Post landslide Investigation of Shallow Landslide: A case study from the Southern Western Ghats, India

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Abstract

Many mountainous regions in the tropics witnessed extreme orographic rainfall episodes in the recent past. The portions of the Western Ghats that fall on the Kerala state also experienced extreme climatic conditions in floods and landslides in 2018 and 2019. More than a thousand small and large landslides occurred during that period in the State's Western Ghats regions. The landslide at Kavalapara in the Malappuram district in 2019 is at the top in the state regarding the causalities, financial loss, and spatial spread.

This study is based on a comprehensive field investigation at the Kavalappara landslide site and we developed a detailed landslide susceptibility map with the local community's involvement. The massive landslide covers 0.34 Sq.km (34 hectares) triggered by the unprecedented monsoon rainfall coupled with unsustainable agricultural practices. The area's risk zones have been identified and spatially mapped with the help of a detailed field investigation using Geographic Information System (GIS) and remote sensing technology. The output of the study can be used for the policymakers and planners working in landslide-prone areas.

Keywords: Landslides, Western Ghats, Kerala flood, Kavalappara, Unsustainable land use, Risk area identification.

Introduction

Kerala is a multi-hazard prone state in the country [10]. The State is considered highly vulnerable to natural disasters and the varying climatic dynamics because of its location between the sea coast and the Western Ghats with a steep gradient along the Western Ghats slopes [23]. For the last two decades, various natural disasters, particularly floods and landslides, have escalated. Various studies indicate that climate change could be a significant reason for natural hazards [13, 22]. Few authors have attempted systematic analyses of climate change and landslides.[4,5,22]

The Western Ghats occupies 47% of the geographical areas of Kerala, experience several types of landslides like rock falls, rock slips, slumps, creeps, debris flows, and rotational types of slides[12]. The debris flows are the most common, widespread, and frequent mass movements called "Urul Pottal" in the local vernacular[12]. In the state, 14.4 % of the geographical areas are prone to landslides[10]. The varying climatic conditions of the Western Ghats have greatly influenced the process of weathering and landslides[17].

Simultaneously anthropogenic disturbances are the leading cause for the occurrence of landslides in the Western Ghats[12]. In August 2018, the state recorded 36% excess rainfall due to a low-pressure system in the Arabian Sea.[14,25] This excess rainfall resulted in the worst floods in the state during the last century and consequently triggered thousands of landslides, causing the death of 483 persons and large-scale loss of property.[14]

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 lesser in August 2019 when compared with August 2018 data. However, the number of rainy days was higher in August 2019 and ten out of fourteen districts have recorded monthly cumulative rainfall higher than August 2018[9]. The northern districts were affected mainly by the landslides in 2019 while southern and central districts were primarily affected in 2018. In 2019, thirteen out of the fourteen districts had received significantly high rainfall, resulting in natural furies like floods and landslides. In the affected districts, 1038 villages were severely affected by property damage and disruption to normal life[7].

The highest percentage of rainfall departure has occurred in Palakkad followed by Malappuram, Kozhikode, Ernakulam, Thrissur, and Thiruvananthapuram. The northern and central districts like Kozhikode, Wayanad, Malappuram, Palakkad, Thrissur, and Ernakulam were the worst affected districts due to the torrential rainfall. During that period, about 65 landslides occurred (Fig. 2) which together took the lives of 83 people and injured several ones, and shattered their livelihood. A total of 125 lives shattered in Kerala between August 8th and 21^{st,} 2019, due to monsoon furies[9]. The present study discusses post-investigation of the factors which influence the shallow landslide. The study intended to carry out the detailed field investigation approach for the landslide area comprehensively.

Methods

This study presents a method for preparing a detailed landslide hazard map of the landslide site. The map prepared

on a 1:4000 scale helps the planners and decision-makers to assess and analyze landslide vulnerability. The study analyzed the topographic and geographical aspects from various data products such as Survey of India topographic maps on 1:25,000 scale, PlanetLab satellite imagery data in digital format (3 m resolution), Google Earth maps and Digital Elevation data –ASTER DEM (30 m resolution). It also utilized the ASTER DEM to understand the elevation as well as the slope of the area.

