LANDSLIDE PRONE AREA IDENTIFICATION OF WAYANAD DITRICT USING GIS

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Abstract

Wayanad, a hilly district in Kerala, is part of the Nilgiri Biosphere Reserve, known for its biodiversity and ecological importance. With an area of 2131 sq.km, 40% of which is dense forest, the region is highly prone to natural hazards, particularly landslides during the monsoon season. On August 8, 2019, a massive landslide occurred in Puthumala, a plantation village located 20 km from Kalpetta. Triggered by intense rainfall, the landslide, originating at an elevation of 1230 meters above sea level, displaced approximately 20 hectares of land, moving it over 2 km, causing severe damage to life and property. This study investigates the key factors contributing to the landslide, focusing on topography, lithology, geological structures, slope relief, land use, and land cover. Using GIS (Geographic Information System) software, geospatial data layers are analyzed to assess the environmental factors that led to

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the event. Rainfall data indicates that the region received 500 mm of rainfall in just 24 hours before the landslide, highlighting the significant role of weather patterns in landslide incidents. The findings of this study will offer valuable insights into landslide susceptibility in Wayanad, enabling better land-use planning, disaster risk management, and mitigation strategies. By employing GIS-based mapping and analysis, this research aims to enhance the region's resilience, promote sustainable development, and improve preparedness for future natural disasters, ensuring the safety of vulnerable communities in Wayanad.

1 INTRODUCTION

Landslides are a significant natural hazard that affect hilly and mountainous regions, often resulting in severe damage to infrastructure, loss of life, and destruction of livelihoods. A landslide is defined as the downward movement of rock, debris, or earth under the influence of gravity, and its impact is particularly devastating in areas characterized by steep slopes, high rainfall, and anthropogenic activities. As populations increasingly settle in vulnerable hilly regions, understanding landslide risk and identifying prone areas is critical for mitigating its adverse effects.

In Kerala, the year 2018 witnessed one of the most catastrophic natural disasters in recent history, with widespread flooding and landslides caused by intense monsoonal rainfall. The monsoon depressions in the Bay of Bengal led to excessive rainfall, especially in the hilly districts of Kerala, including Wayanad, which faced severe landslides, mudslides, and subsidence. The impact was particularly devastating in the district of Wayanad, where six lives were lost, numerous homes were destroyed, and agricultural land was severely damaged. Over half of the district was affected by these landslides, significantly impacting the local population's livelihoods and exacerbating the region's vulnerability to future disasters[1].[2]

Among the most significant incidents was the Puthumala landslide, which, despite starting as a small failure deep inside the forest, became catastrophic due to a combination

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of factors. The soil in the lower regions was saturated with water, causing the hillside to collapse, resulting in a massive landslide that displaced approximately 20 hectares of land. Several factors contributed to the occurrence of landslides in the region, including high rainfall intensity, deforestation, shallow soil depth, cardamom farming on steep slopes, and unscientific construction practices. The 2018 disaster revealed the vulnerability of hilly areas like Wayanad to both natural and anthropogenic influences, underlining the urgent need for landslide risk assessment and mitigation planning.

To address this challenge, Geographic Information Systems (GIS) have emerged as powerful tools for identifying landslide-prone areas by integrating spatial data on topography, soil composition, rainfall, land use, and vegetation cover. GIS-based landslide susceptibility mapping has proven effective in identifying high-risk zones by analyzing multi-layered geospatial data[3].[4] Several studies have demonstrated the application of GIS for landslide hazard assessment in similar regions. For example, a study by[5] used GIS to map landslide-prone areas in the Western Ghats, integrating factors such as slope gradient, soil depth, and land use. Similarly,[6] applied a GIS-based multi-criteria decision-making (MCDM) approach to identify landslide susceptibility zones in Kerala, highlighting the role of rainfall, deforestation, and human activities in exacerbating landslide risks.

