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Resilience of Coastal Communities to Climate Change, in Thiruvananthapuram Region, Kerala State, India

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Abstract: Climate change poses a significant threat to coastal communities worldwide, particularly those in developing countries. The Indian coastline, amongst the world's most vulnerable to climate change impacts, spans over 7,500 km with almost 3.5% of the world's population residing within 50 km of the coast. People living in the coastal region in India are continually experiencing the adverse impact of climate change, such as extreme temperatures, changes in precipitation, sea-level rise giving rise to coastal flooding and erosion, increased risk of drought, and more, leading to loss in the productivity of fisheries, agriculture and aquaculture. Coastal communities are often disproportionately affected by climate change due to their geographic vulnerability and reliance on marine resources. The population living in coastal areas, the infrastructure, and the economies are at risk from storm tide flooding, shoreline erosion, and sea level rise. This climate-induced phenomenon is a direct consequence of ongoing environmental changes. Erosion, a natural geological process shaped by forces like wind and water, continues to play a significant role in shaping landscapes over millions of years. As sea levels rise, the increased frequency of coastal flooding further underscores the vulnerability of coastal areas, necessitating a thorough assessment of the potential impacts on communities and ecosystems. Coastal districts of India being diverse in nature are under constant vulnerability to hazards. High population density, low nearshore bed slope, low coastal elevation, high erosion rates, built-up areas, and roads near the coastline are some of the factors contributing to very high vulnerability in coastal districts of Kerala.

Keeping the aforesaid knowledge in mind Thiruvananthapuram Municipal Corporation, having a coastline length of 27.40 km has been selected for the detailed investigation. The research study aims to assess the differential impact of climate change. This coastline has experienced different issues in the last two decades, especially storm tides, flooding, and coastal erosion, with an eroded area of 650 acres from the mainland affecting the livelihood of coastal communities. The district-wise statistics indicate the maximum shoreline erosion is in the Thiruvananthapuram district, with 23% of its coastline being vulnerable. The study deliberates analytical tools such as Shoreline Detection-Digital Shoreline Analysis System (DSAS), and Socio-Economic and Infrastructure vulnerability by employing weighted overlay analysis to generate the Composite Vulnerability Map (CVM) using Geospatial techniques. Based on the results of the findings, the study explores the high-risk vulnerable zones, to evolve policy framework through spatial interventions which can aid resilience spatial planning in the study region. The study concludes with integrated climate-adaptive livelihood strategies towards the resilience of vulnerable coastal communities for inclusive climate adaptation.

Keywords: Coastal Communities; Climate Change; Coastal Erosion; Coastal Vulnerability; Community Resilience; Inclusive Climate Adaptation.

Introduction

Climate change is causing substantial alterations in coastal locations worldwide. The coastal counties along the Atlantic, Pacific, Arctic, Indian, and Gulf of Mexico coasts are inhabited by around 128 million people. They make substantial contributions to both the economy and culture. In a changing climate, a likely intensification of important climate patterns, coupled with projected changes in storminess and rising sea levels, will likely exacerbate coastal erosion and threaten the future resilience of many coastal communities worldwide (Vos et al., 2023). Climate change has many important consequences for coastal locations, including: The rise in sea levels, resulting from the expansion of saltwater due to increased temperatures and the rapid melting of polar ice caps, which worsens coastal flooding and erosion. Increased ocean temperatures enhance tropical cyclones and winter storms, leading to more frequent and severe coastal flooding, ultimately contributing to extreme storm occurrences. Ocean acidification is the process by which the pH of the ocean drops as it absorbs carbon dioxide. This has harmful consequences for marine life and the interconnected food chains within the ocean. Changes in the distribution of precipitation, which lead to modified precipitation patterns, have significant impacts on both land and water ecosystems. These effects include alterations in river flows, replenishment of groundwater, and levels of soil moisture. Further marginalized coastal communities have limited resources and are disproportionately susceptible to coastal hazards. Global mean sea levels have risen by approximately 8–9 inches (21–24 centimetres) since 1880, primarily due to melting ice sheets and glaciers, along with the expansion of seawater as it warms.

The repercussions pose substantial dangers to infrastructure, ecosystems, and coastal economy; hence, urgent adaptation methods are necessary. Climate change presents many vulnerabilities along the shore, including the following: Minority communities, renters, and lower-income groups often may not have the required means to successfully adjust to climate change. The ports, shipping, tourist, and commercial fishing industries are particularly susceptible to the impacts of climate change. The environmental repercussions of climate change often include habitat degradation, animal extinction, and decreases in fisheries.

Coastal resilience has been defined as "the capacity of the socioeconomic and natural systems in the coastal environment to cope with disturbances, induced by factors such as sea level rise, extreme events, and human impacts, by adapting whilst maintaining their essential functions" (Raub et al., 2021). It necessitates cultivating the capacity to adapt to fluctuating conditions, withstand disruptions, and promptly rebound from crises. Nature plays a crucial role in enhancing coastal resilience by reducing the danger of flooding via the implementation of nature-based solutions, such as restoring coastal ecosystems and using natural infrastructure. Organisations like The Nature Conservancy work on a worldwide level to protect communities by restoring natural elements such as coral reefs, floodplains, mangrove forests, and marshes. This demonstrates the cost-effectiveness of using nature as a means to protect people and property from damage caused by floods and storms. Coastal community resilience, however, is not determined by climate and disaster risks alone, but by other factors as well (Yoshioka et al., 2021). Communities may enhance their resilience to climate change and foster a sustainable future by allocating resources to nature-based solutions and collaborating with diverse sectors.

Coastal erosion is a naturally occurring process influenced by variables such as the increase in sea level, powerful wave activity, and floods along the shore. Coastal erosion is a major global problem and is most acutely felt along developed coastal areas where coastal communities and infrastructures are threatened by storm surge flooding (Khalil & Raynie, 2018). Erosion causes the gradual erosion or removal of rocks, soils, and sands along the coastline. Climate change exacerbates this process, resulting in elevated rates of erosion and global coastal flooding. The concept of global impact encompasses a wide range of effects and influences that occur on a global scale. The United States: Coastal erosion results in property losses amounting to almost $500 million each year, while the federal government allocates an average of $150 million annually for beach nourishment and other measures to mitigate coastline erosion. Africa: The rapid increase in sea levels presents significant dangers to many coastal towns, with forecasts suggesting that 117 million Africans may face the consequences of sea level rise by 2030. Europe: Coastal areas in Europe are susceptible to erosion and floods, with the Netherlands, Germany, Denmark, and Poland being the countries most impacted. Asia: Coastal erosion and floods caused by increasing sea levels and storm surges are prevalent in low-lying Asian nations including Bangladesh, Vietnam, Thailand, Indonesia, and India.

