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A review paper on Civil Engineering Insights into Landslides in Kerala: Failure Mechanism, Case study & Mitigation Measures

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ABSTRACT

Landslides in Kerala pose significant challenges to infrastructure and public safety, primarily due to heavy rainfall, unstable slopes, and unplanned construction. In recent years, the Western Ghats of Kerala have experienced frequent landslides during the rainy season causing significant damage to roads, houses, agricultural fields, forest lands etc. shows that about 40% of the state lies in the highland region that forms the western slopes of the Western Ghats. The main type of Landslide that occurs in Kerala is the flow of debris, although other forms such as debris slides and rock falls are also common. This review examines landslides from a civil engineering perspective, analyzing geotechnical failures, structural impacts, and mitigation strategies. The first phase of review includes the detailed case study of Wayanad Meppadi 2024 landslide, highlighting key failure mechanisms, including soil instability, inadequate drainage, and slope saturation. As the second phase, examination of effective mitigation techniques that are applicable in Landslide prone areas. Here engineering solutions such as slope stabilization, retaining structures, geosynthetics, and effective drainage systems are explored.

This paper underscores the importance of integrating geotechnical engineering, environmental planning, and disaster management to develop sustainable landslide mitigation strategies for Kerala's vulnerable regions.

KEYWORDS;- *Landslide, Western Ghats, mitigation, saturation*

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I. INTRODUCTION

Landslides, or landslips, refer to various types of mass wasting, encompassing different ground movements like rock falls, shallow or deep slope failures, mudflows, and debris flows. It occur in a variety of environments, characterized by either steep or gentle slope gradients, from mountain ranges to coastal cliffs or even underwater, A landslide happened on July 30, 2024, at 02:17 hours, near Mundakki, Chooralmala, Vellarimala Village in Meppadi Panchayat, Vythiri Taluk, Wayanad District, as a result of continuous heavy to extremely severe rains About 700 homes and businesses have been buried under the debris. As reported by the State Emergency Operational Centre (SEOC) Kerala, a total of 231 bodies and 212 body parts have been recovered so far (source reference no: 4). A total of 630 persons have sustained injuries, 214 individuals have been rescued alive, and approximately 119 persons remain missing. As of the evening of August 24th, 2024, all relief camps in Wayanad have been successfully dispersed. A total of 702 families residing in these camps have now been relocated to rented houses, government quarters, and the homes of relatives. The landslide impacted wards 10, 11 & 12 of Meppadi Gram Panchayat, affecting approximately 4,833 people across 1,721 homes. Specifically, ward 10 (Attamala) had 1,424 people in 601 families, ward 11 (Mundakkai) had 1,247 people in 451 families, and ward 12 (Chooralmala) had 2,162 people in 671 families.(source : KSDMA Report)

Map: 1 Wayanad district map (source: google)

Map: 2 Meppadi Grama Panchayat (source: KSDMA report)

II. STUDY AREA & PHYSIOGRAPGHY

Meppadi Panchayat is located at an altitude of more than 7000 feet above sea level. Meppadi panchayat is spread over an area of 125 14 sq. km. The population of this vast area is divided into twenty-four wards on the basis of population. The area exhibits a rugged terrain with ridges and valleys, with relative relief reaching approximately 1,000 meters. Elevations in the region range from 1,000 to 1,400 meters above mean sea level, contributing to its varied landscape. (source: reference no 4)

Geological Features:
Meppadi lies on the Wayanad plateau, which is part of the Deccan Plateau's south western edge. The plateau is characterized by high ranges with both rugged and moderately rugged topographies. The underlying geology consists of ancient crystalline rocks, including charnockites and gneisses, which influence soil formation and stability.

Hydrology:
The region is drained by several east-flowing and west-flowing rivers, with the Kabini River being a significant watercourse. Tributaries such as the Panamaram and Mananthavady rivers contribute to the area's hydrological network, supporting both agriculture and biodiversity.