The topographical and geographical aspects of the area were verified through detailed field investigation. The landslide hazard map prepared is comprehensive. It includes details of the main slide area, details of the destroyed settlements during the landslide, drainage network of the site, details of the crack developed as an aftermath of the disastrous landslide, and settlements under risk.

Study area

The Western Ghats occupies 47% of Kerala state[11] and runs through the eastern side of Kerala for about 450 km. It has a significant role in shaping the climate of state[17] by creating conditions for the orographic precipitation during the southwest monsoon. The Western Ghats region is one of the most densely populated mountain regions in the world. About 8% (1,400 sq.km) of Kerala's area in the Western Ghats is a critical zone for mass movements[8,12].

The study area, Kavalappara, falls in the Muthappankunnu hill slopes of the Western Ghats located in the Pothukallu Grama panchayat of Malappuram district. Kavalappara witnessed one of the most massive landslides in the state's history regarding causalities and damages. The Kavalappara landslide is located at 11°24'23.08"N and 76°14'4.49"E (Fig. 1), spreading over an area of 0.34 sq.km (34 hectares) at a maximum elevation of 220 m above MSL. The area is part of the windward side of the Wayanad plateau in the Western Ghats. The tributaries drain the area of the Chaliyar river.

Landslides events in 2019

Palakkad district witnessed the highest number of landslides (18 numbers) in 2019 followed by Malappuram, Wayanad, and Kozhikode districts. The worst tragedy has happened in the Kavalappara village in Malappuram district. A massive and destructive landslide has occurred in the Kavalappara area in Pothukallu panchayats where 59 people lost their lives.

The gigantic landslide at Kavalappara has happened after a short time after another massive landslide in the Puthumala region in a neighboring village, which is in the Wayanad district. Puthumala, a scenic village on the slopes of tea plantation estates was destroyed and left with a death toll of 17 people.[16]

