



# Integrated Strategies for Landslide Risk Management: A Review of Climate Impacts, Human Activities, and Socio-Economic Dimensions

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## ABSTRACT:

Landslides are among mountainous regions' most devastating natural disasters, posing severe threats to life, property, and the environment. Kerala, a state in southern India, has experienced a significant rise in landslide occurrences, particularly during the monsoon season. This paper aims to investigate the factors responsible for landslides in Kerala, emphasizing geological, climatic, and human-induced causes. Case studies of significant landslides will be discussed to highlight patterns and offer recommendations for mitigation. The review will provide insights into early warning systems, sustainable land use practices, and long-term solutions to prevent future occurrences.

## 1. Introduction

Kerala, a southwestern coastal state of India, is renowned for its scenic landscapes, lush greenery, and diverse topography. However, this geographical beauty also brings inherent vulnerabilities, making the region prone to natural disasters such as landslides. Over the years, Kerala has experienced a significant increase in the frequency and intensity of landslides, particularly during the monsoon season. The Western Ghats, a UNESCO World Heritage site that stretches along Kerala's eastern border, are especially susceptible due to the combination of steep slopes, heavy rainfall, deforestation, and anthropogenic activities.

Landslides in Kerala cause widespread destruction, affecting human lives, infrastructure, and the environment. The 2018 and 2019 landslides, triggered by unprecedented rainfall, serve as stark reminders of

the severity of this problem. In these events, numerous villages were devastated, leaving thousands homeless and causing significant economic losses. The underlying causes of these landslides, both natural and human-induced, need to be examined in detail to formulate effective mitigation strategies.

This review paper aims to investigate the factors contributing to landslides in Kerala, assess the impacts on communities and the environment, and explore potential strategies for risk reduction and management. By analyzing historical data, geospatial factors, and rainfall patterns, we seek to provide a comprehensive understanding of landslide dynamics in the region and suggest policy interventions that can minimize future risks.



## 2. Background of Study Area

Landslides are a common geological phenomenon, especially in regions characterized by hilly terrains and heavy rainfall. In India, the Western Ghats, which stretch across Kerala, are recognized as one of the most landslide-prone regions due to their steep slopes, fragile soil structure, and climatic conditions. Kerala's unique combination of topography and climate makes it particularly susceptible to landslides, especially during the monsoon season, which accounts for more than 70% of the annual rainfall.

### A. Geographical Context:

The Western Ghats, running parallel to the Arabian Sea, form the eastern boundary of Kerala, rising sharply from the coastal plains to elevations exceeding 2,000 meters. This mountainous terrain is interspersed with deep valleys and rivers, creating the perfect conditions for slope instability. The geology of the Western Ghats comprises weathered rock formations and soil types prone to erosion and mass movement. The steep slopes and fragile geological structures, combined with intense rainfall, frequently trigger landslides, especially in regions like Idukki, Wayanad, and Malappuram.

### B. Climatic Influence:

The southwest monsoon, which strikes Kerala between June and September, is the major driver of landslides in the region. The heavy rains saturate the soil, increasing its weight and decreasing its shear strength, making slopes more prone to failure. Over the last few decades, Kerala has experienced more extreme rainfall events, attributed to climate change, which has aggravated the frequency and magnitude of landslides. For instance, in August 2018 and 2019, Kerala witnessed unprecedented rainfall, leading to widespread landslides and flooding across the state.

### C. Human-Induced Factors:

In addition to natural factors, human activities have also played a significant role in exacerbating landslide occurrences. Rapid urbanization, deforestation, quarrying, and unplanned infrastructure development in hilly regions have destabilized slopes and altered the natural drainage patterns. Agricultural practices such as slash-and-burn and terracing have further contributed to soil erosion, increasing the risk of landslides. The expansion of roads and settlements into vulnerable areas

has led to higher exposure and greater damage during landslide events.

