GEOGRAPHICAL ANALYSIS

ORIGINAL ARTICLE

Geospatial Assessment of Flood Vulnerability in Kuttanad Taluk, Kerala

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Abstract

One of Kerala's most destructive natural disasters is flooding, which often affects the low-lying Kuttanad Taluk, dubbed the "Rice Bowl of Kerala." The "Geospatial Assessment of Flood Vulnerability in Kuttanad Taluk, Kerala" study uses multi-criteria weighted overlay analysis and sophisticated geoinformatics methods to map and identify flood-prone locations. To evaluate flood susceptibility, seven factors were chosen: elevation, slope, geomorphology, rainfall, land use/land cover (LULC), drainage density, and proximity to streams. ArcGIS 10.8.2 and ENVI 5.3 software were used to process the spatial data, which came from a variety of satellite and institutional sources, including SRTM, Sentinel-2A, GSI Bhukosh, and PERSIANN-CCS datasets. The study categorized Kuttanad into five vulnerability zones: very high, high, moderate, low, and very low. The findings showed that around 38.94 square kilometres of the region are classified as extremely high-risk. These areas are mostly found in the taluk's northern, south-eastern, and western regions, where low elevation, a moderate slope, high drainage density, and intense agricultural operations are prevalent. Together, the moderate- and high-risk areas cover more than 190 square kilometres, highlighting the taluk's significant susceptibility to flooding. The results demonstrate how useful geospatial methods are for comprehending flood dynamics and directing sustainable management. Enhancing drainage systems, creating regulatory zones alongside significant rivers, and boosting community readiness through early warning systems and awareness campaigns are among the recommendations. The study demonstrates that integrating GIS and remote sensing with multi-criteria decision analysis provides a scientific foundation for flood risk mitigation and resilient land-use planning in Kuttanad Taluk.

Keywords: Flood Vulnerability, Kuttanad Taluk, Geospatial Analysis, Weighted Overlay, Remote Sensing

1 Introduction

Natural and human-induced hazards such as floods, earthquakes, and landslides have increasingly threatened human life, property, and environmental stability across the globe[8]. Among these, floods are one of the most frequent and devastating natural disasters, often triggered by heavy rainfall, river overflow, storm surges, or dam failures. In recent decades, rapid urbanization, deforestation, and climate change have intensified flood occurrences, particularly in low-lying and poorly drained regions[14]. The growing frequency and magnitude of extreme precipitation events, coupled with inadequate land-use planning, have increased the vulnerability of human settlements to floods.

In India, flood disasters pose a major challenge to sustainable development, especially in states like Kerala,

where dense population, intricate river networks, and monsoon-dominated rainfall patterns contribute to recurrent inundations[12]. Kuttanad Taluk, often referred to as the "Rice Bowl of Kerala," is a unique below-sea-level region crisscrossed by rivers such as the Pamba, Manimala, Meenachil, and Achankovil[10]. The area's geomorphological setting, coupled with extensive agricultural activities and inadequate drainage, makes it highly prone to seasonal flooding. Repeated floods have disrupted livelihoods, damaged infrastructure, and affected the socio-economic stability of the region. Understanding the spatial distribution and degree of flood vulnerability in this area is essential for planning effective mitigation and adaptation strategies[1].

Vulnerability mapping is a crucial component of disaster management as it involves identifying and analysing areas and populations most at risk from natural hazards. It helps in understanding the spatial distribution of vulnerabilities and enhances disaster preparedness through targeted planning. By visually representing areas of high risk, vulnerability maps serve as essential tools for decision-makers, emergency responders, and communities[13]. These maps incorporate elements such as hazard intensity, exposure of population and infrastructure, and coping capacities. Remote sensing and GIS play a key role in this process by enabling accurate data collection, spatial analysis, and the generation of high-resolution maps for hazard assessment. Through these technologies, flood-prone areas can be effectively delineated, and resource allocation for risk reduction can be optimized.

Flooding in regions like Kuttanad is caused by a combination of natural and human-induced factors. Heavy rainfall, river overflow, coastal surges, and dam failures are major contributors. The flat terrain and low elevation of Kuttanad prevent effective drainage, leading to prolonged inundation during monsoon seasons. Climate change further aggravates the situation through rising sea levels and increased rainfall intensity. The consequences of flooding are multifaceted, ranging from loss of life and property to environmental degradation, agricultural loss, and public health risks[9]. Therefore, an integrated geospatial analysis that incorporates geomorphology, slope, elevation, rainfall, drainage density, proximity to river channels, and land use/land cover is vital for understanding and managing flood vulnerability in such fragile ecosystems[7, 16].

