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Exploring the Impact and Lessons of the 2019 Kavalappara Landslide Disasters in Kerala, India: A Field Observation Analysis

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Abstract

Kerala, a state in India, stretches approximately 560 kilometres in a northwest-to-south-southeast direction and ranges in width from 35 to 120 kilometres in the east-west dimension. This area is known for its frequent occurrences of landslides. It features a distinctive physiographic and geomorphic landscape characterized by the prominent Western Ghats Mountains running in an NNW-SSE orientation in the east. These mountains are surrounded by a series of parallel landforms, including composite slopes, marginally raised lateritic uplands, and coastal plains that gradually descend in elevation towards the west, creating a terraced topography. Kerala receives substantial annual rainfall during the southwest monsoon season, which, due to its unique geomorphic setup, can lead to catastrophic landslides. As a result, this study extensively examined the region's geomorphology, primarily influenced by tectonic forces, to gain insights into its contribution to landslide occurrences. The Western Ghats in India has long been a focal point for landslide research. On August 8, 2019, Kavalappara witnessed one of the most devastating landslides in the state's history in terms of casualties. Beyond the tragic loss of 59 lives, it wrought unparalleled havoc upon the local community's assets and means of sustenance. This colossal landslide struck around 7:30 pm in Kavalappara, engulfing 100 acres of land. The primary catalyst for this immense disaster was the erratic and unprecedented deluge of monsoon rainfall. Our discerning observations underscore the role of human activities in exacerbating slope instability. Factors such as the transformation of natural vegetation into plantations, the hasty cutting of slopes, the installation of soak pits diverting water into the slopes, the construction of residences atop natural drainage channels, and suboptimal drainage practices, including the unregulated release of water from homes onto the slopes, have all been influential in heightening slope vulnerability.

Keywords : Landslide, Physiography, Rainfall ,Monsoon, vulnerability, Westernghat

1. Introduction

Kerala, often referred to as "God's Own Country," is renowned for its lush landscapes, verdant hills, and picturesque scenery. However, amidst its natural beauty, the state faces the dangers of natural disasters, particularly landslides. The Western Ghats in India have always been a focal point for landslide research (Kuriakose, 2009; Sajin Kumar, 2011; Ramesh & Vasudevan, 2012). In August 2019, the serene village of Kavalappara, situated in the Malappuram district of Kerala, became the centre of a catastrophic event that would have a lasting impact on the region. Kavalappara, a charming village nestled in the Western Ghats, was known for its hilly terrain, dense vegetation, and close-knit community. The villagers lived in harmony with the lush surroundings, but an unrelenting monsoon downpour soon disrupted their peaceful existence. Disaster struck on a fateful evening in August 2019 at around 7:50 pm. Kerala, often referred to as "God's Own Country," is renowned for its lush landscapes, verdant hills, and picturesque scenery. However, amidst its natural beauty, the state faces the dangers of natural disasters, particularly landslides. The Western Ghats in India have always been a focal point for landslide research (Kuriakose, 2009; Sajin Kumar, 2011; Ramesh & Vasudevan, 2012). In August 2019, the serene village of Kavalappara, situated in the Malappuram district of Kerala, became the centre of a catastrophic event that would have a lasting impact on the region. Kavalappara, a charming village nestled in the Western Ghats, was known for its hilly terrain, dense vegetation, and close-knit community. The villagers lived in harmony with the lush surroundings, but an unrelenting monsoon downpour soon disrupted their peaceful existence. Disaster struck on a fateful evening in August 2019 at around 7:30 pm.
In response to the intense and unyielding monsoon rainfall, a significant landslide occurred on Muthappan Hill, a 350-meter-high geographic landmark that towered over Kavalappara. The hill split into three sections, triggering a rapid mudslide that engulfed the village, burying homes and residents beneath a deluge of mud, rocks, and debris. Tragically, 18 families were buried alive as their houses succumbed to the cascading landslide. In the aftermath, 59 people remained trapped under tons of earth, their lives hanging in the balance. The landslide at Kavalappara spurred an

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immediate and extensive response effort, with local authorities, volunteers, and rescue teams working tirelessly to locate survivors. However, the challenging terrain, relentless rainfall, and the scale of devastation presented formidable challenges to these efforts. This natural disaster had far-reaching implications stemming from a combination of geological, meteorological, and environmental factors. It shed light on the vulnerabilities of communities living in hilly terrain, highlighting the importance of disaster preparedness and responsible land use practices. The Kavalappara landslide stands as a stark reminder of nature's relentless power and the critical need to understand and mitigate the risks associated with such disasters. This incident prompted a thorough investigation, a search for valuable lessons, and efforts to enhance disaster resilience in Kerala, showcasing the resilience of the human spirit in the face of adversity.

2. Study area

The Western Ghats cover almost half of Kerala state, extending approximately 450 kilometres along its eastern border. Its significant impact on Kerala's climate is evident in its ability to cause orographic precipitation during the southwest monsoon. Globally, the Western Ghats region is one of the most densely populated mountainous areas. Around 8% (equivalent to 1,400 square kilometres) of Kerala's land within the Western Ghats is classified as a critical zone prone to mass movements. Kavalappara is situated in the Malappuram district of Kerala, India, within the pothukallu Gramapanchayath. Pothukallu Grama Panchayat covers an area of 77.00 square kilometres. Figure 1. The designated study area, Pothukallu (Pothukal), is located between the Grama Panchayats of Palunda and Munderi within Nilambur Taluk, Malappuram District. It stretches across the geographical coordinates of Latitude 11° 40' 41" or 11° 24' 14.8" North and Longitude 76° 25' 27" or 76° 15' 9.6" East. Positioned at the convergence of three distinct districts, Wayanad and Malappuram, within Kerala and the Nilgiris in Tamil Nadu, Pothukallu occupies a strategic location. The specific study area, Kavalappara, is nestled within the Muthappankunnu hill slopes of the Western Ghats in the Pothukallu Grama panchayat of Malappuram district. Kavalappara is notable in Kerala's history due to one of the most extensive landslides in terms of casualties and damage. The Kavalappara landslide is geographically located at 11°24'23.08"N and 76°14'4.49"E, covering an area of 0.34 square kilometres (equivalent to 34 hectares) and reaching a maximum elevation of 220 meters above mean sea level (M.S.L.). Figure 2 . This area is situated on the windward side of the Wayanad plateau within the Western Ghats, with its tributaries flowing into the Chaliyar River.

