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RESEARCH ARTICLE

Assessing Socio-Economic Vulnerability of Coastal Communities in the Southern Coastal Plains of Kerala

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Abstract

The coastal communities of southern Kerala, though rich in cultural and ecological heritage, face mounting socio-economic challenges due to both natural and human-induced pressures. This study offers a comprehensive assessment of the socio-economic vulnerability of 253 villages spread across the coastal plains from Ernakulam to Thiruvananthapuram. Using data from the 2011 Census and household records, the research analyzes key indicators such as population and household density, child and female population ratios, literacy rates, primary workers, and socially weaker groups to evaluate levels of vulnerability. These indicators were spatially mapped and ranked to create a composite vulnerability index, providing a clear picture of where and why vulnerability is most pronounced. Geographic Information System (GIS) tools played a central role in visualizing and interpreting these spatial patterns. To deepen the analysis, hotspot mapping was carried out using the Getis-Ord Gi statistic in ArcGIS, identifying statistically significant clusters of high vulnerability, particularly in villages located in Thiruvananthapuram, Kollam, and Alappuzha. Villages like Ochira, Arattupuzha, Attingal, and Vakkam emerged as major hotspots requiring immediate attention. The findings highlight the spatial disparities in vulnerability across districts and underscore the importance of localized, data-driven strategies for disaster risk reduction and sustainable planning. This study emphasizes the value of integrating socio-economic data with spatial analysis to better target interventions and build resilience among Kerala's most at-risk coastal populations.*

Keywords: Disaster; Vulnerability; Kerala; GIS; Coastal plains

1 Introduction

Kerala's coastal communities are an integral part of the state's socio-economic fabric, shaped by their proximity to the Arabian Sea and their dependence on its resources for livelihood. These regions, though rich in cultural and ecological significance, face unique challenges due to a combination of natural and human-induced factors. The socio-economic dynamics of Kerala's coastal areas are influenced by a complex interplay of factors, including population density, literacy levels, employment patterns, and access to basic infrastructure. In this context, understanding the socio-economic vulnerability of coastal communities becomes crucial for sustainable development and disaster risk reduction.

By assessing the underlying factors that contribute to vulnerability, this study aims to provide insights into the challenges faced by these communities. Seven key socio-economic parameters that influence the vulnerability of coastal plains were carefully selected and analyzed to understand their impact. Each parameter was spatially represented and categorized into five distinct classes, ranked on a scale from 1 (very low) to 5 (very high), reflecting varying levels of vulnerability. This approach allowed for a detailed examination of how different factors contribute to the overall risk faced by coastal communities. The findings, presented with clear interpretations, highlight the complex interplay of socio-economic conditions and their spatial distribution, offering valuable insights. Southern Kerala's coastal belt faces comparable challenges due to its diverse mix of rural and urban communities, many of which rely on agriculture, fishing, and tourism for their livelihoods. Unplanned development, rapid urbanization, and climate change have heightened the risks these communities face [1]. There is growing recognition of the need for localized assessments that combine measurable indicators of vulnerability with insights from the affected communities themselves. Such an approach ensures that mitigation and adaptation strategies are responsive to the unique needs of the region [1–10].