Remote sensing and Geographic Information Systems (GIS) have emerged as indispensable tools in flood zonation and risk assessment. Satellite data and aerial imagery are extensively used to monitor hydrological changes, soil moisture, and surface water extent. GIS enables the integration of multiple spatial datasets, allowing for the modelling and mapping of flood-prone areas with high precision[5, 15]. It facilitates the simulation of flood behaviour, visualization of potential inundation zones, and development of flood hazard maps useful for emergency management and infrastructure planning. Post-disaster assessments using remote sensing also help quantify the extent of damage and guide recovery efforts[11]. These technologies have thus revolutionized the accuracy and applicability of flood hazard and vulnerability mapping in disaster management frameworks.

Objectives of the Study:

The main aim of the study is to identify and map the region's which are vulnerable for flooding. This has been achieved by adopting the following objectives.

- To know the different factors influencing flood in Kuttanad.
- To prepare the flood vulnerability zonation map of Kuttanad taluk by using weighted overlay analysis.

2 Study Area

Kuttanad Taluk, located in the Alappuzha district of Kerala, is a distinctive low-lying region often referred to as the "Rice Bowl of Kerala." It is one of the few places in the world where below-sea-level farming is practiced. The region is characterized by an intricate network of rivers, canals, and backwaters, with the Pamba, Manimala, Meenachil, Achankovil, and Manimala rivers forming its major drainage system. The paddy fields, known as Padasekharams, are cultivated using traditional water management techniques involving bunds, pumps, and water wheels. Kuttanad rich agrarian culture, double-cropping system, and scenic backwaters have not only sustained its economy but also made it a prominent tourist destination. The taluk extends over an area of 289.39 sq. km, lying approximately between 9.5° N latitude and 76.4° E longitude, bordered by the vast Vembanad Lake on the west.

Climatically, Kuttanad experiences a tropical monsoon type of climate with high humidity and an average annual

rainfall of 2,500–3,000 mm, primarily received during the southwest monsoon. The average temperature ranges between 25°C and 32°C throughout the year. Due to its below-sea-level topography and proximity to major water bodies, the region is highly susceptible to flooding during intense rainfall events. According to Census 2011, Kuttanad Taluk has a population of 1,93,007, with a high literacy rate of 97.6% and a sex ratio of 1,075, reflecting Kerala's progressive social indicators. The elevation of the region varies from +42 meters to -36 meters, and the slope ranges between 0° and 77°, with most of the central and southern portions exhibiting low slopes suitable for paddy cultivation.

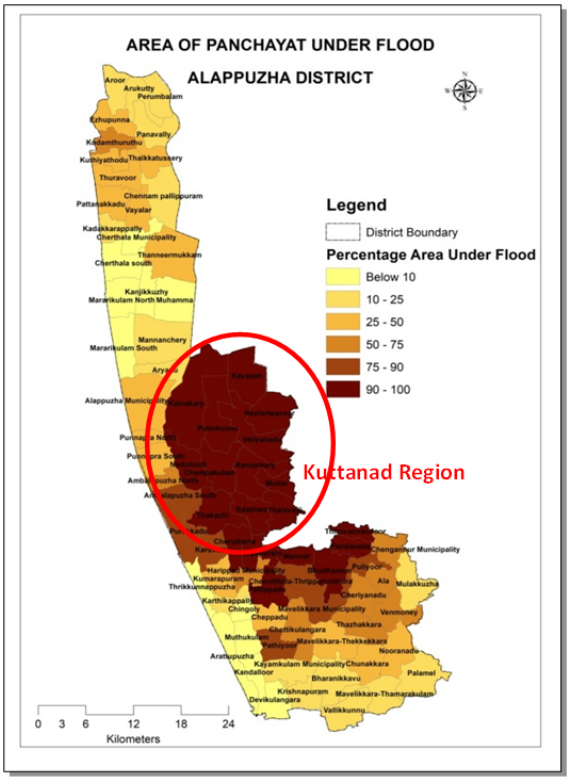


Fig. 1: Kuttanad Region

Geomorphologically, the taluk comprises diverse landforms such as back swamps, tidal flats, beach ridges, and younger coastal and deltaic plains, shaped by fluvial and marine processes. The geological composition is dominated by clay (palaeo tidal flat deposits), along with patches of sand and sandstone in the south eastern part. Drainage analysis shows that the streams generally flow east to west, with first- and second-order streams covering most of the area, while higher-order streams are concentrated in the north and east. The region is well-connected through an integrated network of roadways, railways, and waterways, enhancing its accessibility and trade potential. Overall, Kuttanad unique topography, hydrology, and socio-economic characteristics make it a critical zone for flood vulnerability assessment using geospatial techniques.