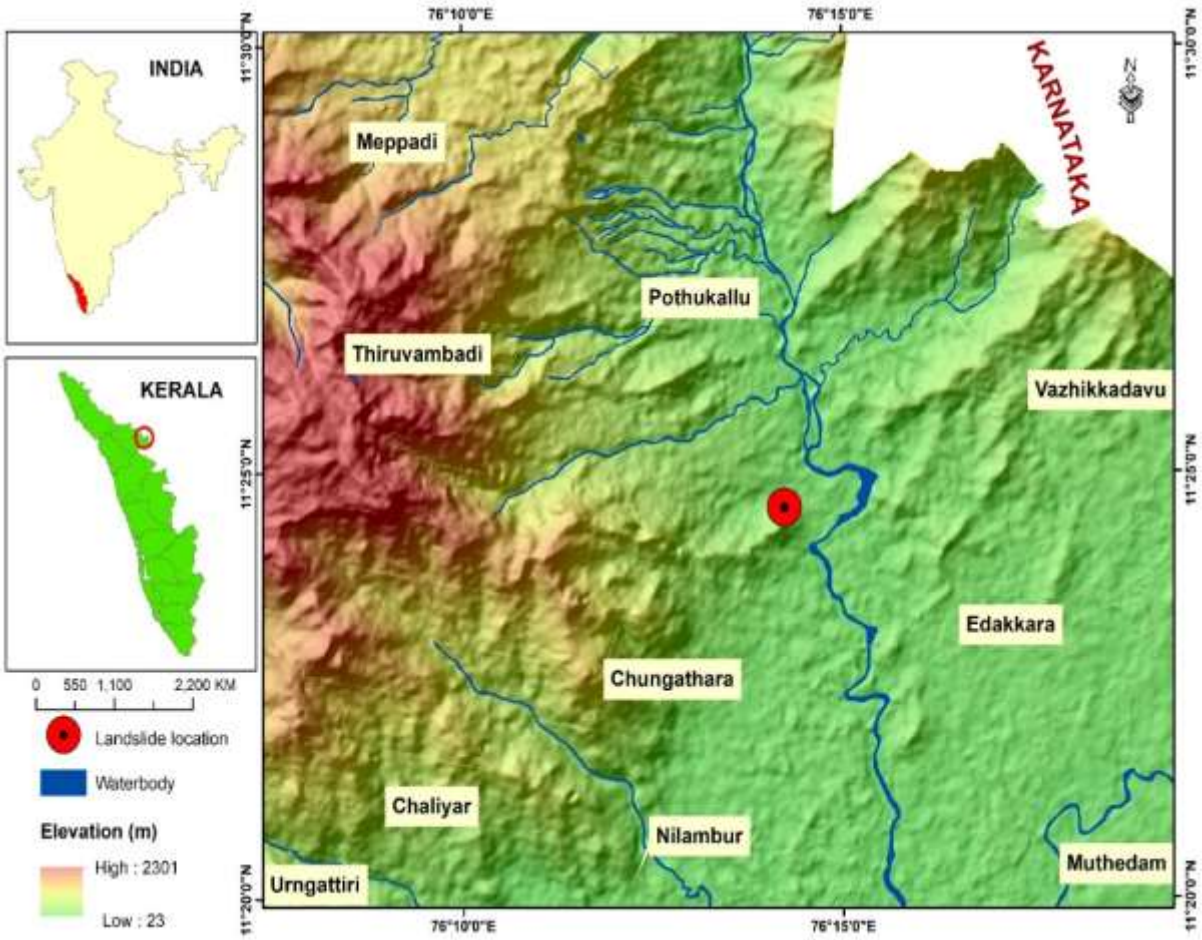
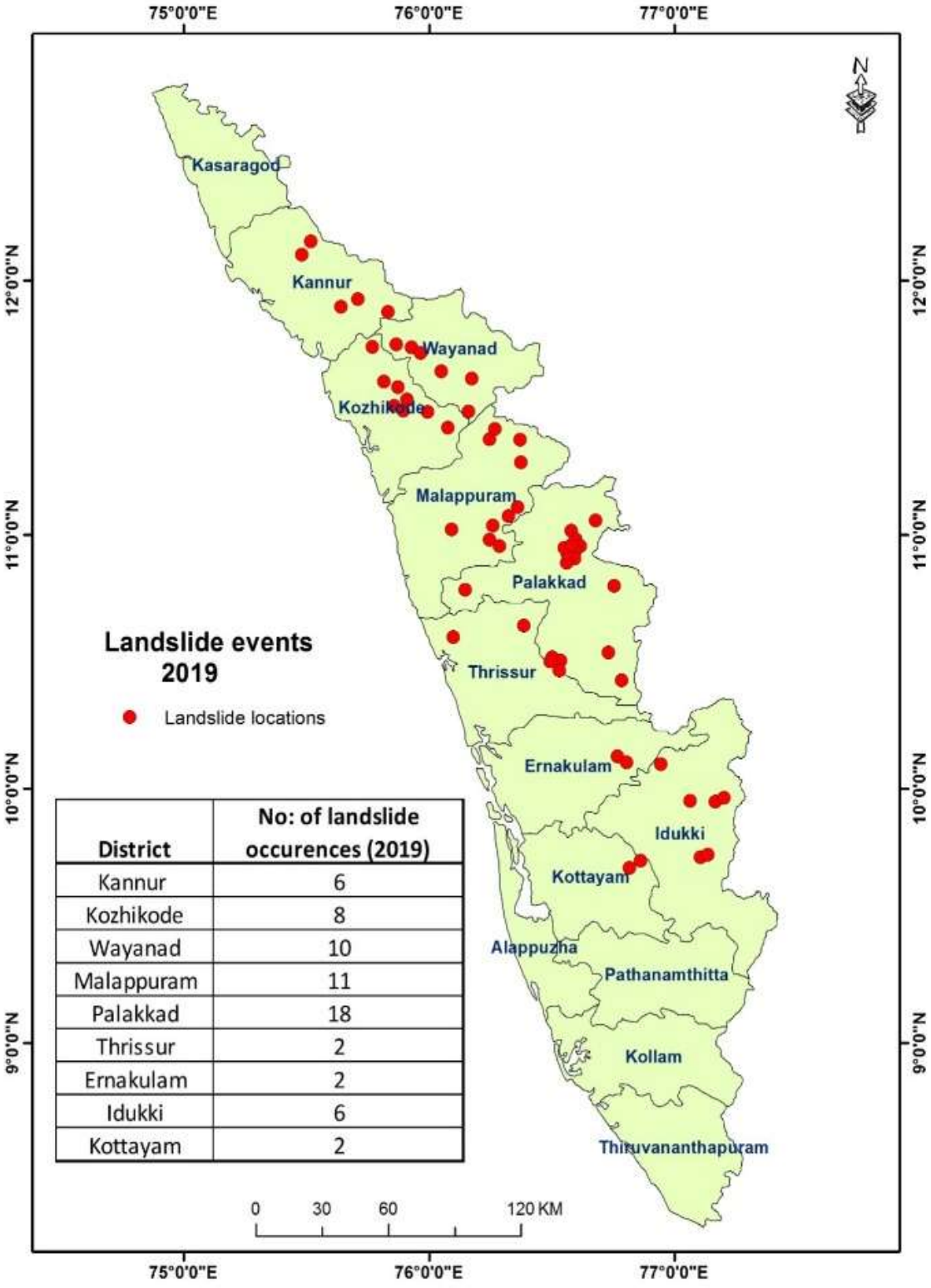