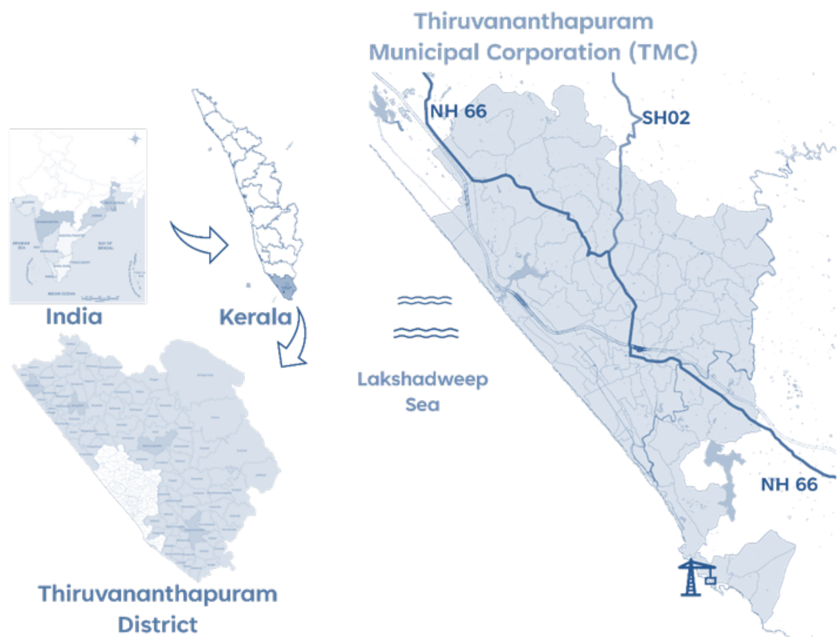
India has a large coastline that includes a variety of scenery and flourishing towns. However, it also faces significant challenges due to coastal erosion and floods. Approximately 33% of its coastline is susceptible to erosion, which presents a risk to over 170 million inhabitants residing in these areas. India has seen significant land loss owing to erosion, resulting in a total of around 235 square kilometres between 1990 and 2016. Regional disparities reveal much greater erosion rates in states such as Kerala (65%) and Gujarat (60%). The National Centre for Coastal Research

(NCCR) has done extensive evaluations of India's shoreline changes over many decades. These analyses have shown that 33.6% of the country's coastline is susceptible to erosion, 26.9% is experiencing accretion (growth), and 39.6% is largely stable. According to future forecasts, it is anticipated that by 2050, up to 36 million Indians may live in locations that are consistently prone to flooding if sea levels continue to rise. These figures highlight the need to create strong coastal management policies and promote community resilience to reduce the increasing hazards of coastal erosion and floods in India.

Study Region

The Thiruvananthapuram district is located in the southern region of the Indian state of Kerala. It is the most southern district in Kerala. The district is the most populous city in Kerala and functions as its political, educational, and administrative hub. The Thiruvananthapuram Municipal Corporation, formed in 1920, is the administrative body entrusted with the administration of Thiruvananthapuram city.

Figure 1: Regional Context of Thiruvananthapuram Study Region



Source: Compiled by the Researchers,2024.

The corporation has 100 wards and 15 coastal wards. These coastal wards constitute the 14 coastal villages in the city. The wider Thiruvananthapuram metropolitan area comprises Thiruvananthapuram corporation, three municipalities and 27 panchayats, as of 2011.

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Figure 2: TMC Ward Map

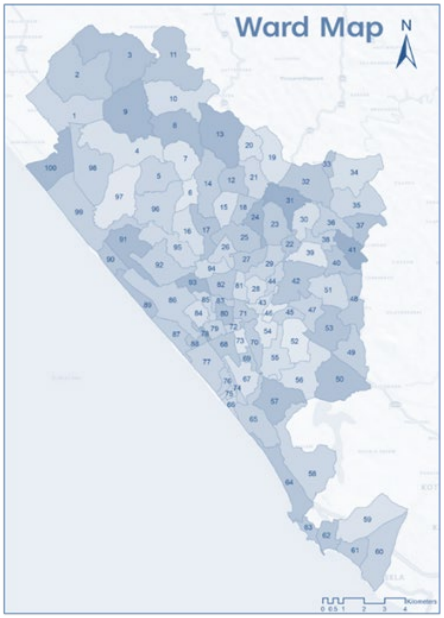

Figure 3: Coastal Ward Map

Source: Generated by the Researchers, 2024

Coastal Erosion

Studying shoreline dynamics and change in Thiruvananthapuram Municipal Corporation is crucial due to the high rate of coastline erosion in the region. This erosion impacts around 23% of the district's entire coastal area. The primary catalyst for this alteration is mostly the formidable marine current in the area, amplified by the shifting climate and regular sea storm surges. Multiple research studies have shown that wave energy, sediment transport, coastal constructions, and sea level rise have a substantial impact on the alterations in the coastline of Thiruvananthapuram Municipal Corporation.

The Kerala State Coastal Area Development Corporation (KSCADC) and the National Centre for Earth Science Studies (NCESS) are now conducting research and monitoring efforts to enhance our understanding of coastal dynamics and changes in the Thiruvananthapuram Municipal Corporation. These organisations often conduct surveys, gather data, and analyse them to evaluate the impact of coastal erosion, sedimentation, and other coastal processes on the shoreline in the region. Research has shown that between 2004 to 2020, around 650 hectares of land in the region have experienced erosion and been lost from the mainland.

Flooding

Flooding is water flooding dry land. A location that is seldom flooded gets submerged when a river, stream, or drainage ditch rises. Rainwater accumulation at its source. Floods may last for days to weeks, unlike flash floods. Intense precipitation in less than 6 hours causes flooding. After significant precipitation, fast floods wash away everything in their path along river channels, city roadways, or mountain valleys. They might occur minutes or hours after heavy rain. They may also occur without precipitation when a levee or dam breaks or when debris or ice blocks water. Land use and land cover changes may affect a region's drainage patterns and flood risk. Urbanisation, deforestation, and the conversion of natural wetlands into residential or agricultural areas may increase floods by increasing surface runoff and decreasing soil water absorption. The soil affects a region's water absorption and the earth's ability to let water in. Clay-rich or compacted soils have decreased permeability, increasing flood and surface runoff risk. Soil surveys and maps help determine flood risk based on soil factors. The intensity, frequency, and duration of precipitation are critical to estimating a region's climatic flood risk. Areas with seasonal monsoons or substantial annual precipitation flood more often. Storms and heavy rains are expected to increase due to climate change. This increased weather activity may increase susceptible areas' flooding danger. Deforestation, urbanisation, and dams and levees may modify hydrological processes and increase flood risk. Poorly designed infrastructure development in flood-prone areas may worsen flood damage and cause severe social and economic losses. To reduce urban flood risk, coordinated water resource management and sustainable land management are needed.