### D. Historical Occurrences:

Kerala has a long history of landslides, with recorded events dating back several decades. However, the frequency and impact of these disasters have increased significantly in recent years. Major landslide events in the past decade, particularly in 2018, 2019, and 2020, have caused massive loss of life, destruction of property, and environmental degradation. The landslides of August 2018 were among the deadliest, killing over 100 people and causing billions of rupees in damages. Several studies have attributed the increase in landslide events to a combination of erratic rainfall patterns and reckless land-use practices.

### E. Previous Research:

Several studies have focused on landslide susceptibility in Kerala, with particular emphasis on the Western Ghats. Research has identified key factors contributing to landslides, such as slope steepness, rainfall intensity, soil characteristics, and land use. Geospatial techniques such as GIS and remote sensing have been widely used to map landslide-prone areas and assess risks. Additionally, hydrological studies have shown how extreme rainfall events linked to climate change have intensified landslide risks. However, there is still a need for comprehensive, multidisciplinary studies that integrate geological, environmental, and social factors to address the challenges posed by landslides in Kerala.

## 3. Causes of Landslides in Kerala

Landslides in Kerala result from a complex interplay of natural and human-induced factors. The state's diverse topography, heavy rainfall, and increasing anthropogenic activities contribute significantly to slope failures, especially during the monsoon season. Understanding the causes is crucial for developing effective mitigation strategies. The primary causes of landslides in Kerala can be categorized into natural and human-induced factors:

### 3.1. Natural Causes:

#### a. Heavy Rainfall:

Rainfall is the most significant trigger for landslides in Kerala. The state experiences two major monsoon seasons: the southwest monsoon (June to September)



and the northeast monsoon (October to November). During these periods, the intensity and duration of rainfall saturate the soil, increasing its weight and reducing its shear strength, thereby making slopes more susceptible to failure. Studies have shown that over 80% of the landslides in Kerala occur during the monsoon season. Rainfall-induced landslides are particularly common in the Western Ghats due to their steep slopes and porous soil, which retains water for extended periods.

## **b. Geological Characteristics:**

The Western Ghats, where most landslides occur, are characterized by steep terrain, loose soils, and fractured bedrock, all of which contribute to slope instability. Weathered rock formations and the presence of soft, clayey soil make the region more prone to erosion. Additionally, the region's complex geological structure, with its high level of tectonic activity, has resulted in unstable and fragmented rock formations that are easily displaced by external forces such as rainfall or seismic activity.

## **c. Seismic Activity:**

Although Kerala is not classified as a high-seismic-risk zone, minor earthquakes, and tremors can still trigger landslides, especially in areas where slopes are already weakened by rain or human activities. Seismic activity can loosen rocks and soil, reducing the stability of slopes and increasing the likelihood of landslides. While this factor is less prominent than rainfall, it has been a contributing cause in certain localized incidents.

## **d. Soil Erosion:**

Natural processes like soil erosion contribute to the gradual degradation of slopes, making them vulnerable to landslides. In regions with high rainfall and poor vegetation cover, soil erosion is accelerated, leading to the exposure of underlying rock and a reduction in slope stability. In Kerala, where deforestation has been rampant, natural soil erosion processes are exacerbated by human-induced activities.

## **3.2. Human-Induced Causes**

### **a. Deforestation:**

Kerala's forest cover has been steadily declining due to uncontrolled deforestation for agriculture, settlements, and infrastructure development. Forests play a critical

role in binding the soil and absorbing excess rainfall. When trees are removed, the exposed soil is more likely to erode, and the natural water absorption capacity of the land decreases, increasing runoff and destabilizing slopes. Clear-cutting of forests in ecologically sensitive areas of the Western Ghats has been a major contributor to landslide susceptibility.

### **b. Unplanned Urbanization:**

The rapid expansion of settlements and infrastructure, particularly in hilly regions, has resulted in a significant increase in landslide risks. Unplanned construction of roads, buildings, and other infrastructure on fragile slopes alters natural drainage patterns, destabilizes soil, and adds load to the slopes. The use of heavy machinery and blasting for construction further weakens the structural integrity of hillsides. Many regions of Kerala, especially in Idukki and Wayanad, have seen rapid urbanization without adequate geotechnical assessments, leading to frequent landslides.