In particular, GIS-based models can analyze and visualize the spatial distribution of landslide susceptibility across different scales, providing valuable insights for risk assessment and land-use planning. Studies such as those by[7] have shown that GIS tools can accurately predict landslide-prone areas by combining physical factors (e.g., slope, elevation, soil type) with environmental variables (e.g., rainfall, vegetation cover), ultimately contributing to disaster preparedness and resilience building. Furthermore, [8] demonstrated the effectiveness of GIS in assessing the influence of anthropogenic activities, such as agriculture and construction, on landslide occurrence, emphasizing the need for sustainable land management practices.

Given the critical role that landslides play in the region's environmental dynamics and

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the increasing vulnerability of Wayanad to such disasters, this study aims to utilize GIS technology to identify landslide-prone areas within the district. By integrating topographical, geological, and land use data, the study will offer crucial insights for improving landslide risk management, enhancing disaster preparedness, and guiding sustainable land-use practices in Wayanad. Through GIS-based mapping, this research will contribute to the development of more resilient communities and better disaster mitigation strategies in one of Kerala's most vulnerable districts.

1.1 LOCATION OF STUDY AREA

Wayanad is one of the hilly districts of Kerala. This strategic region of the Western Ghats is part of the Nilgiri biosphere reserve known globally for its rich biodiversity. The total land area of the district is 2131 Sq.km. The district has, 852 Sq. Kms of forest forming 40% of the total land area. 1280 Sq.km of the total area is used for agriculture, housing and other developmental needs. As per the 2011 Census, the total population of the district is 8,17,420 and 18.53% of which is Adivasi communities. The population of Wayanad is basically agrarian with majority of the working population depending on agriculture as cultivators or labourers. The economy is solely based on agriculture and dairying (Wayanad Initiative 2006). The growing tourism sector also contributes to the economy. Wayanad is among the districts that has experienced farmer indebtedness and suicides due to the crisis in the agricultural sector. The local climate change aggravated by intensive farming, land fragmentation and loss of biodiversity has also led to reduction in farm productivity and income during last two decades. The district is facing acute drought and changes in the pattern of monsoon in last two decades, adding to the farmer distress.

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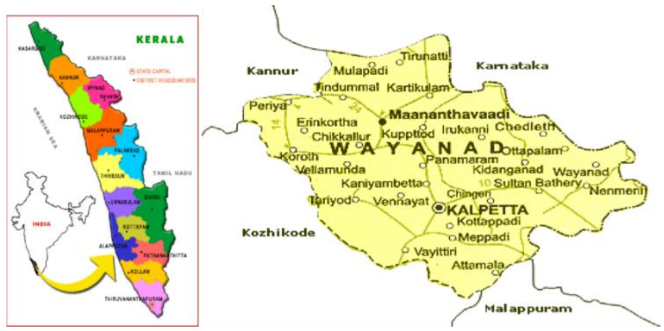

Figure 1: **Location map**

2 OBJECTIVE AND METHODOLOGY

2.1 Objective of the study

- To find the root cause for the recent landslide in Wayanad using GIS
- To analyze the land slide map and studying the critical mass movement activity of the study area.

3 METHODOLOGY

In the present study **f** ollowing factors were considered for the study:

- Topography
- Lithology.
- Slope morphology.
- Land use and Land cover.
- Hydrogeological condition
- Elevation
- Drainage

2.1 TOPOGRAPHY

The arrangement of natural and artificial physical features in an area is generally referred to as its topography. The topography of an area plays a crucial role in landslide risk

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mapping, as the presence of hills and steep slopes significantly increases the likelihood of landslides. Wayanad, nestled in the Western Ghats of Kerala, is characterized by a diverse and captivating topography, with rolling hills, fertile valleys, and lush plateaus. Elevations in the region range from 700 to 2,100 meters, and it is home to prominent peaks such as Chembra and Banasura, which offer breathtaking views and popular trekking opportunities. The landscape is interspersed with dense forests, rivers like the Kabini and its tributaries, and fertile lands that support thriving spice, coffee, and tea plantations. The cool climate, combined with features like the Edakkal Caves and sprawling meadows, enhances Wayanad's appeal as a hub of natural beauty and ecological richness.