Composite Vulnerability Analysis and Risk Mapping

S*ocial Vulnerability*

Social vulnerability pertains to the capacity of communities to withstand and prosper in the face of external pressures on human well-being, such as natural or man-made calamities, or epidemics of diseases. Decreasing societal vulnerability may lead to a reduction in both human suffering and economic loss.

Infrastructure Vulnerability

Infrastructure vulnerability refers to the degree to which a community or area is prone to negative consequences caused by defects or interruptions in important infrastructure systems. This assessment often entails evaluating the percentage of households that have access to or are near critical infrastructure services.

Risk Assessment

Risk is the cumulative effect of both hazard and vulnerability. The impact is quantified as anticipated detriment, including harm to individuals, damage to assets, and interruption of economic operations, resulting from a specific danger. Risk refers to the likelihood that a potential danger will occur at a certain location and moment, as well as the anticipated damages that may be incurred by vulnerable entities over a defined period. To evaluate risk, it is necessary to combine and consider factors such as hazard, exposure, vulnerability, and resilience. A hazard refers to a potentially harmful occurrence, event, or human action that has the potential to result in loss of life, injury, damage to property, disruption of social and economic activities, or deterioration of the environment. Exposed aspects refer to the people, resources, and their monetary worth that are vulnerable to the potential danger. Vulnerability refers to the likelihood of harm occurring due to inherent qualities of individuals, resources, and systems that are exposed. An integrated evaluation of danger, contact, and societal susceptibility offers useful insights for assessing ways to mitigate risk. Risk maps may be created by integrating hazard and vulnerability maps. A risk map is generated by creating a two-dimensional table that assigns risk classes to each combination of hazard and vulnerability classes. This table is then used to apply the risk assessment to the hazard and vulnerability maps.

Methods and Data Analysis

The study used the DSAS 5.0 Tool to identify the wards that are prone to coastal erosion for a span of thirty years. The application enables the identification of erosion, accretion, or stability zones along the coastline via the use of shoreline data, satellite imagery, and geospatial analytic methodologies. Flood vulnerability is assessed using nine parameters. Soil type, storm surge, distance from river, land use, TWI, rainfall, elevation, flood-prone wards, and slope are evaluated. The parameters were developed from extensive literature study and field observations.

Table 1: Flood Susceptibility Indicators and Scoring Logic

Flood Susceptibility						
Parameter	**Scoring**	**Very low**	**Low**	**Moderate**	**High**	**Very high**
	Weight	**1**	**2**	**3**	**4**	**5**
Soil	0.04	Sandy Loam	-	Sandy Clay Loam	Sandy Clay	Gravel
Storm Surge	0.11	-	-	-	-	Yes
Distance from River	0.12	<50	50-100	100-150	150-200	>200
Landuse	0.06	Wetlands	Tree	Shrubland	Barren Land	Built-up
				Grassland		Waterbodies
				Cropland		
TWI	0.12	-3.5	-5.2	-3.6	2.8-6.3	6.3- 9.9

Rainfall	0.15	360-380	380-400	400-420	420-440	440-450
Elevation	0.15	<5	05-Oct	Oct-20	20-50	>50
Wards Affected by floods	0.11	No	-	-	-	Yes
Slope	0.14	0-2	02-05	05-08	08-15	>15

Source: Compiled by the Researchers,2024.

For the Vulnerability assessment, the components were selected by using Factor analysis (FA) using Principal Component Analysis (PCA). Indicator selection involves the careful selection of suitable indicators based on conceptual criteria derived from a comprehensive assessment of relevant literature. These indicators will be used to assess societal and infrastructural vulnerabilities. The selected indicators were further categorised into SVI (Social Vulnerability Index) and IVI (Infrastructure Vulnerability Index) categories. SVI focuses on social aspects, including demography and socioeconomic level, whereas IVI focuses on infrastructure-related issues, such as accessibility and infrastructure quality.

Preprocessing the data is a crucial step before applying factor analysis. This involves overseeing the handling of missing values, standardising variables, and ensuring the integrity of the data. The objective of the factor analysis approach was to determine the existence of underlying latent components that explain the observed data. This phase involves doing a Kaiser-Meyer-Olkin (KMO) Test and Principal Component Analysis (PCA). Factor scores were computed for each observation using the identified latent components. These ratings represent the overall effect of different indicators when combined. A rotational component matrix was created to analyse the association between indicators and latent components. This matrix aids in the analysis of the components and their impact on the Social Vulnerability Index (SVI) and Infrastructure Vulnerability Index (IVI). Afterwards, the districts were given scores and then visually represented using ArcMap to show the geographical distribution of vulnerability values. This allowed for a complete depiction of vulnerability patterns across different locations.

Table 2: Social Vulnerability Variables for PCA Test

Social Vulnerability			
1	Population Density	DEMOGRAPHY	S1
2	Slum Population		S2
3	Sex Ratio		S3
4	SC/ST		S4
5	Female Population		S5
6	Household Income		S6
7	Household Size		S7
8	Communicable Diseases (Infectious Diseases)	HEALTH	S8
9	Non-Communicable Diseases		S9
10	Other Diseases		S10
11	Basic Education	EDUCATION	S11
12	Primary Education		S12
13	Secondary Education		S13
14	Higher Education		S14
15	Non-Educated		S15
16	Primary	Job	S16
17	Secondary		S17
18	Tertiary		S18
19	Kuccha	HOUSING	S19
20	Pucca		S20
21	Semi Pucca		S21
22	Own House		S22
23	Rented		S23
24	Lease		S24

25	Rehabilitated House		S25
26	Migrated House		S26

Source: Compiled by the Researchers,2024.

Table 3:Infrastructure Vulnerability Variables for PCA Test

No.	**Parameters**	**Indicators**	**Unit**
1	Water Supply	**Water Scarcity**	%
2	Waste Disposal		%
3	Electricity Connection	**Power**	%
4	Voltage Variation		%
5	Road	**Transport**	Km
6	Bus Stop		Km
7	Auto Stand		Km
8	Petrol Pump		Km
9	Post Office	**Transport**	Km
10	Pre-primary School		Km
11	Lower Primary School		Km
12	Upper Primary School		Km
13	High School		Km
14	Health Center	**Health System Services**	Km
15	Hospital		Km
16	Ration Store		Km
17	Milk Booth	**Essential Services**	Km
18	Maveli Store		Km
19	Playground		Km
20	Chemical Hazards		Km
21	Vehicle Ownership		%
22	Latrine		%
23	% of Houses with Electricity Connection	**Energy**	%
24	% of Houses with no Voltage Variation		%
25	% of Consumption of Electricity.		%
26	% of Houses with Non-Conventional Sources of Energy.		%
27	Percentage of Money Spent to Total Income		%
28	Firewood		%
29	LPG		%
30	Kerosene		%
31	Electricity		%

Source: Compiled by the Researchers,2024.

