Journal of Integrated Earth Sciences, 2025, Vol.1 (1), December 2025, pp. 31-40
https://doi.org/10.5281/zenodo.18544016

OPEN ACCESS

JOURNAL OF INTEGRATED EARTH SCIENCES

Geotechnical investigation and slope stability analysis of Kallarkutty earth slide, Idukki District, Kerala, South India

Frincy R. M[a], Praveen K. R[b], and Pillay K. R[c]

[a,b,c] Geological Survey of India

ARTICLE INFO

Received. 22 December 2024
Revised. 30 February 2025
Accepted. 05 March 2025

KEYWORDS
Earth slide; Mohr-Coulomb Law; Factor of Safety; Landslide mitigation

How to cite
Frincy R. M, Praveen K. R, & Pillay K. R. (2026). Geotechnical investigation and slope stability analysis of Kallarkutty earth slide, Idukki District, Kerala, South India. Journal of Integrated Earth Sciences, 1(1), 31–40. https://doi.org/10.5281/zenodo.18544016

ABSTRACT

The earth slides that occurred in the Kallarkutty area, Idukki District, Kerala, South India in 2013 and 2017 were studied to identify the causative factors and to suggest the mitigative measures. Geological, geophysical and soil mechanical properties of the area have been studied and the uni-dimensional infinite slope stability model (Mohr-Coulomb failure law) was attempted to calculate the Factor of Safety (FoS). FoS values in three different pore pressure conditions, i.e., as dry, 50% and 100% saturation indicate that stability decreases with saturation. In the downslope side of area towards the cliff edge, the FoS value is less and hence unstable. The landslides in the study area are translational with slip plane being the interface of rock and overburden. The geological factors augmenting the slide is loosely consolidated overburden over the foliated gneiss. The removal of toe support and unscientific slope modification without support intervention by excavation through overburden material rich in lithomarge are the main preparatory factor whereas the pore pressure increment aided by heavy rainfall is the triggering factor. Based on the study, corrective measures, and precautions to avoid further slides have been suggested.

CONTACT Author, Frincy R. M - fincyrm@gmail.com
Supplemental data for this article can be accessed online at our website
© 2025 The Author(s). Published by Geological Society of Kerala
Journal publishing © 2025 by Journal of Integrated Earth Sciences is licensed under Creative Commons Attribution-Non-commercial-No Derivatives 4.0 International.
To view a copy of this license, visit https://creativecommons.org/licenses/by-nc-nd/4.0/

1. Introduction

The Kallarkutty junction (09° 58′ 52.7″ N: 77° 00′ 02.4″ E) is located in the northwestern part of the Kallarkutty dam, Idukki District (TS Nos. 58G/1 and 58C/13) where earth slides occurred on 5th and 6th of August 2013 (Sajeev and Praveen, 2014). The slides damaged a few shops on the downslope side and blocked part of the Adimali – Painavu road. A large rupture with dimension of ~50 m (length) x ~0.3 m (width) has been formed just behind the crown portion of the earth slide that occurred on 6th August, 2013. In view of the critical status of the slope located in the upstream portion of the Kallarkutty Dam, a detailed study was carried out by the Geological Survey of India in the Kallarkutty landslide and its environs with an objective to identify the causative factors of the earth slide and to suggest the mitigative measures. Detailed geological mapping on 1: 1000 scale by tacheometric survey, sub-surface exploration by electrical (VES) and seismic soundings (seismic refraction), preparation of geological sections, collection and testing of samples for mechanical properties and slope stability analysis were carried out to achieve the objective of the study.

2. Study Area

The area is part of the Western Ghats and surrounded by NW-SE ridges and small mounts in between. The Kallarkutty Dam is constructed in Muthira Puzha, which flows towards SSW direction situated at an elevation of more than 400 m above msl with a general slope of 20°.

Kallarkutty Junction is surrounded by ridges in all sides. The reservoir gets its water from all sides except from the SSW side. The Kallarkutty area is extensively cultivated with various plantation crops and the land use is mixed type and both low and high height plantation crops are cultivated without much planning. Terrace farming method is adopted in all places irrespective of the slope angle.