2 Study Area

Kerala is in the southernmost part of India, and it is bounded by Tamil Nadu on the east, Arabian Sea on the west, Karnataka and Andhra Pradesh on the north and the Indian Ocean in the south. The coastal plains of southern Kerala form a distinctive geographical region, characterized by their low-lying terrain, proximity to the Arabian Sea, and unique socio-economic dynamics. Stretching along the southwestern edge of India, this region is known for its vibrant ecosystems, including wetlands, backwaters, and estuaries, which play a crucial role in supporting livelihoods and biodiversity. The coastal plains are densely populated, with communities engaged primarily in agriculture, fishing, tourism, and trade. Despite their natural beauty and economic significance, these areas are highly vulnerable to natural and human-induced hazards, such as flooding, coastal erosion, and cyclonic storms. Socio-economic challenges, such as disparities in infrastructure, health care access, and education, further compound this vulnerability. Understanding the intricate interplay between these factors is essential for developing targeted strategies to enhance resilience and sustainable development in the region. In southern Kerala, spanning from Ernakulam to Thiruvananthapuram, a total of 253 villages have been identified as part of the coastal plains. These areas, situated at elevations ranging from 0 to 10 meters above sea level, are classified based on the data from the Resource Atlas of Kerala. A total of 86, 49, 43, 26, 7 and 42 villages in Alappuzha, Ernakulam, Kollam, Kottayam, Pathanamthitta and Thiruvananthapuram, districts respectively were identified. The area lies between 76.35769°N - 77.10342°N latitudes and 8.29226°E - 10.25394°E longitudes. The total geographical area of the study region is 4062.8km^2. The terrain is spread over 5 districts (Figure 1).

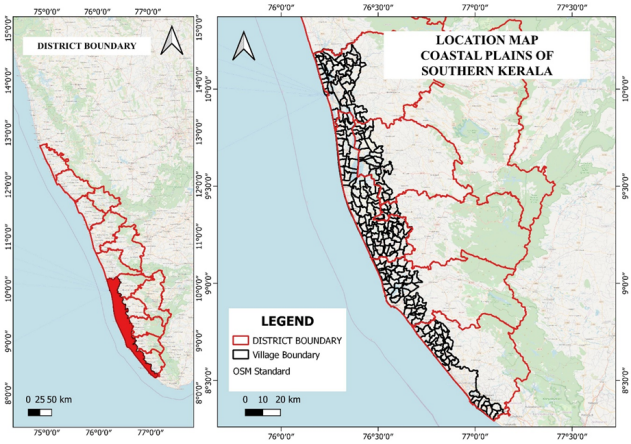

Fig. 1. Location Map

3 Methods and Materials

This study adopts a holistic approach to evaluating socio-economic vulnerability across the coastal plains of southern Kerala, specifically covering 253 villages stretching from Ernakulam to Thiruvananthapuram, as identified in the Resource Atlas of Kerala (areas within 0–20 meters elevation). By utilizing data from the 2011 Census and household records, the research focuses on ten crucial indicators to understand and measure vulnerability. These indicators include population and household density, child and female population ratios, literacy rates, proportion of primary workers, and the representation of socially weaker sections. To effectively capture and interpret the spatial patterns of vulnerability, Geographic Information System (GIS) tools were used to map these socio-economic variables. This enabled the identification of regions with differing levels of vulnerability, providing a clear spatial perspective that can inform targeted policy and planning interventions.

4 Results and Discussions

4.1 Exposure and capacity related indicators

4.1.1 Household Density and Population Density

Population and household density are key indicators of concentrated human settlement and are closely linked to socio-economic vulnerability. Villages with a population density exceeding 1,500 individuals per square kilometer, and a household density of more than 400 households per square

kilometer, are at a high risk of vulnerability. This indicator reflects the number of households per unit area. High household density can strain infrastructure and services, increasing vulnerability during disasters. Major coastal cities like Kochi, Thiruvananthapuram, Kollam, Alappuzha and villages like Kuzhippuly, Puthuvype, show a very high degree of vulnerability. And Very High to High vulnerability can be seen in the regions extending from Kollam to Thiruvananthapuram coastal stretch (Figure 2).