Prior to the 2024 landslide, Wayanad's topography was characterized by its undulating hills, valleys, and plateaus, with elevations ranging from 700 to 2,100 meters above sea level. The natural terrain supported dense forests, fertile agricultural lands, and a well-established drainage system. However, the 2024 landslide caused significant alterations in certain areas, resulting in large-scale soil erosion, changes in slope morphology, and the formation of scarred landscapes. Some valleys were filled with debris, while new gullies and unstable slopes emerged, disrupting the natural balance of the terrain. These changes underscored the vulnerability of the region's topography to extreme climatic and geological events.

3.1 LITHOLOGY

Lithology is defined as the study of the types, characteristics, and distribution of rocks in a particular area, and it plays a significant role in landslide risk assessment. The lithology of a region directly influences the likelihood of landslides; areas with soft, weak rocks or soils are more prone to landslides, while regions with hard, massive, and compacted rocks are less susceptible. In the case of Wayanad, the region's lithology predominantly consists of ancient Precambrian rocks, including gneisses, schist's, and charnockites, which form the backbone of its rugged and undulating terrain. These rocks are known for their relative

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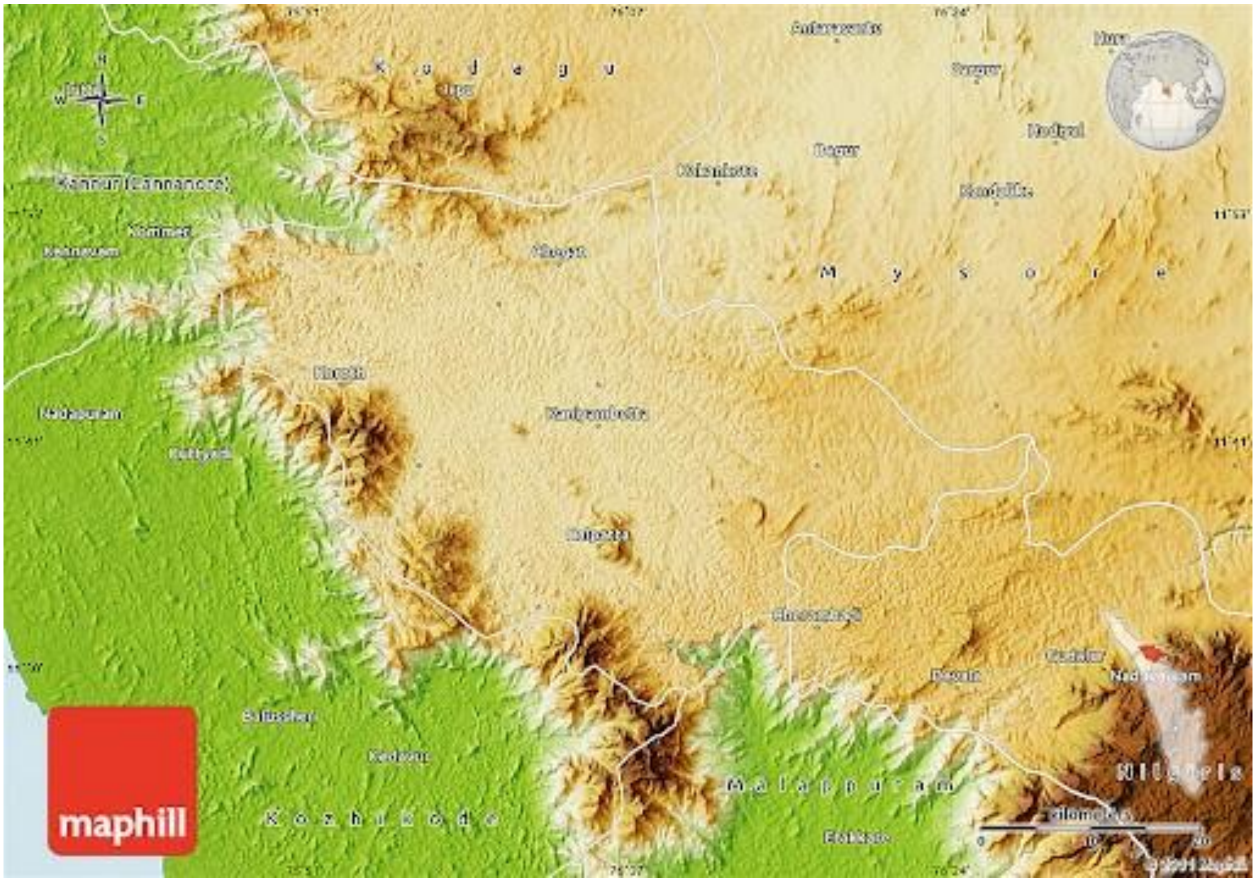