3. Materials and Methods

3.1 Geotechnical assessment of the landslide and its environs

Two earth slides occurred at Kallarkutty (Fig. 1). The first slide, located at Kallarkutty Junction, measured approximately 40 m in length, 20 m in width, 2 m in depth, and had a height of about 35 m (Fig. 2). The second slide, situated northwest of the dam, had dimensions of approximately 15 m length, 15 m width, 0.5 m depth, and a height of around 10 m (Figs. 3 & 4). These incidents resulted in the development of cracks and sub-cracks extending approximately 50 m in length and 0.3 m in width behind the crown portion (Fig. 5). These cracks appeared both on the ground surface and in nearby buildings (Fig. 6). Another landslide occurred north of these incidents, measuring about 10 m in length, 10 m in width, 0.5 m in depth, and with a height of approximately 7 m. The failure mechanism of these landslides is primarily of the shallow translational type (BIS,1998).

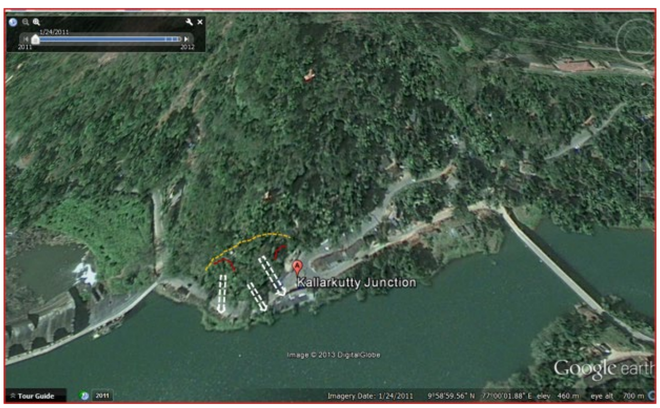

Fig. 1 Google map showing the vulnerable slop near Kallarkutty Junction

The area also witnessed two landslides including one reservoir bank failure on 19th September 2017 (Figs. 7 & 8). The length, width and depth of the reservoir bank slide are ~10 m, ~15 m and ~2 m respectively. Three shops were damaged during the failure. The nature of distressed material shows that the soil in the area is very loose and moist.

Fig.2 Landslide occurred on 06-08-2013 towards south of the Kallarkutty junction.

Fig. 3 Landslide occurred on 05-08-2013 at the Kallarkutty junction

Fig. 4 Status of Landslide location of fig.3 as observed in 2017

Fig. 5 Different segment of cracks developed near the crown of the landslide occurred at Kallarkutty junction

Fig. 6 Impact of landslide occurred on 5th and 6th of August 2013 at Kallarkutty junction

Hornblende biotite gneiss/composite gneiss, biotite gneiss and migmatized gneiss are the country rocks (Geological and Mineral map of Kerala, 1995; Anil Kumar et al., 1984; Nair and Anil Kumar, 1990; Thampi et al., 1979, 1980) in the area. Hard rock formations (HBG/BG) are intermittently exposed along road sections and upslope areas of the hill. The hornblende biotite gneiss exhibits a foliation trend of N 50° W – S 50° E, dipping at 56° NE. The area features moderate to steep slopes, often modified for terrace farming and vertical cuts for house construction. Overburden materials consist mainly of clayey lateritic soil, lithomarge, and saprolite, typically reddish brown to greyish black, fine to medium grained, humus-rich, and moderately sorted. Near the upslope side, hard rock is shallow (<3 m depth), with weathered material starting around 50 cm depth. There are precarious boulders behind houses, some exceeding 10 m in diameter and supported by trees, posing a constant threat (Fig. 9). The largest boulders measure 2x5x5.5 m, 2x4x5 m, 4x3x1.5 m, and 5x3x2 m. A house constructed within a first-order stream on the downslope side obstructs water flow (Fig. 10)

Fig. 7 Bank failure occurred between the road and reservoir on 19th Sep., 2017

Fig. 8 Earth slide occurred on 19th Sep.,2017. Rock overburden contact is exposed

3.2 Sub-Surface Geophysical Exploration

To delineate bedrock depth in and around the landslide area and to work out the thickness of various weathered layers of overburden, Vertical Electrical Sounding (VES), Shallow Seismic Refraction Survey (SSRS) and Ambient Noise Survey (Site Response study) were carried out. VES has been done at 4 locations to understand the weathered/fractured nature of the bedrock. VES conducted near the depletion zone at toe portion is clearly indicating thick soil cover of about 10 m lying above highly weathered rock. SSRS has been widely used for determining the depth to bedrock, has been done at 8 locations. Only two sites indicated the signature of weathered bedrock at 5 to 9m. In the upslope area, velocity is low (350 to 1000 m/s) indicating the presence of soft sediment of 4 to 8 m.

