Multi-criteria Based Assessment of Coastal Vulnerability Along Biodiversity Rich Tropical Coastline in Karnataka

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Abstract

Sea level rise, climate change, and coastal deforestation significantly impact coastal environments, posing threats to unique ecosystems and rich biodiversity. Thorough monitoring and assessment of coastal regions are essential to mitigate economic losses. Satellite imagery offers improved spatial and temporal resolution compared to in-situ data collection. However, detailed spatial datasets are still lacking for the extensive and resourceful Indian coastlines. Additionally, comprehensive vulnerability assessments, considering both single parameters and clusters, are needed to understand future threats. This study computed and mapped the coastal vulnerability index by integrating conventional and remote sensing data. The analysis utilized 46 years of dynamics for eight significant parameters along the west Indian coast, with a 10 m resolution mapping. Results indicated that 37.42 km (27% of the total area) exhibited high or very high vulnerability, with the Karwar shoreline in the north being particularly susceptible across seven out of the eight characteristics. To safeguard this crucial coast for future development, recommended measures include building regulation, urban growth planning, integrated coastal zone management, strict implementation of the Coastal Regulation Zone Act of 1991, and ongoing monitoring and research.

Keywords: *Sea level rise, Coastal morphology, Vulnerability assessment, Remote sensing*

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1. Introduction

Coastal areas are incredibly dynamic settings. Dissimilar geospheres intermingle here to produce unique ecologies. Various such biodiversity hotspots are currently at risk as the global sea level is rising at an accelerated rate. A new record high of 97 mm (above 1993 sea levels) was observed in 2021 (Climate Change: Global Sea Level 2022). Sea level rise and associated wave activities can result in erosion, increased storm impact, accretion, reshaping of the coasts, flooding, creation of continental shelves and even drowning of river valleys (Management 2013). This changing morpho-dynamics is likely to have sensitive impacts on the environment (Hegde 2015). Scott et al. (2012), estimated inundation of 29% of the coastal resort properties in the Caribbean with one meter sea level rise (SLR). The island of Maui in Pacific experienced beach erosion in over 78% of the region due to SLR and associated wave actions. It has hence become pertinent to monitor coastal morphology at regular intervals and in a detailed quantitative fashion. The well-being of coastal residents and protection of valuable coastal ecosystems thoroughly depend on reliable information on the vulnerability of coastal regions. Conventional methods like beach surveys and in situ geographic positioning system shorelines do not offer continuous and frequent data coverage for entire coastlines. However, the emergence of computer science tools, such as Geographic Information Systems (GIS), has greatly facilitated the identification and analysis of coastal areas. Recent advancements in photogrammetry, topographic data collection, and digital image-processing techniques have enabled precise shoreline detection methods (Esteves et al., 2000; Bio et al., 2015).In order to evaluate the danger faced by coastal locations, a variety of predictive methods have been used, including historic rates of erosion, static inundation, erosion caused by sea level rise, and the use of sediment dynamics (Burningham, 2017). The Coastal Vulnerability Index (CVI) is one of the techniques that is most frequently used in every country for assessing coastal risk (McLaughlin & Cooper, 2011; Koroglu et al., 2019; Pantusa et al., 2022). The approach combines the coastal system's tendency for change with its inherent ability to adapt to shifting environmental conditions. In order to offer a relative assessment of the system's innate sensitivity to the effects of sea level rise, the CVI ranks various variables according to their physical contribution to shoreline change. By weighing several variables according to their physical impact on shoreline change, the CVI gives a relative estimate of the system's sensitivity to the effects of sea level rise.

India, having a very long coastline of around 7500 km, is vulnerable to potential loss of natural and man-made resources (Hossain et al. 2022; Princy et al. 2023). In India, even up to this point of time this issue of vulnerability assessment is paid little attention though it costs much less compared to the huge investments on early warning systems.Other nations which experience similar population growth and urban sprawl have an increasing number of densely built settlements, ports, cities growing along the coasts. Accurate prediction of shoreline retreat, beach loss, cliff retreat, and land loss rates is essential for effective coastal zone management planning. These predictions have the potential to enhance the assessment of biological impacts resulting from habitat change or destruction. To support territorial planning and decision-making processes, it is important to incorporate spatial data based on multiple criteria. Integrated Coastal Zone Management (ICZM) offers a valuable approach in this regard, allowing for the integration of measures to control socio-economic development patterns, mitigate natural hazards, and conserve natural resources. By adopting ICZM, coastal areas can benefit from a comprehensive and coordinated approach that addresses various aspects of sustainable coastal management.

This study aimed to create a comprehensive inventory of location-based data on hazard zones and multi-criteria based maps along a specific segment of the Indian coastline. The objectives included assessing parameters such as shore change rate, tidal range, significant wave height, coastal elevation, coastal slope, sea level changes, and coastal geomorphology. Coastal Vulnerability Indices (CVIs) were calculated and used to map the relative vulnerability of the coast to future sea-level rise. To capture a broader range of coastal behaviors, a secondary level of investigation using cluster analysis was proposed. By improving the quantitative understanding of shoreline indicators and their spatial relationship with the land-water boundary, this research contributes to the knowledge of coastal management strategies.