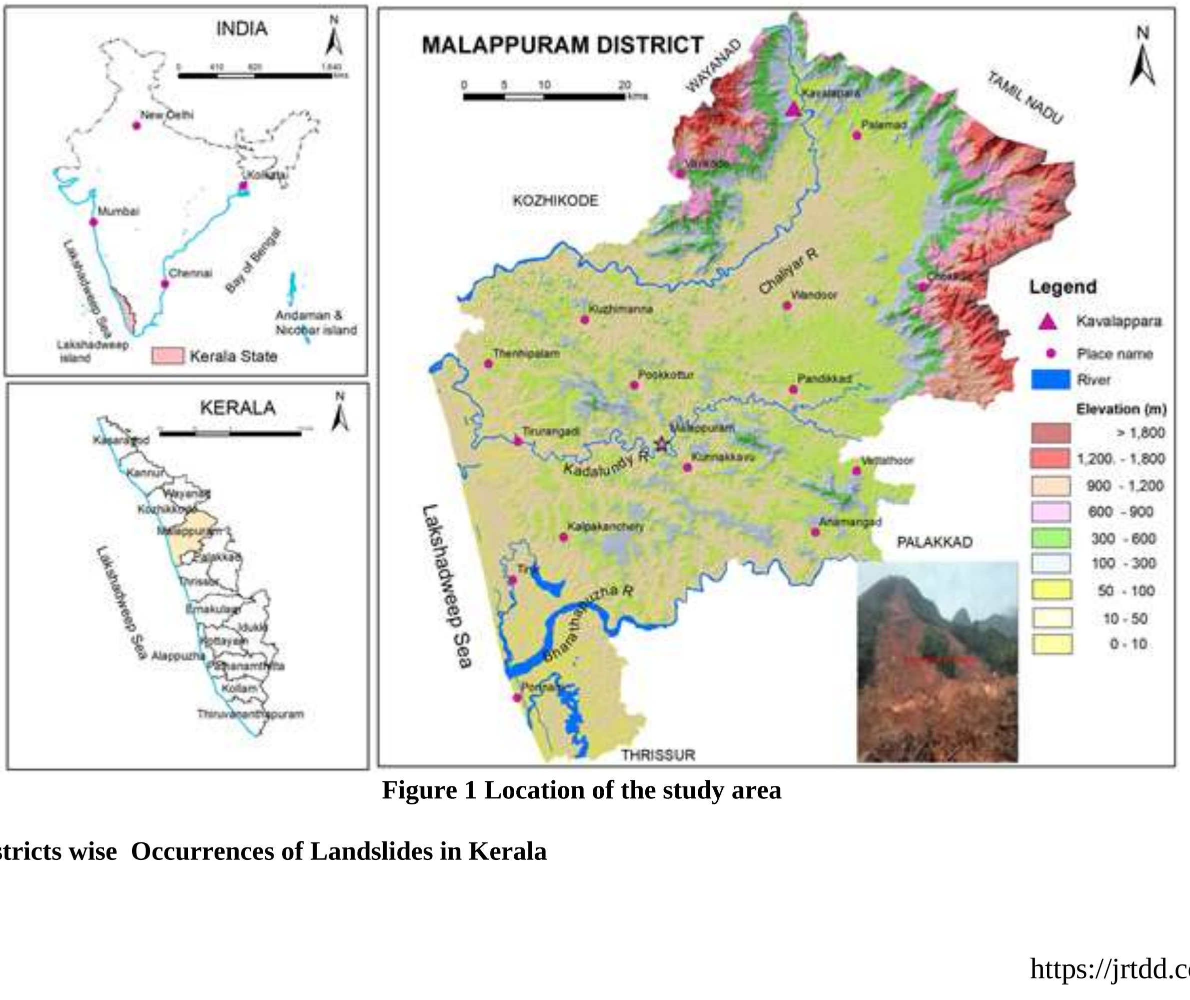

Figure 1 Location of the study area

3. Districts wise Occurrences of Landslides in Kerala

Table 1.1 presents the incidence of landslides in each district. Palakkad has recorded the highest number of landslides, with 18 occurrences, followed by Malappuram with 11 occurrences and Wayanad with 10. Conversely, Thrissur, Ernakulam, and Kottayam have relatively low landslide occurrences, each with only 2 reported incidents. This information can be valuable for evaluating the frequency and distribution of landslides in different districts of Kerala. It can greatly aid in disaster management and mitigation efforts in the region.