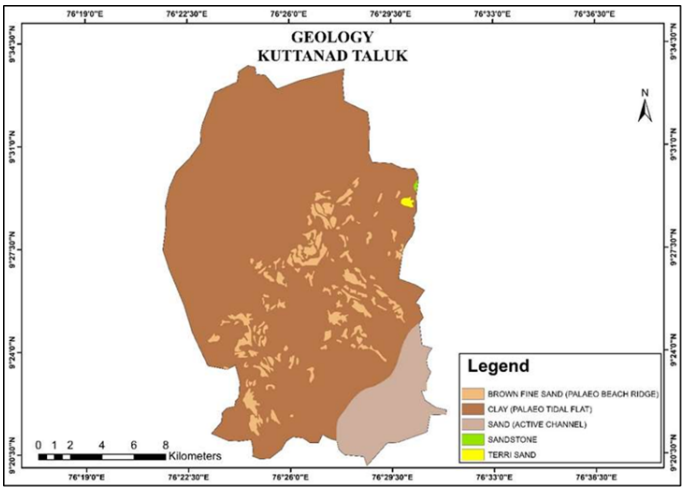


Fig. 2: Geology

3 Material and Methodology

This study completely depends on the geoinformatics software to analyse the Flood vulnerability of Kuttanad taluk. For the Flood vulnerability mapping has seven parameters Slope, Elevation, Geomorphology, Rainfall, Land use Land cover, Drainage density and Proximity from stream.

Table 1: Parameter and Details

Parameter	Satellite/ Sensor	Source	Year
Elevation	SRTM	USGS	2000
Slope	SRTM	USGS	2000
Geomorphology	-	GSI Bhukosh	2024
Rainfall	PERSIAN CCS	CHRS (data portal)	2003-2021
Land use Land cover	Sentinel 2A	ESA datahub	2024
Drainage density	SRTM	USGS	2000
Proximity from stream	SRTM	USGS	2000

The study utilized multiple geospatial datasets from various satellite and institutional sources to ensure comprehensive spatial analysis and accuracy. Sentinel-2A, developed by Airbus Defence and Space under the European Space Agency's Copernicus Programme, provided high-resolution multispectral imagery across 13 spectral bands, useful for land cover mapping, vegetation assessment, and natural disaster monitoring. Elevation data were obtained from the Shuttle Radar Topography Mission (SRTM), which offers near-global digital elevation models between 56°S and 60°N, enabling precise terrain and hydrological analysis. Geological information was sourced from the Geological Survey of India's Bhukosh platform, which provides detailed geological maps and mineral data essential for understanding subsurface characteristics. Rainfall data were derived from the PERSIANN-CCS (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks–Cloud Classification System), an advanced algorithm-based satellite system that classifies cloud patterns and estimates precipitation intensity using dynamic cloud segmentation techniques. Together, these datasets form a robust foundation for flood vulnerability assessment and geospatial modelling in Kuttanad Taluk.

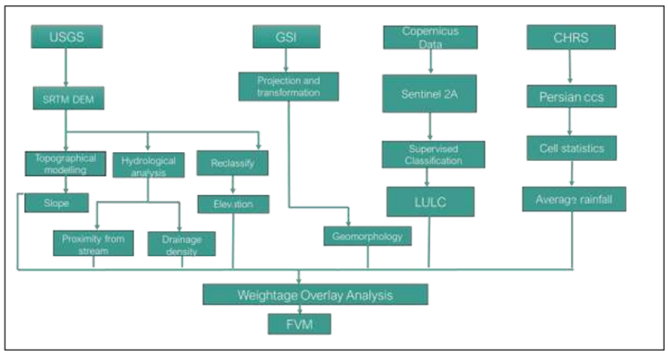


Fig. 3: Methodology Chart

The study utilized ArcGIS 10.8.2 and ENVI 5.3 software for comprehensive geospatial analysis and mapping. ArcGIS, developed by Esri, is a powerful GIS platform used for spatial data management, analysis, and visualization. It enables the integration of multiple datasets, terrain modeling, hydrological analysis, and map generation, making it essential for creating flood vulnerability zonation maps and spatial overlays. ENVI, developed by Harris Geospatial Solutions, is a leading remote sensing software designed for the processing and analysis of multispectral and hyperspectral imagery. It provides advanced tools for radiometric and atmospheric correction, image enhancement, and classification. In this study, ENVI was primarily used for pre-processing and classifying Sentinel-2A satellite data, while ArcGIS was employed for spatial integration, analysis, and visualization, together ensuring accurate and detailed geospatial outputs for flood vulnerability assessment in Kuttanad Taluk.