2. Significance of the Study Area

The study was carried out over the northern coast of Karnataka in Uttara Kannada district. The study area extends from 13.9254°N to 14.8992°N latitude and 74.0921°E to 74.5822°E longitude. The coastline stretches over185 km in length. The location and extent of the area is shown by Figure 1. This coastal region is of immense significance due to the presence of rich biodiversity. The Western Ghats or the Sahyadri mountains run here from north to south nearly parallel to the coast. Between the Sahyadri and the sea there is a narrow coastal strip which is known as the Payanghat. This zone varies from 8 m to 24min width. The brackish water present in these estuaries is a mixture of salt and fresh water and it provides valuable nutrients for marine life. Several backwaters and coastal wetlands also help various species to thrive. The study area is home to fourteen coral species, four sponge species, the protected small giant clams, hundred and fifteen zooplanktons, three threatened Mollusca species, five species of star fish and many more (Karnataka Biodiversity Board, 2010).

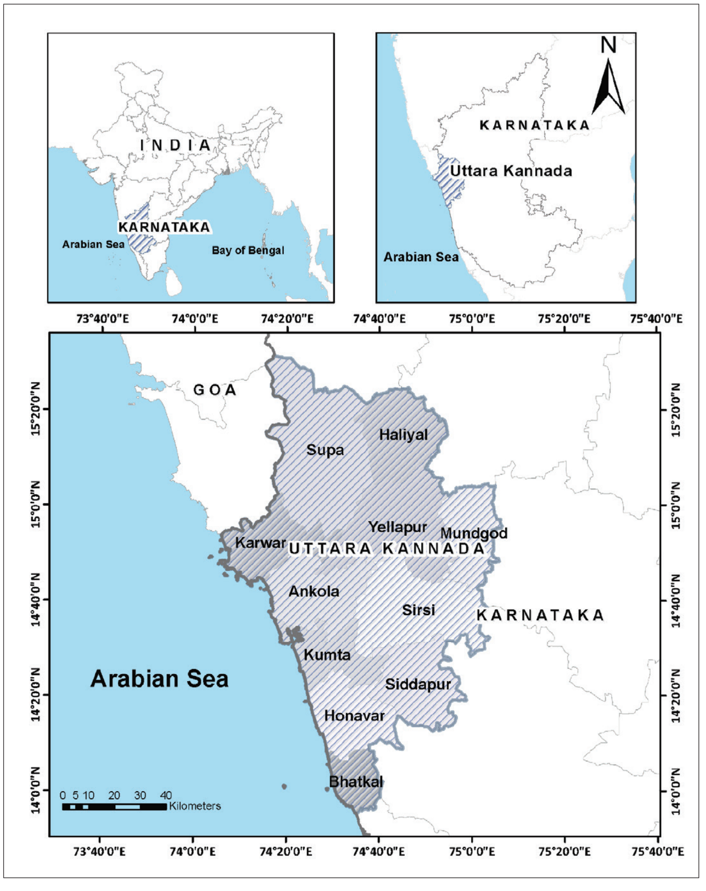

Figure 1 : Extent and location of the study area

Any change in the coastal landscape is likely to disrupt irreplaceable ecologies. Apart from the environmental significance, the coast also has major settlements and numerous tourist attractions. So, submergence or loss of coastal strips will affect economy and human activities in various ways. Hence, detailed monitoring, risk assessment and creation of quantitative databases for future analysis is mandatory for this region.

3. Datasets Description

A set of remote sensing data was used in the study ranging between the years 1973 and 2019.Landsat data from Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper (ETM), Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) sensors were obtained from U.S. Geological Survey (USGS). The list of the data along with other details is shown by Table 1.

Table 1 : List of Landsat data used in the study

Sl. No.	Satellite	Sensor	Path / Row	Date	Spatial resolution (m)
1	Landsat 8	OLI/TIRS	146/050	14.01.2019	30
2	Landsat 7	ETM+	146/050	29.12.2018	30
3	Landsat 7	ETM+	146/050	05.01.2010	30
4	Landsat 7	ETM+	146/050	11.02.2006	30
5	Landsat 5	TM	146/050	14.03.2000	30
6	Landsat 5	TM	146/050	19.11.1989	30
7	Landsat 1-5	MSS	157/050	02.03.1973	30

Several studies (Yang et al., 2022; He et al., 2022) have indicated changes in rainfall patterns during and following the Covid-19 lockdown. Given that the coastal regions are significantly influenced by Indian monsoon rainfall, precautions were taken to avoid any abnormal trends or outcomes in the data. Therefore, data collection was limited to 2019 and did not include the subsequent two years. In addition to Landsat images, various other datasets were utilized to derive specific parameters. They are shown in Table 2.

Table 2 : List of Additional Data for Generating Various Parameters

Sl. No.	Parameter	Data
1	Shoreline Change Rate	Landsat-ETM+
2	Geomorphology	Digital Globe QuickBird
3	Coastal Slope	GEBCO
4	Coastal Regional Elevation	SRTM
5	Beach Width	Digital Globe QuickBird
6	Tidal Range	WX-Tide
7	Significant Wave Height	simulated waves using mike-21
8	Sea Level Change	PSMSL

*GEBCO = General Bathymetric Chart of the Oceans; SRTM = Shuttle Radar Topography Mission; PSMSL = Permanent Service for Mean Sea Level

ERDAS IMAGINE, ArcGIS, Digital Shoreline Analysis System (DSAS) and WXtide-32 software were utilized to pre-process and process the remote sensing data.