### **c. Agricultural Practices:**

Traditional farming methods in Kerala's hilly regions, such as slash-and-burn agriculture and terracing, can contribute to slope instability. These methods disturb the natural vegetation and soil structure, leading to erosion and weakening of slopes. In addition, the use of chemical fertilizers and irrigation practices can affect the natural water retention capacity of the soil, further increasing landslide risks. Expansion of tea, rubber, and spice plantations in the Western Ghats has led to large-scale deforestation and alteration of the landscape, aggravating the problem.

### **d. Mining and Quarrying:**

The demand for construction materials has led to illegal and unregulated quarrying activities in many parts of Kerala, especially in ecologically sensitive zones. Blasting and excavation associated with mining create artificial instability in the hills, making them more vulnerable to landslides. Quarrying often involves removing the top layers of rock and soil, weakening the slopes and leading to slope failure. Several landslides in recent years have been linked to such activities, particularly in districts like Idukki and Kozhikode.



### e. Road Construction and Infrastructure Development:

The development of roads and other infrastructure in hilly regions often involves cutting through hills, which destabilizes the natural slope and increases the likelihood of landslides. Additionally, poorly designed drainage systems associated with these construction projects cause water to accumulate in certain areas, adding to the risk of slope failure. Unplanned road construction in the Western Ghats has been identified as a major factor in triggering landslides, as the excavation of hill slopes leads to destabilization, particularly during periods of heavy rain.

### 3.3. Climate Change:

Climate change is an emerging factor that exacerbates many of the causes of landslides in Kerala. There has been a notable shift in rainfall patterns, with more frequent extreme rainfall events. The increasing unpredictability of the monsoons, with heavy downpours over shorter periods, overwhelms natural drainage systems and leads to higher soil saturation levels. This rapid and intense accumulation of water is one of the main reasons for the increasing occurrence of rainfall-triggered landslides in the region.

Kerala has experienced numerous landslides over the years, many of which have resulted in significant loss of life and property. By examining specific landslide events, we can better understand the factors that contribute to these disasters and the long-term impact on the environment and local communities. Below are some of the major landslides in Kerala in recent history:

*In June 2018*, torrential rains triggered a massive landslide in Kattippara village, Kozhikode district. The landslide occurred after three days of continuous heavy rainfall, causing the hillside to collapse, burying houses and roads, and killing 14 people. Several homes were destroyed, and the village was cut off from the outside world for days due to debris blocking the roads. **Fig. 1.** has been shown the landslide in Kozhikode District.

#### Causes and Impacts:

**a. Heavy rainfall:** The region received over 300 mm of rainfall in just 48 hours, saturating the soil and triggering the landslide.

**b. Deforestation and quarrying activities:** Unregulated quarrying had destabilized the hillside, and deforestation had reduced the slope's natural stability, leading to the collapse.

**c. Steep slopes and weak soil:** The natural topography, combined with the weakened soil structure due to human activities, contributed to the slope failure.

**d. Loss of lives and destruction of property:** The village's agricultural lands were severely damaged, disrupting the livelihoods of local farmers. Infrastructure damage, including roads and water supply systems, left the area isolated,

*On August 8, 2019*, after days of heavy rainfall, a catastrophic landslide hit Puthumala, a remote village in Wayanad district. The landslide buried homes, tea plantations, and roads, killing 17 people and displacing hundreds. Massive boulders and debris swept through the village, making rescue operations difficult. **Fig. 2.** has been shown the Puthumala Landslide, Wayanad District.

#### Causes and Impacts:

**a. Extreme rainfall:** The region received record-breaking rainfall during the 2019 monsoon season, with Puthumala experiencing rainfall levels far above average.

**b. Deforestation for tea plantations:** Large tracts of forest had been cleared for tea plantations, destabilizing the soil and increasing runoff during heavy rains.

**c. Topography:** The steep terrain of Wayanad, combined with the intense rainfall, contributed to the large-scale movement of soil and rocks.