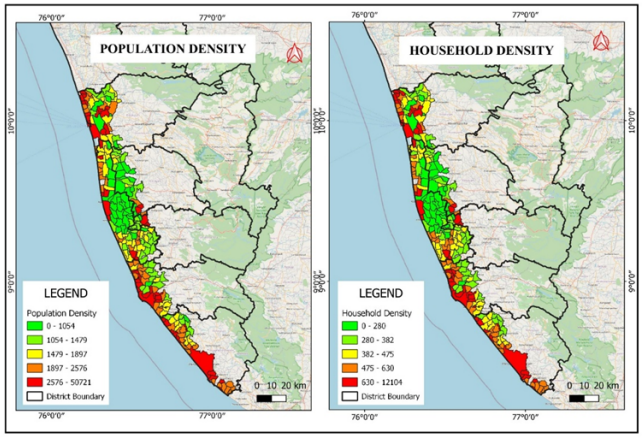

Fig. 2. Population Density, Household Density

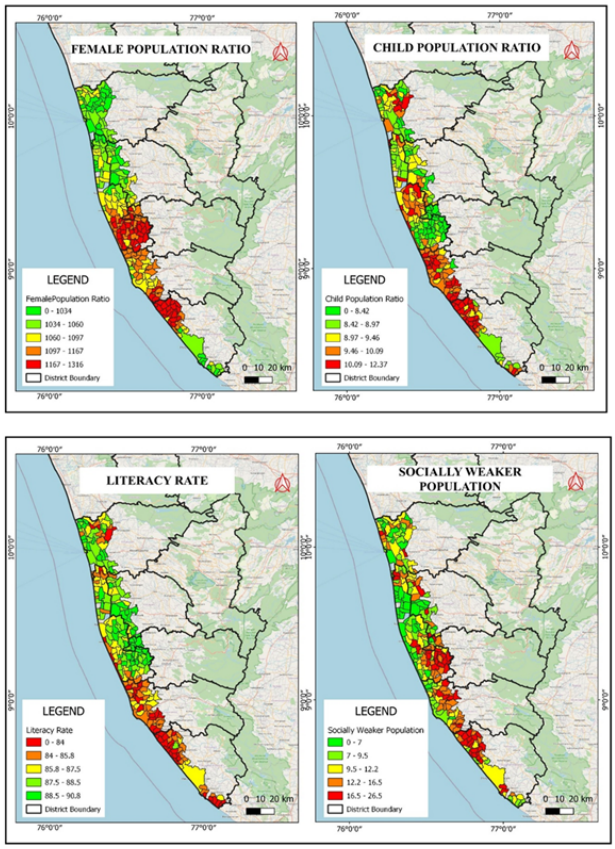

Fig. 3. Female Population Ratio, Child Ratio, Literacy Rate, Socially Weaker Population

4.1.2 Female Population Ratio

The proportion of females in a population is significant, as women may face unique challenges during disasters, including social and economic disparities. Often in times of disaster women and children are mostly vulnerable and might be found alone to tackle a risky situation. In the study villages with female population >51% are categorized as very highly vulnerable. Mavelikkara, Ayiroor, Manamboor, and Thazhuthala fall under this category (Figure 3).

4.1.3 Child Population Ratio

A higher proportion of children indicates greater vulnerability, as children are particularly susceptible during disasters due to their dependence and limited capacity to respond. In the study villages with children (between 0 -6 years) were taken and areas with child population >10% were categorized as very highly vulnerable. Kudavoor, Veiloor, Ayiroor, Sarkara are some of the villages ranked under very high vulnerability. A high number of villages in the Kollam and Thiruvananthapuram district fall under high vulnerability due to increased number of child population (Figure 3).

4.1.4 Primary Workers

This refers to individuals engaged in primary sectors like agriculture, forestry, and fisheries. These workers are often more vulnerable to natural hazards that directly impact their livelihoods. Primary workers play a crucial role in driving rural development, yet they often face significant vulnerabilities due to various insecurities and challenges. In this study villages with more than 30 percent of the working population that has primary workers are taken and are classified as very highly vulnerable population. Villages in the Alappuzha district were mostly included in this category and villages in Pathanamthitta were also included in this category. Kumarakom, Kainakary North, Veloor are some of the villages (Figure 4).

4.1.5 Socially Weaker Population

Understanding socio-economic vulnerability requires examining the proportion of socially disadvantaged groups within the total population. While it can be challenging to precisely identify the socially weaker sections in a village, census data on marginalized communities, such as Scheduled Castes (SC) and Scheduled Tribes (ST), offers a reliable estimate, especially within the Indian context. Populations marginalized due to socio-economic factors often have limited access to resources, making them more susceptible to disaster impacts.