4. Methodology

The primary objective of the work was to assess coastal vulnerability with CVI while incorporating the relative contributions and interactions of eight risk variables. The overall methodology of the work is shown by a flowchart in Figure 2

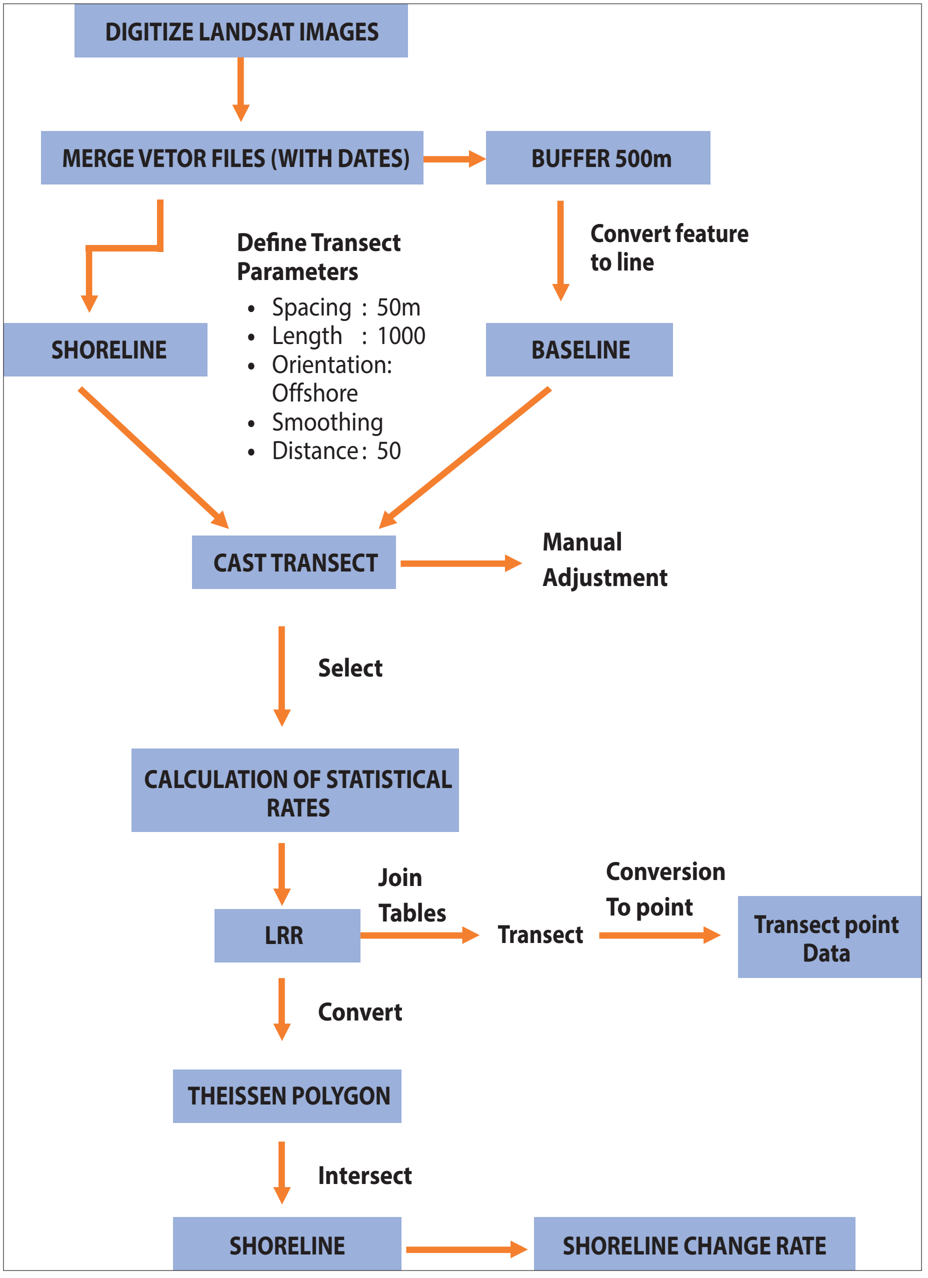

Figure 2 : Layout of the current work

4.1 Creating Spatial Layers of the Risk Variables

4.1.1 Coastal Geomorphology (G)

The parameter in question represents the erosivity risk associated with the coastal area. The Uttara Kannada coast exhibits various geomorphology types, such as very low rocky head, rocky beach, low vulnerable mud flat, moderate vulnerable rocky beach, and highly vulnerable areas like sandy beach, ports, or sea walls. The classification of these different geomorphologic regions along the coast was accomplished through a visual interpretation technique utilizing interpretation keys. Subsequently, these segments were grouped into different risk rate classes and assigned linear rankings before computing the Coastal Vulnerability Index (CVI).

4.1.2 Shoreline Change Rate (SCR)

The measure used to assess the historical tendency of a shoreline to either retreat or advance in response to sea level rise was employed. Shorelines exhibiting accretion were classified as low-risk categories, while those experiencing erosion were assigned correspondingly higher risks. Vector layers representing the shorelines for the years 1973, 1990, 2000, 2006, 2010, 2018, and 2019 were created using ArcGIS software. To analyze the data, the Digital Shoreline Analysis System (DSAS), an add-in software developed by the U.S. Geological Survey (USGS), was utilized. The Linear Regression Rate (LRR) method, as described by Thieler et al. (2009), was applied to quantify the rate of shoreline change over the 45-year period. Subsequently, the shorelines were categorized into risk classes ranging from very high to very low based on their relative values (Thieler et al., 2009).

4.1.3 Sea Level Change (SLC)

The sea level was defined as the average height of the ocean's surface between high tide and low tide. To determine this parameter, the primary source of information utilized was the tide gauge data set from the Global Sea Level Observing System (GLOSS) spanning the past century. Additionally, a secondary dataset consisting of monthly mean tide gauge data recorded by Indian tide stations was selected to estimate sea level trends. In order to standardize changes in tides and wave conditions over time, an average was taken. This allowed for the identification of sea level changes and the measurement of land height above the sea level, referred to as the still water level. Based on the observed values along the shoreline of the study area, they were subsequently classified into five risk categories.