Fig. 1: Location Map

Puthumala in Wayanad district and Kavalappara in Malappuram district separated by six kilometres across the hills. Another landslide also happened at Pathar, located in between Puthumala and Kavalappara. The landslide at Pathar has turned a vast area into barren land filled with large boulders, the debris of trees trunks, and concrete wastes. However, no life was lost in the landslide, but it wiped out hundreds of houses and other buildings. Landslide at Pathar has also happened on the same day on August 8 of 2019. Besides these, another landslide occurred at Kottakunnu in Malappuram district on the same day, taking away two lives.



District	No: of landslide occurences (2019)
Kannur	6
Kozhikode	8
Wayanad	10
Malappuram	11
Palakkad	18
Thrissur	2
Ernakulam	2
Idukki	6
Kottayam	2

Fig. 2: Landslide events associated with 2019 flood

In 2019 landslides, 77 human fatalities were reported (Table 1). Malappuram district witnessed the loss of 62 lives, where the Kavalappara landslide was the worst hit. In Wayanad district, 17 human mortalities happened in which Puthumala was the major landslide incident. Kozhikode district lost four lives that account for about 5 % of the total landslide fatalities in 2019.

Table 1
District wise landslide death details during the 2019 flood

2019 FLOOD District wise landslide death details	
District	**No. of Landslide Deaths**
Malappuram	62
Kozhikode	4
Wayanad	17
Total	**77**

Results and Discussion

Post Landslide Investigation of the landslide site in 2019: On August 8, 2019, Kavalappara witnessed one of the most massive landslides in the State's history regarding causalities. Apart from the loss of 59 lives, it caused unprecedented damage to the local community's property and livelihood. The gigantic landslide occurred around 7:30 pm in Kavalappara on August 8, where 100 acres of land got swept away. The massive landslide was triggered mainly by the erratic and unprecedented nature of monsoon rainfall.

Status of the area after the landslide: The hard rock got exposed beneath the crown portion of the landslide site in the Kavalappara region, where the entire topsoil got removed (Fig. 3b). The central portion of the crown area exhibits a steep rocky slope. The main scarp is situated in the upper part of the landslide and covered by weathered rock material with a steep slope. The landslide body contains some minor rough scarps also. The huge scar of the landslide was visible, resembling a roughly triangular shape (Fig. 3a). The debris flows bifurcated into three streams and left out two green islands on both sides of the slide. The two patches are covered by rubber plantations and possess 19 houses within them. The houses were intact, and the residents were safe after the landslide event.

The main slid body extends up to about 800m from crown to toe with a width of 450 m (Fig. 3d). Unsaturated soil particles mainly cover the toe portion. A considerable amount of debris having a length of 100 m and a width of 20m deposits along the toe portion, the zone of accumulation. A total of 81 houses were wholly or partially affected by the landslide incidence. Out of these, 35 settlements and the inhabitants were destroyed and vanished by the debris flow. Moreover, 46 settlements were partially damaged or were in uninhabitable condition.

