

# Coastal Vulnerability Assessment of Kochi City, Using the Analytical Hierarchical Process

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**Abstract**— The world's average sea level rise occurred in the 20th century, and is at a continuous rise more specifically due to global warming. This leads to a variety of impacts, including increased floods risks, salt damage to surface and groundwater, and morphological changes such as wetland erosion and habitat loss. Potential human and ecosystem impacts in the 21st century is important to be addressed, but uncertain. Similarly, the increasing sea level proposes an emerging problem in the coastal regions of Kochi city. By 2040, Kochi will likely see a sea level rise of 0.6m compared to 0.15m in 2020. So, the study assesses the level of vulnerability in the Kochi city using AHP method considering both the physical vulnerability and the social vulnerability.

**Keywords:** AHP (Analytical Hierarchical Process) Method

## I. INTRODUCTION

Coastal cities around the world are of high vulnerability. The issues are more evident in developing countries due to the impact of rapid urbanization rates. Sea level rise would result in coastal flooding issues which causes contamination of drinking water with sea water and increased impact of storms, increases the risk of coastal erosion. Climate change is expected to continue over the next century in spite of the international effort to reduce greenhouse gas emissions, which are considered to be the main causes of climate change [1]. This change is expected to exacerbate the already existing environmental problems in many areas. In particular, coastal areas all over the world are expected to suffer from the impacts of Sea Level Rise (SLR), such as: intense floods, coastal erosion, subsidence, salt-water intrusion and deterioration of ecosystems [2].

South Asia is anticipated to experience a good range of effects due to global warming. In India various events will occur concurrently with existing development challenges. Inundation, flood and storm damage associated with severe surges, erosion, saltwater intrusion, and wetland loss will affect the coastline in India in a variety of ways. There are major existing and proposed economic and infra-structure developments including ports, power plants, highways, airports, which are being planned very close to the shoreline along India's coast [3].

The World Bank in a 2010 reported that sea level rise will impact thirteen of the world's largest cities along the coast and more than a third of the world's people is reported to live near shoreline. Low-lying coastal areas represent two percent of the world's land area, but contain 13 percent of the urban population [4].

The developing countries seem to be in more danger than the developed countries. A recent study of 136 port cities showed that much of the increase in exposure of population and assets to coastal flooding is likely to be in cities in

developing countries, especially in East and South Asia [5]. Due to its high economic value on the national and local scale, coastal areas are developed and inhabited in spite of impending sea-level rise and coastal flooding. Coastal planning and development must be integrated to mitigate sea level rise due to climate change.

## II. RESEARCH AIM AND OBJECTIVES

The aim is to assess the coastal vulnerability of Kochi city considering both the physical vulnerability variables and the social vulnerability variables.

- To study the tools for assessment which is used to determine the effect and vulnerability of Sea Level Rise.
- To investigate physical and social vulnerability of Kochi using the assessment tools studied and figure out the most impacted zones.

## III. STUDY AREA INTRODUCTION

By 2050, it is estimated that 36 million Indians may be at affected by flooding and inundation due to sea level rise. This projection is a several folds from a previous estimate of 5 million and the impact is concentrated in Mumbai, Kolkata, Odisha, coastal Gujarat, Chennai and Kochi, the study shows. [6].

By 2100, sea level will rise and storm surges will occur once a year instead of once a century. The above figures are based on a moderate sea level rise scenario, but studies show that by 2100, 640 million people will be at risk if carbon emissions increase sharply or the ice sheet melts faster.

The Shoreline Assessment Map of Kochi display truly how risky the coast is. Shoreline change represented by Jiya Benni in 2013 is depicted in "Fig. 1". In one location close to Cochin, approximately km width of land has been eroded due to the fact 1850 [7]. Erosion could be very extreme all through the monsoon months of June - September.