4.1.4 Tidal Range (TR)

This parameter has risks of both continuous and intermittent inundation. Wide intertidal zones with little relief are characteristic in coastal areas with large tidal waves, making them susceptible to ongoing flooding from sea level rise. Additionally, when storm surges coincide with high tides, these places are more vulnerable to sporadic flooding brought on by storm surges. Tidal range information for January 2018 was gathered for the current study from the WX Tide programme. For several coastal areas in India, the base data and maximum amplitudes of the tide were determined, and risk rates were assigned according to the corresponding values.

4.1.5 Coastal Regional Elevation (E)

Understanding the possible effects of future sea level rise depends heavily on coastal regional elevation, which is the average height of a given area above mean sea level. It helps to identify places that could be impacted by rising sea levels. Data on coastal elevation are useful for evaluating the amount of land accessible for wetlands migration in reaction to sea level rise and determining how sea level rise would affect urban settings. In this project, a coastal regional elevation model was created using data from the Shuttle Radar Topography Mission (SRTM). Theisen polygons were created after the data was transformed into point data. The elevation data was then intersected with the current shoreline using these polygons. Higher elevation coastal locations were thought to be less vulnerable, but lower elevation places were thought to be extremely exposed to the effects of sea level rise.

4.1.6 Coastal Slope (S)

The rate of shoreline retreat and how susceptible a coast is to flooding are both influenced by the coastal slope. The relative susceptibility to flooding and the possible speed of coastline retreat are both determined by the slope. Using the General

Bathymetric Chart of the Oceans (GEBCO) data, the slope tool of the QGIS programme was used in this work to calculate regional slope values. Regions with lower slope values were categorised as higher risk zones (Rao et al., 2008). The slope values were expressed in degrees.

4.1.7 Beach Width (W)

This was obtained as the horizontal measurement of the beach. High beach width values represented the lower risk rates or accretion, and the lower beach width values depicted that the risk rates or erosion were high. The width was determined from the Google Earth Pro software. A path file was created along the beach horizontally i.e., perpendicular to the coast. These paths were exported into ArcGIS as vector layers. Their respective lengths were then calculated, and they were converted into point files first and then into Thiessen polygons. The polygons were then intersected with available shoreline information. In the case of sea walls, ports, headlands or rocky beaches the beach width value was zero.

4.1.8 Mean Significant Wave Height(H)

The average significant wave height is a useful indicator of wave energy, which plays a key role in coastal sediment transport. Significant wave height refers to the average height of the one-third highest waves over a 12-hour period, measured from trough to crest. This parameter directly influences the amount of beach material that can be transported offshore, potentially leading to permanent removal from the coastal sediment system. As wave height increases, wave energy also increases, resulting in a higher risk of land loss due to increased erosion and inundation along the shoreline. Therefore, coastal areas characterized by greater wave heights were considered more vulnerable, while those with lower wave heights were deemed less vulnerable.

4.2 Risk Rating

The five risk classifications of extremely low, low, moderate, high, and very high were applied to all eight criteria. The following table displays the ranges used to group the risk rates for all parameters.

Table 3 : Categorization and Risk Rating of Input Parameters

Data Range	Very low 1	Low 2	Moderate 3	High 4	Very high 5
Shoreline change rate (m/y)	>0.5	±0.5	-0.5 to -4	-4 to -8	<-8
Sea Level Change Rate (mm/y)	<1.25	1.25 to 1.27	1.27 to 1.29	1.29 to 1.30	>1.31
Geomorphology	Rocky Head	Rocky Beach	Headland	Seawall & Port	Sandy Beach
Tidal Range (m)	<2.13	2.13 to2.17	2.17 to 2.23	2.23 to 2.27	>2.27
Elevation (m)	>80	60 to 80	40 to 60	20 to 40	<20
Slope (degree)	>1.3	1.1 to 1.3	1.1 to 0.7	0.4 to 0.7	<0.4
Beach width (m)	>120	80 to 120	40 to 80	10 to 40	<10
Significant wave Height (m)	<1.479	1.479 to 1.484	1.484 to1.489	1.489 to 1.494	>1.494

4.3 CVI Computation

The Coastal Vulnerability Index (CVI), which provides a measure of the comparative vulnerability of a shoreline to physical changes brought on by future sea level rise, enables a measurable relationship among the factors mentioned above. The total research area's 1-minute grid cells were used to get the composite index value. Four general levels of susceptibility were determined using a macro-synoptic scale (at a ratio of 1:100,000): very high, high, medium, and low vulnerability. When calculating the CVI, this classification was used. The CVI was then calculated as the square root of the ranked variables, divided by the total amount of variables, by allocating vulnerability values to each individual data variable.

$$CVI = \sqrt{\frac{(G \times SCR \times SLC \times TR \times E \times S \times W \times H)/}{8}}$$

It was ranked from 1 to 5 on a linear scale basis indicating the vulnerability level due to shoreline change. Vector Algebraic techniques were applied on the risk values assigned to input parameters to calculate the index values for coastal segments. This was executed with ESRI Arc Map software.

4.4 CVI Ranking

The final mapping of CVI ranks was performed with percentile values. CVI incorporated aspects of both geology and structure along the coast (Kumar & Kunte 2012; Mujabar & Chandrashekhar 2013). The percentile values for CVI were calculated as,

$$\text{CVI to percentile} = \frac{(\text{CVI-minimum})}{(\text{maximum-minimum})} \times 100$$

Thus, the actual values were converted to a 0 to 100 range. The CVI values ranging from 0 to 25 are lower risk rates. Values ranging from 25 to 50 are Moderate risk areas. High risky areas range from 50 to 75 and the values from 75 to 100 are the areas which are highly vulnerable areas which are prone to severe damage. The categorization of CVI percentiles is shown by the Table 4.