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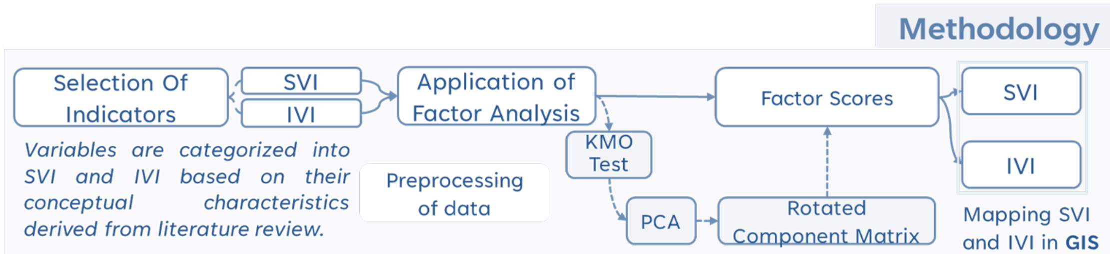
Figure 4: PCA Methodology



Results and Discussion

The coastline change investigation revealed that some wards within the municipal corporation are very vulnerable to coastal erosion, characterised by a noticeable and steady retreat of the shoreline. Typically, these areas coincide with densely populated coastal wards and critical infrastructure, hence exacerbating the socio-economic impacts of erosion. Furthermore, the research highlighted the dynamic character of coastal processes, whereby erosion rates vary spatially and temporally owing to variables such as sediment availability, wave intensity, and coastline morphology. The wards in the area that are most vulnerable are as follows.

Figure 5: Wards with Shoreline Change for Thiruvananthapuram Region

Valiyathura	Poonthura
5	3
Harbour	Thiruvallam
5	3
Vizhinjam	Sangumugham
5	3
Beemapalli East	Vellar
4	2
Kottapuram	Vettucaud
4	2
Mulloor	Poundukadavu
4	2
Beemapalli	Pallithura
4	1
Manikkavilakom	
3	

Valiyathura, Harbour, and Vizhinjam are the worst-affected districts. At these rates, the continent loses 4.15 metres annually. These locations are near Vizhinjam port. Dredging, land reclamation, and breakwaters and jetties are part of the Vizhinjam Port project. These changes may affect material movement, wave patterns, and coastal erosion. Due to wave action and ship wakes, port operations may aggravate coastal erosion.

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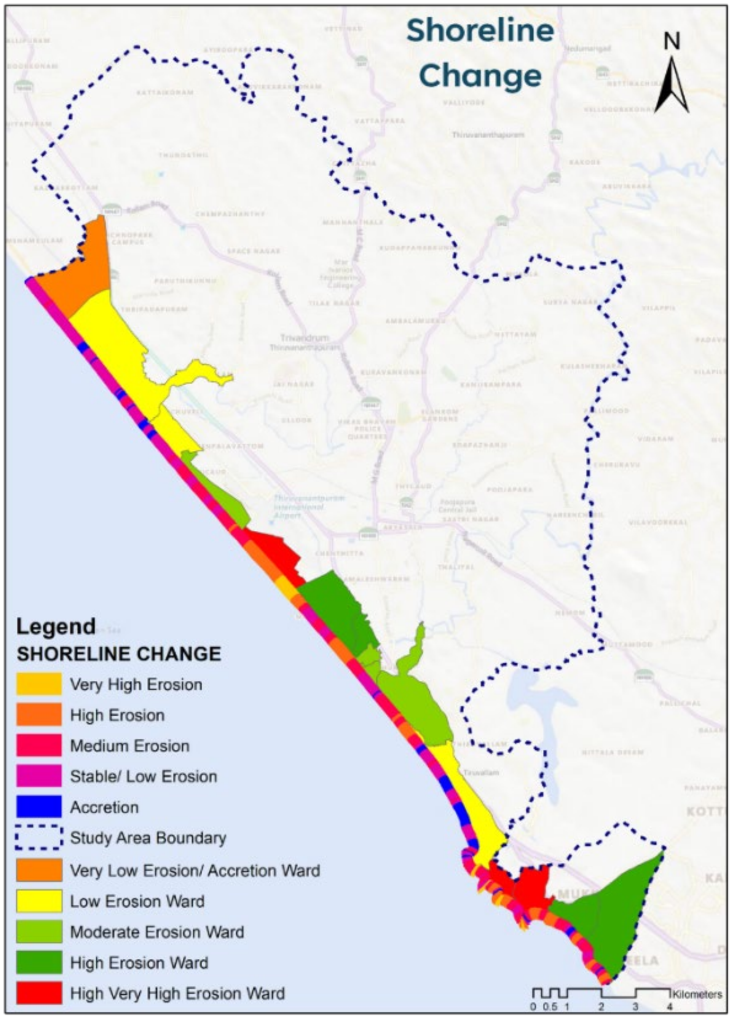
Figure 6: Erosion Map for Thiruvananthapuram Region,2024



Source: Generated by the Researchers,2024.

Flood Susceptibility

The study's results on flood susceptibility suggest that coastal wards are more prone to flooding compared to wards located farther east. The high flood-prone zones include an area of 17.83 square kilometres and are characterised by their extreme susceptibility to floods. The flood has severely affected many significant wards, including Manikkavilakom, Bheemapalli, Bheemapalli East, Vettucaud, Pallithura, Poonducavu, Kannamoola, Pattom, Karikonam, and Melamcode. The prevalence of storm surges in the research region and the existence of low-lying zones are the primary factors that contribute to these issues. Furthermore, the wards in the vicinity that were previously affected by floods also contribute to this predicament.