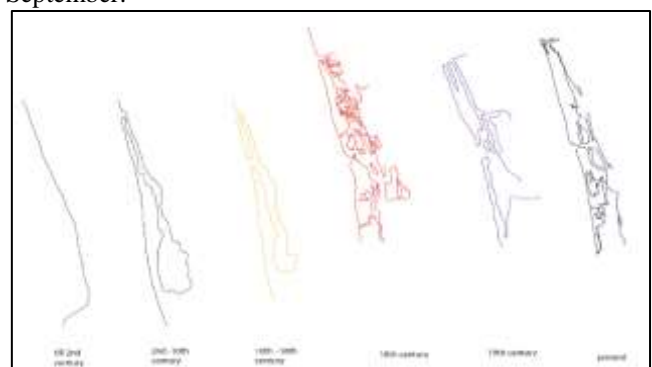


Fig. 1: Status of shoreline change due to erosion

The 2004 Indian Ocean Tsunami, left in its wake a brand-new seashore at Puthuvype in one of the islands. Though no direct correlation among erosion and fisheries is

on record, the socio-financial effect of this environmental phenomenon at the fishermen network thru sizable discount withinside the conventional shore touchdown centre is pretty alarming. [7]

**A. Inundation Mapping**

Although reports indicate that sea level due to high tide is increasing in the Kochi area. “Fig. 2” depicts the inundation levels for 2050 and 2100 with a stable increasing global temperature change of 0.5 degree. The more serious issue is global projections of climate change which indicate that the globally averaged sea level will rise significantly by 2100, perhaps as much as 0.9 meters.

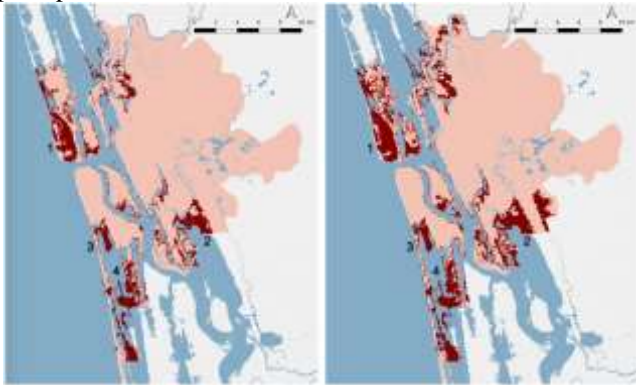


Fig. 2: Probable inundation zones by 2050 and 2100

Considering results of global and regional analyses, the likelihood of sea-level rise in the Kochi area in coming decades is very high. Rates of change and the eventual stabilization level are difficult to estimate, but it appears quite possible that sea level in the Kochi area will rise by as much as one-third meter by 2050.

It has been analysed from “Fig. 3” that by 2100, 19% of the region which is about 70.24 sq. km. area is going to be affected. From the above analysis Elamkunnappuzha, Tripunithura Municipality, Chellanam, and Kumbalangi tend to be the most affected regions in the KCR which ultimately affects a population of around 1,85,000.

**B. Implications of Sea-Level Rise**

Sea level rise would increase chances of coastal flooding, which might affect some areas of tourism interest. It would increase saltwater intrusion in both surface waters and ground water sources. It would increase the extent of water logging in the Kochi area, especially due to the rising storms in the region.

It has been analysed from “Fig. 3” depicting the impacted regions due to sea level rise that the land use in Cochin is diversified. According to the area focused in the study area, 78% of the land area is residential, followed by 9% for transport and communication, 3% for commercial establishments, 3% for industry, 6% for public and semi-public institutions, and 1% for open space.

