

# Landscape Alteration and Landslide Risk: Insights from the 2024 Rainfall-Triggered Landslides in Wayanad.

Vaishnavi T S U<sup>1</sup>, Prof. Nimisha Varghese<sup>2</sup>, Prof. Ashik S.<sup>3</sup>, Dr. Shilpa Madangopal<sup>4</sup>

<sup>1</sup>Vaishnavi T S U, B.Arch, School Of Architecture, Christ (Deemed to be University), Bengaluru

<sup>2</sup>Prof. Nimisha Varghese, Assistant Professor, School Of Architecture, Christ (Deemed to be University), Bengaluru

<sup>3</sup>Prof. Ashik S., Assistant Professor, School Of Architecture, Christ (Deemed to be University), Bengaluru

<sup>4</sup>Dr. Shilpa Madangopal, Assistant Professor, School Of Architecture, Christ (Deemed to be University), Bengaluru

\*\*\*

**Abstract** - The landslides that happened in Wayanad, Kerala in 2024 due to the rainfall revealed the growing susceptibility of the hill landscape in the Western Ghats. Although the extreme monsoon rainfall served as the short time precipitating factor, the landscape changes, namely slope cutting, deforestation, quarrying and unregulated hill settlements, played an important role in the intensity of the disaster. This study examines how the geomorphology, intensity of rainfall and anthropogenic alteration of terrain interact in developing the landslide hazard. The study presents the movement of debris-flow and vulnerability to settlement using terrain examination, satellite monitoring and published research on disasters. The research identifies the necessity of the hazard sensitive planning of settlements on hills and landscape-responsive building to minimize the risk of landslides in mountainous landscapes.

**Key Words:** Landslides, Wayanad, Western Ghats, Landscape alteration, Debris Flow, Hill settlement planning, Disaster risk reduction

## 1. Introduction

Mountainous landscapes are considered to be dynamic and the most vulnerable geomorphological systems. Stability of them is based on the equilibrium of the geological structure, slope gradients, vegetation cover and hydrological processes. Disruption of this balance can cause slopes to collapse and cause landslides and refluxes.

Western Ghats of India is one of the ecologically important mountain systems worldwide. The steep slopes, intense monsoon rainfalls and highly eroded rocky features are the defining features of the region making it highly prone to slope failures.

Over the past few decades, the Western Ghats has experienced a huge change in the natural landscape due to the growing pressure on development. Road building, quarrying, plantation farming and settlements have altered terrain conditions and disrupted the natural drainage, causing activities. With extreme rains, such changes may predispose landslides.

A region of Kerala called Wayanad is found in the northeastern region of the state, and over the decades, several landslides have been witnessed in this region. The rugged topography of the area and the heavy rainfall and rising infrastructure development causes it to be especially susceptible to slope instability.

Extremely heavy rainfall on July 2024 monsoon caused devastating landslides in parts of Wayanad. Some of the villages had serious slope failures and rubble flow that led to settlement damages, road and agricultural land damages.

More recent scientific studies on the event stress the fact that the catastrophe cannot be attributed to the intensity of rainfall.

According to research by Krishnapriya (2024) and Wang (2025), the landslides were caused by the relationship between the triggers of the rainfall and the unstable terrain conditions as well as landscape alteration by human activities. According to Krishnapriya (2024), the event was a long-runout debris flow so the landslide material went long distances down the valley systems following slope failure. Wang (2025) goes on to state that disasters like the Wayanad landslides are caused by a mixture of environmental factors, triggering mechanisms and vulnerability of human beings.

The knowledge of these interactions is required to come up with more secure planning plans on mountain regions. Traditional development does not take into account geomorphological limitations, which lead to the fact that settlements are built in dangerous areas.

This study thus analyses the correlation between landscape transformation and the risk of a landslide in Wayanad that involved landslides as a result of the 2024 rainfall.

The study aims to:

- Study land features affecting landslides in Wayanad.
- Research the role of human landscape change in slope instability.
- Understand Valley systems: Behaviour of the debris- flow.

- Suggest hazard sensitive planning principles of the hill settlements.

The results are valuable in the general debate on disaster-resilient development in mountainous areas.

## 2. Literature Review

Geomorphology, environmental science and disaster risk management Landslides have been researched long in geomorphology, environmental science and disaster risk management. Studies have always revealed that slope failures are as a result of interactions between geological conditions, rainfall intensity and vegetation cover as well as land-use practices.

Landslides are the most prevalent in wet tropical mountainous areas that receive a substantial amount of rainfall. High rainfall in the soil layers will cause the pore water pressure to rise that will make the soil shear strength lower and the slope destabilized.

