 2008 keeping the year 1973 as the basis. The erosion is dominant in all coastal districts of Kerala with maximum at Thiruvananthapuram district and minimum at Thrissur district. The maximum values of accretion occur at Kozhikode and minimum accretion at Kollam. Also the erosion and accretion statistics   with percentages of erosion, accretion and stable coast for the Kerala coast is shown in Fig.3.
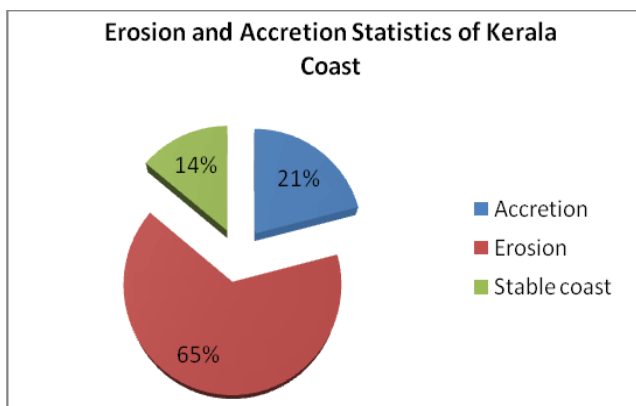

Fig.3. Erosion and Accretion Statistics of Kerala Coast

C.   Social Vulnerability Index

The SVI value of the three zones in the study area were computed on the basis of population density, landuse and road network pertaining to the zone were made use of to calculate the social vulnerability index. The SVI values for the three zones are given in Table 7. It can be observed that higher SVI values are associated with those areas having higher population density and landuse belonging to builtup and agriculture category.

D.   Physical Vulnerability Index

The physical vulnerability index were computed for the South, Central   and North zones on the basis of coastal erosion, coastal processes and terrain conditions. The range of values of PVI zone wise is given in Table 7.

TABLE 7. SVI AND PVI VALUES FOR THREE ZONES

Zone	SVI Values	PVI Values
South zone	1 - 4	1.57 - 3.56
Central zone	1.12 - 4	1.6 - 3.83
North zone	1 - 4	1.61 – 3.89

E.   Coastal Vulnerability Index

Combining the PVI and SVI values of the respective zones, CVI value of the zones were derived. The CVI for the South zone is in the range 1.57 to 3.66, Central zone in the range 1.95 to 3.85 and North zone in the range 1.51 to 3.84. The CVI maps prepared for South, Central and North zones are given in Fig. 4 to 6 respectively

The coastal stretches of Kerala classified as low, medium, and high risk based on their vulnerability values. CVI values for the different segments of the coastline were classified as low (lesser than 25th percentile), medium (between 25th–50th percentile) and high vulnerable (greater then 50th percentile) classes.

The 25th and 50th percentiles CVI value of South zone are 2.85 and 3.12 respectively. Accordingly, about 120 km length under high vulnerable, 27 km under medium vulnerable and 50 km is of low vulnerable. Coastal vulnerability is high at Poovar, Punathura, Poonthura to Veli, Kadinamkulam, Kollam   to Chavara regions and Punnapura. The medium vulnerable regions   are Ambalapuzha, Kovalam and   low vulnerable regions are Azheekal , Arattupuzha and Cherthala.

The 25th and 50th percentiles CVI value of Central zone are 3.13 and 3.38 respectively. The highly vulnerable areas in Central zone include Fort Kochi to Vypin, Cochin Harbour to Azhikode, Chavakkad and Ponnani. The regions of medium vulnerability are Parappanangadi,Vakkad and places such as Tirur, Chellanam, Cherai are less vulnerable. Out of the 170 km, about 72 km falls under high

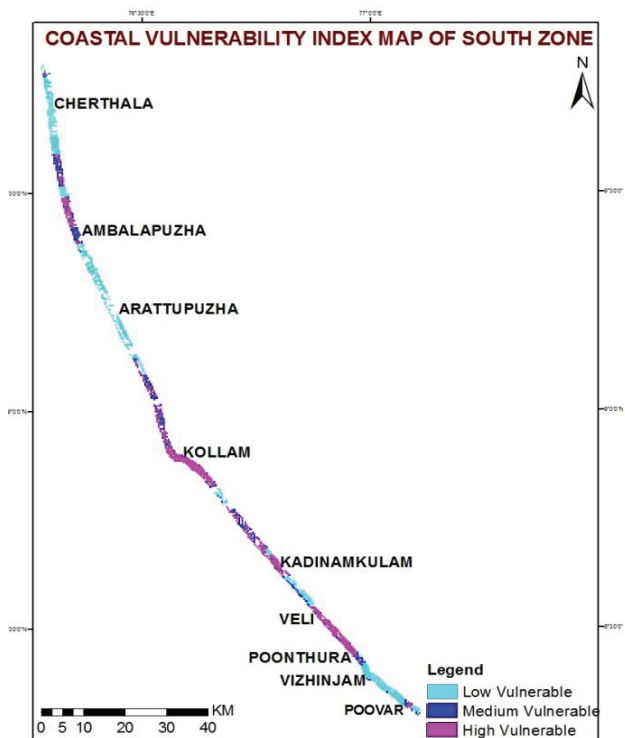vulnerable, 55km under medium vulnerable and 43 under low vulnerable category.