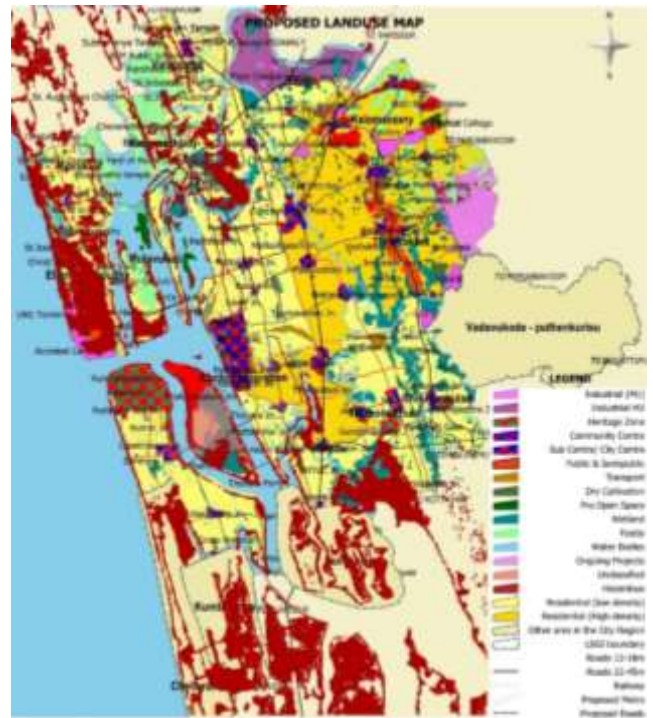


Fig. 3: Land use impacted due to Sea level rise of 1 meter.

Land Use	Percentage
Agriculture / Crop Land / Vegetation	41.81628
Forest	17.08646
Urban Built-Up	11.91825
Water Body	12.29301
Wetlands	16.886

Table I: Impacted Land Use Areas

**IV. DATA ANALYSIS FOR COASTAL VULNERABILITY ASSESSMENT**

Analytical hierarchical process (AHP) was developed by Saaty (1977) to calculate the weighted factors with the help of a comparison matrix, where all relevant criteria are compared with each other. In this study the weights are adopted from a similar Coastal vulnerability assessment of Puducherry coast, India by R. Mani Murali et al. (2013). In AHP method a comparison is carried out for all the factors to be considered and a matrix is derived based on relative importance of all the factors considered. In this matrix, each factor is ranked against each factor by assigning a relative value between 1 and 9 to the concerned cell.

Having a comparison matrix, a priority vector is derived which is the normalized vector of the matrix. For this each of column is divided by the corresponding sum of the comparison matrix. At last, the mean value of each row is calculated and this value is used as weights for calculating the PVI and SVI. The PVI and SVI are calculated using the weights to derive maps for each case. Both physical-geological (geomorphology) and socio-economic parameters have been selected to understand the sensitivity of the coast of Kochi to natural hazards. The study includes socioeconomic parameters in vulnerability studies. Socio-economic factors are important, as the data related to these aspects vary across the study area which includes parameters such as land use, transportation, and cultural heritage and hence is important to determine disaster vulnerabilities. The

parameters considered as well as their ranking criteria are discussed more elaborately in the following “TABLE II” which is adopted from a Coastal vulnerability assessment of Puducherry coast, India by R. Mani Murali et al. (2013).

A. Variables for Assessment

- 1) Coastal slope: Coastal slopes are an important variable to consider in vulnerability assessments as they are associated with relative sea level rise and flood risk from storm surges [8].
- 2) Geomorphology: Geomorphology is the study of terrain and the geological processes that produce them, identifying similarities between terrains [8]. Particularly relevant to coastal fragility is that geomorphology defines the erosion of different terrain types.
- 3) Elevation: Coastal elevation is important to include in vulnerability assessments because elevation can be utilized to identify and estimate extent of land threatened by inundation from sea level rise, estimate potential available land for wetland migration, and identify sea level rise impacts to human populations and [8].
- 4) Shoreline Changes: The coastal shield changes according to the range of coastal processes such as waves, coastal circulation, sediment characteristics or beach shape due to erosion or accretion [8].
- 5) Sea level change: Coasts with high relative sea level rise are considered high-risk areas due to the potential for coastal floods [8].
- 6) Significant wave height: Significant wave height is similar to average wave height. However, the height of the significant wave is one-third the average height (valley to mountain) of the highest wave in 12 hours [8].
- 7) Tourist Spots: Vulnerability of tourist infrastructure and the people using it, is one of the major concerns considering the mitigation.
- 8) Population: Coastal population is an estimated number of people living near the coast. Population variables are sometimes considered economic variables because people invest in protecting their property from erosion and floods [9].
- 9) Road network buffer: Road and rail networks occupy a defined length and width, so road and rail networks are included in the coastal vulnerability assessment [10].