Rainfall is however not the sole cause of landslide calamities. The influence of the anthropogenic landscape alteration in enhancing the slope instability is emphasized in many studies.

The road cutting, deforestation and quarrying activities modify the natural terrain conditions and destabilize the slope. Clearance of vegetation lowers the cohesion of soil, and the construction of roads eliminates the structural support of hillsides.

Recent research on the 2024 Wayanad landslides is an important revelation on these processes.

Krishnapriya (2024) examined the incident as a long-runout debris flow, which showed the manner in which landslide material moved through valley systems following slope failure. In the paper, the research problem of saturated soil conditions and steep slopes in the formation of massive overland flows is highlighted.

Wang (2025) explored the incident using a wider disaster framework. The paper contends that massive landslides are as a result of combination of three key factors:

- Environmental susceptibility
- Causative agents like rainfalls.
- Human settlements and their exposure and vulnerability.

Based on this model, calamities take place when vulnerable conditions (unstable states in the environment) come into contact with severe triggering events and human activities.

These views are especially applicable to the western ghats where development is gaining grounds thus shifting terrain stability in most places.

### 4.1 The regulatory framework Analysis.

The study analyzes national and ecological regulations which apply to development in areas of ecological sensitivity on hills. The primary regulatory frameworks to be taken into account are:

These analyses are the analytical basis of the relationship between rainfall causes, landscape and topography changes in the Wayanad landslides.

Table 1 Core Literature Used in the Study

Author	Year	Focus of Study	Key Contribution
Krishnapriya	2024	Wayanad landslide debris flow analysis	Demonstrates long-runout debris flow behaviour during the 2024 event
Wang	2025	Analysis of the July 2024 Wayanad landslide	Explains landslide disaster through environmental conditions, triggers and vulnerability

## 3. Study Area

The Wayanad district is located in northern part of Kerala bordering the mountain range of Western Ghats. The district lies between about 700 and more than 2000 meters above the sea level.

The landscape is composed of steep hills, deeply cut valleys and drainage systems. The region is highly productive in streams, rivers which ultimately form part of the Kabini River system.



## 4. Methodology

The paper will use a regulatory compliance and space analysis approach that will help determine whether settlements impacted by the Wayanad landslides in 2024 were compliant with the relevant environmental and construction regulations. It is a technique that combines topography, disaster research and policy investigation.

The following are examples of national building codes that can be used to regulate this:

- National Building Code of India (NBC 2016) - structural safety standards with such

regulations as the constructions in the area risky of landslides such as slopes.

- MoEF Environmental Regulations - rules passed by the Ministry of Environment, Forest and Climate Change on developing in the ecologically sensitive areas within the Western Ghats.
- Western Ghats Ecologically Sensitive Area (ESA) guidelines - proposals to limit quarrying, mining and development that destroys the environment in delicate terrain.
- Kerala Disaster Management Authority (KSDMA) guidelines on hazard mapping - which landslides are likely to occur where land-use planning should be recommended.

Such regulatory systems provide environmental and structural benchmarks that are aimed at minimizing risk of disasters.

#### 4.2 Analysis of Affected Areas on a Space Basis.

The physical attributes of the sites that were affected by landslides were analyzed using satellite imagery, terrain data, and published reports. The analysis focused on:

- Slope gradients
- Land use patterns
- Drainage systems
- Settlement distribution

This data is used in order to know whether the affected areas are in terrain conditions that are normally considered as high landslide susceptibility zones.

#### 4.3 Analysis of Case Studies of Landslides.

The disaster reports and topography were studied to analyze reported landslides sites during the July 2024 event. The assessment was done on the consistency of the development patterns at these sites against the building rules and environmental standards that are in place.

#### 4.4 Framework on Compliance Evaluation.

To make the analysis systemic, the case examines three compliance dimensions:

Table 2 Compliance Evaluation Framework

Dimension	Key Question
Terrain suitability	Were settlements constructed on slopes considered unstable or high-risk?
Environmental regulation	Were activities such as quarrying or deforestation permitted under MoEF guidelines?
Construction safety	Did building practices follow structural safety guidelines for hazard-prone areas?

This framework enables the research to connect the environmental hazards to the planning and compliance with regulations.

### 5. Results and Analysis

The findings explore the connection between the effects of landslides and the compliance of regulations in the affected areas.

**5.1 Suitability in Terrain and Settlement Location.** Land study indicates that the Wayanad terrain is covered by numerous affected regions, which are steep and with narrow valleys, mainly related with landslides.