Factors that influenced the landslide occurrences

a) Rainfall: Torrential rainfall in a short period can be a significant causative factor for the shallow landslide occurrence. The Malappuram district experiences unprecedented rainfall during August 2019 compared to other districts in the state. Usually, the Malappuram district experiences an average rainfall of around 392.7 for August and the actual rainfall was 1084.2 mm which was a considerable excess.

The study area lies on the Western Ghats' windward side which acts as a barrier for the southwest monsoon wind causing orographic rainfall. During the southwest monsoon season of 2019, the area witnessed an unusual downpour. As per the Malappuram district Meteorological subdivision observation, the area received 189.4 mm of rain from August 1 to August 7, 66% more than the average 114.3 mm rainfall (The Indian Express, 2019). Moreover, on August 8, the Nilambur rain gauge station, the one nearest to Kavalappara, recorded Kerala's highest rainfall. This torrential rainfall increased the pore pressure of the area by high infiltration causing a sudden landslide.

b) Geomorphology of the area: Understanding the landforms and their morphology is indispensable to any landslide analysis[18]. Geomorphology has contributed enormously to understanding and assessing landslides[1]. Moreover, many landslide occurrences are geomorphologically related[24]. Here, the area's geomorphology forms a part of the Wayanad plateau scattered by denudational and isolated structural hills. The Kavalappara area exhibits pediplains, residual hills, structural hill ranges characterized by moderately dissected slopes[6]. The area consists of few perennial springs which spout at different places indicating the shallow groundwater levels.

Generally, landslide chances depend upon the amount of water infiltrated to geomorphologically unstable slopes with loose soil and weak rocks. The response of the underlying rocks to weathering and erosion processes is considered as one of the main criteria for landslide activities[24]. The area encompasses rocks of the Achaean age's gneissic complex, which is highly decomposed and well foliated. The dominant exposed rock type is laterite found in the moderate to steep slope regions.

c) Soil: Soil plays a vital role in the landslide activity of an area. One of the main reasons for the landslide is the progressive deterioration of soil due to erosion [21]. Soils of the region belong to the Vazhikadavu series[2] in the central upland areas of the Malappuram district. These are dark brown to black, very strongly acidic to medium acidic and texturally belong to sandy clay loam. These soils are formed on gneissic material on moderately steep to steep slopes. It is well-drained with moderate to moderately slow permeability. This kind of deep, acidic, well-drained soil is highly susceptible to soil erosion.