3.3 Site Response Study

The site response study, as detailed by Biswas et al. (2015), is an effective method for estimating the depth to rock where there is a significant acoustic impedance contrast between sediments and the underlying rock. This study was conducted at 26 locations, with high amplification values indicating the softness of the sediments.

The sediment thickness, estimated from an ambient seismic noise survey, shows a spatial variation ranging from 1 to 19m. Specifically, sediment thickness between 5 and 10m is observed on the up-slope side (western), while it ranges from 1 to 19m on the down-slope side (eastern). A shallow seismic survey in the mid-slope area delineated highly weathered rock at a depth of 5m and weathered bedrock around a depth of 9m. Most of the surveyed area is dominated by very soft sediments, such as topsoil and soft clay, with very low P-wave velocities in the range of 350 m/s to 1000 m/s. The highly weathered and fractured nature of the subsurface rocks is reflected in Vertical Electrical Sounding (VES) results. The resistivity survey also indicated a lateritic clay thickness of 10m near the depletion zone.

3.4 Geological Section Studies

The geological map with section lines is shown in Fig. 11. Four geological sections have been prepared (Figs. 12 to 15) viz., i) A-A′ – across the scar of one of the major slide, ii) B-B′- across the scar of the second major slide, iii) C-C′- across the small slide occurred just before the Kallarkutty junction, iv) D-D′- parallel to the scars.