The study integrated multiple geospatial parameters to assess flood vulnerability in Kuttanad Taluk using data from diverse sources and analytical tools. Elevation and slope maps were generated using SRTM DEM data from the USGS portal. The elevation map classified terrain into five altitude-based categories, while the slope map, derived through ENVI's topographic modelling tool, represented surface inclinations influencing runoff and water accumulation. Geomorphology data, obtained from the GSI Bhukosh portal, were processed in ArcGIS to delineate landforms and assign appropriate ranks and weightages based on susceptibility to flooding. Rainfall data from the PERSIANN-CCS (2003–2021) dataset were processed using ArcGIS, where average precipitation was interpolated through the Kriging method to identify spatial rainfall variations. Land Use and Land Cover (LULC) mapping utilized Sentinel-2A imagery from the ESA Copernicus hub, processed using ENVI's supervised classification technique with a minimum of 50 training samples per class, followed by accuracy refinement in ArcMap. Drainage density was derived from SRTM DEM through ArcGIS hydrological analysis and stream ordering, classifying the area into five categories based on drainage concentration. Finally, proximity from stream mapping involved hydrological extraction of the main stream network and multi-ring buffering in ArcGIS to determine distance-based flood risk zones. Each thematic layer was categorized into five classes with assigned ranks and weights to support the integrated flood vulnerability assessment.

Weighted overlay analysis is a common method used to find a suitable site. In disaster management weighted overlay analysis is used to identify the places which are vulnerable to hazards. In this case weighted overlay analysis is applied to identify the map of flood vulnerability zone in Kuttanad taluk based on seven parameters and all the parameters were assigning the weightage and rank.

Table 2: Weightage and Ranking

Parameters and Class	Weight	Rank
Geomorphology		
Back Swamp		5
Back Water		5
Beach Ridge-Swale Complex		3
CosOri - Younger Coastal Plain		3
CosOri - Younger Deltaic Plain		3
Tidal Flat		5
WatBod - Lake	1.25	5
WatBod - Others		5
WatBod - Pond		5
WatBod - River		5
Drainage Density		
0 - 266.59		1
1066.36 - 1332.93		5
266.6 - 533.17		2
533.18 - 799.76		3
799.77 - 1066.35	1	4
Rainfall		
2268.2 - 2304.8		1
2414.63 - 2451.23		5
2304.81 - 2341.41		2
2378.03 - 2414.62		4
2341.42 - 2378.02	1.4	3
LULC		
Crop land		4
Open land		2
Settlement		3
waterbody	0.9	1
Elevation		
-35		5
-1.99		4
1.01 - 4		3
4.01 - 7		2
7.01 - 42	2.3	1
Slope		
58.2 - 68.5		2
24.86 - 58.19		3
.13 - 24.85	1.7	4
68.51 - 77.29		1
0 - 2.12		5
Proximity Fromstream		
<100		5
101-200		4

Parameters and Class	Weight	Rank
201-400		3
401-800		2
>800	1.5	1

4 Result and Discussion

The mapping process plays a crucial role in understanding flood risk and supporting informed decision-making for mitigation and management strategies[4]. Floods are one of the most devastating natural disasters, and Kuttanad Taluk in Kerala is particularly vulnerable due to its low-lying terrain and below-sea-level farming systems. This study analyzes the extent and impact of flooding in such areas, highlighting the severe damage to property and the loss of hundreds of human lives each year. The dissemination of flood risk information through accurate and detailed maps can significantly reduce these impacts by raising public awareness, guiding emergency preparedness, and facilitating effective planning and response measures.

Elevation:

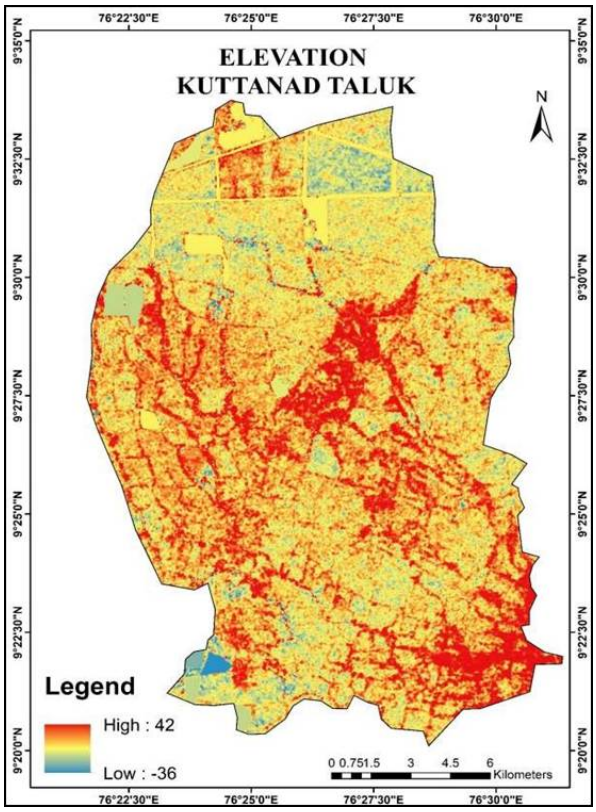


Fig. 4: Elevation

Elevation is a critical factor influencing flood occurrence, as regions with lower elevations are generally more susceptible to inundation[3]. The elevation of an area directly affects its vulnerability, with low-lying regions being at higher risk and higher areas less prone to flooding. Kuttanad Taluk, being a low-lying region below mean sea level, is particularly vulnerable to floods. According to the analysis, the lowest elevation areas, at -36 meters, are located in the northern and southern parts of the taluk, while the highest elevation zones, reaching 42 meters, are found in the southern, eastern, and western portions of the study area. This variation in elevation highlights the differential flood risk across the region.

Slope:

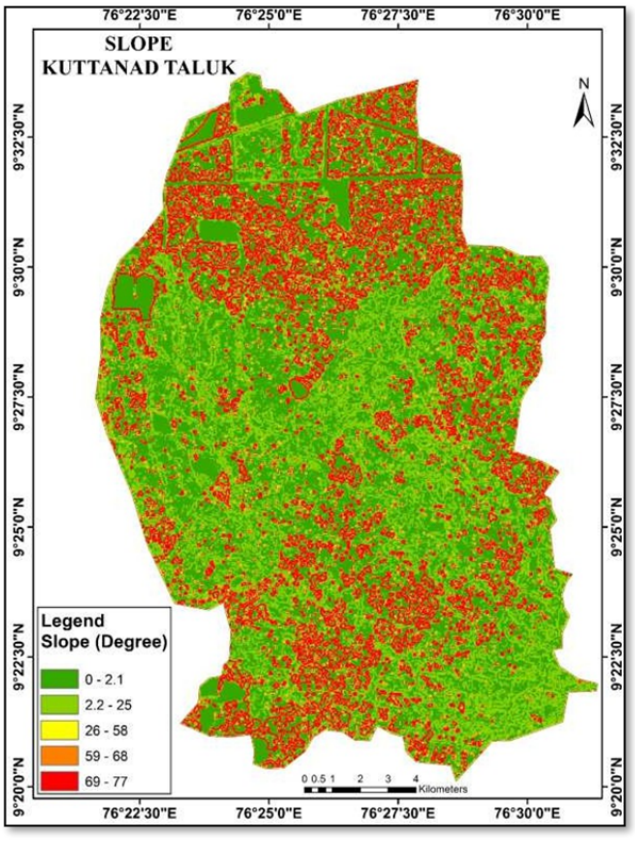


Fig. 5: Slope

Slope and topography define the shape and relief of the land, with topography representing elevation and slope indicating the rate of change in elevation over a given distance[17]. In this study, the slope of Kuttanad Taluk was derived from SRTM DEM data obtained from the USGS Earth Explorer, with slope degrees calculated using ENVI 5.0. The slope was classified into five categories: 0–2.1°, 2.2–25°, 26–58°, 59–68°, and 69–77°. Areas with lower slope values represent gentle terrain, making them more susceptible to flooding due to slower runoff, whereas steeper slopes facilitate faster water movement and reduce flood accumulation. Consequently, low-gradient areas, particularly in the lower reaches, are highly vulnerable to flood events compared to regions with higher slopes.

Geomorphology:

The geomorphology of Kuttanad Taluk was classified into ten categories: back swamp, backwater, beach ridge–swale complex, cosOri–younger coastal plain, cosOri–younger deltaic plain, tidal flat, waterbody lake, waterbody pond, waterbody river, and other waterbodies. Among these, the cosOri–younger deltaic plain dominates the landscape, followed by tidal flats and various waterbodies. These low-lying and water-associated landforms contribute significantly to the region's flood vulnerability, as they are more prone to water accumulation and inundation during heavy rainfall and monsoon events.