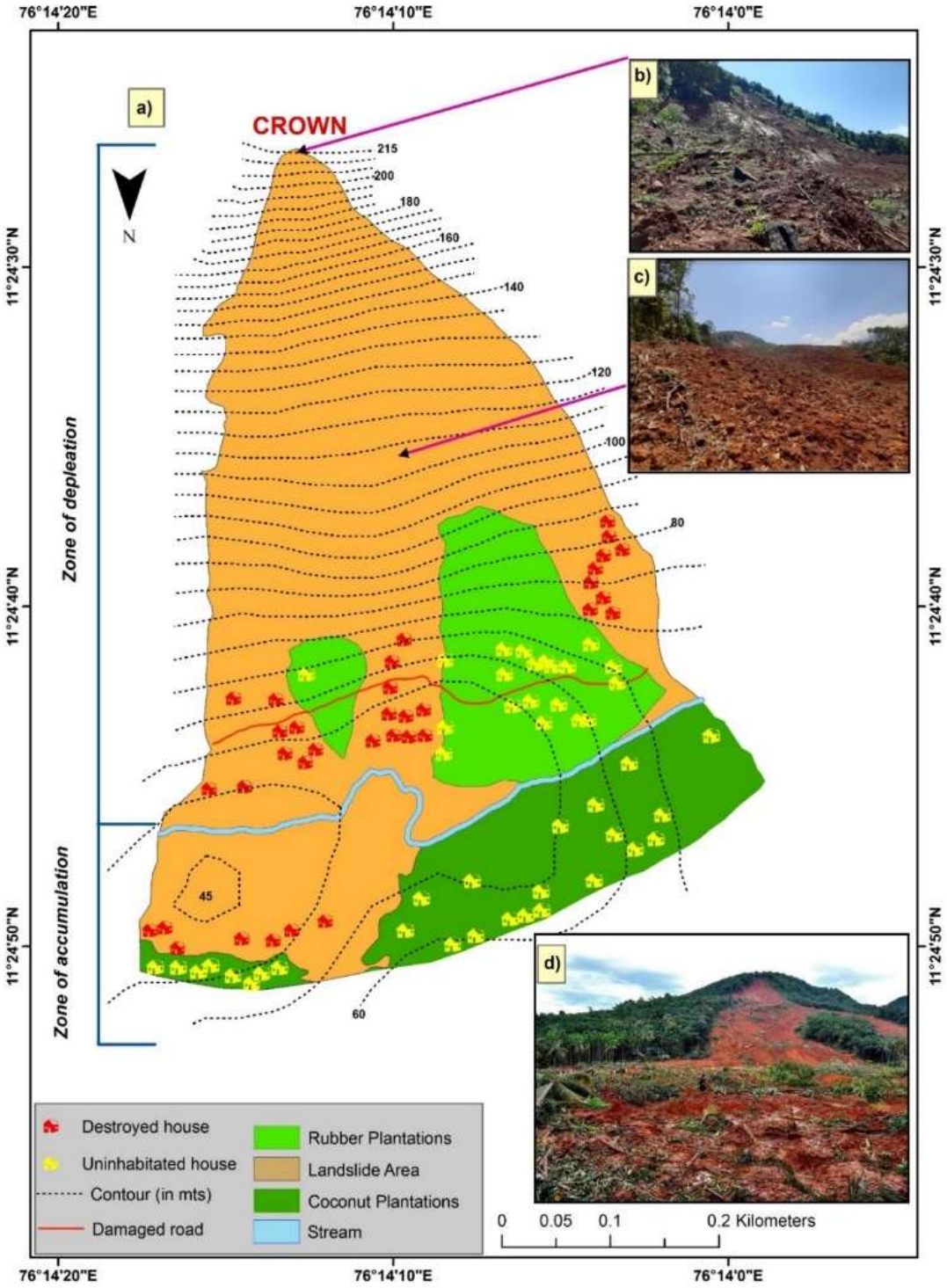


Fig. 3: a) Detailed map of Kavalappara landslide site prepared on 1:4000 scale b) hard rock exposed in the crown area after the landslide c) body part of the landslide site covered with debris d) overall view of landslide site from crown to toe portion

Here, subsurface soil is exposed leading to accelerated soil erosion and a greater risk of landslides. Since these soils are prone to landslide, it is better to keep the soil under permanent vegetative cover with zero tillage. Additionally, unscientific agricultural practices like rubber plantation on the slopes lead to loosening soil and soil erosion.

d) Slope of the area: In the Kavalappara region, the slope ranges between 10-30 degree which influences the landslide activity at a certain level. The torrential rainfall before the landslide leads to the over-saturation of the slopes. This rainfall may result in increased hydrostatic pressure, and hence the infiltration of rainwater becomes the primary triggering mechanism for landslides and associated debris

flows. The region is hydrologically saturated with few springs spout at different places indicating the shallow groundwater levels. During the rainy season, through seasonal rivulets, water gushes through the landslide body [15]. The Kavalapparathodu is one of the mainstream that joins the main Chaliyar River flowing through the main slide's eastern portion.

e) Land use: The influence of human activity on the landforms has multiplied natural hazards[19,20]. In earlier times, local communities mainly cultivated native plant species in the region. The area witnessed the cultivation of mountain paddy (Moda) during those days, which has changed to cashew for several years, and later it was replaced by rubber. The presence of rubber plantations in the affected area as the main agricultural crop is visible in the area's old satellite images.

At that time, the cultivation practices were mainly done without hampering the natural slope of the area and not disturbing the natural drainage network. The field study conducted on 22 and 23 of October 2019 found that a substantial portion of the area still possesses rubber plantation.

It increases the risk of landslides by accelerating soil erosion. Rubber cultivation in problematic areas with varying slopes is more likely to increase the risk of landslides due to intensive monoculture practices[26]. The practice of cultivating rubber on slopes vulnerable to slope failures is not appropriate since it can enhance water percolation and accumulate pore-water pressure [15].