Table 1.1Districts wise Occurrences of Landslides in Kerala

Districts	Landslide occurrence in 2019
Kannur	6
Kozhikkode	8
Wayanad	10
Malappuram	11
Palakkad	18
Thrissur	2
Ernakulam	2
Idukki	6
Kottayam	2

Source: SDMA 2019

Table 1.2 District Wise Human Fatalities in 2019

District	Fatalities	Gratuitous relief @ ₹4 lakhs/ person (Rs. in lakhs)
Alappuzha	6	24
Kottayam	2	8
Idukki	5	20
Thrissur	9	36
Palakkad	1	4
Malappuram	60	240
Kozhikode	17	68
Wayanad	14	56
Kannur	9	36
Kasaragode	2	8
Total	**125**	**500**

Source: SDMA 2019

Table 1.2 shows the fatalities due to landslides and floods in each district and the financial assistance provided to the affected families through gratuitous relief. The total number of fatalities across all districts is 125, and the total relief amount disbursed is ₹500 lakhs (₹5 crores). This assistance is meant to support the families of the deceased during times of distress or calamity.

4. Methods

Hazards can be defined as processes, phenomena, or human activities that have the potential to result in loss of life, injury, property damage, environmental degradation, or social and economic disruption. Increasing our understanding of hazards can help improve risk perception and preparedness, leading to reduced vulnerability in the future (Hurnen & McClure, 1997; Gaillard, 2008). Individuals need to have a clear understanding of hazards and risks in order to actively engage in mitigation measures for natural disasters (Wegscheider, 2011). This study utilizes systematic field observations to analyze the causes and impacts of the 2019 Kavalappara landslide disaster in Kerala, India. The approach involves comprehensive data collection efforts, including extensive field surveys that capture the immediate aftermath of the landslide.

Field researchers, armed with photography and videography equipment, document the extent of damage, alterations in topography, and the profound impact on the local community. These on-site observations are further complemented by G.P.S. coordinates, facilitating precise mapping of the affected area. Moreover, geological data play a pivotal role in uncovering the geological factors contributing to the landslide. Detailed records are kept regarding soil composition, rock types, and geological structures. Geological reports and maps provide valuable insights, while soil and rock samples are collected for thorough laboratory analysis. Meteorological data, including rainfall records and weather

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information leading up to the landslide, is crucial for understanding the meteorological context of the disaster. Historical meteorological data is essential for evaluating weather patterns and anomalies that may have contributed to the event. Geospatial data, including Geographic Information Systems (G.I.S.) and remote sensing tools, is used to create comprehensive maps and spatial models of the affected area. G.I.S. data helps map the evolution of land use and landscape alterations. Satellite imagery and remote sensing are employed to monitor land changes, enhancing the research's depth and accuracy. Community interviews are conducted with residents, survivors, and experts to capture the human dimensions of the disaster. Qualitative data in the form of personal accounts, narratives, and perspectives offer a unique insight into the socio-economic impact of the landslide.

Furthermore, the study extensively documents the community's response and resilience, providing a comprehensive understanding of the human experience in the face of such calamities. It also incorporates risk assessment data, delving into the complexities of land use practices, deforestation, and natural drainage patterns. These are crucial for identifying potential areas at risk for future landslides.

In addition, the research is enriched by secondary data such as historical records, government reports, and scientific studies related to the Kavalappara landslide. The comprehensive analysis and interpretation of this data deepen our understanding of the causes, consequences, and lessons learned from the Kavalappara landslide, paving the way for comprehensive risk assessments and informed recommendations. This approach exemplifies the significance of field observation analysis in comprehending the multifaceted nature of landslide disasters and their far-reaching implications.

Results

Figure 2 Cross section of Kavalappara landslide.

Table 1.3 District-wise departure of average rainfall in Kerala

District	Normal rainfall (mm)	Actual rainfall (mm)	Percentage Departure	
Kasargode	658.9	1194.5	81	Large Excess
Kannur	554	1107.2	100	Large Excess
Kozhikode	510.8	1407.8	176	Large Excess

Wayanad	568.3	1190.8	110	Large Excess
Malappuram	392.7	1084.2	176	Large Excess
Palakkad	324.8	1030.6	217	Large Excess
Thrissur	467.9	1062.0	127	Large Excess
Ernakulam	398.5	957.7	140	Large Excess
Alappuzha	339.1	676.1	99	Large Excess
Kottayam	375.7	763.0	103	Large Excess
Idukki	590.5	979.4	66	Large Excess
Pathanamthitta	333.6	717.7	115	Large Excess
Kollam	258.2	549.3	113	Large Excess
Thiruvananthapuram	144	325	126	Large Excess
State	**426.7**	**951.4**	**123**	**Large Excess**

Source KSDMA 2019

Table 1.3 shows the District-wise departure of average rainfall during August 2019 (August 1 - 31). It provided a data table related to rainfall in various districts of an area, Kerala, India. Districts with a positive percentage departure indicated they received significantly more rainfall than usual. This leads to flooding and landslides. Based on this data, all the districts in the area experienced large excess rainfall during the specified period, which typically poses challenges regarding flooding and landslide management. After the deluge of August 2018, Kerala again witnessed incessant rain in 2019, accompanied by floods and landslides. The number of extreme rainfall events was lower in August 2019 than in August 2018. However, the number of rainy days was higher in August 2019, and ten out of fourteen districts recorded monthly cumulative rainfall higher than in August 2018.(KSDMA2019)

In August 2019, Kerala experienced an exceptional 123% surplus in rainfall compared to the long-term average for the state. The previous year, in August 2018, there was also a significant excess rainfall, at 96% above the long-term average. The most severely affected districts in North and Central Kerala were Kozhikode (176%), Wayanad (110%), Malappuram (176%), Palakkad (217%), Thrissur (127%), and Ernakulam (140%), all of which experienced well over 100% more rainfall than the normal average during August. Impressively, 7 out of the 14 districts, spanning from Kasargode to Thrissur, received over 1000 mm of rainfall from August 1 to August 31, 2019.