Figure 2: **Topography Map**

hardness and stability, which contribute to the area's overall structural integrity. The region is also characterized by laterite soils, which result from intense weathering of the underlying rock. These soils are not only significant for the region's agricultural productivity but also contribute to its unique geological features. In addition, Wayanad is home to significant mineral deposits, including gold and bauxite, further underscoring the geological importance of the area. Together, the lithology and the undulating landscape of Wayanad support diverse ecosystems and have been integral in shaping the area's natural and cultural history.

However, the 2024 landslide exposed deeper rock layers and disrupted the lithological structure in several affected areas. Large volumes of lateritic soil and weathered rock were displaced during the event, leading to increased sedimentation in the region's rivers and valleys. The disruption also created unstable slopes and rockfalls, significantly altering the natural lithological balance. This highlighted the vulnerability of the region's geological

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features to extreme events, underscoring the need for sustainable land-use practices and better management of the natural resources to prevent further degradation of the region's fragile lithological structure.

3.2 SLOPE MORPHOLOGY

Slope morphometric maps define slope categories based on the frequency of occurrence of specific slope angles in a given area. The slope of an area is directly proportional to the likelihood of landslide occurrences. Generally, the steeper the slope, the higher the risk of a landslide. In contrast, flatter ground with a slope angle of less than 15 degrees significantly reduces the chances of landslide events. Slope categories are typically classified as very gentle slope, gentle slope, moderately steep slope, steep slope, and cliff. In the study area of Wayanad, the slope angles vary from 0 to 60 degrees, with some areas dominated by steep slopes, while others feature gentler gradients. The flatter, less sloped areas are considered less hazardous due to their low gradient, which mitigates landslide risks. However, certain sections within these areas also include moderately steep or gentle slopes, where landslide risks remain significant. The western boundaries of Wayanad, characterized by moderately steep to steep slopes, are particularly hazardous and prone to landslides, especially during heavy rainfall events. These areas are more vulnerable due to the combined effect of steep terrain and intense monsoonal rains.

Before the 2024 landslide event, Wayanad's slopes were predominantly characterized by gentle to steep gradients, shaped by the undulating topography of the Western Ghats. These slopes supported dense forests, plantations, and settlements, with the stable vegetation cover playing a crucial role in preventing soil erosion. However, the 2024 landslide significantly altered the slope morphology in the affected areas. Steep slopes became even more unstable due to large-scale soil displacement, leading to the formation of exposed scarps and new gullies. In some regions, the slope was flattened as debris accumulated, while other areas became increasingly prone to further erosion and future landslides. These changes

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underscored the urgent need for improved slope management and soil conservation practices to mitigate the risk of landslides in the future. Proper land-use planning, along with sustainable agricultural practices and reforestation efforts, will be critical in reducing the impact of such events moving forward.

