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Rainfall – Induced Landslides in Kerala, India: A General Review

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Abstract**:** Landslides are a profoundly upsetting and devastating natural catastrophe. In comparison to previous decades, landslides have been recorded to occur significantly more frequently worldwide in this decade. The landslide susceptibility map is crucial for identifying landslide hotspots in the study area, identifying different factors/parameters that affect the landslide and critically examining their involvement in landslide occurrences. The significance of rainfall patterns in initiating landslides has been widely acknowledged. In Kerala, it may be possible to understand the geographical patterns of landslide distribution by examining the hotspots for landslides that have been found using maps of landslide susceptibility. Due to the spatial issues of precipitation, the impacts were mostly concentrated along valleys in the study area's lower part. Furthermore, well-forested hillslopes were more prone to landslides, indicating that trees have a limited role in stabilising slopes during extreme rainfall events.

The study is being done in response to the landslides that occurred in the state of Kerala, India, between 2018 and 2020. The review addresses the major physical causes of landslides in common and major cause of landslide in Kerala which is Rainfall **-** Induced landslides. The triggering and progression of rainfall-induced landslides are also reviewed in this review article.

Keywords: landslide; rainfall-induced landslide; rainfall pattern; Kerala

Introduction

Landslides are the large-scale, gravitationally-driven movements of rock, debris, or earth down a slope, changing the geomorphology of the earth's surface (Srinivasaperumal et al., 2011). Intense rainfall, earthquakes, and other triggering variables are combined with accelerating elements (landscape modifications) to create the hydro-geomorphic processes, which lead to the occurrence of landslides. These factors along with high population density pose an increased risk of vulnerable situations in developing countries like India (Santini et al., 2009).

The Geological Survey of India estimates that 0.42 million km2 (12.6%) of India's land area, excluding areas covered in snow, is within the landslide hazard zone. The Western Ghats and Konkan Hills, which run across Tamil Nadu, Kerala, Karnataka, Goa, and Maharashtra, cover this 0.09 million km2 (*NDMA Annual*

Report 2018–2019). According to the National Disaster Management Authority, the Western Ghats are India's second-most prone region to landslides after the Himalayas(Jain et al., 2021). Through September 2022, data from the Ministry of Home Affairs' National Emergency Response Centre is accessible. During the monsoon season, 10 Indian states reported 182 landslide-related fatalities in various areas. Over the past ten years, attempts to create landslide susceptibility maps have been made, however experts point out that these maps cannot be relied upon to predict when and where landslides will occur (Premlet B, 2019).

Landslides are a serious threat in mountainous areas. It has an impact on the lives and livelihoods of locals as well as the local economy, and it can have intergenerational psychological effects that can take decades to heal (Sahoo, 2009). The threat and potential risk of landslides to human life and livelihoods has increased over the last century as mountain villagers degrade forest resources and seek opportunities in foothills and low-lying areas (Sahoo, 2009).

It's critical to distinguish between landslide triggers and causes. In a broad sense, a slope becomes unstable due to an accumulation of factors known as a cause. Some of the most prominent causes are classified under geological, physical, morphological and human causes. Proper and specific studies of all variant causes are to be studied for the better understanding of landslides and slope instability due to these physical factors.

Methodology

The entire paper is a review paper and was focused to gathering data from online and student-written sources. With the keyword's 'Landslide', 'Physical Causes', 'Rainfall-induced Landslide', 'Landslide Prone Area' and 'Kerala landslide scenario', the majority of searches were made in Google Scholar, Jstor, Elsevier and Research Gate. All of the studies were initially evaluated using the reference paper's abstract and according to how well they related to the subject being investigated. The essential conclusions from each chosen paper were then analysed and added to this. The papers of different publications are not compared because the study focuses on the review of several criteria pointing leading to the understanding of rainfall-induced landslide.

Study Area

Kerala, a 38,863 km2 state in the southwest of peninsular India, is situated between 10.8505° N latitude, 76.2711° E longitude. With physiographic divisions extending from low lands on the west to the midlands, the state has a diversified topography (Jain et al., 2021). From the eastern Western Ghats to the western Arabian Sea, there is a gradual incline. Anamudi (2695 m), the tallest mountain peak in the Western Ghats, 44 rivers, and a coastal plain dotted with numerous lagoons and barrier systems are just a few of Kerala's distinctive geomorphic feature (Jones et al., 2021). Geologically, the state is a part of the south Indian shield with a predominance of crystalline rock formation. Kerala, during 2018, experienced the most severely extreme rainfall since 1924. The torrential rainfall triggered many landslides and floods, causing extensive damage to property (Andrewwinner & Chandrasekaran, 2021).