The crown portion of the main slide area of Kavalappara exhibits to be an uninhabited hillock with frequent intense tillage for rubber plantations[3]. 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[15]. The current land use pattern, which is instrumental in blocking the natural drains by the construction activities and poor agricultural practices such as mono-cropping, has exacerbated the risk of landslides. The poor agricultural practices could loosen the subsoil leading to the triggering of landslides. Extreme rain events caused by climate change and inadequate early warning measures have made situation worse.

f) Unsustainable practices: Unsustainable land-use practices adopted in the region during the last few years might have been instrumental in destabilizing the slopes of the hill which paved a perfect background for the initiation of landslides. There is no quarry in the study area except for a laterite quarry on a hill opposite Muthappankunnu hill. Rubber plantations cover a significant portion of the study area. The use of heavy earth movers to dig huge rain pits for the rubber saplings is frequent in the area. Later these waterlogged pits act as a driving force that triggers the landslides. Several rain pits of varying depth have been dug out across the hill slopes to cultivate rubber. The pits were constructed mainly for applying fertilizers and also for the percolation of rainwater.

This practice might have destabilized the slopes during the heavy rainfall. Large pits constructed for harvesting rainwater as an initiative of Grama Panchayath to solve the drinking water scarcity in this region might have caused the building of pore pressure in the soil column and accelerated the movement of debris. Slope modifications in the hill slopes for rubber plantation also promoted slope failures. The integrated effect of the geological instability coupled with the unsustainable land-use practices and the heavy downpour had led to the worse landslide situation.

Risk areas noticed during field survey: Kavalappara is situated on the Muthappankunnu hill, where the landslide hit one side of the hill, destroying the Kavalappara village. Muthappankunnu in Pothukallu Grama Panchayat is located along the northeastern part of Malappuram District. A new crack, identified in the Thudimutti area during the field visit, lies on the opposite side of the Kavalappara landslide site. (Fig. 4). Most of the settlements were located along the foothills in the Thudimutti area. A large and long crack has formed in the higher slopes of the Thudimutti area on the same day of the landslides that struck the Kavalappara region.

The land use along the large fissure noticed on the opposite side of the main slide area includes recently planted rubber plantations, coconut plantations and mixed vegetation. The field investigation identified almost 50 settlements situated along the foothill portion of the crack, which is at risk. According to GSI officials, the area is prone to landslide and consists of several cracks with varying width found on the ground. If something similar to Kavalappara happens here, the entire area of the Thudimutti area may be affected.

Conclusion

The study is mainly concentrated on the detailed site investigation and landslide hazard mapping of the Kavalappara landslide area and identifying the landslide risk zones. The 2019 landslide assessment in the Kavalappara area indicates that the massive landslide was triggered mainly by the unprecedented nature of monsoon rainfall within a shorter duration of time. Along with this, the torrential rainfall leads to the oversaturation of the slope of the area varying from 10 -30 degrees. The other primary reason that impacts the landslide at its worst is land-use conversion, a phenomenon in Kerala's Western Ghats region.

The unsustainable rubber cultivation in inappropriate areas also accelerates the risk of landslides due to the destabilization of the slopes. Apart from this, the area's deep, acidic, well-drained soil was also highly susceptible to soil erosion.