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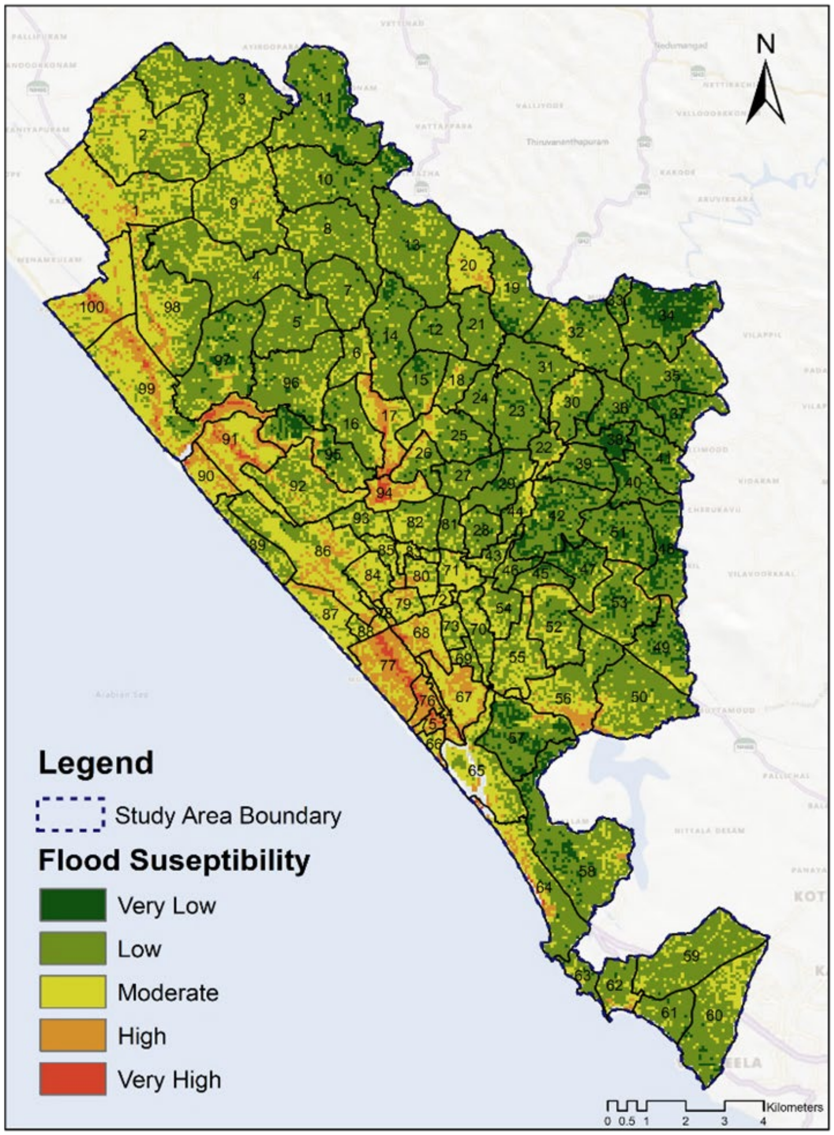
Figure 7: Flood Susceptibility Map for Thiruvananthapuram Region,2024



Source: Generated by the Researchers,2024.

Multi-Hazard Susceptibility

According to the multi-hazard susceptibility map, thirteen out of the fifteen wards that make up the coastal area are situated in regions that have a high or very high sensitivity to several disasters. The eastern part of the study region is less vulnerable than the coastal region, which is characterised by a higher degree of vulnerability. Those wards that are most susceptible to harm include:

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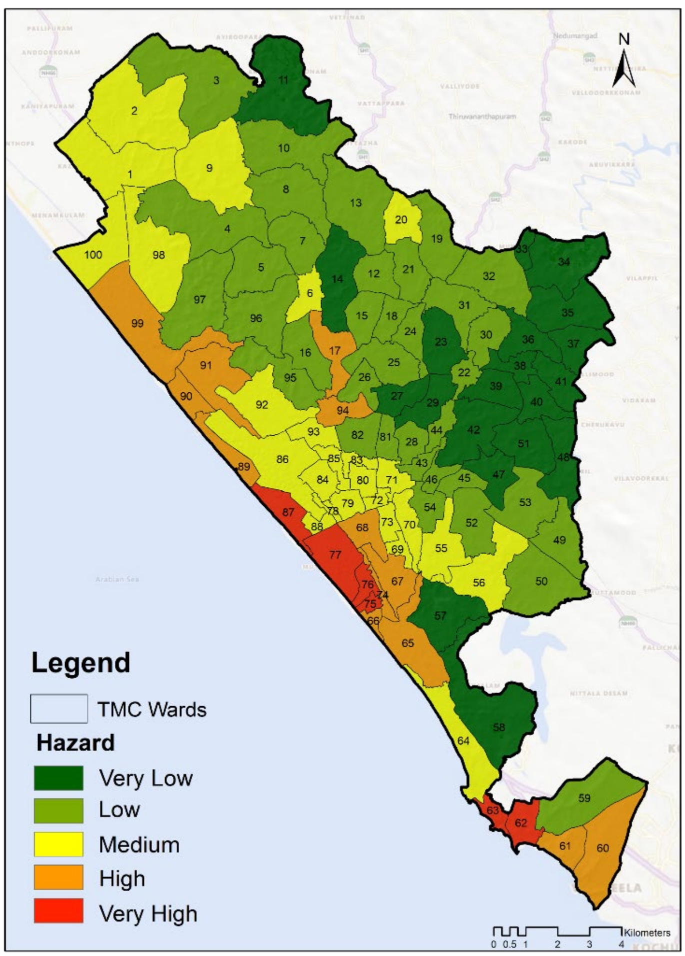
Table 4: Multi-Hazard Susceptible Wards

1	Pallithura
2	Valiyathura
3	Bheemapalli East
4	Manikkavilakom
5	Poonthura
6	Thiruvallam
7	Harbour
8	Vizhinjam
9	Sangumukhom
10	Vettucaud
11	Poundukadavu
12	Bheemapalli
13	Pattom

Figure 8: Multi-Hazard Susceptibility Map for Thiruvananthapuram Region,2024



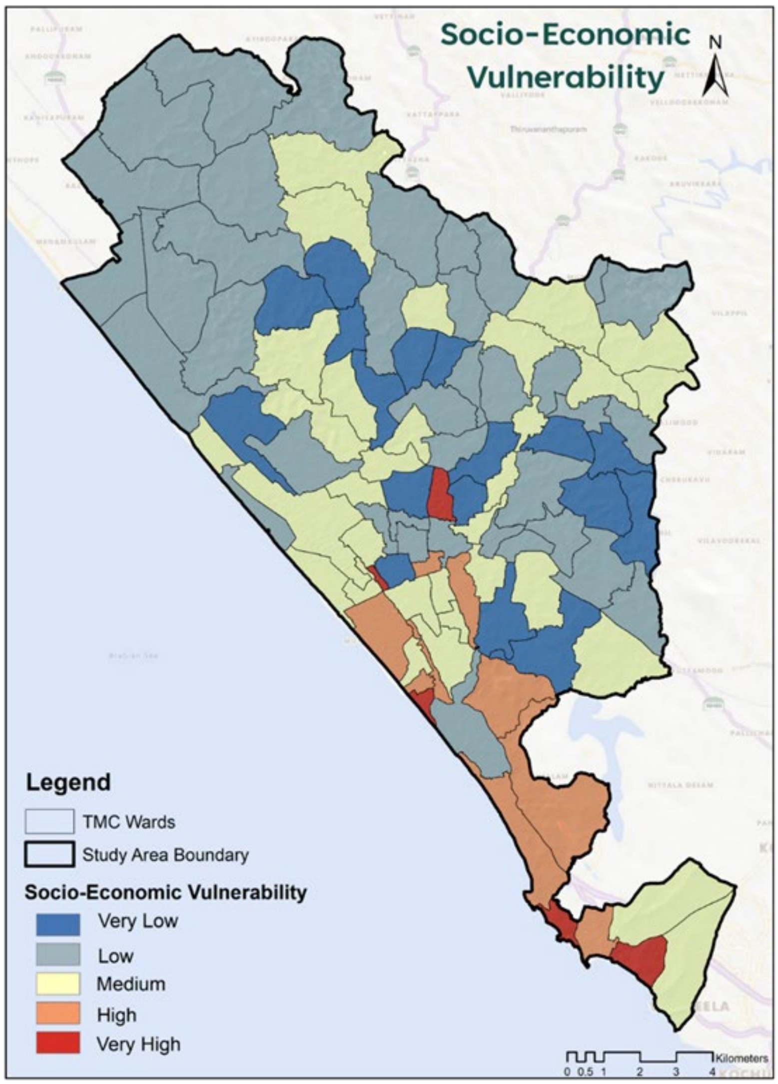
Source: Generated by the Researchers,2024.