Table 4 : Ranking CVI for Risk Assessment

Data Range	Low 1	Moderate 2	High 3	Very High 4
CVI Percentile Rank	0 to 25	25 to 50	50 to 75	75 to 100

5. Results and Discussion

The parameters indicating coastal vulnerability were first assessed and also compared in terms of risk rates. In the later section, the obtained CVI results were evaluated.

5.1 Coastal Geomorphology

As for coastal geomorphology, the highly vulnerable sandy beaches dominated the study area. These zones' spatial distribution is displayed by Figure 3. Beaches like Murudeshwar, Belekeri, Belambar, Honnavar, Shirali, Bhatkal which in total extends 102.20 km came under the highly vulnerable category. Alternately, parts of the northern coast with seawalls and ports have lower risk rates. In the Uttara Kannada coastline, the sea walls and ports together covered a stretch of around 15.80 km. The rocky beaches and rocky headlands dominated this part of the coastline constituting only 21% of the study area.

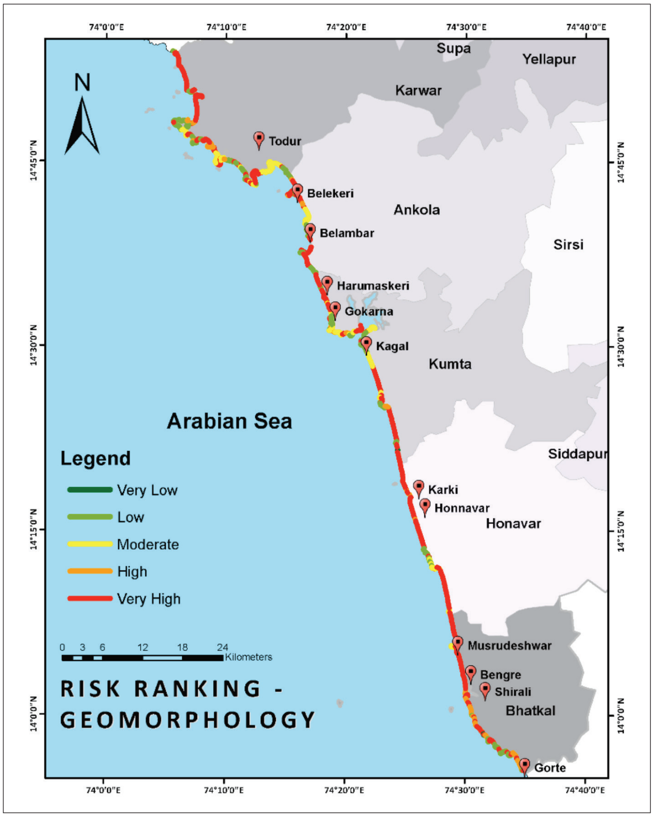

Figure 3 : Coastal geomorphology risk rate categories

5.2 Shoreline Change Assessment

The dynamic nature of shoreline along the study area over forty-six years is shown by Figure 4. The results depicted that only 0.87 km stretch of the coast was under very high-risk class; 0.42 km shoreline was under high-risk class. A considerable stretch of 35.2 km was under moderate risk class. This zone extended over the coasts of Karwar, Ankola, Murudeshwar. The erosion rate in the study area is low and limited to very few pockets. This has happened due to elevated coasts, pocket beaches adjoining rocky headlands, etc. The low-risk areas covered the majority of the Uttara Kannada coast extending for about 76.48km. A long stretch of 73.03 km of the study area was found to be under very low risk classes. Overall, the current study proved that during these 46 years from 1973 to 2019 the majority of the coast is facing accretion than erosion.

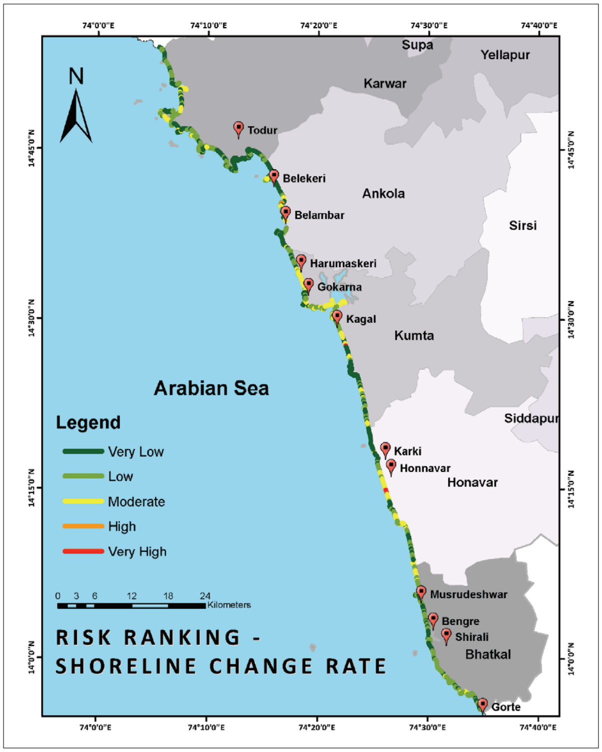

Figure 4 : Shoreline change risk rate categories

5.3 Sea Level Change

The relative distribution of the risk class along the Uttara Kannada Coastline for the sea level changes is shown through Figure 5. Only around 5.11 km length of the study area belonged to the low sea level change risk rate category. This was solely concentrated near Karwar in the northern most parts. The value of sea level rise was around 1.237 mm/year over here. On the other hand, the study showed the coasts starting from the southern parts like Bhatkal, Bengre, Murudeshwar, Honnavar up to the north like Ankola, Todur were prone to much higher risk. The sea level change rate was around 1.340 mm/year over these regions.