The 25th and 50th percentiles CVI value of North zone are 2.97 and 3.18 respectively. Accordingly, out of the 220 km of North zone about 116 km falls under high vulnerable, 41 km falls under medium vulnerable and 63 km under low vulnerable. The highly vulnerable areas in the zone include Kasargod Harbour, Azhikal to Mappila fishing harbor, Kizhunn to Dharmadam, Kozhikode beach to Kuttichira and Beypore. The medium vulnerable regions are Payyoli and Bekal. The places like Manjeshwar and Payyanur comes under low vulnerable category.
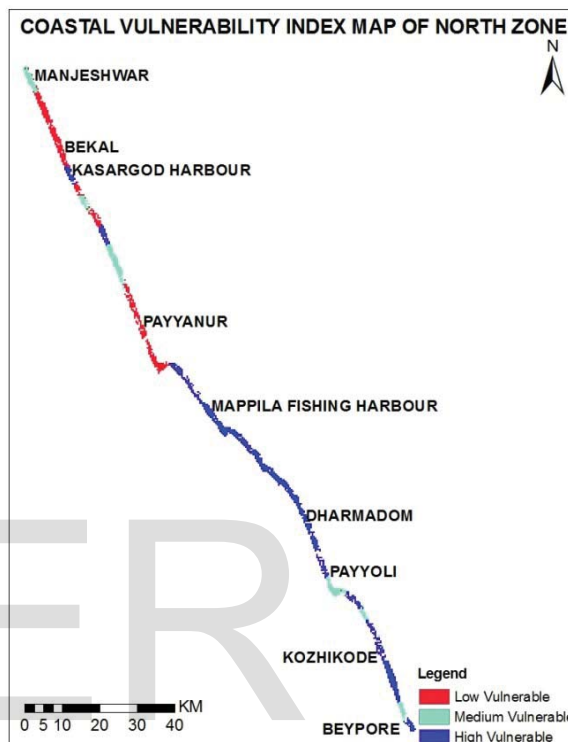

Fig.4. Coastal Vulnerability Index Map of South Zone

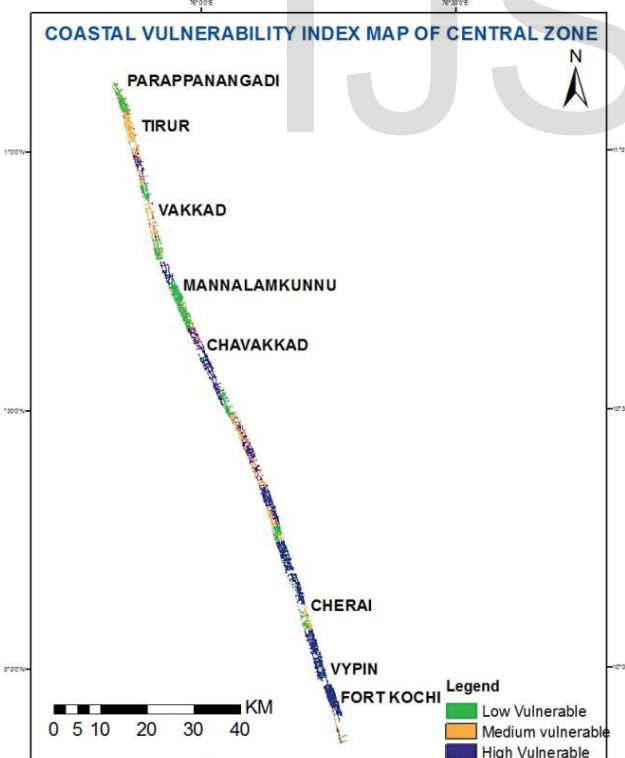Fig.6. Coastal Vulnerability Index Map of North Zone

Fig.5. Coastal Vulnerability Index Map of Central Zone

V. CONCLUSIONS

The present study advocates an Analytic Hierarchy Process (AHP) based approach to coastal vulnerability studies incorporating Physical Vulnerability Index (PVI) and Social Vulnerability Index (SVI). The study also analyze the changes in shoreline positions on temporal and spatial scales and investigates the coastal erosion and deposition along Kerala coast covering a period of three decades. The specific conclusions of the study are as follows:

- The analysis of shoreline changes indicates regions of erosion and accretion along coastline.
- It is seen that about 65% of the Kerala coastline is eroding, 21% comes under accretion and about 14% falls under stable coast.
- Higher Social Vulnerability Index values are associated with those areas having higher

population density and landuse belonging to builtup and agriculture category. Physical Vulnerability Index value is higher in the regions of gentle slope and lower elevation.

- This study revealed that 52% of the Kerala coastline is in the high vulnerable category, 21% in the medium vulnerable category and 27% in the low vulnerable category.

- Coastal vulnerability is high at Poovar, Punathura, Poonthura to Veli, Kadinamkulam, Kollam to Chavara regions and Punnapura in South zone.

- The highly vulnerable areas in Central zone include Fort Kochi to Vypin, Cochin Harbour to Azhikode, Chavakkad and Ponnani.

- The highly vulnerable areas in North zone include Kasargod Harbour, Azhikal to Mappila fishing harbor, Kizhunn to Dharmadam, Kozhikode beach to Kuttichira and Beypore.

From the study it is seen that the major stretch of Kerala's coastline comes under eroding category area. The sensitivity of a coastal region to coastal hazards can be effectively assessed by using the CVI index. Vulnerability maps prepared can be used as a valuable tool for managing and protecting the resources along the coast.

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