Between August 8 and 31, 2019, Kerala once again grappled with devastating floods and landslides. The 2019 monsoon season had a slow and delayed start, with the official onset of the monsoon declared by the Indian Meteorological Department on June 8, 2019. Up until July 31, Kerala had experienced a 32% deficit in rainfall. Usually, June and July are considered the 'rainy months' in Kerala. By the end of July 2019, Wayanad, one of the severely affected districts, had recorded a significant 55% deficiency in rainfall compared to the long-term average. Fortunately, the situation improved in August due to the influence of low-pressure areas and depressions forming over the Bay of Bengal, coupled with the strengthening of monsoon winds. This shift in weather patterns resulted in Kerala receiving an excessive amount of rainfall during August.

5. The devastating Kavalappara Landslide in Kerala: A Tragic Account of Natural Disaster

The heart-wrenching tragedy at Kavalappara in Malappuram district resulted in 18 families being engulfed by their collapsing houses under a hillock. Fifty-nine individuals are trapped beneath the massive amounts of mud and soil that engulfed the extensive residential area situated on the outskirts of the hillock. This catastrophic occurrence serves as a poignant reminder of the dangers of residing in mountainous areas, especially during the monsoon season. It emphasizes the critical importance of disaster preparedness and risk reduction in such vulnerable regions. Figure 1.3

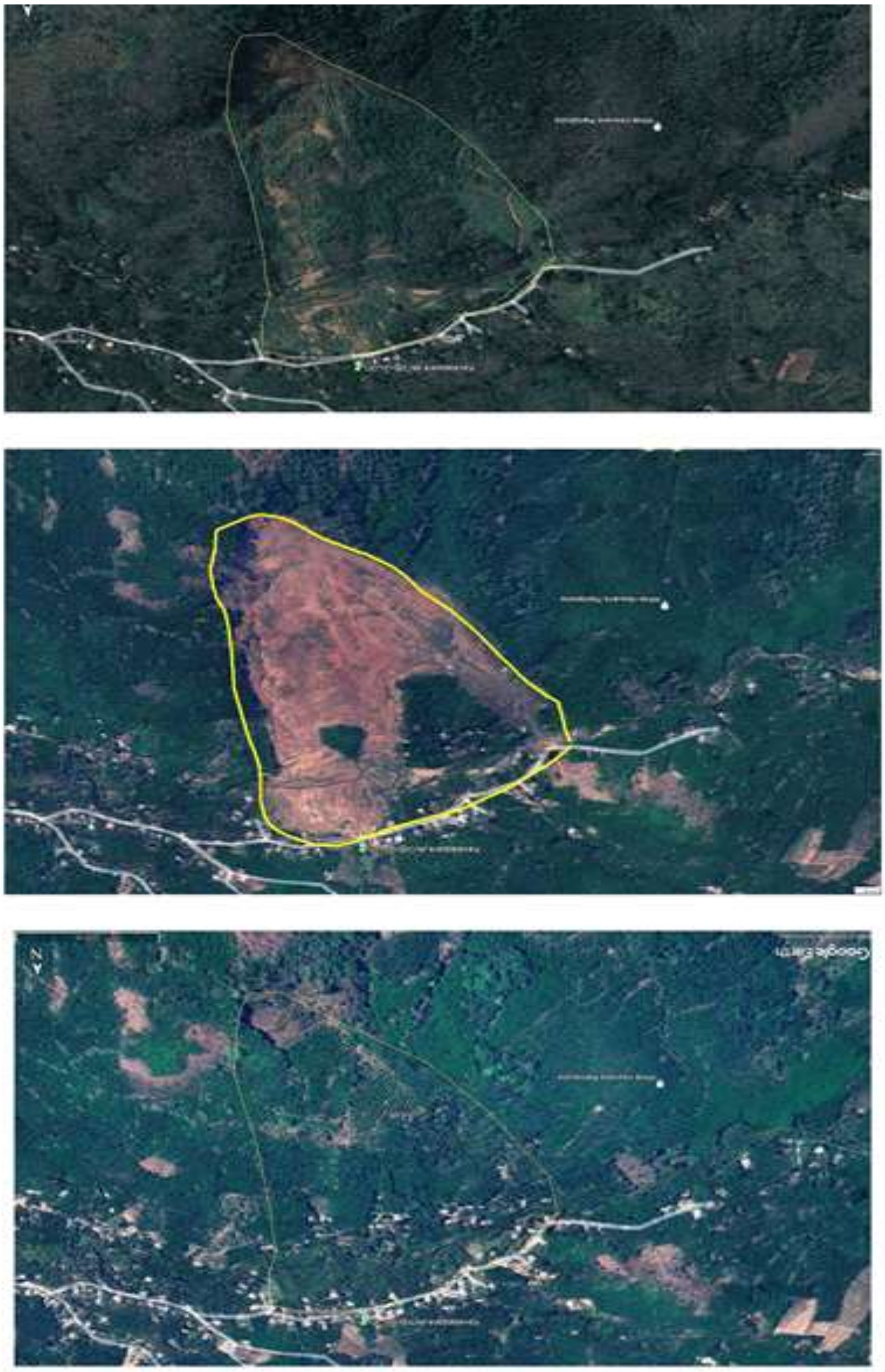

Figure 1.3 Google images before and after the Kavalappara landslide in Kerala.

The landslide that occurred in MuthappanKunnu on August 8 at 7:30 pm had devastating repercussions. The hill split into three parts, unleashing a substantial amount of soil and pebbles, reaching up to three meters in height, which then cascaded into residential areas. This kind of event is particularly dangerous, as the collapse of the hill and the resulting debris flow can lead to extensive destruction, posing a threat to lives and property in the affected area. Landslides of this scale can be extremely destructive, underscoring the importance of preparedness and the implementation of preventive measures**.**

An alarming event has caused widespread distress in the area as a large landslide in Muthappankunnu near Nilambur has resulted in the loss of 59 lives and the disappearance of many others. The landslide took place in a mountainous region, burying numerous homes and roads under a significant amount of debris. This devastating event occurred on August 8, 2019, when intense rainfall and soil erosion led to an unprecedented landslide. Taking place in a secluded village near Pothukallu panchayath, this incident caught both residents and local authorities off guard, leaving them grappling with the emergency.