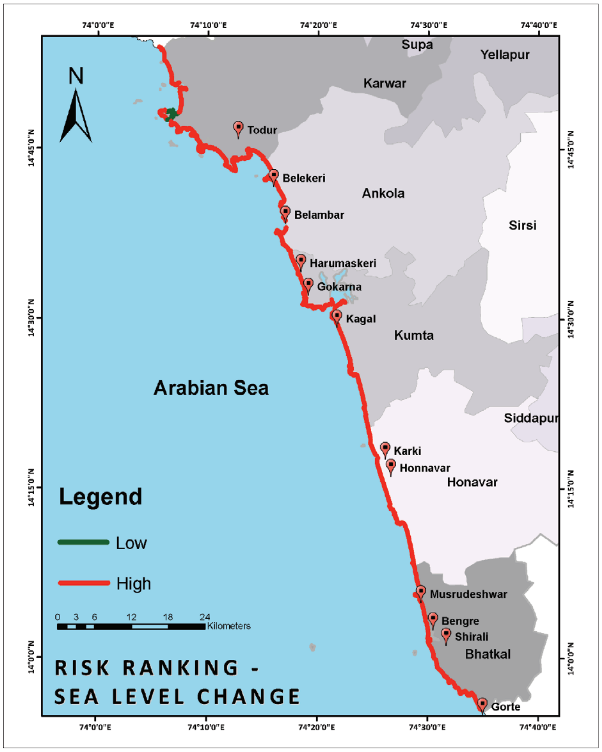

Figure 5 : Sea level change risk rate categories

5.4 Mean Tidal Range

A greater tidal range was observed at the northern parts of the region. Around 51.41 km of the present study area extending mostly over the coasts of Karwar came under very high-risk zone in terms of the mean tidal range values. The value was noted to be more than 2.17m. The risk rates gradually dropped towards southern sections. Near Gokarna the coastline indicated moderate risk rate stretching for around 31.61 km. A length of 18.21 km between Kumta and Honnavar reflected lower risk rate. An extensive 54.23 km coastline between Bhatkal and Honnavar belonged to the very low risk rate. The location based tidal risk categories are shown in the following Figure 6.

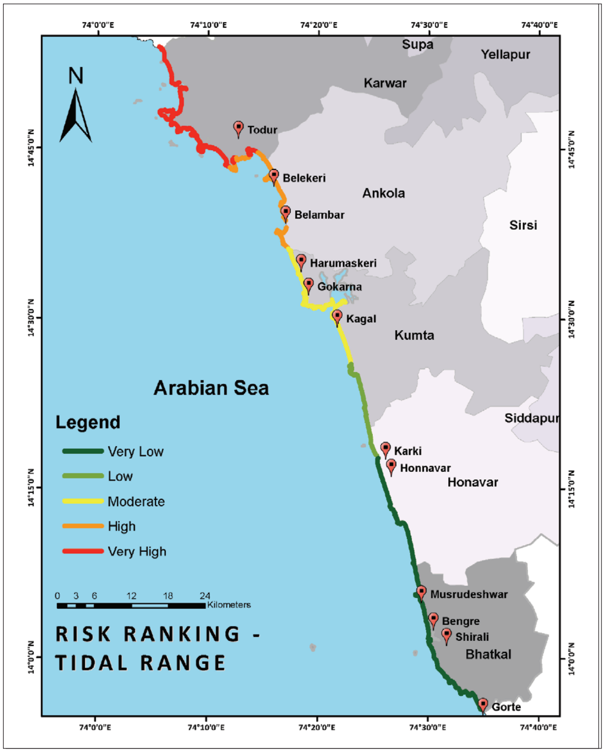

Figure 6 : Mean tidal range risk rate categories

5.5 Coastal Elevation

A vast majority of the study area reflected very high risks in terms of coastal elevation. The region with low-risk rates constituted only 1% of the total coastline. The low-risk areas were mostly the cliffs and rocky beaches from northern parts. Only 8.08 km length depicted moderate risk and 3.49 km showed low risk rates. These low to moderate risk category areas spread throughout the coast in patches. The remaining stretch of the coast mostly came under very high-risk class. This class covered 86% of the area, extending up to 157.51 km length. A stretch of 16.88 km came under high-risk zones. So, based on this parameter it can be concluded that the study area is greatly under threat due to low lying zones. The variation in spatial pattern of coastal elevation risks is shown by Figure 7.