Fig. 9 Precarious boulders seen at the mid slopes

Fig. 10 A house in the first order stream

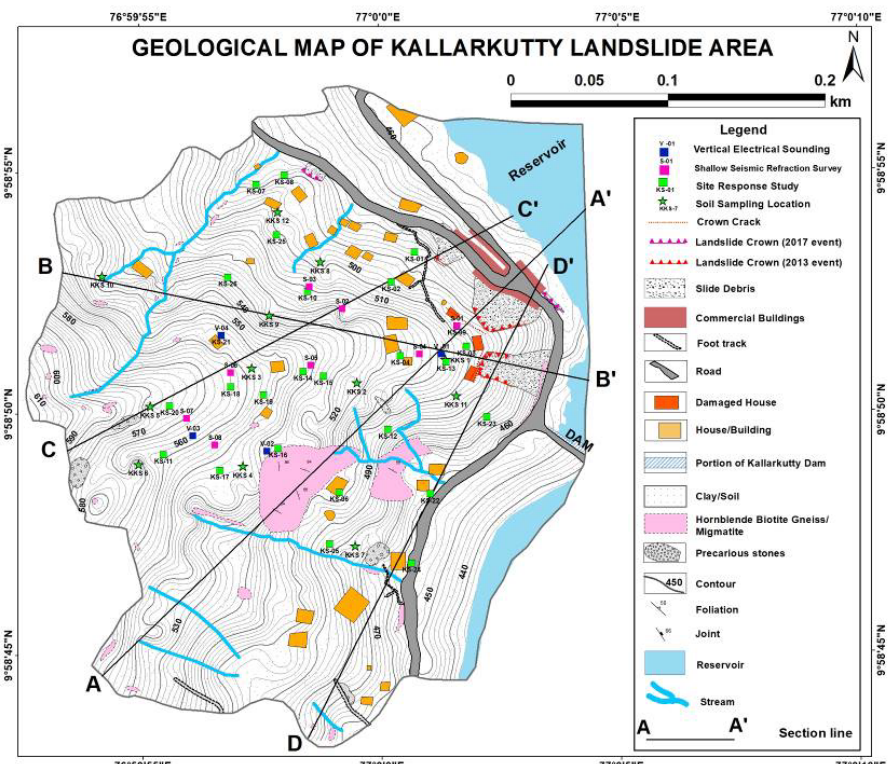

Fig. 11 Geological map of Kallarkutty Landslide area showing the section lines

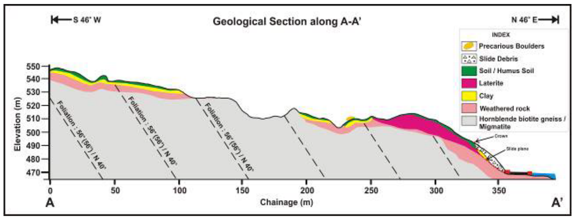

Fig. 12 Geological section along line AA′

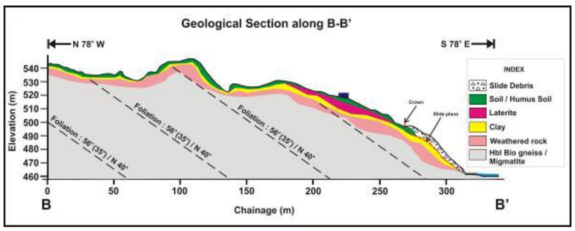

Fig. 13 Geological section along line BB′

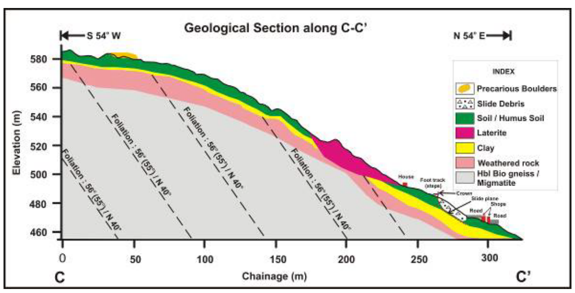

Fig. 14 Geological section along line CC′

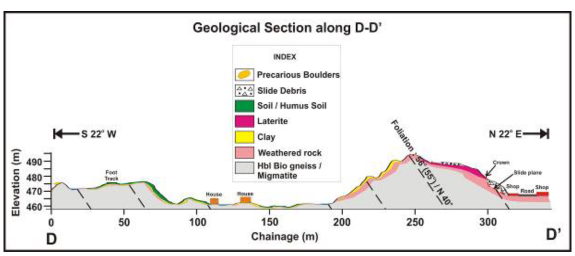

Fig. 15 Geological section along line DD′

3.5 Mechanical Properties of Soil

Few sites are specifically studied for its environments, geomorphology and soil properties and twelve undisturbed soil samples (Fig. 11) were collected in a 42 cm long GI pipe having a diameter of about 10 cm, viz., (i) areas with detached boulders, (ii) hard rock exposed (iii) thick soil cover (iv) plantation with terrace farming-medium slope (v) plantation with sleep slope (vi) black forest soil (vii) thin humas soil (viii) reddish brown soil - cultivated (ix) reddish brown forest soil with rock particles (x) forest soil, humus rich, rock particles (xi) forest soil, fine grained - no hard rock, sticky (xii) clayey reddish soil and physico-mechanical parameters were determined (Table 1).

Textural characteristics of the soil material (USDA, 1971) indicates that the majority of soil samples belong to slightly gravelly muddy sand to muddy sand as represented in the ternary diagram (Fig. 16).

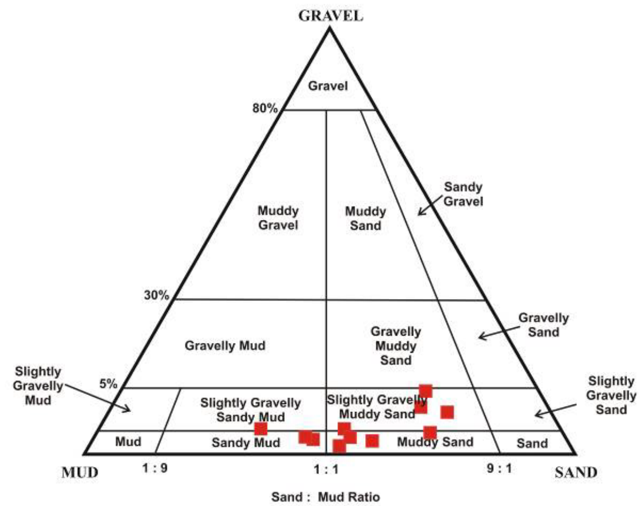

Fig. 16 Ternary diagram showing the textural characteristics of undisturbed soil samples

3.6. Slope Stability Analysis

Slope stability analysis is the assessment of equilibrium conditions of natural and manmade slopes considering the extent of the study area, geomorphological condition, type of data available and type of landslide present (Towhata, 2008). It is preferred to use deterministic approach to model slope stability condition along the section line on 1: 1000 scale.