Height (M)				
Tidal Range (M)	< 1	> 1 & < 4	> 4 & < 6	> 6
Population (Number)	< 50 000	> 50 000 & < 100 000	> 100 000 & < 200 000	> 200 000
L& Use/L& Cover	Barren L&	Vegetated L& Or Open Spaces	Agriculture/Fallow L&	Urban, Ecological Sensitive Regions
Road Network (Distance From)	2 Km Buffer	1 Km Buffer	500 M Buffer	250 M Buffer
Cultural Heritage (Tourist Areas)	Absent	Absent	Present	Present

Table II: Assessment Variables and Ranking Used For Kochi Study Area

For impact assessment study the following parameters are used to derive the vulnerability assessment maps for the study region. The study region comprises of 45 km. coastal stretch which includes Kochi corporation, Willingdon Island, Fort Kochi, Vypin and Vallarpadam regions. This stretch is divided into fifteen segments of three kilometre each.



Fig. 4: Study Area Map

V. PHYSICAL VULNERABILITY ASSESSMENT

A. Coastal Slope

Coastal vulnerability to flood floods and associated land loss is a direct function of coastal slopes [11]. In a study of a coastal slope of 1.2 was determined for the Kochi region. The study also obtained vulnerability ranking of 2 for the region along the beach and sections of Willingdon Island.

Parameter	Coastal Vulnerability Ranking			
	Very Low (1)	Low (2)	High (3)	Very High (4)
Coastal Slope	> 1	> 0.2 & < 1	> 0.1 & < 0.2	> 0 & < 0.1
Geomorphology	Rocky Coast	Embayed/Indented Coast	Dunes/Estuaries & Lagoons	Mudflats, Mangroves, Beaches, Barrier-Spits
Elevation (M)	> 6	> 3 & < 6	> 0 & < 3	< 0
Shoreline Change (M/Yr)	Accretion > 1	Accretion < 1	Erosion < 1	Erosion > 1
Sea Level Change (Mm/Yr)	< 0	> 0 & < 1	> 1 & < 2	> 2
Significant Wave	< 0.55	> 0.55 & < 1	> 1 & < 1.25	> 1.25



Fig. 5: Coastal Slope Vulnerability

**B. Geomorphology**

From the remote sensing data of the study region obtained from Bhuvan- Platform the geomorphology of the region was found to be of coastal origin.

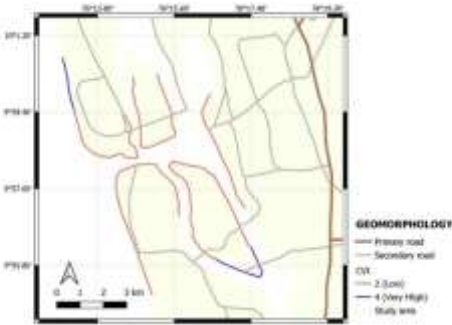


Fig. 6: Geomorphological Vulnerability

But beach stretches and wetland areas are highly vulnerable regions. Rest areas are either artificial coasts or indented coast which are more stable.

**C. Elevation**

Defined as the average elevation of a particular area above mean sea level, regional elevations play an important role in identifying the extent of land threatened by future climate change scenarios.