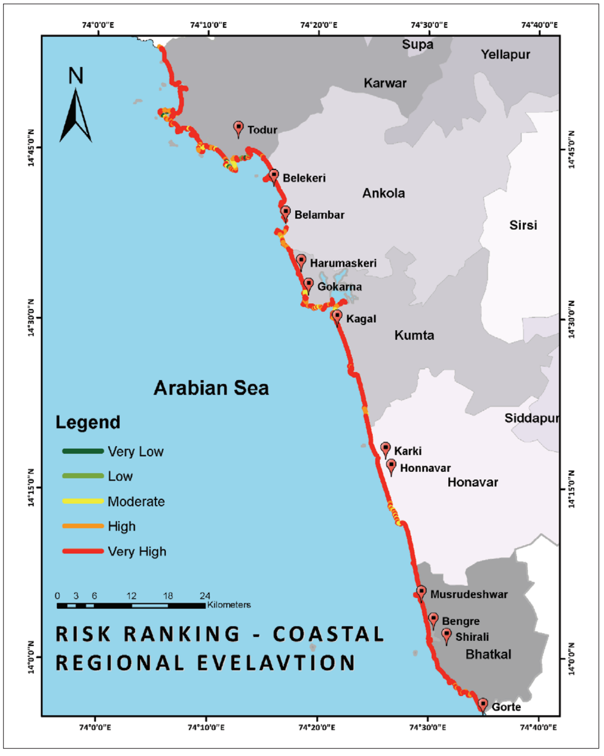

Figure 7 : Coastal elevation risk rate categories

5.6 Coastal Slope

The results depicted that slope values for the current study region ranged between 0.046° to 8.877°. The very high coastal slope risk rate category was dominant extending up to a length of 169.31 km. This class was primarily present between Bhatkal and Karwar. Further 4.78km of the study area was dominated by the high coastal slope risk rate category. On the contrary, very low, low and moderate risk zones as per coastal slope only covered 8.79 km, 1.75 km and 1.35 km respectively. Higher slope and low risk were observed at the southern parts of the shoreline. The spatial distribution of various risk zones as per the coastal slope is shown by Figure 8.

Figure 8 : Coastal slope risk rate categories

5.7 Beach Width

A considerable stretch of 82.76 km of this study area had very narrow beaches and hence was under the very high-risk rate category. The areas with such low beach width were prominent along the coasts of Karwar and some parts of Bhatkal. Another 49.11 km area came under the high-risk rate class. These zones also laid along the coasts of Karwar and Bhatkal. The moderate risk rate category was spreading for about 41.05 km of coastal length. Only 13.07 km of the study area expected low risk rate in terms of beach width. Here, the beaches were nearly 100 m wide. Overall, only a few parts of the region have accretion and led to the development of broad beaches. The spatial pattern of the above mentioned zones is shown by the following Figure 9.

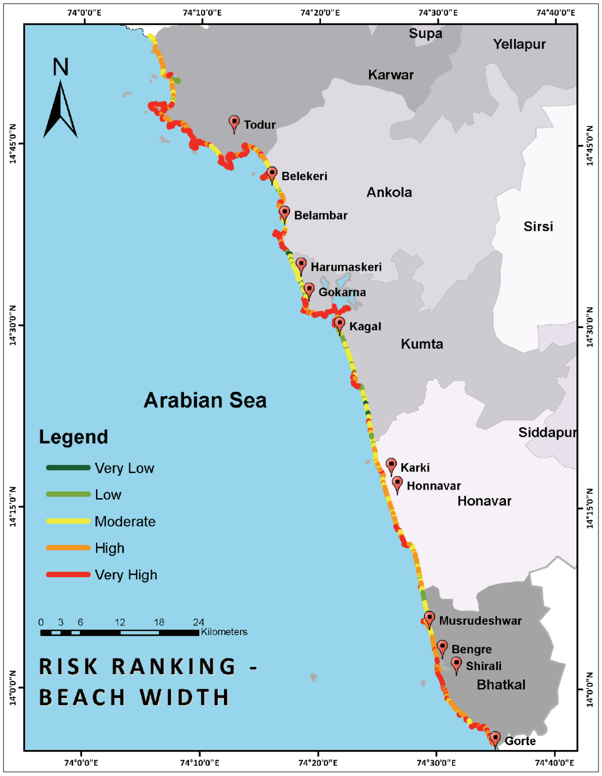

Figure 9 : Beach width risk rate categories

5.8 Significant Wave Height

The distribution of risk levels along the coast in terms of wave height is shown by Figure 10. The coasts of Karwar were notably vulnerable due to waves reaching up to 2m height. High-risk rate classes also extended along Karwar and parts of Ankola. This category stretched up to 36.95 km. Coastal regions of Gokarna mostly depicted the presence of moderate risk rate covering 24.33 km of the coastline. Uttara Kannada coast had lower wave height and hence was less prone to be a vulnerable coast. The wave heights have gradually decreased from north to south. Around 76.51km of the study area, particularly towards the southern side of the coast, had low risk rates. Such low vulnerability was especially notable along the coastal regions of Honnavar and Bhatkal.

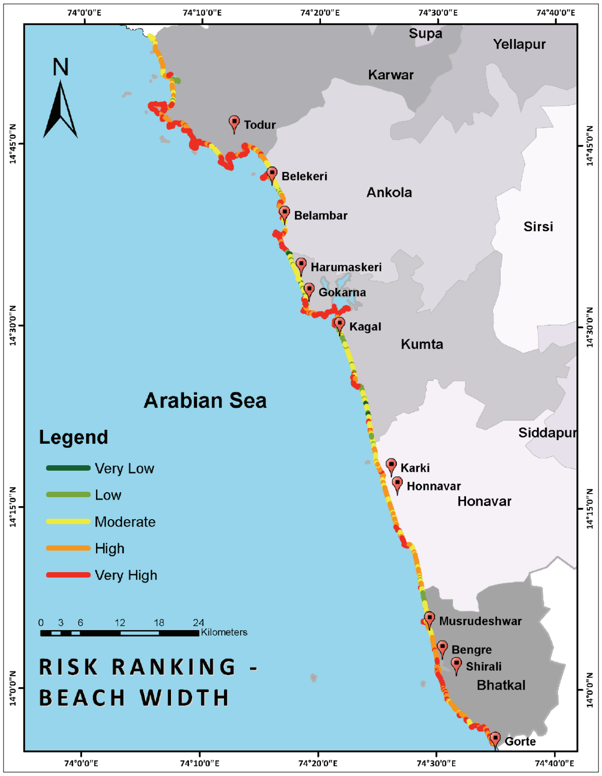

Figure 10 : Significant wave height risk rate categories

5.9 Comparative Analysis of Various Parameters

The percentage of risk areas varied considerably from one parameter to the other. These divisions are shown by the following pie charts in Figure 11. Results suggest that out of all the parameters, the study area was most vulnerable in terms of sea level change, coastal slope and coastal elevation. On the other hand, very low percentage area was vulnerable in terms of shoreline change rate. In case for factors like geomorphology, tidal range, beach width and significant wave height, the study area had mixed nature covering all the risk category zones.