3.6.1 Deterministic approach for slope stability analysis

Slope stability analysis can be carried out by using the deterministic slope stability models (Heneberg, 2007), when the geomorphological and geological conditions are fairly homogenous over the entire study area and the landslides are simple translational type (Cho, 2014). The landslides present in the study area are translational with slip plane being the interface of rock and overburden. Hence the uni-dimensional infinite slope stability model (Mohr-Coulomb failure law) is found to be suitable. In the present model, it is assumed that the entire overburden material lying over the rock, slips down on a surface in the form of a translational failure.

The formula for the infinite slope model is :

$$\text{Factor of Safety (FoS)} = \frac{\left[c+\left\{\gamma \cos^2 \beta - \mu\right\}\right]\tan\varphi}{(\gamma Z \sin\beta \cos\beta)}$$

Where, c = soil cohesion (kPa), γ = Unit weight of soil (kN/m^3), Z = Depth of the soil (slip surface) in metre, μ = Pore water pressure (kN/m^2), β = Angle of the topographical slope and φ = Angle of internal friction.

The pore water pressure is related to the height of the groundwater above the slip plane in the slope as follows:

$$\mu = \gamma_w \times Z_w \times \cos^2 \beta$$

where, γ_w = Unit weight of water (kN/m^3) and Z_w = Height of the water table above the slip surface (m).
Factor of Safety (FoS) is expressed as the ratio of forces or moments resisting movement to the forces or moments driving movement. Limiting equilibrium is attained when FoS = 1, stable condition is attained when FoS > 1 and Unstable condition is attained when FoS < 1 (Das, 2007).

Variation in ground water which controls the pore pressure is the important factor in the factor of safety. Due to the difficulty of modeling ground water variation or fluctuation in hill slopes, five scenarios have been used to calculate the factor of safety viz., (a) considering zero pore pressure (Zw = 0), (b) considering 25% pore pressure (Zw = Z/0.25), (c) considering 50% pore pressure (Zw = Z/0.50), (d) considering 75% pore pressure (Zw = Z/0.75) and (e) considering maximum pore pressure (Zw = Z) i.e., complete saturation. The FoS under different saturated slope conditions are given below (Table 2) and the plots were prepared based on the FoS value at dry condition, 50% saturation and 100% saturation (Figs. 17 to 19). Spline with barrier technique in ArcGIS is adopted to generate 2D pictorial representation of FOS, using the equation for the infinite slope stability analysis model FoS = $FoS_{friction}$ + $FoS_{cohesion}$ – $FoS_{pore\ pressure}$. The derived results indicate FoS < 0.8 is highly unstable, FoS 0.8 to 1 is unstable, FoS 1 to 1.2 is stable and FoS > 1.2 is very stable. The FoS values in the present study area varies from 0.569 (Red) to 1.787 (Green) under the dry condition (Fig. 17), 0.463 (Red) to 1.444 (Green) under 50% saturation (Fig. 18) and 0.357 (Red) to 1.101 (Green) under 100% saturation (Fig. 19).The FoS value in the uphill side is relatively higher and this is mainly due to the less thickness of soil/overburden and the low degree of slope. At the cliff edge, the soil thickness is more and hence the FoS value is decreasing.