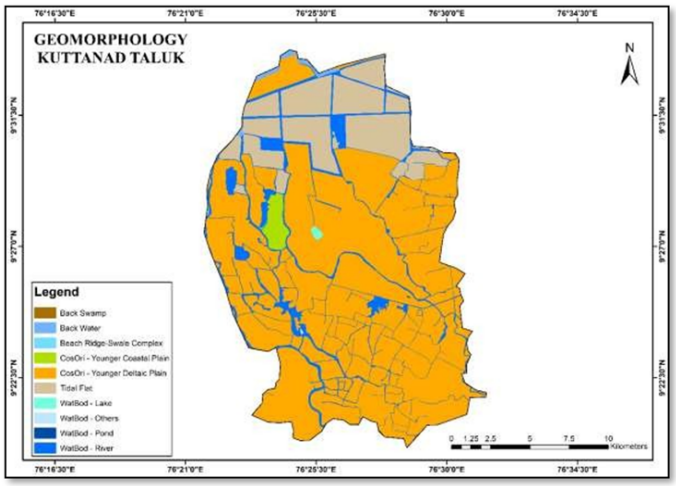


Fig. 6: Geomorphology

Rainfall:

Rainfall, defined as the precipitation reaching the Earth's surface, plays a critical role in flood occurrence, as it directly influences river discharge and water accumulation[6]. In this study, the average rainfall in Kuttanad Taluk was categorized into five classes: 2268.2–2304.8 mm, 2304.81–2341.41 mm, 2341.42–2378.02 mm, 2378.03–2414.62 mm, and 2414.63–2451.23 mm. Analysis revealed that the lower rainfall zones, receiving 2268.2–2304.8 mm, are located in the northern and western parts of the taluk, while the highest rainfall areas, receiving 2414.63–2451.23 mm, are found in the northern, southern, and eastern regions. These spatial variations in rainfall influence the flood susceptibility of different parts of the taluk.

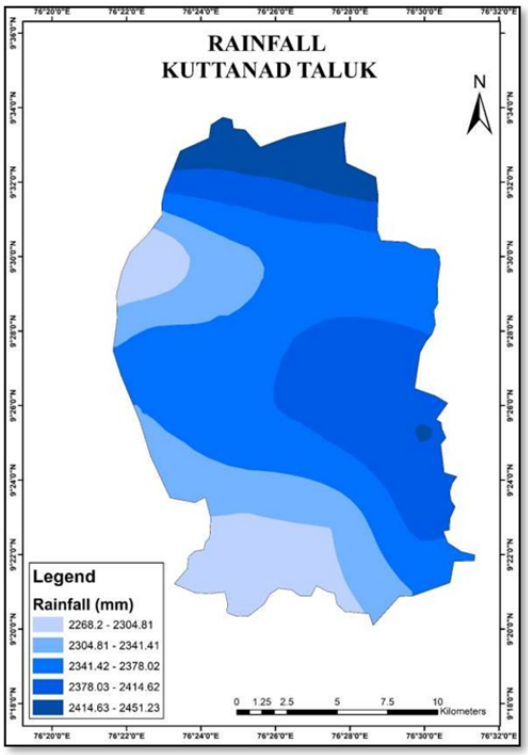


Fig. 7: Rainfall

Drainage Density:

Drainage density, derived from stream delineation using SRTM DEM data, indicates the concentration of streams within a given area and is a key factor in flood susceptibility[2]. In this study, drainage density was classified into five categories: 0–266.59, 266.6–533.17, 533.18–799.76, 799.77–1066.35, and 1066.36–1332.93 per sq. km. Areas with lower drainage density have fewer streams and thus lower water accumulation, making them less vulnerable to flooding. Conversely, regions with the

highest drainage density (1066.36–1332.93 per sq. km) experience greater water concentration and runoff, indicating a high vulnerability to flood events.