These factors mostly stem from the wards being located close to the sea, as well as the impact of storm surges, coastal erosion, and floods. These factors exacerbate the hazardous conditions in the area. The map showing the spatial variability of the multi-hazard is shown in the Figure 8.

Socio-Economic Vulnerability

Fifteen percent of the wards in the study area are classified as either high or extremely highly susceptible. The southwestern portion of the study region, mostly consisting of coastal wards, has a greater degree of social vulnerability compared to the other half of the territory. Education, living conditions, and the prevalence of infectious and non-communicable illnesses are the primary factors leading to socioeconomic vulnerability in the area.

Figure 9: Socio-Economic Vulnerability Map for Thiruvananthapuram Region,2024



Source: Generated by the Researchers,2024.

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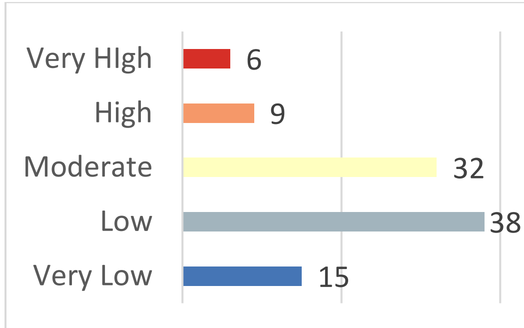
Figure 10: Ward statistics of Social Vulnerability

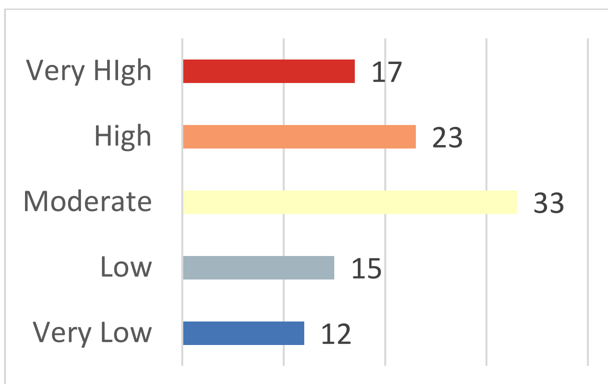


Source: Generated by the Researchers,2024.

Infrastructure Vulnerability

Infrastructure vulnerability refers to the degree to which a community or area is prone to negative consequences caused by defects or interruptions in important infrastructure systems. This inspection usually entails evaluating the percentage of households that have access to or are close to critical infrastructure services. Forty per cent of the wards in the study area are classified as either high or very highly vulnerable wards. All of these wards are considered to be very vulnerable. The risk is spread out over the area, with the southern and northeastern parts of TMC being the most susceptible. The main reason which is contributing to the infrastructure vulnerability is proximity to schools, health centres and other essential services as indicated in the percentage of households for each ward in the study region.

Figure 11: Ward statistics of Social Vulnerability



Source: Generated by the Researchers,2024.

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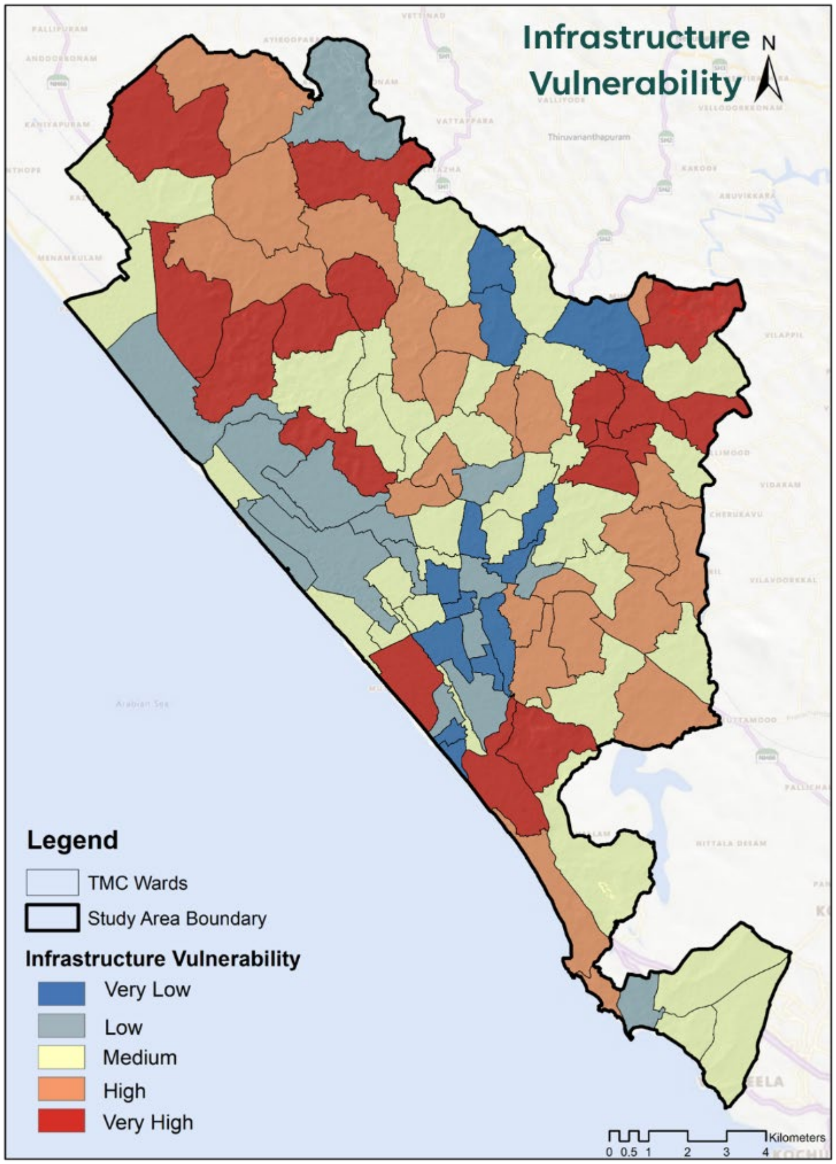
Figure 12: Ward statistics of Social Vulnerability



Source: Generated by the Researchers,2024.