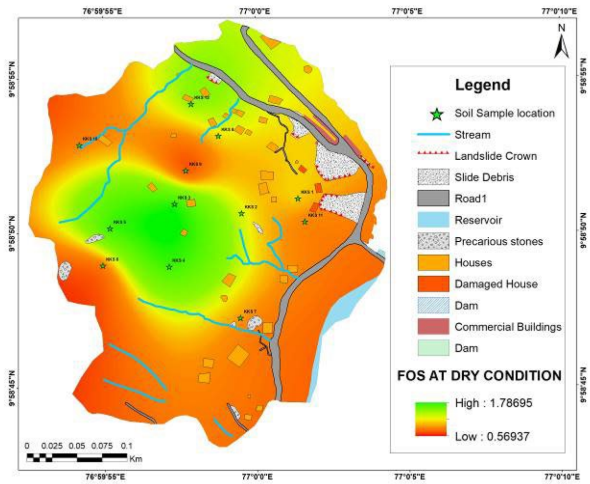

Fig. 17 Factor of Safety of the study area under dry condition

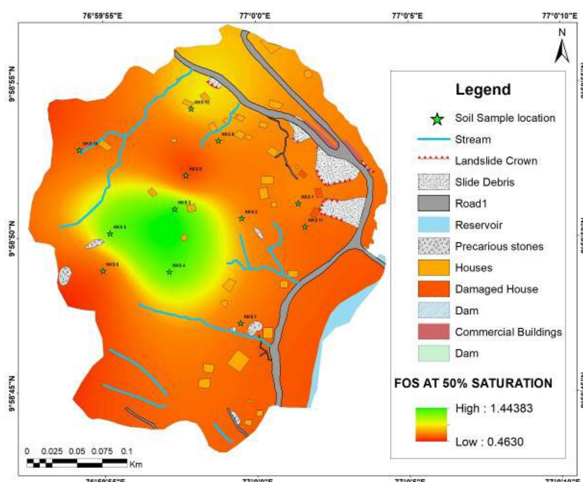

Fig. 18 Factor of Safety of the study area under 50% saturation

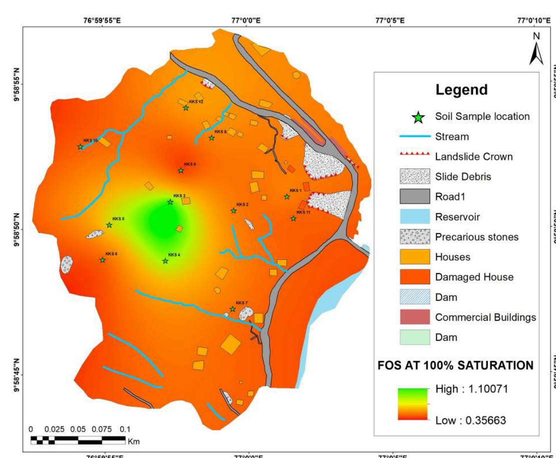

Fig. 19 Factor of Safety of the study area under 100% saturation

Table 1: Analytical results of undisturbed soil samples from Kallarkutty landslide area

Sample No.	Density gm/cc	Specific Gravity	NMC %	Gravel %	Sand %	Silt %	Clay %	Cohesion kgf/m^2	φ (°)
KKS-1	2.54	2.65	21.75	6	33	52	9	0.23	32
KKS -2	2.21	2.79	13.47	4	52	36	8	0.25	31
KKS -3	2.60	2.80	10.96	3	45	43	9	0.29	33
KKS -4	2.51	2.46	4.85	15	62	17	6	0.25	34
KKS -5	2.19	2.79	21.94	2	51	40	7	0.28	31
KKS -6	2.65	2.72	6.23	10	69	16	5	0.22	27
KKS -7	2.65	2,79	7.36	11	63	24	2	0.23	28
KKS -8	2.53	2.71	21.54	3	57	38	2	0.25	29
KKS -9	2.66	2.78	18.15	2	51	44	3	0.29	27
KKS -10	2.41	2.77	14.62	5	68	24	3	0.28	26
KKS -11	2.42	2.69	20.06	6	50	42	2	0.22	32
KKS -12	2.40	2.66	19.82	4	43	45	8	0.24	31

Table 2: Factor of Safety (FoS) under different saturated slope conditions

Sample No.	**Soil Depth**	**FoS Dry (Zw=0)**	**FoS 25% (Zw=25%)**	**FoS 50% (Zw=50%)**	**FoS 75% (Zw=75%)**	**FoS Sat (Zw=100%)**
KKS-1	16.41	0.93	0.56	0.84	0.75	0.65
KKS-2	11.51	1.04	0.57	0.93	0.81	0.69
KKS-3	13.01	1.79	1.10	1.62	1.44	1.27
KKS-4	6.64	1.67	1.01	1.51	1.34	1.18
KKS-5	12.09	1.65	0.90	1.47	1.27	1.09
KKS-6	9.66	0.73	0.45	0.66	0.59	0.52
KKS-7	1.72	0.83	0.52	0.75	0.68	0.60
KKS-8	13.0	0.96	0.58	0.87	0.77	0.68
KKS-9	6.42	0.57	0.36	0.52	0.46	0.41
KKS-10	6.14	0.76	0.44	0.68	0.60	0.52
KKS-11	16.41	0.77	0.45	0.69	0.61	0.53
KKS-12	5.0	1.18	0.69	1.06	0.94	0.82