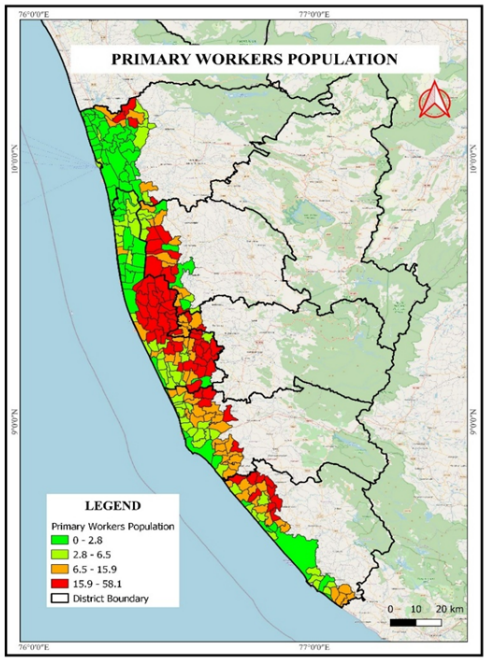

Fig. 4. Primary Workers Population

In this study a proportion of more than 20 percent of these deprived castes in villages were perceived under very high vulnerability and below 15 percent was classified as high vulnerability. Northern villages of Thiruvananthapuram and southern villages of Alappuzha district mostly come under the category (Figure 3).

4.1.6 Literacy Rate

Literacy rates play a significant role in disaster preparedness and tend to have an inverse relationship with socio-economic vulnerability—higher literacy often corresponds to lower vulnerability levels. As the average literacy rate of Kerala is 94 percent, Literacy rate below 80 percent is taken as very high vulnerability. Karode, Karumkulam, Kadinamkulam, Azhoor, Kadakkavur are some of the villages (Figure 3).

Indicators related to exposure, such as population density, household density, child population ratio, female population ratio, primary workers, and socially disadvantaged groups, were categorized into five vulnerability levels: very high, high, moderate, low, and very low. This classification assumed that higher values indicate greater vulnerability. On the other hand, literacy rates are grouped into the same levels, but here, higher values reflect lower vulnerability. To assess combined socio-economic vulnerability on a normalized scale, it is essential to assign ranks to each vulnerability class across all indicators. This approach ensures a standardized evaluation, allowing for a more accurate and comprehensive analysis of socio-economic vulnerability. (Sanchez-Martin et al., 2019). The ranges for these classes were determined using histogram distributions, ensuring the analysis was grounded in the data. In this study, vulnerability was categorized into five levels, ranked on a scale of 1 to 5, with 1 representing very low vulnerability and 5 representing very high vulnerability. The rankings assigned to each indicator for every village were added together to calculate composite socio-economic vulnerability. To simplify the analysis and identify similar vulnerability patterns, the composite scores were further classified into five categories, ranging from very high to very low vulnerability. Hotspot analysis is used to identify clusters within a specific area, where these clusters represent either high or low values of a particular variable, referred to as hot spots and cold spots, respectively in the coastal regions. To pinpoint these areas, the Getis-Ord Gi statistic was applied, a method available through the Mapping Clusters tool in the Spatial Statistics Tools suite of ArcGIS. (Sanchez-Martin et al., 2019). The spatial autocorrelation tool analyzes the ranking of each village in relation to the ranks of its neighboring villages. It evaluates whether there is a spatial pattern by testing hypotheses about the clustering of the sum of x-values associated with the j points within a specified distance (d) from the ith point. The statistics are denoted as

$$Gi(d) = \frac{\sum_{j=1}^{n} wij(d)xj}{\sum_{j=1}^{n} xj}$$

Here, w_{ij} represents a symmetric spatial weight matrix, where a value of 1 is assigned to all links within a specified distance d of a given point i, and 0 is assigned to all other links, including the self-link of point i. The statistic Gi(d) is used to assess the concentration or dispersion of village ranks based on socio-economic vulnerability variables in the coastal plains, providing insights into spatial patterns of vulnerability. Villages are classified into spatially significant hot or cold spots based on the concentration of ranks, with varying levels of confidence. Villages that have rankings notably different from those of their neighboring villages are considered statistically insignificant and do not contribute to the formation of hot or cold spots.

