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Geological Factors Contributing to Landslide Incident in Malaysia - Case Study Batang Kali Landslide Disaster, Hulu Selangor, Selangor.

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Abstract

The Batang Kali landslide that occurred at 2.08 a.m. on 16 December 2022 had struck almost entirely the agriculture and campsite areas of Father's Organic Farm, Batang Kali, Hulu Selangor, Selangor. The deadly landslide claimed 31 lives including 13 children and 61 survivors were rescued. The search and rescue (SAR) operation was carried out immediately and continued for nine days before it ended after the last victim was found. The Department of Mineral and Geoscience Malaysia (JMG) was informed of the event and actively involved in conveying geological information during the SAR operation. JMG was also responsible for conducting a forensic investigation to understand the geological factors that contributed to this catastrophic event. An extensive field geological study including LiDAR data capture, geophysical surveys, geological surface mapping, hydrogeological, and in situ field testing were carried out. These data were analyzed to ascertain the causal geological factors and establish of subsurface profile for landslide simulation modeling. The landslide is classified as a complex which is a combination of rotational slide and earth flow. The landslide body measured approximately 550m long, 110m wide, and 14m deep with 282,170m^3 total estimated volume of debris which mainly consists of sandy silt beside block boulders and tree trunks. Analyses indicate that the colluvium layer which is deposited at the foot slope and the groundwater regime have contributed significantly to the failure. Landslide simulation modeling shows the velocity of the flow is 13.2m/s with the average thickness of the accumulation zone ranging from 0.8m to 10.5m. The result from the investigation also indicates that geological causal factors should be taken into consideration in slope repair works and mitigation measures.

Keywords: Batang Kali Landslide, Disaster Risk Reduction, Forensic Geology

1. Introduction

Landslide incidents in Malaysia were recorded as one of the most common natural disasters that occurred frequently which had an impact in terms of damages and losses including fatalities, injuries, property damage, disruption and destruction of services as well as economic and financial losses (Komoo et al., 2011). Data showed the total economic losses due to landslide incidents in Malaysia since 1973 was approximately more than USD 1 billion (Abdullah, 2013). According to Akter et al. (2019) from the year 1993 to 2014, there were 26 major landslide events recorded which had an impact on death, damage to properties, and economic losses. Among the memorable tragedies was the collapse of one block in Highland Tower resulted in 48 fatalities back in December 1993. Further analysis of the history of landslides in Malaysia shows a significant increase in the trend of landslide occurrence in Malaysia and most cases are related to slope failure that occurred during the housing development stage in the hill slope area. In Selangor state, a record from 1993 to 2022 shows the number of fatalities from 8 landslide incidents increasing to 114 deaths including the Batang Kali landslide which claimed 31 lives (Table 1).

Batang Kali is one of the tourist attraction hotspots in Selangor state which offers recreational activities related to ecotourism such as hiking, glamping, and trekking. A landslide disaster that occurred at 2.08 a.m. on 16 December 2022 involved an agricultural area and campsite at Father's Organic Farm, Batang Kali, Hulu Selangor, Selangor. This incident destroyed almost the entire campsite and farming area which claimed 92 victims with 31 deaths including 13 children and 61 survivors (Fig. 1). The search and rescue (SAR) operation was carried out for 9 days and ended on 25 December 2022 after the last victim was found. Department of Mineral and Geoscience Malaysia (JMG) was assigned to support the SAR team as a technical advisor during the operation as well as conducting the geological forensic investigation to understand the failure mechanism and identify the geological factors that contributed to this catastrophic event. An extensive field geological study including Light Detection and Ranging (LiDAR) data capture, geophysical surveys, geological surface mapping, hydrogeological, and in situ, field testing were carried out. This paper will discuss the result of the investigation which indicates the geological causal factor of the landslide.

2. Study Area

2.1 Geology and Geomorphology

The geology of the site and surrounding area is underlain by the Main Range Granite, metamorphic rocks, and colluvium deposits. Metamorphic rocks consisting of schist and phyllite interlayer are the oldest rock units. The Main Range Granite consists of porphyritic biotite granite with the boundary between the two bedrocks located in the middle of the investigation area. Colluvium deposits also form the surface sediment that overlies both bedrock units in the valley. The granitic and metamorphic bedrock in this area shows the most distinctive features that indicate the existence of the fault and tectonic activity.