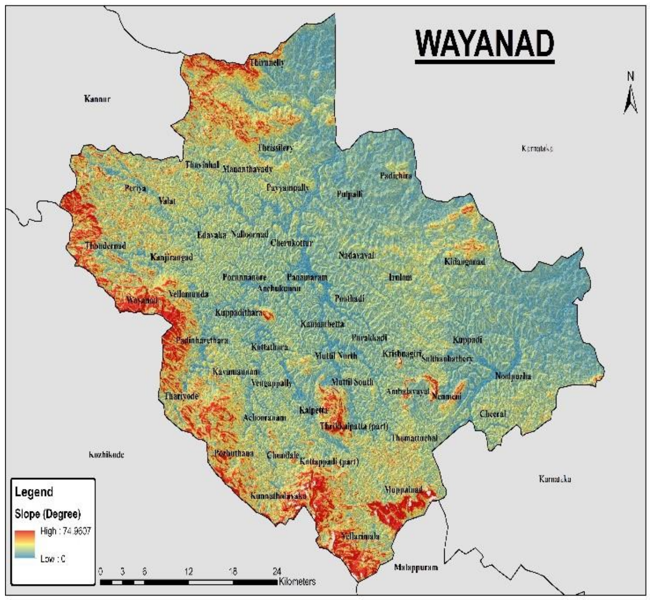

Figure 3: **3: Slope Map**

3.3 LAND USE AND LAND COVER

The nature of land cover is an indirect indication of the stability of hill slopes. Forest covers in general smoothers the action of climatic agents on the slope and protects them from the effects of weathering and erosion. A well spread root system increases the shearing resistance of the slope material. The barren and sparsely vegetated areas show faster erosion and greater instability. Agriculture in general is practiced in low to very low slopes though moderately steep slopes are also used at some places. However, the agricultural lands represent areas of repeated artificial water Stable. The boundaries of the district are covered densely with thick vegetated area. The land use and land cover of Wayanad are characterized by a mix of natural forests, agricultural land, plantations, and built-up areas. Dense tropical and deciduous forests dominate a significant portion, supporting rich biodiversity and ecological

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balance. Agriculture is a major activity, with land primarily used for cultivating rice, spices, coffee, and tea. Plantations of rubber, areca nut, and coconut also contribute to the economy. Additionally, the district features grasslands, water bodies, and human settlements. The harmonious blend of natural and managed landscapes makes Wayanad a unique region with both environmental and economic significance. However, the 2024 landslide caused widespread disruption, with forested areas being destroyed, agricultural fields buried under debris, and plantations damaged. New barren lands and exposed soil surfaces emerged in affected zones, reducing vegetation cover and increasing erosion risks. These changes underscored the importance of sustainable land-use planning and afforestation efforts to restore the ecological balance of the region.