With the rules of hazard-sensitive planning, the development of such a terrain should be evaluated and stabilized against slopes.

Table 3 Terrain Characteristics of Affected Areas

Terrain Factor	Observation
Slope gradient	Steep slopes common
Valley systems	Narrow drainage channels
Rainfall intensity	Extremely high during monsoon

The settlements that were in the valleys or the foot of steep slopes had been more exposed to debris flows that were caused during the landslides.

#### 5.2 Environmental Regulation and Land Use.

The paper investigated the compliance of land use activities in the affected regions to environmental guidelines published by the Ministry of Environment, Forest and Climate Change (MoEF).

A number of types of land-use change were identified in the greater area: •

- Growth of plantation farming.
- Development of infrastructures.
- Construction of roads on hilly slopes.
- Some quarrying done in some areas.

The Western Ghats have environmental regulations which show that there should be minimal activities that destabilize slopes or eliminate vegetation cover. Slope stability can be influenced in case of such alterations in landscapes where the changes are widespread.

Table 4 Environmental Activities and Regulatory Implications

Activity	Potential Regulatory Concern
Slope cutting for roads	Requires slope stabilization measures
Deforestation	Reduces soil reinforcement
Quarrying	May affect geological stability
Settlement expansion	Requires hazard-sensitive planning

Although the activities in question do not necessarily involve illegal activities, the lack of regulation or enforcement may heighten the risk of landslides.

### 5.3 Construction Safety and Structural Code.

The National Building Code (NBC) contains the construction guidelines to be followed in hazard prone regions, such as landslide prone slopes. These guidelines emphasize:

- Structural reinforcement
- Proper drainage systems
- Slope stabilization provisions.

Nonetheless, most of the settlements in the mountainous areas are built in bits and not by planned construction. Uncontrolled or informal development can be incomplete in terms of structural safety.

Consequently, the structures built in the unstable land could be more vulnerable in landslides.

### 5.4 Movement of Debris Floes and Settlement Exposure.

The debris flows produced by the landslides were passed through the valleys found in nature and travelled to great lengths in the downward direction.

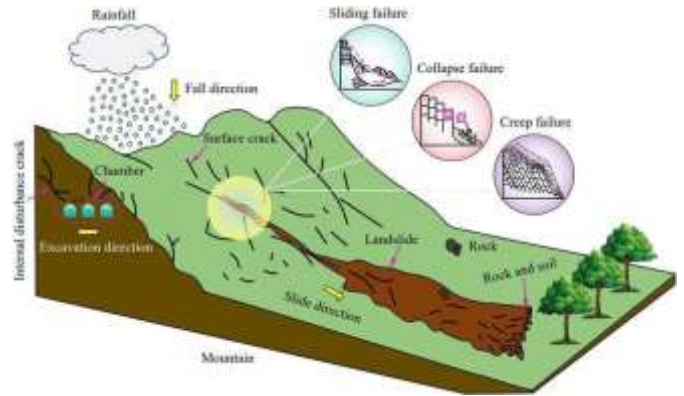


Figure 1 Debris flow pathways moving through valley systems toward settlements.

This observation is aligned with Krishnapriya (2024), which explains the event as a long-runout debris flow, in which the landslide material moved along valley systems following the slope failure.

The settlements in these routes were more affected.

## 6. Discussion

The results show that the magnitude of the Wayanad landslides in the year 2024 was caused by the interplay between the environmental vulnerability, precipitation, and developmental trends.

This relationship can be studied with the help of the framework suggested by Wang (2025). This approach suggests that disasters are manifested through the interaction of environmental conditions, triggering mechanisms and exposure of humans to them.

A number of factors that were related to landslide risk occurred in the case of Wayanad.

First, the steep topography of the area and the intense monsoon rains are a pre-determined unstable topography. These are the environmental factors that have made landslides a common risk.

Second, the change of the landscape by means of infrastructure construction and changing land-use may impact slope stability. Road cutting and cutting vegetation are some of the activities that change the structural balance of hillsides.

Third, disaster exposure is determined by settlement patterns. In cases where structures are placed in the valley system or on unstable slopes the effects of landslides are worse.

The development excellence model in the ecologically sensitive regions is supposed to minimize such hazards.

Planning and construction safety on hazards-sensitive plans and structural safety are highlighted by guidelines that are set by MoEF and building standards like National Building Code.

Nevertheless, the usefulness of such structures lies in application and practice. Informal development and incremental building can practise in hilly areas that develop very fast without being subjected to formal regulation.

Thus, the risk of landslides cannot be viewed only as an environmental risk. It should also be perceived as a planning and governance issue.