Soil and Vegetation:
The soils in Meppadi are predominantly lateritic, resulting from the intense weathering of the parent rock material. These soils support a variety of vegetation types, including tropical evergreen and semi-evergreen forests, as well as plantations of tea, coffee, and spices. The diverse vegetation contributes to the region's rich biodiversity.

Climate:
The elevation and landscape of Meppadi result in a tropical monsoon climate, with heavy rainfall during the monsoon season and mild temperatures year-round. The orographic effect of the Western Ghats causes substantial precipitation, impacting both the local ecosystems and agricultural activities in the region.

Land Use:
Land use in Meppadi is a mix of forested areas, agricultural lands, and settlements. The Kerala Department of Town and Country Planning has developed a Proposed Land Use Map for the region, outlining zones designated for residential, commercial, agricultural, and conservation purposes. This zoning aims to promote sustainable development while mitigating environmental risks.

Slno	**Items**	**Area (in Hectare)**
1	Total Area	12594
2	Forest	1200
3	Plantation	2509
4	Agriculture	6966
5	Wasteland	55
	Agricultural use	15
	Non-Agricultural	40
6	Non-agricultural purposes	564

Table 1 ***Source:KSDMA report***

III CAUSES OF LANDSLIDE

The catastrophic landslide in Meppadi Panchayat, Wayanad district, on July 30, 2024, resulted from a combination of natural and human-induced factors:
Heavy Rainfall: Intense monsoon rains saturated the soil, increasing pore water pressure and reducing slope stability. The region received 572 mms of rain over 48 hours, more than double the forecasted value.

slno	Areas/ Places	Rainfall (in mm)
1	Puthumala	372
2	Lakkidi	320
3	Vythiri	280
4	Banasurasagar	234.6
5	Maananthavaadi	205
6	Kalpetta	200.8

Table 2

Source: The Hindu report

Geological Factors: The area's intricate geology, marked by sheared rocks and structural faults, played a role in slope instability. Water seepage through cracks in the gneissic formation caused significant weathering and erosion, resulting in soil depths surpassing 30 meters, which heightened the vulnerability to landslides.

Deforestation and changes in land use: Large-scale deforestation for agriculture and construction led to a decline in soil cohesion. From 1950 to 2018, Wayanad lost 62% of its forest cover, while the area dedicated to tea plantations grew by around 1,800%. This dramatic loss of green cover contributed to the destabilization of slopes.

Improper Drainage and Infrastructure Development: Unplanned construction and inadequate drainage systems altered natural water flow, leading to water accumulation and increased pore pressure in soils. Such conditions heightened the risk of slope failures during heavy rainfall.

Climate Change: Human-induced climate change intensified monsoon rains by approximately 10%, contributing to the severity of the landslide. Warmer atmospheric conditions have led to heavier downpours, increasing the likelihood of such disasters.

IV. MITIGATION TECHNIQUES

Landslide mitigation in Kerala requires soil-specific approaches due to its diverse geology and climatic conditions.

Laterite Soil (Midlands & Highlands)

Retaining Walls: Reinforced concrete or gabion walls to support unstable slopes.

Retaining walls are sturdy structures designed to support soil laterally, allowing it to be maintained at different levels on either side. These are structures built to hold back soil on a slope that it would not naturally maintain, typically a steep, near-vertical, or vertical incline. They are utilized to contain soil between varying elevations, particularly in regions with steep terrain, where significant landscape modifications are required for specific applications such as hillside farming or roadway overpasses.. Types of retaining wall suitable for landslide prone areas in Kerala include

Gabion walls:

- Constructed using wire cages filled with stones, they are flexible, permeable, and can conform to the natural curves of the slope, making them ideal for rough terrain in Wayanad.

Reinforced soil retaining walls:

- Utilize geogrids to reinforce the soil behind the wall, providing excellent stability and allowing for efficient use of available soil material.

Anchored retaining walls:

Employ tiebacks or anchors to secure the wall against sliding, particularly effective on steep slopes.

- Drainage Control: Surface and subsurface drainage to reduce water infiltration.
- Vegetative Stabilization: Deep-rooted native plants like Bamboo, reed, and vetiver to improve soil cohesion.
- Soil Nailing: Installing steel bars to reinforce loose lateritic slopes.