Composite Vulnerability

The composite vulnerability map shows that there is a greater vulnerability along the wards in the coastal side of the study region than in the inner side of TMC or the CBD of the study region.

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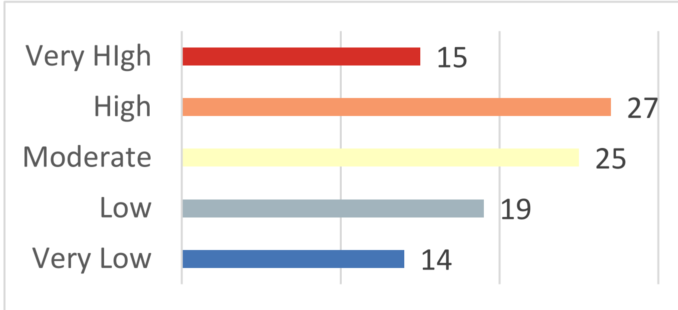
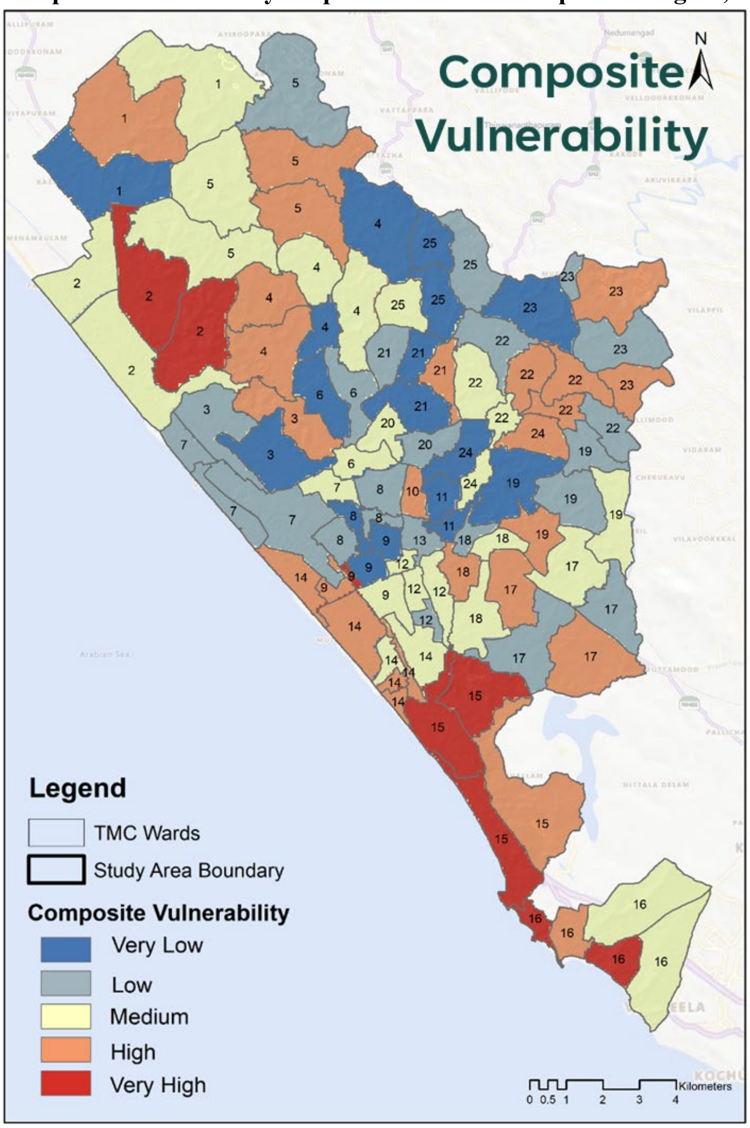
Figure 13: Composite Vulnerability- Ward Statistics



From the analysis, it can be found that 32 % of wards are coming under the highly vulnerable zones and 25 % of wards are coming under moderately vulnerable zones.

Figure 14: Composite Vulnerability Map for Thiruvananthapuram Region,2024

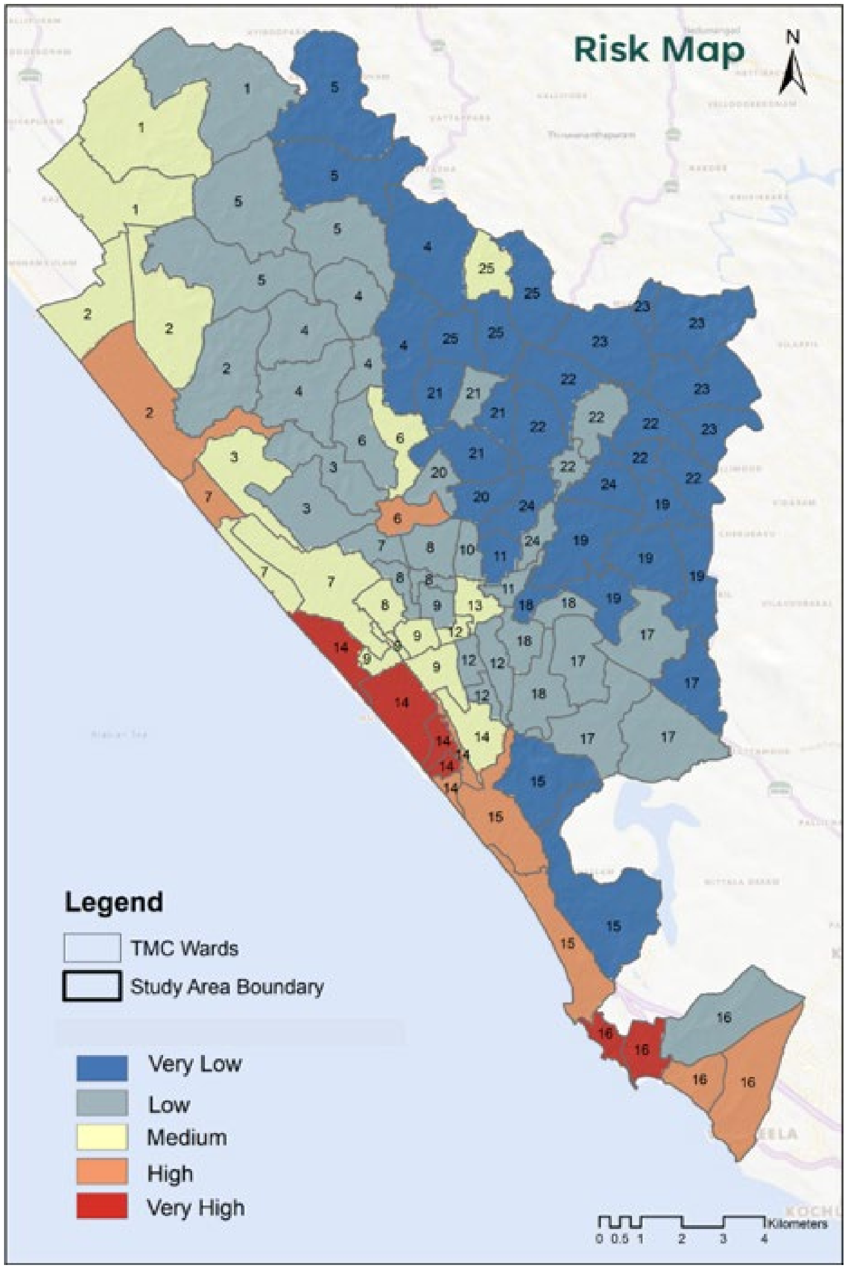


Source: Generated by the Researchers,2024.