4.2 Composite Socio-Economic Vulnerability

The vulnerability classes of all the indices (in the scale of 1-5) were summed up to show composite socio-economic vulnerability in the study area. The summed-up ranks were categorized as very high (19-25), high (17-19), medium (15-17), low (12-15) and very low (7-12) vulnerability levels according to the analysis. The summed-up ranks were categorized as very high, high, medium, low, and very low vulnerability levels based on the histogram distribution. A total of 53 villages are under the very high vulnerability category out of which 24 villages are in Thiruvananthapuram district. Villages like Chellanam, Edavanakkad etc. in the Ernakulam district fall under the high vulnerability category according to the map (Figure 10).

Table 1. Formula and sources for computation of socio-economic vulnerability indicator

Sl No.	Categories	Subcategories	Formula
1	Population Density (PD)	Total Population	$PD = \frac{Number\ of\ Population}{Total\ Geographical\ Area}$
2	Household Density (HD)	Total Households	$HD = \frac{Number\ of\ Household}{Total\ Geographical\ Area}$
3	Female Population Ratio (FPR)	Total Female Population	$FPR = \frac{Total\ Female\ Population}{Total\ Population}$
4	Child Population Ratio (CPR)	Total Child Population (0-6 Years)	$CPR = \frac{Total\ Child\ Population}{Total\ Population}$
5	Literacy Rate (LR)	Total Literacy Population	$LR = \frac{Total\ Literates}{Total\ Population}$
6	Socially Weaker Population (SWP)	Scheduled Castes Population (SCP), Scheduled Tribes Population (STP)	$SWP = \frac{SCP+STP}{Total\ Population}$
7	Primary Workers (PW)	Main Cultivators (MC), Main Agricultural Labors (MAL), Marginal Cultivators (MrC), Marginal Agricultural Labors (MrAL)	$PD = \frac{MC+MAL+MrC+MrAL}{Total\ Working\ Population}$

Table 2. District-wise number of villages under different classes of composite socio-economic vulnerability

District/Vulnerability Class	Very Low	Low	Medium	High	Very High
Alappuzha	20	29	16	14	7
Ernakulam	16	10	6	16	1
Kollam	4	5	6	10	18
Kottayam	18	4	-	4	-
Pathanamthitta	1	4	-	1	1
Thiruvananthapuram	1	2	2	11	26
Total	60	54	30	56	53

Table 3. Percentage of District-wise number of villages under different classes of composite socio-economic vulnerability (Figures 5, 6, 7, 8 and 9)

District/Vulnerability Class	Very Low	Low	Medium	High	Very High
Alappuzha	23.3%	33.7%	18.6%	16.3%	8.1%
Ernakulam	32.7%	20.4%	12.2%	32.7%	2.0%
Kollam	9.3%	11.6%	14.0%	23.3%	41.9%
Kottayam	69.2%	15.4%	-	15.4%	-
Pathanamthitta	14.3%	57.1%	-	14.3%	14.3%
Thiruvananthapuram	2.4%	4.8%	4.8%	26.2%	61.9%