**d. Impact:** The landslide destroyed homes and infrastructure, leaving many families homeless. Tea plantations, which are the backbone of the local economy, were devastated, resulting in a significant loss of income for the community. The region remains vulnerable to future landslides due to the deforested landscape and altered drainage patterns.

*The Kavalappara landslide*, which occurred on August 8, 2019, was one of the deadliest in Kerala's recent history. Triggered by continuous rainfall, the landslide engulfed an entire village, burying more than 50 houses under debris. Rescue efforts were hampered by the scale



of the disaster, with 59 bodies eventually recovered. The landslide occurred in an area known for its steep slopes and human activity. **Fig. 3.** has been shown the Kavalappara Landslide, Malappuram District

### Causes and Impacts:

**a. Excessive rainfall:**The Kavalappara area received over 300 mm of rainfall within a few days, causing the waterlogged soil to collapse.

**b. Unregulated land use:** Widespread deforestation and illegal quarrying in the region had weakened the stability of the slopes, leaving them prone to failure during the monsoon season.

**c. Terrain:** The village was located on a steep hillside, which, when saturated with rain, led to the rapid downhill movement of debris.

### d. Impacts:

Significant loss of life of 59 people were killed, and dozens of homes were destroyed.

Environmental damage of Large sections of forest and agricultural land were swept away, causing long-term environmental degradation.

Economic losses of The local economy, which was reliant on agriculture and small-scale industries, was severely affected.

**On August 6, 2020,** the Pettimudi village in Idukki district was devastated by a landslide that claimed 70 lives. The region had experienced unusually heavy rainfall, and the landslide occurred in the early morning, catching many residents while they were sleeping. The landslide buried workers' quarters belonging to a nearby tea estate, leading to a large-scale humanitarian crisis. **Fig. 4.** has been shown the Pettimudi Landslide, Idukki District.

### Causes and Impacts:

**a. Monsoon rains:** The region received intense rainfall over a few days, leading to soil saturation and slope failure.

**b. Deforestation and unplanned development:**The extensive tea plantations in the region had altered the natural topography, removing vegetation that would have provided stability to the slopes.

**c. Human encroachment:** The construction of workers' quarters and other infrastructure on vulnerable slopes contributed to the disaster.

**d. Impacts:** The landslide caused the loss of 70 lives, many of whom were tea estate workers. Property damage was extensive, with entire buildings and roads destroyed. The local community suffered severe economic losses, as the tea estate was a major source of employment for the villagers.

*In August 2018,* the Idukki district experienced multiple landslides triggered by record-breaking rainfall during Kerala's worst flooding in over a century. The most severe landslides occurred in Adimali and Munnar, where entire hillsides collapsed, burying homes and roads. Over 50 people were killed, and entire villages were rendered uninhabitable. **Fig. 5.** has been shown the Idukki District Landslides

**a. Exceptional rainfall:**Idukki received one of the highest rainfalls recorded in its history, with more than 400 mm falling in a short span.

**b. Geological vulnerability:**The region's steep terrain and soft soil, combined with deforestation and quarrying, made the slopes vulnerable to collapse.

**c. Infrastructure development:**Construction activities in tourist areas like Munnar, including hotels and roads, destabilized the fragile slopes.

**d. Impacts:**The landslides led to the loss of life, destruction of property, and displacement of thousands of people. Tourism in the region was severely impacted, as many roads and resorts were destroyed. The local economy, largely dependent on tea and spice plantations, suffered significant losses due to the destruction of agricultural land.



**Fig. 1. The 2018 Kattippara Landslide in Kozhikode District.**



**Fig. 2. The 2018 Puthumala Landslide, Wayanad District.**



**Fig. 3. The 2019 Kavalappara Landslide, Malappuram District.**



**Fig. 4. The 2020 Pettimudi Landslide, Idukki District.**



**Fig. 5. The 2018 Idukki District Landslides**

#### 4. Environmental Impact of Landslides in Kerala

Landslides in Kerala have had widespread and devastating effects on both human populations and the environment. As a result of frequent landslides, particularly during the monsoon season, Kerala faces significant social, economic, and environmental challenges. The impacts of these landslides are multifaceted and can be classified into several key areas.