Risk Mapping

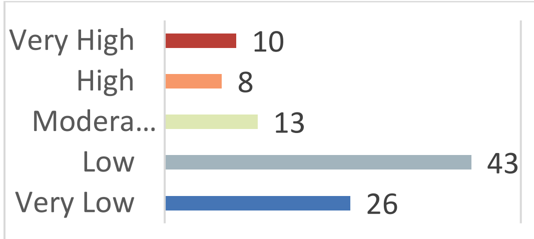
High-risk coastal regions are highly susceptible to severe weather events, rising sea levels, erosion, and floods due to population expansion, urbanization, and development. The risk map, which integrates the analysis of several hazards susceptibility and vulnerability, indicates a significant level of risk in the coastal wards within the study zone. The significant decline in risk towards the eastern portion of the research area is seen in TMC. It is seen that 18 per cent of the total wards in the study region are under high-risk zones. 13 per cent of the wards are in the moderate zones.

Figure 15: Risk Map for Thiruvananthapuram Region,2024



Source: Generated by the Researchers,2024

Figure 16: Ward Statistics of Risk Mapping



Observations and Findings

The Thiruvananthapuram Municipal Corporation (TMC) is confronted with a significant challenge when it comes to coastal erosion. Certain areas of the city are seeing an annual loss of land that may reach up to 4.15 metres. Valiyathura, Harbour, and Vizhinjam are the wards that have been impacted the most profoundly by the disaster.
Thirteen of the fifteen coastal wards that make up the TMC are located in areas that are identified as having a high or very high degree of sensitivity to numerous hazards. Several reasons contribute to this occurrence, including their geographical position as well as the effects of storm surges, coastal erosion, and floods.

A greater degree of social vulnerability is seen in the coastal wards located in the south-western region of the TMC as compared to the eastern half of the neighbourhood. Several variables, including education, living conditions, and the prevalence of infectious and non-communicable illnesses, are included in the criteria that determine the outcome.
A high or very high degree of risk in terms of infrastructure is categorised as being present in forty per cent of the wards that make up the TMC. The southern and northeastern regions of the TMC are home to the districts that are classified as the most vulnerable. The insufficient closeness to educational institutions, medical facilities, and other necessary services has resulted in this situation. According to the risk mapping, eighteen per cent of the wards at TMC are located in regions that suffer from a high degree of risk. The majority of the high-risk wards are situated in coastal geographic regions. These wards are very vulnerable to the effects of severe weather, increasing sea levels, erosion, and flooding of the environment.

Some strategies include the strategies for Protecting Coastal Areas:

Living Breakwaters:

- Implemented in the Pallithura, Poundukadavu, Vettucaud, Thiruvallam, and Vellar Wards.
- The objective is to decrease the amount of wave energy, enhance the accumulation of silt, and facilitate the establishment of shellfish populations.
- Incorporate mangrove restoration efforts to bolster fishery resources and mitigate the potential for flooding.

Offshore breakwaters:

- Offshore breakwaters are scheduled to be constructed at Valiyathura, Harbour, and Vellar.
- Minimise the power of ocean waves, safeguard structures, and assist in the accumulation of silt to restore the environment.

Geotubes:

- Geotubes will be erected at Vizhinjam, Kottapuram, Poonthura, Manikkavilakom, Sangumugham, Bheemapalli, and Bheemapalli East locations.
- Minimise the impact of wave energy, facilitate the accumulation of silt, and facilitate the restoration of coastal ecosystems.
  The strategies for the protection against flood include:
  i. Riparian zones, which are natural barriers located near rivers and streams that serve to avoid floods. They boost the stability of the soil, mitigate erosion, boost the process of infiltration, and improve the quality of water.

ii. Embankments, which are structures built beside rivers to confine water and mitigate the risk of floods. The locations include Pazhavangadi Thodu, Ulloor Thodu, Thekkanakkara Canal, and Killi River.
iii. Reinforce the stability of riverbanks and safeguard critical infrastructure.
iv. Detention Ponds, Bioswales, and Rain Gardens:

These measures have been put in place at Bheemapalli, Pallithura, and Pattom. - They serve the purpose of temporarily storing excessive rainfall, replenishing groundwater, and mitigating the danger of flooding. Filter and assimilate rainfall-runoff, alleviating pressure on drainage systems. These integrated plans have the objective of improving the ability of coastal areas to withstand and recover from floods, safeguarding the natural environment, and promoting the economic well-being of local populations.

Conclusion

In the context of the resilience of coastal communities to climate change, particularly focusing on the Thiruvananthapuram region in Kerala, India, it is evident that coastal areas are facing significant challenges due to climate change impacts such as sea-level rise, coastal flooding, erosion, and changes in precipitation patterns. These challenges are exacerbated by factors like high population density, low coastal elevation, and high erosion rates, making coastal communities highly vulnerable to climate-related hazards. Studies have shown that coastal communities are disproportionately affected by climate change due to their reliance on marine resources and geographic vulnerability. The vulnerability of these communities is further compounded by factors such as limited resources and susceptibility to coastal hazards. The impacts of climate change on coastal communities are multifaceted, affecting not only the environment but also the livelihoods and well-being of the people living in these areas.To address the challenges faced by vulnerable coastal communities, it is essential to adopt integrated climate-adaptive livelihood strategies that enhance resilience. This can involve leveraging local and indigenous knowledge to increase community resilience against climate change impacts and disasters. Additionally, promoting alternative livelihood options and enhancing the adaptive capacity of smallholder farmers are crucial steps in increasing the resilience of coastal communities.

Furthermore, building assets that enhance people's ability to exploit natural resources should be done cautiously to avoid undermining the long-term sustainability of coastal ecosystems, which could increase the vulnerability of coastal communities to climate change. It is also important to consider the role of cognitive variables in influencing adaptation behaviour and resilience in the face of climate change. In conclusion, enhancing the resilience of coastal communities to climate change requires a comprehensive approach that integrates scientific knowledge, local and indigenous wisdom, and sustainable livelihood strategies. By understanding the unique challenges faced by coastal regions like Thiruvananthapuram in Kerala, India, and implementing targeted interventions based on sound research and analysis, it is possible to build adaptive capacity and promote resilience in these vulnerable communities towards inclusive climate adaptation.

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