On August 9, rescue operations started with Local authorities, including the National Disaster Response Force (NDRF) and state agencies, immediately launched rescue and relief operations. Rescue teams, consisting of personnel skilled in disaster response, were rushed to the scene to search for survivors and retrieve the bodies of those who lost their lives in the disaster. While rescue efforts are ongoing, the prospects of finding survivors diminish as hours pass. Continuous rainfall and treacherous terrain have made rescue operations a formidable challenge. The landslide has also disrupted road connectivity, hampering access for rescue teams. In the wake of the devastating landslide in Kavalappara, heavy machinery such as J.C.B.s (Hydraulic Excavators) earth movers played a critical role in the search and rescue operations to locate missing persons. Nearly 14 J.C.B. deployed in the areas. These robust machines were deployed to clear debris, remove earth and rocks, and create access points for rescue teams. The use of J.C.B.s significantly expedited the search efforts, allowing rescue workers to cover a larger area to find missing persons buried under the landslide. Their versatility and strength were invaluable in helping the rescue teams navigate the challenging terrain and offer a glimmer of hope in the face of this tragic event.

On August 18, the deployment of Ground Penetrating Radar (GPR) by the National Geophysical Institute in the areas affected by the Kavalappara landslide signifies a significant advancement in improving the effectiveness of search and recovery operations. The experts at the National Geophysical Institute have demonstrated their ability to analyze GPR data with precision, thereby increasing the likelihood of accurately locating buried bodies and other irregularities. However, the rugged terrain in certain areas could impede the effectiveness of GPR.In regions characterized by complex geology, excessive debris, or highly irregular landscapes, GPR might require assistance to yield accurate readings. Moreover, the immense volumes of debris and rubble resulting from the landslide might obstruct the radar waves, hindering their ability to penetrate the ground and provide valuable data. The composition of the soil and rock in the area can also impact the performance of GPR, as certain types may absorb radar waves, making it challenging to obtain clear subsurface images. Additionally, excessive moisture saturation in the soil could interfere with GPR readings, as radar waves are absorbed by water. GPR technology is generally more effective at detecting objects buried at shallow depths. If the bodies were buried deep beneath the landslide debris, GPR might not have been able to reach them effectively.

On August 20, the recovery of the last victim from the Kavalappara landslide site marked a poignant and meaningful moment in the ongoing search and recovery endeavours. The calamity that befell the village left a profound impact, and the retrieval of the final victim is a testament to the unwavering and dedicated efforts of the rescue teams and volunteers who worked tirelessly to bring closure to the affected families. This tragic August 27 is a poignant reminder of the formidable challenges encountered during landslide disasters and underscores the critical importance of effective disaster preparedness and mitigation measures.

On August 27, the rescue operation in Kavalappara concluded after an arduous and unwavering effort, resulting in the successful recovery of 48 deceased individuals out of the 59 initially reported missing due to the catastrophic landslide. The operation highlighted the resolute dedication of rescue teams, volunteers, and all those involved in the mission to locate and recover the victims. Although the search and rescue operations were unable to bring closure to all the affected families, they underscored the significant challenges presented by natural disasters. They emphasized the necessity of ongoing disaster preparedness and response efforts.

The government of Kerala has declared this incident a state-level emergency, pledging all available resources to mitigate the disaster's effects and support the affected communities. The state government has announced compensation for the victims' families and the injured, with financial assistance for those who have lost their homes. Residents have come together to support one another during this difficult time, providing shelter and aid to those displaced by the landslide. Relief camps have been set up to provide essential supplies, medical care, and shelter to the affected families. As the nation grapples with the tragic loss of lives in Pothukallu panchayath, questions about land use practices and the impact of climate change on such disasters are being raised. Environmental experts and geologists are assessing the area to understand better the factors contributing to the landslide and to develop strategies for preventing similar occurrences.

The tragedy in Pothukallu panchayath is a sombre reminder of the vulnerability of hilly regions during the monsoon season, and it underscores the importance of proactive measures to minimize such risks and protect the lives of those living in these areas. The nation mourns the lives lost in this devastating event, and efforts are ongoing to provide assistance and support to the affected communities. Authorities and relief organizations continue their rescue and relief efforts, working tirelessly to mitigate the effects of this natural disaster and provide solace to the victims' families during this difficult time.

6. Discussion

Heavy monsoon rains played a pivotal role in the Kavalappara landslide. The intense and prolonged monsoon rains that preceded the disaster were a primary contributing factor. Between August 1st and 7th, Nilambur received 189.4 millimetres of rainfall, 66 per cent higher than the average rainfall for the same period. The average rainfall during this timeframe in Nilambur typically measures around 114 millimetres. This increase in rainfall indicates a deviation from the usual weather patterns and can cause concern, especially in areas prone to landslides and flooding. Monitoring and responding to such deviations in rainfall is crucial for disaster preparedness and safety measures.

Table 1.4 Location - Palemad (Rainfall data extracted from IMD Gridded data in August 2019)

Date	Rainfall
8 /1/2019	0
8/2/2019	0
8/3/2019	3.3723
8/4/2019	9.6779
8/5/2019	56.0272
8/6/2019	66.8081
8/7/2019	98.4351
8/8/2019	188.9571

Source :Rainfall data extracted from IMD Gridded data

Table 1.4 shows that August 7, 2019, experienced the highest rainfall in this dataset, with a measurement of 98.4351 mm in Palemad near Kavalappara. On August 8, 2019, there was substantial rainfall, measuring 188.9571 mm, significantly higher than the previous days. The data shows an increasing trend in daily rainfall, with a notable spike in rainfall on August 7 and 8, 2019.