Kerala State Disaster Management Authority (KSDMA) estimates that 14.43% of the state is vulnerable to landslides, especially during the monsoon season (fig.1). The most frequent landslides in Kerala are called Debris Flows or "Urul Pottal" in the local language. The largest disaster to hit the state since 1924 occurred there in 2018 and 2019. The 2018 tragedy, which had an impact on 5.4 million people, resulted in the deaths of 483 people, significant property loss, and massive floods (Jones et al., n.d., 2021).

In the state of Kerala, landslides completely destroyed two hamlets in 2019: Puthumala in the Wayanad district and Kavalappara in the Malappuram district (Achu et al., 2021). The landslide hotspots are concentrated in Idukki, Ernakulam, Kottayam, Wayanad, Kozhikode and Malappuram districts (Jones et al., 2021).

A reliable early warning system would undoubtedly aid in management, planning, and lifesaving. Experts at the Geological Survey of India say it is time to re-evaluate land use planning and zoning restrictions in the wake of the terrible Kerala floods and landslides that claimed over 400 lives in order to prevent landslide damages and increase disaster preparedness (Geological Survey of India).

This highlights the significant need of an accurate and updated landslide susceptibility map in the pertinent prone areas. (Abraham et al., 2021; Akgun, 2012; Dikshit, Sarkar, Pradhan, Jena, et al., 2020; Jain et al., 2021; Srinivasaperumal et al., 2011; Wadhawan et al., 2020).

Literature Study

Major Causes:

The causes for landslides are more common classified into four. Each cause affects differently and may or may not act as base for the other causes. The causes area as follows:

Geological Causes: Weak, sensitive, weathered, sheared, joined or fissured materials are just a few examples of the geological reasons. Discontinuities that are adversely oriented (such as bedding, schistosity, faults, unconformities, contacts, and so forth); structural discontinuity that is directed in the wrong direction (fault, unconformity, contact, etc.); compare the permeability of; stiffness contrast (between dense, stiff materials and plastic materials); thickness of the weathering crust; bedrock characteristics. Stable bedding

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sequences are a significant geological feature in landslide hazard analysis. This can happen when water infiltrates through the top regolith layer and weakens the strength of the clay deposit, or when pore water pressures build at the interface of two different alternating regolith (such as sandstone and clay stone). As a result, landslides frequently happen during prolonged periods of heavy rainfall (Khanh, n.d.).

Morphological Cause: Tectonic or volcanic uplift, glacial rebound, wave erosion of the slope toe, glacial erosion of the slope toe, erosion of the lateral edges, subterranean erosion (solution, piping), deposition loading of the slope or its crest, and vegetation clearance are some examples of morphological reasons (by forest fire, drought). (Khanh, n.d.).

Human Cause: Deforestation, irrigation, mining, artificial vibration, water leakage from utilities, construction of highways and railroads are a few examples of human-caused factors. Other factors include loading slopes or their crests, excavating slopes or their toes, drawing down reservoirs, and deforestation. People's actions may cause landslides either directly or indirectly.

Physical Cause: Intense precipitation, extended exceptional precipitation, rapid drawdown (of floods and tides), earthquakes, volcanic eruptions, thawing, and shrink-and-swell weathering are examples of physical causes. Seismicity is one of the main variables that cause landslides. Rock falls and slides of rock fragments that occur on steep slopes are the most frequent types of landslides brought on by earthquakes. One particular sort of landslide—liquefaction failure, which can result in ground fissuring or subsidence—is inextricably linked to earthquakes (Khanh, n.d.).

Rainfall Induced Landslides:

Landslides frequently occur in clusters during intense rainfall events and may turn into debris flows or occur together with flash floods, resulting in numerous casualties and economic damages. The onset of rainfall-induced landslides can be linked to infiltrated water's helping effects in diminishing slope stability: raising soil unit weight and groundwater pressure, and decreasing matric suction (Yang et al., 2020).

Yearly landslides have been connected to extensive vegetation removal, hill cutting, particularly crowded camps, weak shelters, unstable soils, and excessive monsoon rainfall. Torrential rains, rapid changes in precipitation patterns, reckless hill cutting and deforestation, unplanned urbanisation, settlement expansion in dangerous locations slopes, and other criteria associated to social vulnerability were important triggering elements of such landslide tragedies (Kamal et al., 2022). Debris flows can be related with landslides by three approaches:

- Landslides immediately turn into debris flows owing to liquefaction
- Landslide silt accumulates in the drainage channel and is subsequently entrained by following streamflow.
- If landslide dams have established, breaching such dams may result in debris flows.