Besides, the extensive cutting and un-supported vertical cut surface which is made unscientifically along the cliff edge for the construction of road and commercial buildings, made the slope more unsafe which resulted in landslide incidences. The crown cracks developed in the area indicates the retrogressive nature of the landslide and if a slope failure occurs in future, the soil material in the downslope side may enhance the intensity of damage in this area.

4. Causal factors of the landslide

Removal of toe support without support intervention by excavation through overburden material for road construction is assessed to be the preparatory factor, whereas pore pressure increment aided by heavy rainfall is the triggering factor of the slide. The monthly rainfall in the year 2013 as recorded in Idukki Rain gauge station, which is in the vicinity of the study area shows a high rainfall in the month of June to August 2013 (Fig. 20). The intensity of rainfall in the month of June and July is relatively more when compared to August, but the landslide incidence took place in the month of August 2013. Hence, on the analysis of the daily rainfall data from June to August (Fig. 21), it is found that the failure of slope occurred as a result of continuous rainfall in August 2013.

The hourly rainfall data is therefore more significant for the landslide studies. The important causative factors of Kallarkutty earth slides are (i) Unscientific toe modification for anthropogenic activities. (ii) Untreated cut slope resulting in overhanging soil mass.

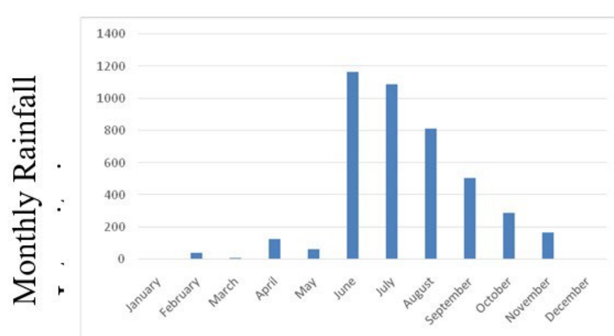

Fig. 20 Bar diagram of monthly rainfall in 2013 as recorded in the vicinity

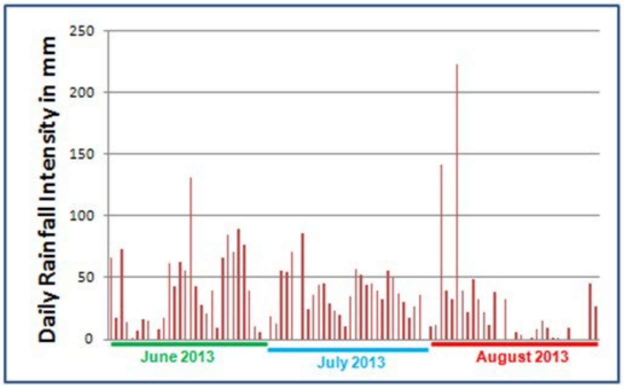

Fig. 21 Bar diagram of daily rainfall from June to August 2013 as recorded in the vicinity

(iii) Improper land use practice in the uphill side resulting in alteration of natural drainage lines and increase in surface water infiltration (iv) Incessant rainfall is the triggering factor which resulted in the reduction of strength on supersaturation and increase in pore water pressure.

5. Conclusion and recommendations

The recurring earth slides occurred at Kallarkutty hill slope is a threat to the commercial establishments and houses located at the foothills. The unscientific constructions blocking the natural drainage and ignoring the precarious boulders along the hill slopes which are threat to the dwelling units. The preparatory factors for the landslide to occur are mainly the removal of toe support and unscientific slope modification without support intervention by excavation through overburden material rich in lithomarge, whereas pore pressure increment aided by heavy rainfall is the triggering factor.