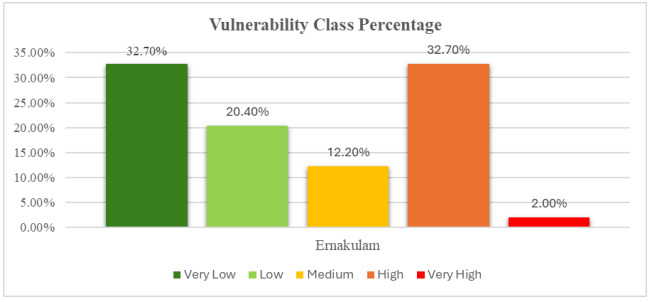

Fig. 5. Vulnerability Class Percentage of Ernakulam

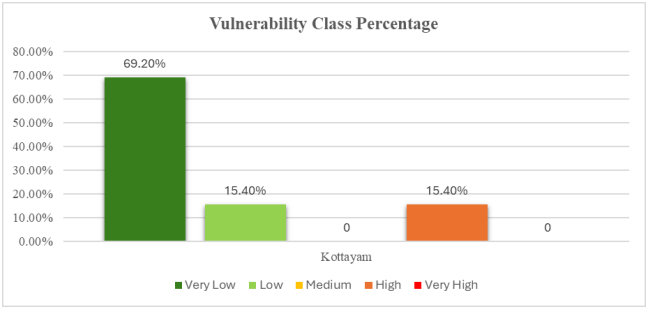

Fig. 6. Vulnerability Class Percentage of Kottayam

4.3 Hotspots of Socio-Economic Vulnerability

This study employed a comprehensive approach to identifying vulnerable coastal villages through an integrated analysis of socio-economic vulnerability rankings.

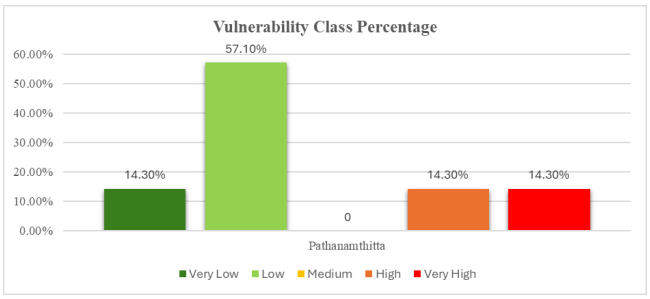

Fig. 7. Vulnerability Class Percentage of Pathanamthitta

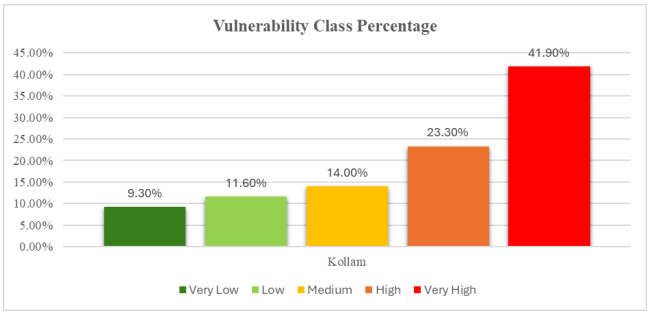

Fig. 8. Vulnerability Class Percentage of Kollam

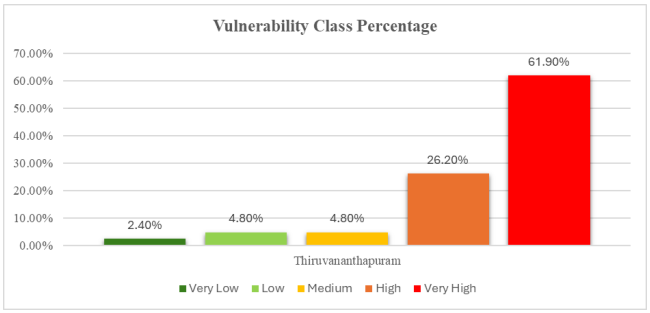

Fig. 9. Vulnerability Class Percentage of Thiruvananthapuram

A specialized hotspot analysis tool was utilized to statistically aggregate and identify villages with significant socio-economic vulnerability. Strategic clustering of high-vulnerability villages revealed critical risk patterns and potential areas requiring immediate attention. The data-driven approach ensures a systematic and rigorous understanding of community-level socio-economic challenges in coastal environments. The major hot spot with 99 per cent confidence level is formed by the villages of Ochira, Arattupuzha, Attingal, Thiruvananthapuram, Vakkam, Azhoor. A minor hot spot with 99 per cent confidence level is found in Mulavukada, Karumalloor, Udayamperur in Alappuzha district and northern part of the study area (Figure 11).