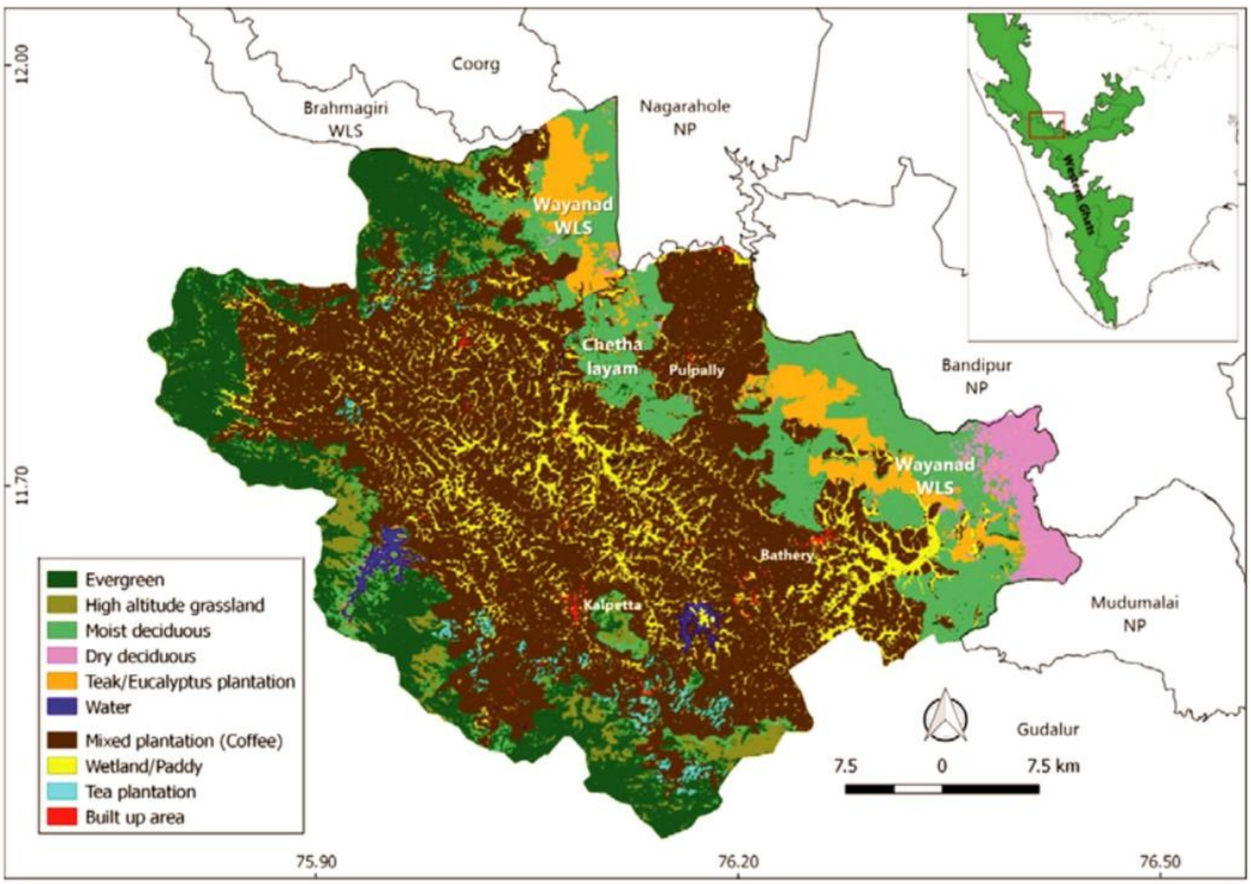

Figure 4: **4: Landuse and Landcover Map**

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3.4 HYDROGEOLOGICAL CONDITIONS

In hilly terrains, groundwater flow is often irregular, influenced by structural discontinuities in rocks, making large-scale evaluation challenging. Due to field access limitations, surface indicators such as dampness, wet patches, dripping, and flowing water were used to assess groundwater conditions in Wayanad. The region's hydrogeological conditions are shaped by its topography, geology, and climate, leading to a diverse water resource profile. Groundwater is primarily found in weathered and fractured zones of Precambrian rocks like gneisses and schist's, with laterites also functioning as aquifers. Wayanad is well-drained, and its rivers, including the Kabini and its tributaries, contribute significantly to surface water availability. High rainfall aids groundwater recharge, but the uneven terrain results in varying distribution patterns. Springs and wells support agricultural and domestic water needs, although careful management is needed for sustainability. After the 2024 landslide, Wayanad's hydrogeological conditions changed dramatically. Terrain disruption blocked natural infiltration pathways in some areas while creating new recharge zones in others. Springs and wells in affected regions experienced reduced yields or contamination from sediment deposition. River courses were obstructed, causing temporary waterlogging and altered surface water flow. These impacts underscore the need for improved watershed management and groundwater monitoring to maintain sustainable water resources and resilience against future disasters.

3.5 ELEVATION

Elevation refers to the height of a location above or below mean sea level. It is often represented on maps using contours or by labeling specific elevations. Wayanad, known for its hilly terrain and lush greenery, has elevations ranging from around 700 meters to over 2,100 meters above sea level. The district, with its rolling hills and steep slopes, is a popular destination for nature lovers and tourists.

However, after the catastrophic landslide in 2024, the landscape was drastically altered.

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Areas with already unstable slopes experienced significant erosion, reshaping the landforms and increasing vulnerability in elevated regions. The once lush hills now bear the scars of the disaster, with shifts in elevation due to debris and shifting land. This has raised concerns about the safety of settlements in high-altitude areas, especially as erratic weather patterns become more frequent, making these regions more prone to further instability and landslide risks.