*Loss of Life and Human Displacement: Landslides in Kerala have resulted in tragic loss of life, particularly in densely populated rural areas where houses and infrastructure are often constructed on or near unstable slopes. During major landslide events, entire families have been buried under debris, and many survivors*

*have been displaced from their homes. In events such as the 2019 Kavalappara Landslide and the 2020 Pettimudi Landslide, dozens of people lost their lives, with many bodies being buried so deep under the debris that recovery took days or weeks.*

**Displacement:** Thousands of people are displaced every year due to landslides. Those living in landslide-prone regions are often forced to relocate, and many end up in relief camps or temporary shelters, leaving behind their homes and livelihoods. Displacement causes long-term emotional and financial stress on affected families.

**Psychological Impact:** Survivors of landslides face significant psychological trauma, including post-traumatic stress disorder (PTSD) and depression. The suddenness of landslide events and the inability to



recover bodies or property can leave lasting emotional scars on survivors and families of victims.

**a. Damage to Property and Infrastructure:** The destruction of homes, buildings, and infrastructure is a major consequence of landslides in Kerala. In steep, mountainous regions, landslides cause extensive damage to roads, bridges, power lines, and water supply systems, cutting off access to affected areas for days or even weeks.

**b. Housing Destruction:** Entire villages have been wiped out by landslides, with homes buried under rocks, mud, and debris. In many cases, families lose their lifelong savings invested in building homes, leaving them homeless.

**c. Infrastructure Damage:** Landslides often block roads and railways, making rescue operations and the delivery of aid challenging. The destruction of key infrastructure such as bridges and electrical grids in remote areas disrupts transportation and communication, slowing down relief and rehabilitation efforts.

**d. Economic Losses:** The cost of rebuilding damaged infrastructure is enormous. Kerala has spent billions of rupees on rebuilding roads, bridges, and public services following major landslides. In addition, landslides damage critical infrastructure such as schools, hospitals, and businesses, leading to long-term economic losses for communities and the state.

#### 4.1. Impact on Agriculture and Livelihoods:

Kerala's economy is heavily dependent on agriculture, particularly in hilly regions where crops like tea, coffee, spices, and rubber are grown. Landslides not only destroy crops but also degrade the land, making it unsuitable for future agricultural activities.

**a. Loss of Crops:** Landslides swept away crops and agricultural land, leading to a direct loss of income for farmers. In districts like Wayanad and Idukki, which are reliant on plantation agriculture, landslides can ruin entire harvest seasons, leaving farmers and laborers without livelihoods.

**b. Soil Degradation:** Landslides strip the topsoil from agricultural land, reducing its fertility and making it less productive in the future. Farmers may have to abandon lands damaged by landslides and move to less

productive areas, leading to long-term economic hardship.

**c. Unemployment:** Many laborers working on plantations or in agriculture lose their jobs when landslides destroy crops and land. Unemployment increases, particularly in rural areas, as local economies dependent on farming and plantation work collapse following landslides.

**d. Environmental Degradation:** Landslides cause widespread environmental degradation, leading to the destruction of ecosystems, loss of biodiversity, and long-term changes in the natural landscape.

**e. Forest Destruction:** Landslides often occur in forested regions, leading to the destruction of large areas of forest cover. In regions like the Western Ghats, landslides can cause irreversible damage to ecosystems, with the loss of flora and fauna endemic to the region. The destruction of forest ecosystems also affects the region's water cycle, further destabilizing the environment.

**f. Soil Erosion:** Landslides strip away topsoil, which is vital for plant growth and maintaining soil fertility. This can lead to desertification in areas where landslides occur frequently, making the land barren and unsuitable for agriculture or habitation. **Water Contamination:** Landslides frequently cause rivers and water bodies to be contaminated with debris, soil, and chemicals, leading to water pollution. In some cases, landslides cause dams to overflow or rivers to change course, affecting downstream communities and ecosystems.