Enhancing adherence to environmental policies, enhancing the quality of hazard mapping and incorporating the terrain analysis into the planning decision-making is a way to decrease the risk of disasters in mountainous areas in the future.

## 7. Planning Implications

The discussion of the 2024 Wayanad landslides shows that the disaster susceptibility in mountainous areas is directly related to the development trends and the enforcement of the regulations. Although the extreme rain was the immediate cause eventual triggering factor, the effects of the landslides were influenced by interactions between settlements and infrastructure that came into play regarding the terrain conditions.

India has various laws in place, which aim at curbing environmental risks in the sensitive scenery. These are the National Building Code (NBC 2016), the environmental regulations that have been issued by the Ministry of Environment, Forest and Climate Change (MoEF) and hazard assessment guidelines created by different agencies, including the Kerala State Disaster Management Authority (KSDMA). These frameworks reiterate that there is a need to have terrain-sensitive development, slope stabilization, and environmental protection.

The National Building Code contains the structural safety regulations, which direct the construction in the risky regions. The code suggests that in the landslides prone areas, correct drainage, slope reinforcement and site selection should be taken. Such provisions are aimed at making sure that the structures erected on hilly slopes are able to overcome environmental pressures.

The ecologically sensitive parts of the Western Ghats are also covered by environmental regulations by MoEF that refer to development. These guidelines advise against activities that destabilize slopes such as massive deforestation, quarrying

and unregulated growth infrastructure. The importance of vegetation cover and protection of natural drainage systems is highlighted as the most important measure to adopt in order to ensure stability in the slope.

These regulatory frameworks are however effective and rely on implementation and enforcement. The development in most of the mountainous areas is incremental and sometimes informal and is usually not done with a careful observation of the terrain. Consequently, the settlements can be created in the regions, where the risk of landslides is much higher.

A landslide that occurred in Wayanad is a demonstration of the effects of this discrepancies between the environmental conditions and the development patterns. Observations made revealed that settlements in steep slopes or even on the valley lines were highly susceptible to the debris flows that were formed as a result of the landslides.

Planning that is sensitive to hazards thus needs closer coordination of geomorphological information with the regulations of development. Terrain analysis, hazard mapping, and environmental guidelines have to be included in the land-use planning.

- This analysis yields several strategies of planning:
- Enforcement of building codes in landslides prone places.
- Incorporating hazard maps in the regional planning systems.
- limiting development in high slopes and debris-flow areas.
- maintaining vegetation cover to stabilize the slope.

This would be through better drainage management of hillside developments. Ensuring that development practices are aligned with environmental regulations can help to greatly mitigate risks of landslides by the mountain regions.

## 8. Conclusion

The landslides that took place in the year 2024 due to the rainfall in Wayanad bring out the intricate interplay between the state of the nature, topography and anthropogenic activities in the mountainous terrain.

Very severe monsoon rainfall was the direct cause of slope failures. Nevertheless, the intensity of the catastrophe was predetermined by the interplay of environmental predisposition and development trends.

Terrain map depicts that most of the areas affected are steep slopes with narrow valleys, which by their nature are

susceptible to landslides. Once the precipitation is a lot and soaks these slopes, the chances of the slope failure also rise.

Meanwhile, the disruption of the landscape and the development of settlements have an impact on the development of disasters. Slope stability and drainage systems can change as a result of activities like road construction, vegetation clearing and infrastructure construction. The impact of landslides is even worse when the settlements are situated in any of the unstable terrain or the part of the build-up.

The rules and regulations that operate in the hill areas such as the National building code and environmental regulation by MoEF are meant to mitigate these risks. These regulations focus on environment-based planning, environmental conservation and structural protection.

But the Wayanad landslides show that regulatory frameworks may not only stop a disaster when well in place, but rather they need to be implemented. Lacuna of enforcement, gradual evolution and insufficient evaluation of the terrain may lead to settlements that are placed at risky locations.

The conclusions of this study thus provide more weight to the need of incorporation of geomorphology, environmental regulation and planning practice.

The development strategies of the mountain areas in reducing the hazards associated with a disaster risk should be built with consideration of the natural terrain conditions, and not trying to overpower them. Building resilient hill settlements require a strong regulatory enforcement and environmental management as well as Hazard-sensitive planning.

The teachings of Wayanad do not only pertain to one calamity. With the growing pressure of development and development across mountain zones across the globe, the task of harmonizing human intervention with the stability of the landscape is going to be a more significant issue.

It is only under the conditions of the correspondence between development and the realities of the environment that mountainous landscapes can stay habitable and safe.