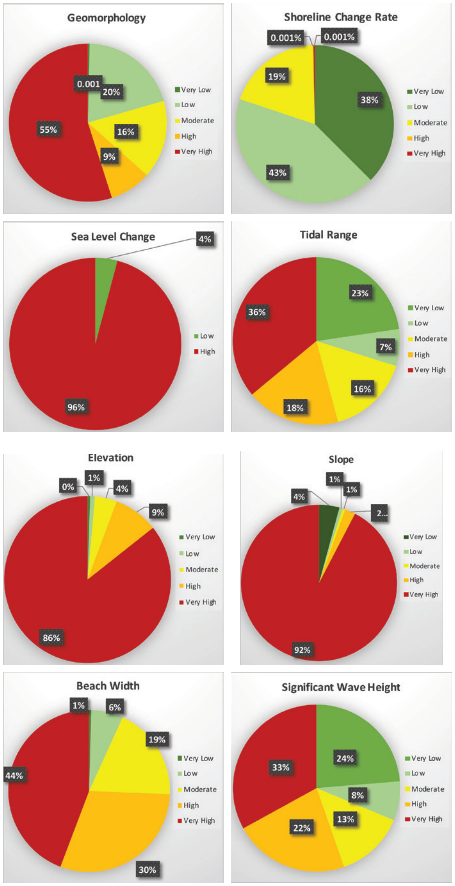

Figure 11 : Percentage risk areas for various parameters

5.10 Coastal Vulnerability Index

The total coastal vulnerability was calculated taking into account all of the input variables. The following illustrates how the four risk zone categories are distributed. Figure 12 shows the percentages of the four risk classes' coverage. As per the final CVI values, about 5% of our total study area was facing very high risk. The northern parts of Uttara Kannada, especially the Karwar coast depicted very high vulnerability for a stretch of around 6.35 km. About 22% of the total study area was under the high vulnerability category. This category extended up to 31.07 km of and was also seen along the coasts of Karwar. Some places of Gokarna coast were additionally part of high-risk zones as per the CVI. Urgent preventive measures and sustainable planning should be applied on these critical areas. Around 34% of the total study area was under moderate risk category. Moderate risk coasts ranged up to 60.02 km of Uttara Kannada. This category was dominant along the Gokarna and Ankola coasts. Low risk values were primarily observed in the southern coasts of this region. Parts of the coastline from Bhatkal to certain stretches of Gokarna and also some parts of Ankola coast were recorded with low vulnerability. Very few patches of Karwar coast reflected low risk. The low vulnerability category covered nearly 39% of the study area, with a length of 88.55 km.

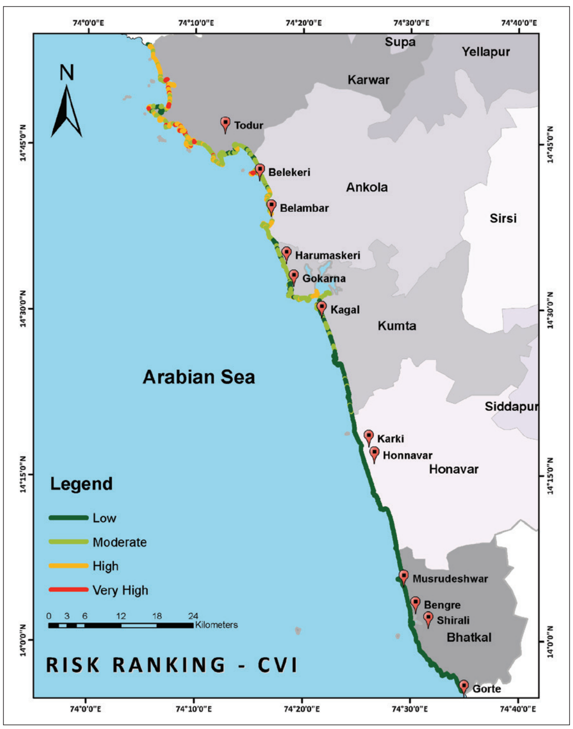

Figure 12 : Spatial depiction of Coastal Vulnerability Index

6. Conclusions

The study successfully carried out the coastal vulnerability assessment of Uttar Kannada Coast in India. The separate analysis of multiple significant parameters along coastline have created a much needed spatial database for the Indian coast. Useful insights were provided for upcoming morphological changes. The southern parts of the study area were comparatively less vulnerable than the northern parts. The relative potential of coastal damage was very high for parameters like, geomorphology, coastal elevation, slope and sea level change rate. As per the CVI, 34% of the study area came under moderate risk while 22% and 5% area were under high and very high risk respectively. The most severely affected area was one of the main developing cities of the Uttara Kannada district, Karwar. The region consists of residential areas, public infrastructure, agricultural sectors, recreational areas, fishery facilities, ports and also natural ecosystem hotspots. Long-term sustainable development necessitates an Integrated Coastal Zone Management (ICZM) strategy. A spatiotemporal dataset based on many criteria is required for this strategy. The information and methods employed in this investigation were appropriate for this goal and provide a framework for subsequent assessments of coastal risk.

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