Clayey Soil (Western Ghats)

- Proper Drainage Systems: French drains, horizontal drains, and surface runoff control.
- Terracing and Benching: Reducing slope gradient to minimize water buildup.
- Geo-textile Reinforcement: Improves stability and reduces soil movement.
- Chemical Stabilization: Using lime or cement to increase shear strength.

Sandy Soil (Riverbank Regions)

- Vegetative Cover: Planting deep-rooted vegetation to bind soil particles.
- Geosynthetics and Matting: Using geotextiles to prevent erosion.
- Gravel or Rock Revetments: Protecting slopes from undercutting by water flow.
- Soil Cementing: Mixing with cement or stabilizers to improve cohesion.

Colluvial Soil (Debris Deposits on Slopes, Common in High-Risk Areas)

- Reinforced Retaining Structures: Gabion walls, crib walls, or anchored walls.
- Subsurface Drainage: Horizontal and vertical drains to remove excess water.
- Bioengineering Techniques: Vetiver grass, bamboo, and other stabilizing plants.
- Regrading Slopes: Reducing steepness to minimize landslide risk.

Weathered Rock & Mixed Soil (Western Ghats & Hill Slopes)

- Rock Bolting & Anchoring: Stabilizing large rock masses.
- Shotcrete Applications: Spraying concrete on unstable rock surfaces.
- Check Dams & Debris Flow Barriers: Controlling landslide debris movement.
- Early Warning Systems: Monitoring cracks and slope movement.

V. RECOMMENDATIONS

Advanced Early Warning Systems

- Install automated rain gauges and soil sensors in landslide-prone villages
- Integrate AI with KSDMA's (Kerala State Disaster Management Authority) disaster response systems for real-time alerts.

Geosynthetic Reinforcement

- Use coir geotextiles to reinforce slopes, reducing soil erosion.
- Combine geogrids and geonets with retaining structures for better slope stability.

Soil Nailing & Micropiles

- Deep anchoring with soil nails to strengthen weak soil layers.

- Micropiles for foundation stabilization in unstable building areas.

Subsurface Drainage Systems

- Install horizontal and vertical drains to remove excess groundwater and reduce pore pressure.
- French drains & trench drains along slopes to improve water flow and prevent saturation.

Rainwater Harvesting

- Construct rainwater retention ponds and percolation pits to control runoff and groundwater recharge.

Rockfall Barriers & Catchment Systems

- Install steel wire mesh barriers on steep cliffs and slopes to prevent rockfall impacts on roads and settlements.
- Construct rockfall catchment trenches at the base of slopes.

Check Dams & Debris Flow Barriers

- Build rubble masonry check dams in landslide-prone streams to slow debris flow.
- Use flexible wire-mesh check dams to filter out debris while allowing water flow.

Landslide-Resistant Road & Building Design

- Implement bench terracing to reduce slope gradient and distribute building loads evenly.
- Construct buildings on deep-pile foundations in unstable areas to prevent settlement and slope failure.

VI. CONCLUSION

Thus the review has provided a comprehensive examination of the civil engineering insights into landslide phenomena in Kerala, focusing on failure mechanisms, case study, and mitigation measures employed. The analysis of failure mechanisms revealed that the interplay of geological heterogeneity, intense monsoonal rainfall, deforestation, and unplanned urbanization significantly contributes to slope instability in the region. Through detailed case study, of Wayanad landslide, the review has underscored both the complexity and the local specificity of landslide events in Kerala.

On the mitigation front, the paper highlighted a range of engineering interventions—from traditional retaining walls and soil nailing to advanced geosynthetic reinforcement etc.

Ultimately, the insights presented in this review emphasize the need for a multi-disciplinary, region-specific approach to landslide mitigation. Future research should focus on developing sustainable, cost-effective engineering solutions that can be seamlessly integrated into local practices and policies. Such endeavors will be crucial for reducing landslide risks and ensuring resilient infrastructure development in Kerala.

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