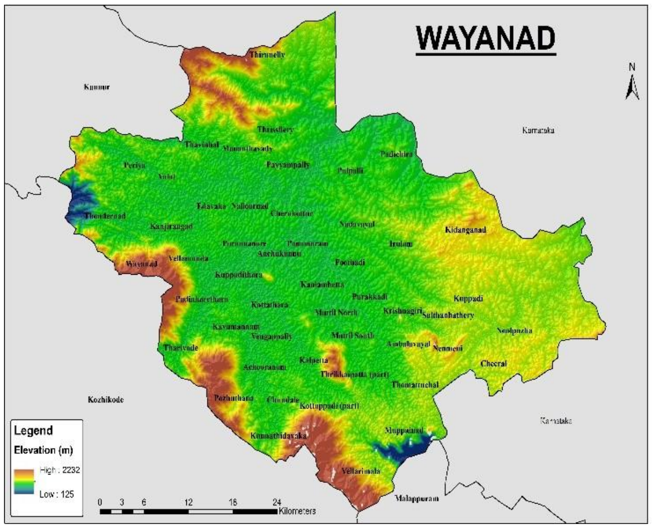

Figure 5: **Elevation Map**

3.6 DRAINAGE

Drainage refers to the natural or artificial removal of excess surface and sub-surface water from an area. Wayanad, located in the Western Ghats of Kerala, features rugged terrain, steep hills, valleys, and heavy rainfall, making its drainage system critical for the region's ecology, agriculture, and flood/landslide risk management. The district's drainage system is mainly governed by its topography and abundant rainfall. The Kabini River, a tributary of the Cauvery, flows through Wayanad, alongside tributaries like the Panamaram and Mananthavady rivers. The drainage pattern is primarily dendritic, shaped by the region's geology and landscape. Numerous streams and springs originating from the Western Ghats support the fertile lands and agriculture.

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Before the 2024 landslide, Wayanad's drainage system was efficient, with a well-organized river network sustaining agriculture and ecology. However, the landslide drastically altered the system. River courses were blocked, leading to waterlogging and the formation of new channels and temporary ponds. Increased sedimentation impacted water flow and quality. These disruptions highlighted the need for improved watershed management and disaster mitigation strategies in the region.

Figure 6: **Landslides at site 1:Kavalappara, Malappuram District, Kerala**

4 RESULTS AND DISCUSSION

4.1 CAUSATIVE FACTORS:

4.1.1 THE CATCHMENT APPROACH:

The Chaliyar River was flooded because of incessant rains for four consecutive days, followed by heavy torrential rains on the fifth day, at both Kavalappara (site 1) and Puthumala (site 2). Both the sites fell within the same drainage basin of the Chaliyar River, inparts of Malappuram and Wayanad districts of Kerala. In addition to the rising levels of flood waters,

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the river was simultaneously charged heavily with huge amount of debris and loose earth materials. These materials were mainly sourced from the downslope mass wasting, in the upper catchment of the drainage basin (from Puthumala region in the north). The Archaean rocks, exposed in the riverbed, were easily erodible along the structurally weak planes, joint sets, and fractures. The riverbed was loaded with very large boulders, indicative of excessive discharge and high stream power of the deluge. Angularity of well-cut large blocks of rocks indicates original structural influence on dislodgement and transport of rock boulders, under rapid, forceful flow of water. The presence of large boulders, seen as rolling and traction load, had the potential to down-cut slopes during sheet wash, and ferociously erode the stream banks causing aggravated devastation in the floodplains, further down-stream.

4.1.2 THE EXTREME WEATHER EVENT:

High floods were very sudden and unprecedented in the study area. Human settlements along the path of the river were vulnerable to perilous living. Other houses constructed closer to the riverbanks were also damaged during the deluge of the extreme weather events. In some places, the slopes were abruptly truncated, possibly because of road widening; few shallow slumps and earth flows were noticed along the major transport corridors in the area.

4.1.3 THE STRUCTURAL CONTROL:

Structurally, the upper catchment sections of the landslide-affected area were predisposed to mass-failure hazards. They were contributed by factors such as the originally steep natural topography, relatively deep weathering, and incompetent residual alteration products that envelop around the cores of unaltered Archaean rocks. Additionally, the existence of structural discontinuities, such as faults and closely spaced joint sets, master fractures, and large lineaments, has made the area, dissected terrain, susceptible to mass movements during the excessive rains.