#### 4.2. Social and Economic Disruption

Landslides have a profound social and economic impact on Kerala's population, particularly on those living in vulnerable, remote regions. The destruction of homes, infrastructure, and agricultural land leads to long-term disruptions in social and economic stability.

**a. Economic Disruption:** Landslides cause a ripple effect in local economies, disrupting agriculture, trade, and tourism, which are vital sectors of Kerala's economy. The loss of crops and land not only affects the livelihood of farmers but also impacts industries dependent on agricultural products. Similarly, landslides can cut off tourist destinations, affecting



businesses reliant on tourism, such as hotels and restaurants.

b. **Increased Vulnerability:** People living in landslide-prone areas are often among the most vulnerable populations, with limited access to resources and support. Landslides exacerbate poverty, as affected families lose their homes, possessions, and sources of income. The costs of rebuilding and rehabilitation often push these communities further into debt and hardship.

c. **Public Health Challenges:** Landslides create significant public health challenges, particularly when access to clean water, food, and medical care is disrupted. In the aftermath of landslides, diseases such as cholera, dysentery, and malaria can spread due to the contamination of water sources and poor sanitation in temporary relief camps.

d. **Impact on Tourism:** Kerala is a major tourist destination known for its natural beauty, including its hills, forests, and backwaters. Landslides in the state's hilly regions, particularly in places like Munnar and Wayanad, disrupt tourism activities and cause economic losses for those reliant on tourism.

e. **Damage to Tourist Destinations:** Popular hill stations such as Munnar and Wayanad have been heavily affected by landslides. Roads leading to these areas are often blocked, cutting off access to tourists. The destruction of natural beauty, along with the risk of landslides, deters tourists from visiting, resulting in economic losses for the local hospitality industry.

f. **Loss of Revenue:** The tourism industry in Kerala, particularly in hill stations and ecotourism sites, suffers due to landslides. Hotels, homestays, tour operators, and other businesses dependent on tourism face severe economic challenges when landslides affect the region, leading to job losses and a decline in revenue. The impact of landslides in Kerala is both immediate and long-term, affecting the social fabric, economy, environment, and health of its population. While landslides are a natural phenomenon, human-induced factors such as deforestation, unplanned construction, and climate change have exacerbated the scale and frequency of these disasters. Addressing these impacts requires a multi-faceted approach, including sustainable land-use planning, improved early warning systems, and post-disaster recovery measures.

## 5. Mitigation and Management Strategies:

a. **Early Warning Systems:** The Kerala State Disaster Management Authority (KSDMA) has developed early warning systems using rainfall data, soil moisture monitoring, and satellite imaging. These systems aim to provide real-time alerts to vulnerable communities. However, more investment is needed to enhance accuracy and reach.

b. **Afforestation and Sustainable Land Use:** Replanting trees and vegetation in deforested areas can help stabilize soil and reduce the risk of landslides. Promoting sustainable agricultural practices that do not compromise slope stability is crucial.

c. **Restricting Unplanned Development:** Strict regulations need to be enforced on construction activities in landslide-prone areas. Any developmental projects should undergo environmental impact assessments, and land use plans should prioritize slope stability.

d. **Community Awareness and Preparedness:** Educating communities in landslide-prone areas about the dangers of deforestation, improper construction, and unsustainable farming practices is key to reducing human-induced causes of landslides. Community-based disaster preparedness programs can save lives during such events.

## 6. Conclusion

Landslides in Kerala are the result of complex interactions between natural forces and human activities. While heavy rainfall and the region's geology play a significant role, deforestation, unplanned urbanization, and unsustainable land use practices have amplified the problem. There is an urgent need for a comprehensive approach that combines technology, sustainable development practices, and community involvement to mitigate the risks of landslides. By investing in early warning systems, promoting afforestation, and enforcing regulations on land use, Kerala can reduce the impact of landslides in the future.



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