Fig. 7: Elevational Vulnerability

Low-elevation coastal areas are considered very vulnerable, and high-altitude coastal areas are considered low-vulnerability. From the elevation data obtained from Google Earth Pro 7.3.0.3832 (32-bit), the areas at risk in the survey area are shown in "Fig. 7".

**D. Shoreline Change**

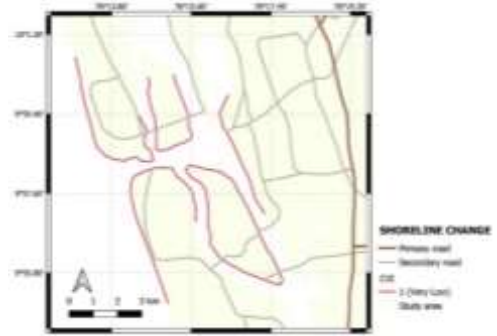


Fig. 8: Shoreline Vulnerability

The coastline change data for the study area was obtained using multitemporal data from long-term coastline monitoring of the Cochin estuary system on the southwest coast of India, with an increase of 3.4 m / year in the study area. Therefore, according to the ranking, it was classified as very low.

**E. Sea Level Changes**

The statistics recorded in Cochin station at some stage in the duration from 1939 to 2013 turned the sea degree extrudes at 1.40mm/yr, hence it had a rating of two as consistent with the criteria.

**F. Significant Wave Height**

Significant wave height (SWH) is used as an alternative to wave energy and is important for studying coastline fragility. Wave heights in the study area range from 0.5 to 1.5 meters.



Fig. 9: Wave Height Vulnerability

**G. Physical Coastal Vulnerability**

The physical coastal vulnerability derived from these factors show the stretch near Puthuvype Beach and Katari Bagh in Willingdon Island are more vulnerable in the study area.

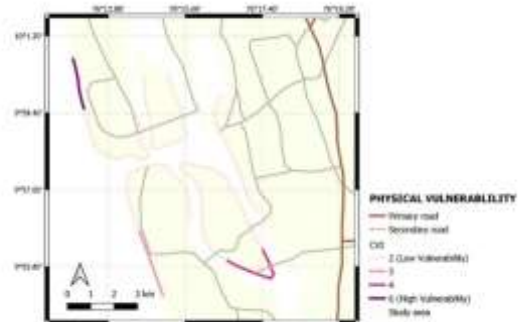


Fig. 10: Physical Coastal Vulnerability

## VI. SOCIAL VULNERABILITY ASSESSMENT

### A. Tourist Spots

The study area attracts a large audience from different parts of the world. Kochi, also known as Cochin Backwater, is a collection of islands on Lake Benbanard.

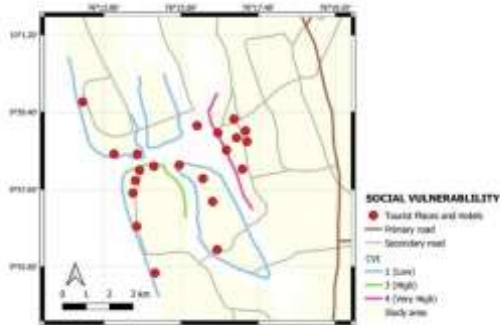


Fig. 11: Tourism Spots - Coastal Vulnerability

The most popular of them are Bolgatty, Vypeen, Gundu and Vallarpadam. Kochi is a natural beauty that tourists visit to relax in the calm backwaters. About 39.5% of tourism contributions comes from the Cochin coast as per tourism statistics of 2015.

### B. Population Density

From the spatial map of population density of the study region is could be noted that the Mattancherry and Fort Kochi region dues to its high population density is more vulnerable.



Fig. 12: Population Density - Coastal Vulnerability

### C. Road Network Buffer

The classification of the road network is usually done by making buffers of 250 m, 500 m, 1 km, 2 km or beyond from the shoreline. It is considered that the proximity of the road to the shoreline makes it more vulnerable.