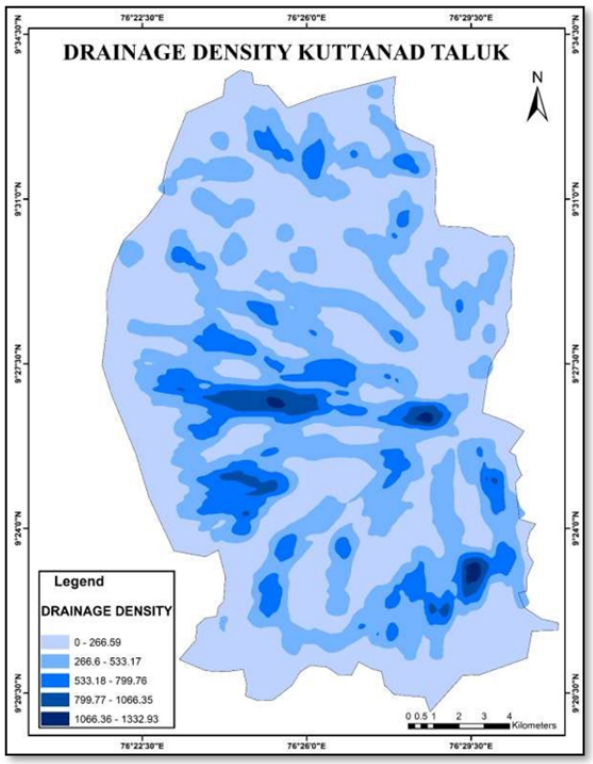


Fig. 8: Drainage Density

Proximity from Stream:

The Proximity to the main streams, particularly the highest order streams (4th and 5th order) in the sub-basin, is a crucial parameter in flood risk assessment. The distance from these main streams was classified into five categories: <100 m, 101–200 m, 201–400 m, 401–800 m, and >800 m. Areas located closer to the main rivers, within 100 meters, are at the highest risk of flooding due to their immediate exposure to rising water levels. In contrast, regions situated more than 800 meters away from the main streams face a very low flood risk, as the impact of river overflow diminishes with increasing distance from the channel.

Land Use/Land Cover:

Land use and land cover (LULC) provide critical information for flood vulnerability assessment, as they reflect both the physical characteristics of the land and how it is utilized by humans. In this study, the LULC map of Kuttanad Taluk was generated using Sentinel-2A imagery from the Copernicus Data Hub and processed through ENVI software using a supervised image classification technique. The area was classified into four categories: cropland, open land, settlements, and waterbodies. Cropland dominates the region, covering 183.466 sq. km, followed by open land at 58.647 sq. km. Settlements occupy a smaller portion, while waterbodies cover the least area, 15.449 sq. km. This classification highlights that flood vulnerability is higher in low-lying cropland and open areas, which are more prone to water accumulation during flood events.

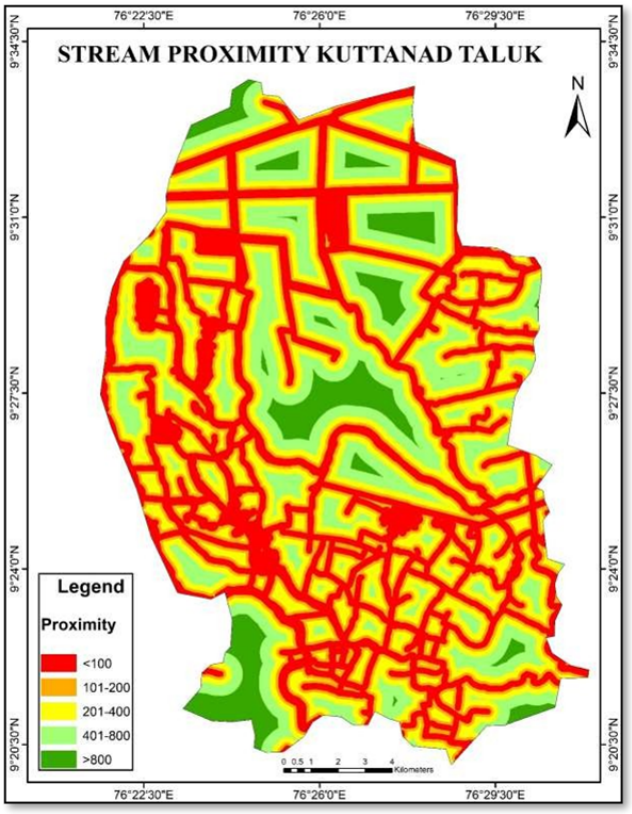


Fig. 9: Stream Proximity

Flood Vulnerability Map:

Floods Floods are among the most frequent and destructive natural disasters, occurring when water overflows and submerges areas that are typically dry. They can result in extensive loss of life, property damage, and disruption to livelihoods, infrastructure, and public utilities. Kuttanad Taluk, with its unique low-lying terrain and below-sea-level paddy fields, is particularly susceptible to flooding, making flood risk assessment critical for effective planning and disaster mitigation.

In this study, flood vulnerability mapping was carried out using a weighted overlay analysis of multiple parameters including elevation, slope, geomorphology, drainage density, proximity to streams, rainfall, and land use/land cover. The resulting flood vulnerability map was categorized into five distinct risk zones: very high, high, moderate, low, and very low. By overlaying this analysis onto the administrative boundaries of Kuttanad Taluk, it was possible to spatially identify areas with varying degrees of flood risk.