The landslide at Kavalappara originated from the northern slope of the 350-meter-high Muthappan hill. Figure 4. The landslide was triggered when a mud block measuring 3 meters in thickness began moving downward from 300 meters. As it descended, it accumulated loose soil and rocks along its path, eventually resulting in the devastating landslide that impacted the area. The steep terrain and the accumulation of debris made it challenging to mitigate the effects of the landslide, leading to significant destruction and loss of life. Landslides are complex geological events influenced by various factors, including topography and weather conditions.

The topographic sheets reveal that the hill at Kavalappara was host to two first-order streams. These streams served as natural drainage channels designed to collect excess rainwater from the hill and channel it out of the area. However, it has been observed that both streams have been filled up entirely up to 100 meters from the valley. This filling of the streams likely obstructed the natural drainage system, preventing it from effectively carrying rainwater away from the hill. As a result, excess rainwater became trapped in the area, potentially saturating the soil, increasing the weight on the slope, and contributing to the hill's instability. This could have played a role in the occurrence of the landslide. The alteration of natural drainage patterns and the blocking of streams can have significant implications for the stability of hilly terrain, particularly during periods of heavy rainfall. It underscores the importance of considering the environmental impact of land use and development in such regions and the potential consequences for disaster risk.

Figure 5 shows that the mechanical alteration of the terrain for rubber cultivation further exacerbated the situation at Kavalappara. The process of creating pits for the rubber plantation had a significant impact on the natural landscape and soil structure. The crown portion of the main slide area of Kavalappara is an uninhabited hillock with frequent intense tillage for rubber plantations(Chattopadhyay Srikumar2015). Moreover, the construction of terraces using random rubbles in the rubber-cultivated area results in the blockage of free passage of water, leading to the increased infiltration of water (Naidu Shruti, 2018).

Figure .4 Devastating Landslide Pathway in Kavalappara Region

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a. Land slide area
b. Partially demolished building
c. Devastated rubber plantation
d. Abandoned laterite quarry

Figure 5 Field photograph of Kavalappara landslide areas

The pits dug for rubber cultivation significantly altered the soil structure in the area. This type of mechanical disturbance can change the soil's composition and stability, making it more vulnerable to erosion and landslides. Water that entered these pits due to heavy rainfall had its natural flow patterns disrupted. Instead of percolating into the ground, it remained on the surface. This increased surface water flow can lead to soil erosion and contribute to landslides. Rubber cultivation in problematic areas with varying slopes is more likely to increase the risk of landslides due to intensive monoculture practices(Winai Wangpimool, 2017). The area had a relatively shallow topsoil depth of only 2 meters. When this limited topsoil is disturbed, it can expose the underlying rocky layers. The soil in the area was held together by lethargic clay, which played a critical role in stabilizing the terrain. However, the steady percolation of water, especially due to the blocked drainage channels, diluted and washed away this clay, weakening the bond between the rocky base and the topsoil. The combination of these factors, including the altered soil structure, surface water flow disruption, and the weakening of the lethargic clay, collectively increased the risk of a landslide. This highlights the importance of responsible land use practices and the potential environmental consequences of land development in geologically sensitive and hilly regions.

6.1 Soil Composition and Kavalappara Landslide

Soil plays a vital role in an area's landslide activity. One of the main reasons for the landslide is the progressive deterioration of soil due to erosion (Sharma, 2010). Soils of the region belong to the Vazhikadavu series in the central upland areas of the Malappuram district (Benchmark Soils of Kerala, Department of Soil Survey and Soil Conservation, Kerala 2010). Heavy monsoon rains saturate the soil, making it more vulnerable to landslides. When the soil becomes waterlogged, it loses its stability, and the additional weight from the water can increase the likelihood of a landslide. Continuous rainfall leads to soil erosion, especially in hilly regions like Kavalappara. Erosion can weaken the slope and cause the displacement of soil, rocks, and debris, making it easier for a landslide to occur. The heavy rainfall also results in increased surface water flow, which can undermine the stability of slopes. This flow of water can infiltrate the soil, making it less cohesive and more prone to sliding. The accumulation of water in the soil increases the hydraulic pressure, which can further destabilize the slope and contribute to landslides.

6.2 Soil composition and Soil erosion

Soil composition played a crucial role in the Kavalappara landslide. The type of soil in a region can impact its susceptibility to landslides. In the case of Kavalappara, the predominant soil composition likely contributed to the disaster. Some types of soil, particularly clayey soil, are more prone to retaining water and becoming saturated. When clayey soil is exposed to heavy rainfall, it can hold a significant amount of water, making it heavy and unstable. This increased weight can contribute to landslides. Clayey soil has a high moisture retention capacity, which means it retains water for more extended periods. When exposed to prolonged heavy rain, this type of soil can become saturated, further weakening the stability of the slope. Clayey soil is less porous than other soil types, making it less capable of allowing water to percolate through it. Instead, the water runs off the surface, contributing to surface erosion and increasing the risk of landslides. In hilly and geologically active regions like Kavalappara, the presence of clayey soil can be a contributing factor to landslide events, especially during the monsoon season. The soil's properties, combined with heavy and sustained rainfall, can create a situation where the slope becomes unstable and prone to sliding. Understanding the soil composition and its behaviour in response to weather conditions is essential for assessing and mitigating landslide risks in such areas.