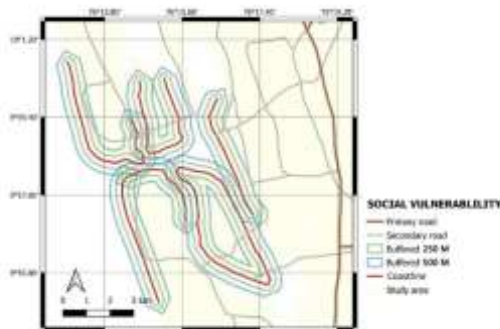


Fig. 13: Road Network - Coastal Vulnerability

### D. Social Coastal Vulnerability

The social vulnerability derived from these variables is described in the “Fig. 15”. It can be inferred that coastal region of central Kochi and regions on Mattancherry are socially vulnerable majorly because of population concentration in these regions.

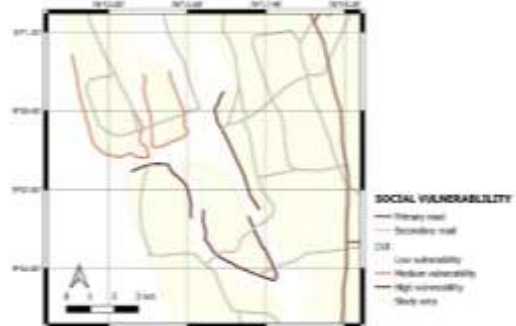


Fig. 14: Social Vulnerability Map

## VII. RESULTS AND DISCUSSION

Potential Impact of Rising Sea Levels on Coastal Land Use Unless measures are taken to address the potential for rising sea levels to threaten land use on or near the coastline, climate change will be associated with partial coastal land use. It can change patterns and threaten your livelihood. Because about 12% of the body of water is affected, even the slightest rise in sea level can be associated with floods, floods, and salt content in some lowland backwater islands that can threaten current lifestyles. If some of the islands in which they currently live become uninhabitable, refugees may move to other parts of the Cochin region, perhaps without housing or work, causing another problem for the city government. Concerns about these effects can be mitigated by certain potential adaptation measures, but only if sea level rise is moderate rather than large.

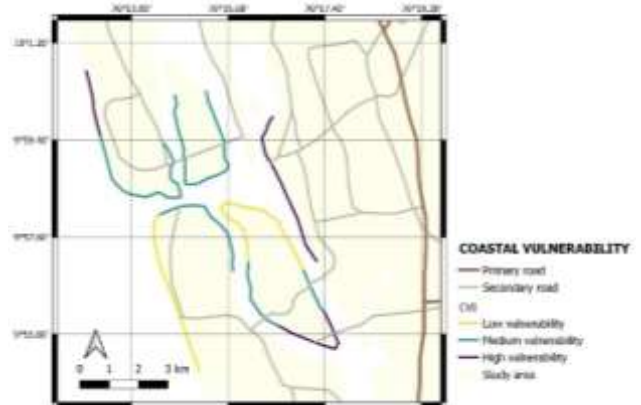


Fig. 15: Coastal Vulnerability Map

As the CVI indices of certain points with slightly high stress should be given for preventive measures, construction of shelters and sustainable land use planning strategies to reduce exposure to risks. Enhance the capacities as well as effectiveness of early warning systems of coastal disasters for communities in Mattancherry and Fort Kochi region due to its high vulnerability to sea level rise.

## VIII. CONCLUSION

As from the study of the assessment tools CVI for the Kochi region has been analysed based on the geological variables, physical variables and socio-economic variables. This further needs to be analysed with other adaptive and socio-economic factors which would generate better result of vulnerability. From the results obtained, CVI indices of certain points are slightly highly vulnerable and should be given more importance in terms of preventive measures, construction of shelters and sustainable and integrated land use planning to minimize exposure to risks. This will enhance the capacities as well as effectiveness of early warning systems of coastal disasters.

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