The results indicate that a significant portion of the taluk is highly vulnerable to flooding. The very high-risk zones, covering 38.94 sq. km, are concentrated primarily in the northern, south-eastern, and western parts of the taluk. These areas are characterized by low elevation, gentle slopes, high drainage density, proximity to major streams, and intensive agricultural land use, making them highly prone to inundation. The high-risk zone, spanning 93.3 sq. km, extends over large portions of the northern and south-eastern areas, reflecting regions where one or more flood-contributing factors combine to create substantial risk.

Moderate-risk zones account for 96.86 sq. km and are mainly found in the central, south-eastern, and western portions of the taluk. These regions exhibit a balance of moderate elevation, slope, and distance from main rivers, which slightly reduces their flood susceptibility compared to the high-risk zones. Low-risk zones, covering 60.77 sq. km, and very low-risk zones, covering 15.13 sq. km, are primarily located in the central and southern areas of the taluk, where higher elevation, steeper slopes, and greater distance from rivers decrease flood exposure. The flood vulnerability mapping highlights that the majority of Kuttanad Taluk is exposed to medium-to-high flood risk, emphasizing the need for targeted mitigation strategies. These include strengthening embankments, improving drainage systems, implementing early warning systems, and educating the local population about flood preparedness. The spatially explicit information provided by this analysis can serve as a critical tool for local authorities, planners, and disaster management agencies to prioritize interventions and allocate resources effectively, ultimately reducing the adverse impacts of floods on life, property, and livelihoods.

The map [Fig. 10] shows the high-risk zone, which is 38.94 sq. km and the second most predominant class is moderate risk zone which is 96.86 sq. km and the very low risk zone, which is 15.13 sq.km. Kuttanad taluk mostly covered by crop land and open land also and there is low elevation and slope. Then there is high in flooding, The areas which is high in elevation and slope found with in moderate there is low risk for flood.

Table 3. Area of each flood vulnerability class

Class Name	Area (Sq. Km)
Very low	15.13
Low	60.77
Moderate	96.86
High	93.3
Very high	38.94

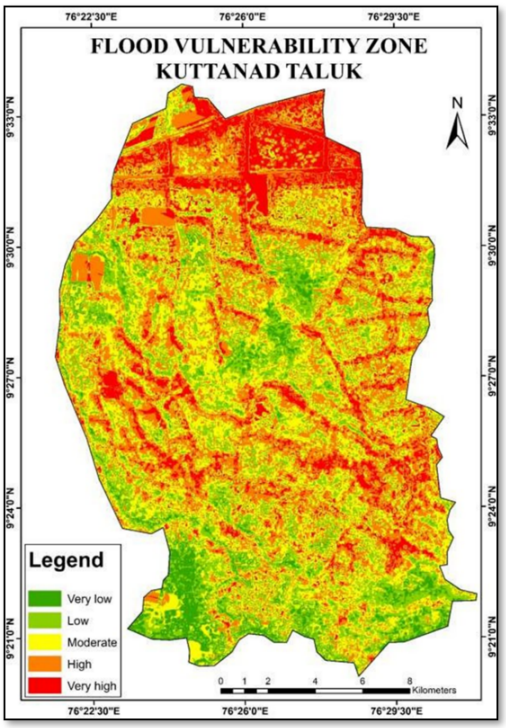


Fig. 10: Flood Vulnerability Zone

5 Conclusion

The study concludes that flooding is a severe and recurring natural hazard in Kuttanad Taluk, posing major threats to life, property, and infrastructure. Through the application of geospatial techniques and multi-criteria analysis, the research effectively identified and mapped flood vulnerability zones based on key parameters such as elevation, slope, geomorphology, rainfall, drainage density,

proximity to streams, and land use/land cover. The results reveal that large portions of Kuttanad fall under high and very high flood risk zones, mainly due to its low-lying terrain, heavy rainfall, and inadequate drainage systems. The findings highlight the importance of geospatial tools in understanding flood dynamics and supporting sustainable disaster management. To mitigate flood impacts, it is crucial to establish regulatory systems along major rivers like Pamba and Manimala, enhance drainage infrastructure, restrict construction in flood-prone areas, and conduct regular maintenance of waterways. Additionally, educating the public on flood risks, safety measures, and evacuation plans will strengthen community preparedness and resilience. Overall, the study demonstrates that integrating scientific mapping with effective planning and public awareness can play a transformative role in reducing flood vulnerability and promoting sustainable development in Kuttanad Taluk.

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