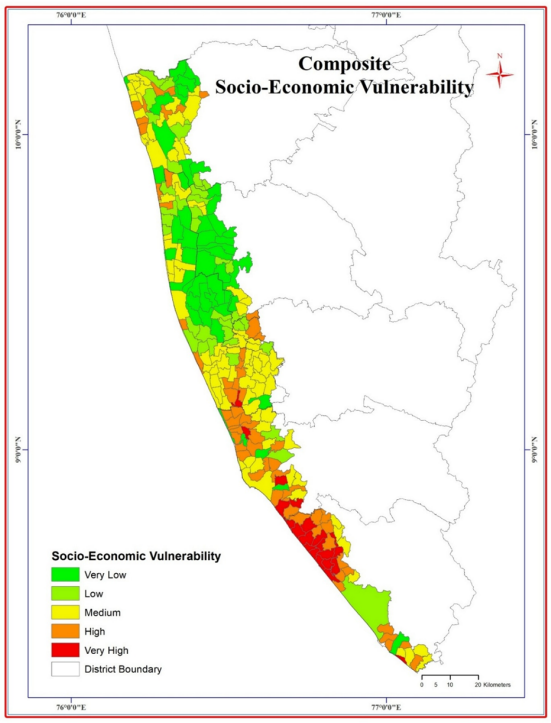

Fig. 10. Composite Socio-Economic Vulnerability Map

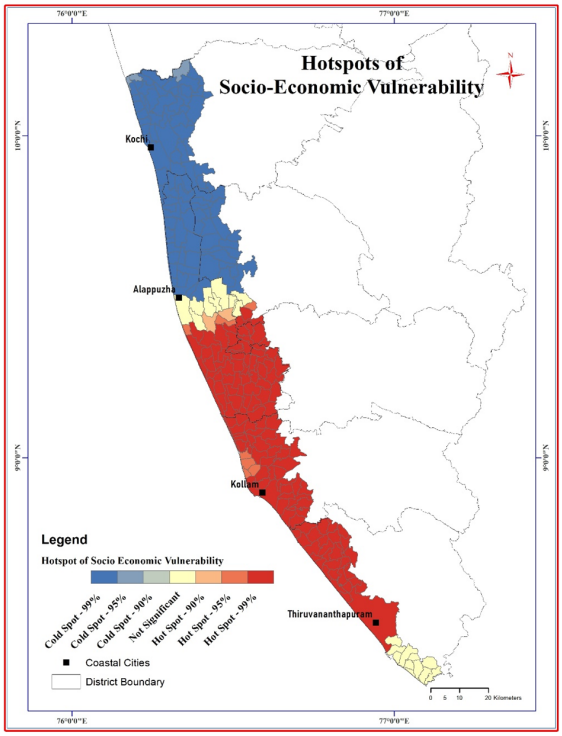

Fig. 11. Hotspots of Socio-Economic Vulnerability Map

5 Conclusion

The integrated hotspot analysis conducted in this study offers valuable insights into the spatial clustering of socio-economic vulnerability along the coastal plains of southern Kerala. Using the Getis-Ord Gi* statistic in ArcGIS, the study successfully identified statistically significant clusters, or "hot spots," where vulnerability is most concentrated. Villages such as Ochira, Arattupuzha, Attingal, Thiruvananthapuram, Vakkam, and Azhoor emerged as major hotspots, while areas like Mulavukada, Karumalloor, and Udayamperur represented smaller clusters with similarly high levels of vulnerability. These patterns, visualized through a socio-economic vulnerability map, reveal that the southern regions particularly in Thiruvananthapuram, Kollam, and parts of Alappuzha and Kottayam are more affected. Meanwhile, northern areas including parts of Ernakulam display lower vulnerability or no significant clustering. The findings highlight the importance of spatial analysis in identifying at-risk communities and can serve as a crucial tool for planners and policymakers to design region-specific interventions aimed at reducing vulnerability and strengthening community resilience.

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