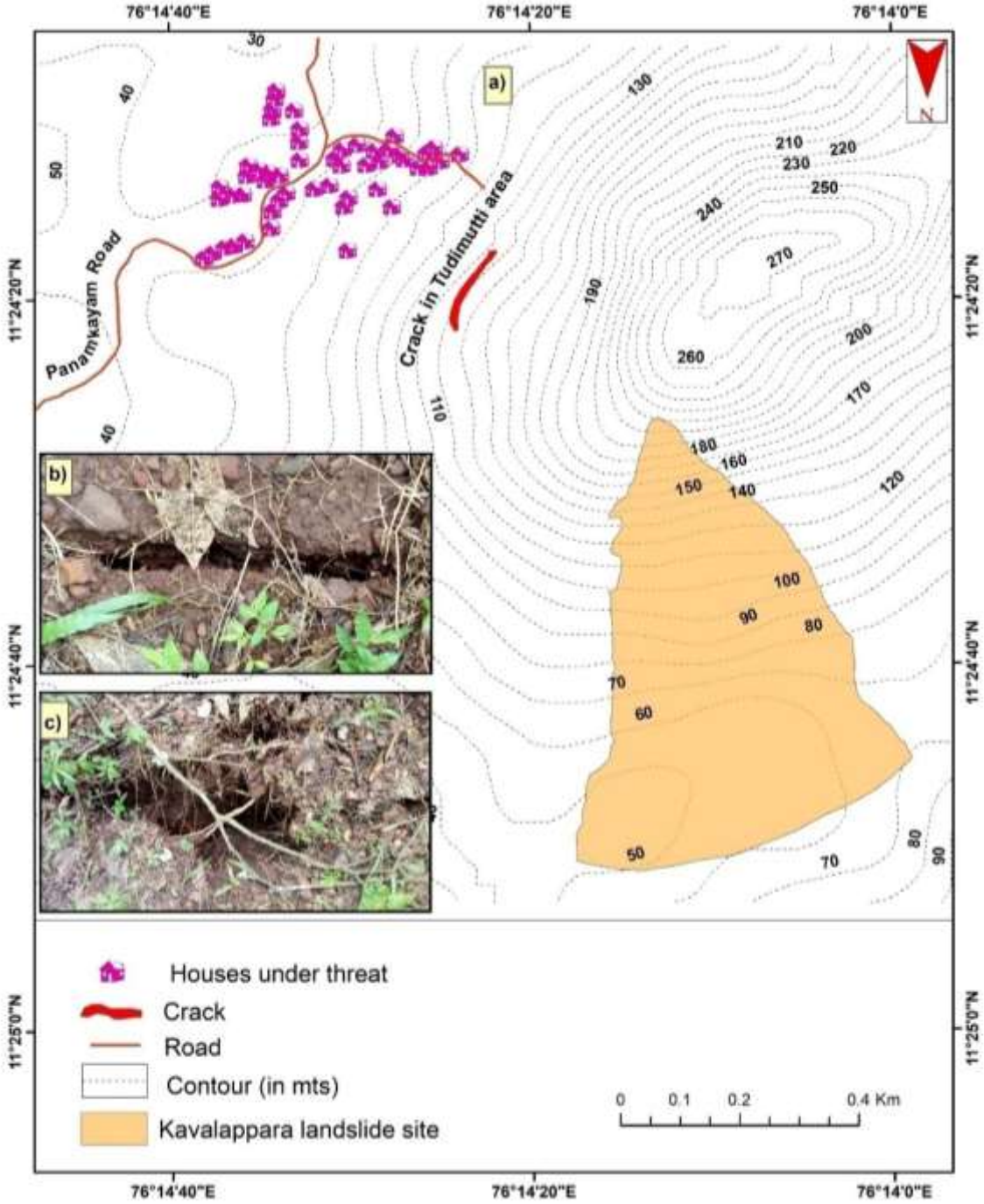


Fig 4: a) Detailed map showing the cracks developed on the opposite side of Kavalappara landslide site and the houses under threat near to the crack prepared on 1:4000 scale b) and c) photographs showing the cracks in the Tudimutti area

Unsustainable land-use practises like using heavy earthmovers to dig huge rain pits for the rubber saplings, digging large rain pits for rainwater harvesting act as a driving force triggering the landslide activity. The detailed map of the Kavalappara landslide site prepared on a 1:4000 scale illustrates the appalling destruction of the area. A total of 81 houses were totally or partially vanished by the landslide incidence. Out of these, 35 settlements got destroyed entirely by the debris flow. The detailed landslide hazard maps prepared on 1:4000 show the status of the area after the landslide. The detailed field investigation identified a large crack of more than 200 m in length on the opposite side of the main Kavalappara landslide site. Almost 50 settlements are under the risk situated along the foothill portion of this crack.

On the whole, it is essential to plan comprehensive mitigation measures to reduce the existing vulnerability. As part of this, the state should promote sustainable land-use practices along the Western Ghats regions.

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