One of the main reasons for the landslide is the progressive deterioration of soil due to erosion (Sharma L.P2010). Soil erosion is a significant factor that contributed to the Kavalappara landslide. Soil erosion, particularly in hilly and mountainous regions like Kavalappara, can weaken the stability of slopes. The removal of the topsoil and vegetation cover exposes the underlying rocks and soil to the impact of rainfall and flowing water, making the slope more vulnerable to landslides. Vegetation, including trees and shrubs, plays a crucial role in stabilizing slopes. Their root systems bind the soil and prevent it from being easily washed away during heavy rainfall. When vegetation is lost due to deforestation or other factors, the soil is more prone to erosion. The soil eroded from higher up on the slope often accumulates at the base of the hill. This buildup of sediments can increase the weight on the lower portion of the slope, making it more unstable and susceptible to landslides. Soil erosion can lead to the formation of channels or gullies along the slope, directing the flow of water. These channels can cut into the hillside and further destabilize it.

In the case of the Kavalappara landslide, the combination of these factors created a situation where the hillside was weakened and unable to withstand the immense pressure from the heavy monsoon rains. This ultimately led to a catastrophic landslide that buried part of the village, resulting in a tragic loss of life and property. Landslides are common in hilly and geologically active regions during the monsoon season, and they are a sobering reminder of the need for disaster preparedness and mitigation in such vulnerable areas.

6.3 Loss of Natural Drainage:

The absence of natural streams to carry soil and mud down to the valley had a significant impact on the events at Kavalappara**.** During the rainy season, through seasonal rivulets, water gushes through the landslide body. (Naidu Shruti 2015). Streams typically act as natural drainage channels, allowing soil, mud, and water to flow safely downhill during heavy rainfall. Without these streams, there was no structured path for the debris to follow. In the absence of the streams, the debris from the landslide was free to travel down the hillside in any direction it found. This uncontrolled flow of debris could take anything in its path, including saturated soil, loose boulders, and even uprooted trees. The debris that was eventually deposited near the Kavalappara Thodu or channel demonstrated the scale of the tragedy. The canal itself may have been obstructed by the landslide debris, potentially causing flooding and further complicating the situation for the local community. The loss of natural drainage channels can have severe consequences in hilly and mountainous regions, especially during heavy rainfall or landslide events. It underscores the importance of preserving natural drainage systems and considering the environmental impact of land use practices to reduce the risk of such disasters. In the case of the Kavalappara landslide, the heavy monsoon rains likely caused soil erosion, weakening the hillside's stability over time. The saturation of the soil due to heavy rainfall and the loss of vegetation cover may have made the slope more vulnerable to sliding. The combination of these factors, along with the hilly terrain, played a crucial role in the devastating landslide that occurred in the region. This highlights the importance of land management practices, afforestation, and erosion control measures in hilly and geologically active areas to reduce the risk of landslides during periods of intense rainfall.

6.4 The terrain of Kavalappara

The physiography and geomorphology of Kerala are well defined with step-like descending topography with a westerly slope from the Western Ghats in the eastern to the coastal plains in the western parts of Kerala (Fig. 1). So, the southwest monsoon water that impounds on the plateaus of the Western Ghats, which used to be normally heavy in Kerala every year, quickly descends towards westerly, cutting across the escarpments and reaches the sea. (Ramaswamy 2020). The hilly terrain in Kavalappara, Kerala, was a significant factor in the Kavalappara landslide. Hilly and mountainous regions are inherently more susceptible to landslides. In the Kavalappara region, the slope typically falls within the range of 10-30 degrees, exerting a notable influence on the occurrence of landslides. This susceptibility is exacerbated by heavy rainfall prior to landslides, leading to the saturation of slopes. Such rainfall can result in heightened hydrostatic pressure, making rainwater infiltration the primary triggering mechanism for landslides and accompanying debris flows. The area is hydrologically saturated, with intermittent springs emerging in various locations, indicative of shallow groundwater levels. During the rainy season, seasonal rivulets carry water through the landslide area, ultimately merging with the main Chaliyar River, which courses through the eastern section of the primary landslide zone.

The steep slopes and complex geology in such areas create a natural environment where landslides can occur, especially during heavy rainfall. The inclination of the terrain can make the soil and rock on the hillsides less stable. This makes it easier for the soil to become dislodged and for landslides to occur, particularly when the soil is saturated due to heavy monsoon rains. Gravity plays a significant role in landslides, and the steeper the slope, the more influential gravity becomes in pulling down unstable materials. In hilly regions, water drainage can be complex, as water can flow down the slopes rapidly during heavy rainfall. This increased surface water runoff can undermine the stability of the slopes and contribute to landslides. In the case of Kavalappara, the hilly terrain made the region particularly vulnerable to landslides, especially during the monsoon season. The intense and prolonged heavy rains saturated the soil, causing soil erosion and further destabilizing the slopes. These factors combined to create a tragic landslide event, burying part of the village beneath tons of debris and causing a significant loss of life and property. The disaster underscores the need for comprehensive disaster preparedness and mitigation measures in hilly and geologically active regions to reduce the risk and impact of landslides.