Slope stability analysis suggests that FoS values decreases with saturation and towards downslope side at the cliff edge, FoS values are less and hence unstable. The increase in soil thickness and the extensive cutting with unsupported vertical cut surfaces made the cliff edge more unsafe which may attribute landslide incidences in future.The following corrective measures are suggested based on the study: (i) Easing of the slope at the vertical cliff edge (ii) Retaining wall / gabion wall with proper drain holes may be provided at the base/toe of the slided slope (iii) Slope above the retaining wall / gabion wall may be dressed and turfed (iv) Filling of the cracks in the crown area with impervious clay or bitumen (v) Catch water drains or chute drains may be provided above the crown of the landslide to divert or channelize the water away from the slided area. (vi) Strengthening of the filled slope at the slided road side by constructing proper retaining structure from the base of the reservoir to the road level to avoid reservoir bank failure. To avoid further slide, the following points may be taken care: (i) Unscientific road construction / widening should be avoided (ii) Houses/buildings constructed on the nala path located in the northern portion of the study area may be evacuated and further construction should not be allowed in such locations and natural drainage system may be preserved without obstructing the flow of natural streams (iii) People staying just above the road cut at the cliff edge may be evacuated during incessant rainfall (iv) Waterlogging condition along the vulnerable slopes has to be avoided (v) Precarious boulders lying on the hill slope are to be removed/ supported and (vi) People should be educated about the ill-effects of unscientific slope modifications to avoid slope failures in future.

CRediT authorship contribution statement.

Frincy R. M: Writing–original draft, Software, Data curation. **Praveen K. R**: Investigation, analysis, Writing original draft **K. R. Pillay:** Supervision, Review & editing.

Declaration of competing interest

The authors declare that they have no known financial or personal conflicts of interest that could have influenced the work reported in this paper.

Acknowledgements

The authors express their sincere thanks to the Geological Survey of India for this work.

References

Geological and Mineral Map of Kerala, 1: 500,000 (1995), Geological Survey of India, Published Maps. Compiled by Mallikarjuna, C., Nair, M. M., Gopalakrishna, L. S., Adiga, K. S., Nambiar, A. R., Balakrishnan, P. and Sukumaran, P. V.

Anil Kumar, Thomas Mathai and Venkataramana, B. (1984) Report on the Geological mapping and preliminary mineral assessment in parts of Devikulam and Peermade Taluks, Idukki District, Kerala State. Unpublished GSI Progress report, FS 1981-82, 16p.

BIS (1998) Preparation of landslide hazard zonation maps in mountainous terrains – Guidelines, Bureau of Indian Standards IS 14496 (Part - 2).

Biswas, R. Baruah, S. and Bora, D. K. (2015) Mapping Sediment Thickness in Shillong City of Northeast India through Empirical Relationship. Journal of Earthquakes, V. 2015.

Cho, S. E. (2014) Probabilistic stability analysis of rainfall-induced landslides considering spatial variability of permeability. Engineering Geology, 171 (2014), pp. 11-20

Das, B. M. (2007) Fundamentals of Geotechnical Engineering (3rd ed.). Cengage Learning. 622p

Duncan, J. M. (2000) Journal of Geotechnical Geoenvironment, v.126 (4) (2000), pp. 307-316

Heneberg (2007) PISA-m Map-based Probabilistic Infinite Slope Analysis: User Manual Haneberg Geoscience, USA (2007)

Nair, M. M. and Anil Kumar P. S. (1990) Detailed studies on the acid intrusives of Kerala with reference to their stratigraphic, structural and tectonic significance in the evolutionary history of Precambrian crust and associated metallogeny. Unpublished GSI Progress report, FS 1987-88, 33p.

Sajeev, R. and Praveen, K. R. (2014) Report on Landslide Susceptibility Mapping on Macro Scale along the major road corridors in Idukki District, Kerala. Unpublished GSI Progress report, FSP 2013-14.

Thampi, P. K., Attre, J. K. and Singh. K. K. P. (1979) Geological mapping and preliminary mineral survey in parts of Devikulam Taluk of Idukki District, Kerala State. Unpublished GSI Progress report, FS 1973-74, pp 9-21.

Thampi. P. K., Jayaram, S. and Rengamannar, V. (1980) Report on geological mapping and preliminary mineral survey in parts of Devikulam Taluk of Idukki District, Kerala State. Unpublished GSI Progress report, FS 1975-76, pp.8-13.

Towhata, D. (2008). Fundamentals of Geotechnical Engineering. Springer. 414p

U.S. Department of Agriculture, Soil Conservation Service (1971) Guide for interpreting engineering uses of soils.