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4.1.4 ENHANCED EROSIVE POWER OF FLOODED RIVER:

The river bank and toe erosion were enhanced by the flooding of higher order Chaliyar River, flowing down-stream near Kavalappara. Loading of coarse clastic sediments and debris-charged high velocity flowing water, received from the upper catchment of the river in Wayanad region to the north, intensified their erosive powers in the adjoining Puthumala. Other geoscientific factors included degraded cohesive strength of the super saturated soil and weathered zone that accentuated the flowage and toe erosion, by naturally organized but a thropogenically disrupted network of streams.

4.1.5 HUMAN INTERVENTIONS:

Degrading anthropogenic activities, such as unplanned tree-cutting, high bench terracing, adverse modification of slope, and indiscriminate construction of houses, across the active first-order channel courses and within active floodplain of higher order streams, were vulnerable to natural processes of erosion and destruction, precipitated by heavy downpour. At Kavalappara, the land was observed to be wet, with surface runoffs flowing in a network of small streams. The exceptionally high flood levels in the river resulted in cutting through its own banks and creation of post-flood braided channels that course through several channel bars of the bed-load of very coarse gravel and boulders. At the Puthumala, the water flows through the channel, where the drainage courses were obstructed by careless human interventions. The houses constructed within the active river flood plain were dislodged by the on rush of flood waters; the drainage culverts across the road were not properly located to drain effectively. Therefore, a lot of damage to property could have been avoided by proper application of sound civil geotechnical engineering.

Secondly, plenty of rainwater was observed running over the sloping mountainous roads due to lack of properly engineered drainage system which is needed to be laid through well-maintained hill-side trenches 2696 so that surface runoff water is suitably channelized and outlet is created at appropriate sites by considering the geomorphology and discharge

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characteristics of the area.

4.2 SUGGESTED REMEDIAL MEASURES:

1. Remedial measures in human settlements and crucial in stallations susceptible to landslides include adoption of scientific land use practices and regular scrutiny of geoscientific and meteorological machine data essential for making informed decisions.

2. Natural drainage courses need to be kept clear of slope modifications, leveling, improper terracing, and alternate land uses. All drainage channels need to be cleared of the runoff debris to enable smooth channelized flow of surface water.

3. Construction of houses along hazardous zones prone to flooding must be strictly avoided.

4. Natural afforestation should be taken up for stabilization of the slopes and restoration of ecological balance.

5. Monitoring of rivers for floods in the area should be considered for prediction of multiple hazards and disaster risk reduction.

6. Disaster risk awareness and preparedness by the people in the hazard prone and affected areas are important considerations for hazard management. A participatory approach and community resilience model for risk management need to be implemented in landslide hazard zones.

7. Effective and accurate exchange of information between the stakeholders; i.e., risk communication is required which is the central part of disaster risk management. This could help in the dissemination of heightened risk awareness and promotion of protective and cooperative behavior. Public preparedness towards a structured, coordinated response fosters credibility among the stake holders, i.e., individuals, community, and institutions. People should be involved in risk management, right from the beginning of risk management, by regular conductance of workshops and community engagement/outreach programs.

8. Important considerations while designing of hazard risk communication systems are

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the social and environmental aspects of habitations which may vary in terms of their skill sets, beliefs, financial status, gender, cultural background, likes and dislikes, etc., together with the crucial factors of warning time and the credibility of the alarming system with cooperative but firm civic administration. A collective and collaborative team effort is imperative to avert such disasters in the future.

5 CONCLUSION

It can be further concluded that the dominant causative factor of the landslides in the Wayanad district is mainly due to the Soil Piping, heavy rainfall, unstable soil conditions etc. Hence the major high hazard zone lies in the south and west part of study area. The area prone to landslide in Wayanad district is found to be the Puthumala and Kavalappara region with rainfall of 409mm on the day of landslide tragedy which occurred on 30^{th} July 2024.

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