6.5 Land use change in Kavalappara

The influence of human activity on landforms has multiplied the number of natural hazards (Sajin Kumar, 2010). A collection of studies and observations at Kavalappara and other sites have shown that human activity plays a major role in aggravating slope instability and causing landslides in these parts (Rajkumar, 2011; Gadgil, 2011; vasudevan2016; Froude Mj, 2018; Ramanathan 2021,). Deforestation and improper land use practices are indeed significant factors that contributed to the Kavalappara landslide. Here is how they played a role in the disaster. Deforestation, which involves the clearing of forests and vegetation cover, significantly reduces the stabilizing effect of roots in the soil. Trees and plants help bind the soil and prevent erosion. When vegetation is removed, the soil becomes more vulnerable to erosion and landslides, particularly during heavy rainfall. The removal of trees and vegetation exposes the soil to the full force of heavy rainfall. Without the protective canopy of trees, the soil can become saturated more quickly, increasing the risk of landslides. Deforestation and changes in land use can alter natural drainage patterns. Water that was once absorbed by forests or followed natural pathways is disrupted, leading to increased surface water runoff. This runoff can erode soil and exacerbate landslide risks. Unplanned or poorly regulated development in hilly and geologically sensitive areas can increase the risk of landslides. Construction of buildings, roads, and other infrastructure can disturb the natural balance of the environment, destabilizing slopes and making them prone to sliding. When deforestation and improper land use practices coincide with heavy monsoon rains, the risk of landslides becomes especially high. The combination of these factors can lead to catastrophic events like the one witnessed in Kavalappara. These causes highlight the need for responsible land management and land-use planning practices in hilly and geologically active regions to minimize the risk of landslides and protect the safety and well-being of communities living in these areas.

6.6 Geological factors played a significant role in the Kavalappara landslide.

Geological factors played a significant role in the Kavalappara landslide. The geological characteristics of the region contributed to the occurrence of the disaster. Here are some geological factors that were relevant to the landslide Kavalappara is located in the Western Ghats, a region with complex geological structures. The predominant rock types in Pothukal Panchayat are hornblende-biotite gneisses of the Peninsular Gneissic Complex and charnockites of the Charnockite Group, both of the Archaean Eon (G.S.I. 1981, KSLUB, Wadwan 2020) Highly weathered biotite granite gneiss and charnockite were observed at the landslide site, along with brownish-red laterite soil. These structures, such as fault lines and rock formations, can influence the stability of slopes and make them more prone to landslides. The types of rocks in the area can vary, and some rock types may be more susceptible to weathering and erosion. Weaker or fractured rock can affect the overall stability of the hillside. The presence of fault lines in the geological makeup of the area can create zones of weakness. Landslides can be triggered along these fault lines, where rocks and soil are more likely to shift. Regions with a history of geological instability, including previous landslides, can be at higher risk for future landslides. The geological history of the area can influence the vulnerability of slopes. In the case of the Kavalappara landslide, the geological features of the Western Ghats, along with the hilly terrain and the presence of fault lines, likely played a role in making the region susceptible to landslides, especially when coupled with heavy monsoon rains and deforestation. Understanding these geological factors is essential for assessing and mitigating landslide risks in such regions.

6.7 The absence of early warning systems in the Kavalappara

The absence of early warning systems in the Kavalappara landslide incident is a significant concern. Early warning systems are crucial in disaster-prone areas, particularly for events like landslides. Landslides can occur suddenly, leaving very little time for residents to evacuate safely. Early warning systems can provide critical lead time for people to move to safer ground, reducing the risk to life and property. With early warnings, communities and authorities may have had the opportunity to prepare adequately for the impending landslide. This can include reinforcing vulnerable slopes, implementing evacuation plans, and securing critical infrastructure. Early warnings not only help in evacuating residents but also enable rescue and relief teams to mobilize in advance. Such warnings can help the rapid response to a disaster, delaying search and rescue operations. Early warning systems can provide data on the likelihood of landslides based on meteorological and geological factors. The absence of such assessments can make it challenging to predict the potential risk to an area. Early warning systems help raise awareness among the population about the risks they face. A lack of awareness can lead to a lack of preparedness among residents. To mitigate such risks, the implementation of early warning systems, including rainfall monitoring, geological surveys, and community education, is essential in landslide-prone areas. These systems can help save lives and reduce the impact of such disasters. The absence of early warning systems in Kavalappara underscores the importance of investing in disaster preparedness and mitigation measures for vulnerable regions.

6.8 Conclusion

The Kavalappara landslide was a devastating event that resulted from a combination of natural and human-induced factors. The heavy monsoon rains preceding the disaster were instrumental in creating the conditions for the landslide. From August 1 to 7th, Nilambur received 189.4 millimetres of rainfall, which was 66 per cent higher than the average for that time frame, indicating a departure from typical weather patterns. This increase in rainfall raised concerns, especially in areas prone to landslides and flooding. The steep terrain and accumulation of debris along the slope of the Muthappan hill contributed to the severity of the landslide and posed challenges for mitigating its effects. Furthermore, the filling of natural drainage channels in the area obstructed the flow of rainwater, potentially saturating the soil, increasing the slope's weight, and contributing to its instability.

Human activities, such as deforestation and the improper use of land for rubber cultivation, have significantly altered the soil structure and disrupted natural drainage patterns. The pits dug for rubber cultivation have exposed the rocky layers beneath, weakening the soil's stability. Additionally, the loss of natural vegetation and the haphazard creation of terraces using random rubble have obstructed the free passage of water, leading to increased surface water runoff and erosion. The shallow depth of the topsoil in the area has made it more vulnerable to erosion, particularly when the soil has been disturbed by land development. The geological factors in the Western Ghats, including the presence of fault lines and various rock types, have also influenced the stability of the slopes, making the region more susceptible to landslides, especially during periods of heavy rainfall.

The absence of early warning systems in Kavalappara has underscored the need for comprehensive disaster preparedness and mitigation measures in landslide-prone areas. Implementation of early warning systems can provide crucial lead time for residents to evacuate and for rescue and relief teams to mobilize, ultimately reducing the risk to life and property.The Kavalappara landslide was a tragic incident caused by a combination of factors, such as heavy rainfall, terrain, geological features, human activities, and the lack of early warning systems. This event highlights the significance of responsible land management, afforestation, erosion control, and disaster preparedness in hilly and geologically active areas to minimize the risk and impact of landslides during periods of heavy rain.

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