The final two causes are largely noticed in the earthquake devastated areas(Yang et al., 2020).

Depending on 21 rainfall-induced landslides that happened in the area of Hulu Kelang, three rainfall thresholds were created in Malaysia to attempt to predict the occurrence of rainfall-induced landslides. Based on the local rainfall conditions, the rainfall intensity-duration threshold produced a reasonably accurate prediction of landslide occurrence (Lee et al., 2014). The Random Rainfall Patterns affect the time evolution of triggered landslides (Zhao et al., 2022).

Deforestation can cause surface erosion, which can subsequently lead to shallow, quick landslides precipitated by a single severe rainfall event. Large-scale landslides occur across a vast region and are more prone to occur after soils have accumulated a large amount of water over time, such as during a monsoon season. Although their role in preventing erosion and shallow landslides is better recognised, forests can limit or minimise both shallow and large-scale landslides (Brandon, n.d.).

In the review paper titled 'Rainfall Induced Landslide Studies in Indian Himalayan Region', Landslides damaging vital economic sectors such as transportation and agriculture are not uncommon in the Indian Himalayan region. The region is vulnerable to 15% of all rainfall-induced landslides worldwide. Landslide forecasting is a critical component of catastrophe risk reduction, but it is also the most difficult.

Precipitation analysis for landslide occurrence can be done by estimating minimum rainfall conditions, subsurface monitoring, or slope stability analysis. There are two techniques to determining minimal rainfall conditions, commonly known as thresholds. Physical models evaluate the link between rainfall and soil hydrology, which influences slope stability (several factors such as geotechnical parameters, soil depth, volumetric water content, geology, and topography are used to determine the pore water pressure change and estimate the factor-of-safety). Empirical approaches use statistical methods to examine rainfall circumstances in order to estimate precipitation threshold values. These models are easier to implement because they simply require a spatial and temporal dataset of precipitation and landslide events (Dikshit, Sarkar, Pradhan, Segoni, et al., 2020).

From cases of Hulu Kelang area of Malaysia, Landslides were caused by poor design and building methods. These poorly designed and built slopes usually fail during or after a series of rainstorms. Another probable contributing cause to the landslides is poor maintenance of the internal drainage system of slopes and retaining structures (Lee et al., 2014).

Rainfall Induced Landslides in Kerala:

Kerala state is located in peninsular India and is one of the most densely populated states in India. Table 1 depicts a most rainfall induced landslide occurrence data of Kerala state and the severity. Figure 1 depicts a most landslide occurrence map of Kerala state during 2018-2019 years. Except for Alappuzha, all districts in Kerala are subject to landslides. Many residential buildings were destroyed or severely damaged as a result of vertical cut failures and landslides caused by rainfall during the monsoons of 2018, 2019, 2020, and 2021 (Santhosh Kumar & Chandrasekaran, 2022).

Landslide Location	District	Event Date	Deaths
Padinjarethara(Kappikalam)	Wayanad	19 June 1992	11
Pazhampallichal	Idukki	21 July 1997	9
Pamba	Pathanamthitta	15 January 1999	25
Amboori	Thiruvanthapuram	9 November 2001	39
Nittukottamala	Kozhikode	10 August 2004	10
Karinchola	Kozhikode	14 June 2018	14
Nemmara	Palakkad	16 August 2018	8
Upputhode	Idukki	16 August 2018	4
Kavalappara	Malappuram	8 August 2019	59
Puthumala,	Wayanad	8 August 2019	17
Rajanmalai	Idukki	7 August 2020	60
Koottickal	Kottayam	17 October 2021	22
Kokkayar	Idukki	17 October 2021	13

Table 1. Major rainfall induced landslide in Kerala (Source:(Santhosh Kumar & Chandrasekaran, 2022))

Common Measures

- Forests help to prevent landslides by anchoring soils and providing soil stability.
- Deep roots operate as anchors, whereas shorter root systems hold dirt in place. Breaks are formed by thick, buttressed roots that traverse the forest floor. Deep root systems operate as channels, allowing water to infiltrate and lowering the likelihood of landslides.

- Moist soils have better soil cohesiveness and are healthier. The soils beneath the canopy stay together, strengthening the soil profile.
- Forests lower rainfall intensity (up to 66 percent), reducing the harmful impact of severe and heavy rain on soils as well as erosion and debris flow.
- Evapotranspiration allows forests to quickly eliminate excess water. In forests, the combination of evaporation from water sitting on the leaves and branches and transpiration (the water that efficiently flows from the soil up through root systems and is recycled back into the air by the tree) is significant, minimising landslide danger (Brandon, n.d.).

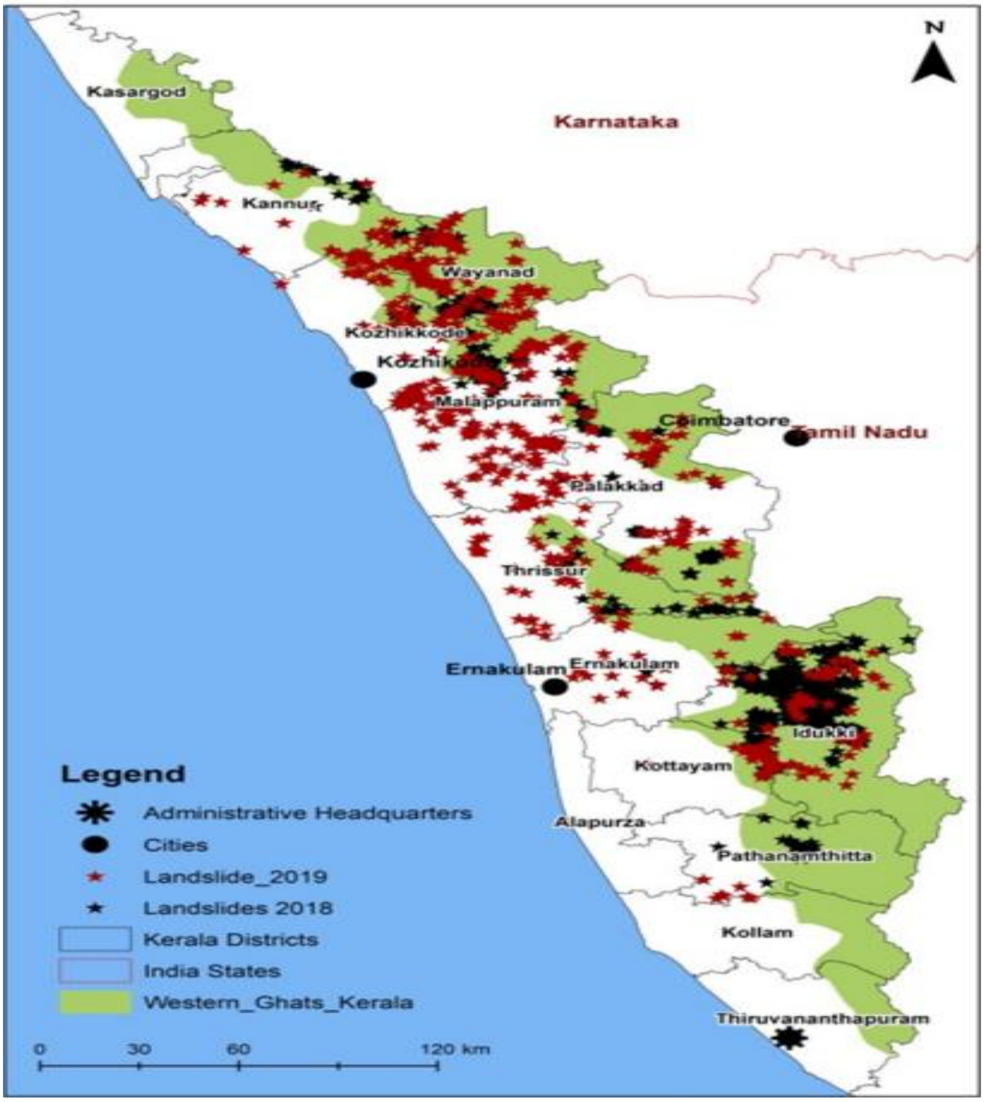

Figure 1: Major Landslide occurring spots during 2018 and 2019 in the state of Kerala, India (Source:(Jones et al., 2021))

Conclusion:

This review paper makes an attempt to comprehend Kerala, which contributes significantly to global rainfall-induced landslides. Rainfall-induced landslides are a serious calamity that occurs all over the world. The southwest monsoon rains heavily in the state from June to August, and the northeast monsoon rains heavily from October to November. The southwest monsoon often generates more rainfall than the northeast monsoon. Kerala had the most severe excessive rains since 1924 in 2018. The heavy rains caused numerous landslides and floods, causing considerable property damage. Reviewing these papers highlights the importance of thorough understanding and research into rainfall-induced landslides.

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