The geomorphology of the area consists of a valley surrounded by hilly topography with elevations ranging from 590 m to 900 m. The area is generally located in the western foothills of the Banjaran Utama mountain range. Generally, it lies to the west of the foot of the Banjaran Utama mountain range. Between the peaks and the lowlands, there are high-

Table 1 Major landslide incident record in Selangor State 1993-2022.

No.	Date	Location	Toll
1.	11 Dis 1993	Highland Tower, Bukit Antarabangsa	48
2.	20 Nov 2002	Taman Hillview, Ulu Kelang	8
3.	30 Nov 2008	Ulu Yam Perdana, Hulu Selangor	2
4.	06 Dis 2008	Taman Bukit Mewah, Bukit Antarabangsa	4
5.	21 May 2011	Rumah Anak Yatim At Taqwa, Hulu Langat	16
6.	18 May 2014	Kg Melayu Subang, Sungai Buloh	1
7.	10 Mac 2022	Taman Bukit Permai 2, Hulu Langat	4
8.	16 Dis 2022	Jalan Batang Kali-Genting Highland, Hulu Selangor	31
		Total	**114**

Fig. 1: Photo during Search and Rescue (SAR) Operation at the campsite and agriculture area

-banked river valleys filled with granite boulders of various sizes. The nature of the valley and the high cliffs form a dendritic stream pattern. This stream is a branch to the Pencheras River which is found in the south and flows northwest. Analysis of the terrain's gradient indicates that 50% of the slopes in the area are equal to or steeper than 15°.

2.2 Rainfall Analysis

Based on Malaysian Meteorological Department (METMalaysia), the Northeast Monsoon (MTL) began on 7 November 2022 and almost the entire country has received higher than normal rainfall levels. For the landslide area, there are 7 nearby rain gauge stations around the main route from Genting Sempah to Genting Highland owned by Genting Berhad. The closest rain gauge station is in the area of Institut Aminudin Baki, Gohtong Jaya (RG 3 IAB) which is located approximately 3 km upstream of the incident site. The rainfall data for the period of 1 December to 30 December 2022 shows the heavy rainfall outflow of the Northeast Monsoon occurred in early December 2022 with the highest rate at 92.2mm a day. The cumulative rainfall record 15 days before the incident for the nearest Station (RG 3 IAB) was also at a level of 205.6mm. However, there was no rainfall recorded during the day of the incident.

3. Method and Results

3.1 Landslide Morphology

The landslide occurred on a man-made slope that was originally constructed to provide a platform for the Batang Kali-Genting Highlands Road. The cut slope at the top of the road platform is still intact, while the fill slope at the bottom has failed. The height of the fill slope from the road platform to the foot of the slope is approximately 50m and the gradient of the slope is approximately 25°-30°. The width

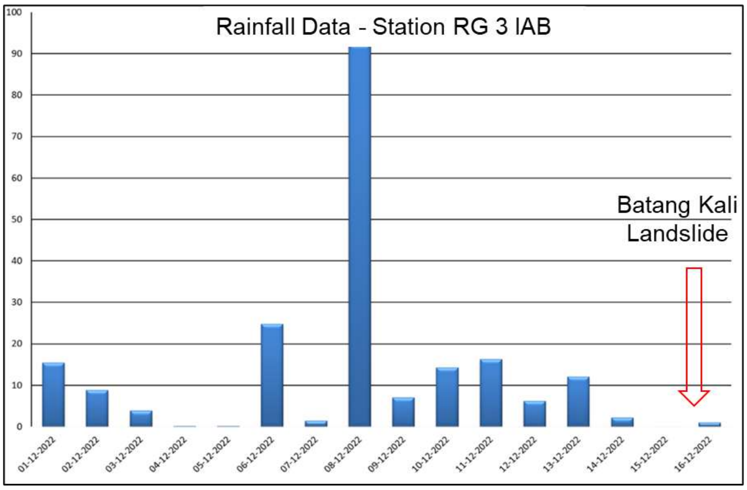

Fig. 2: The cumulative amount of rain 15 days before the event for the closest station RG 3 IAB was 205.6mm with the highest amount of daily rainfall being 92.2mm.

of the main scarp is 110m, the depth is 14m and the length of the path and accumulation area is approximately 550m (Fig. 3). The total volume of the landslide debris is approximately 282,170 m3 which includes the initiation zone and the accumulation zone. In addition, the landslide also transported soil materials, boulders, and trees along the route and deposited at the lower and sloping part of the valley downstream. According to Varnes (1978), landslides are classified as complexes that combine a rotational slide with earth flow.

During Search and Rescue (SAR) Operations, JMG has carried out a risk assessment for any subsequent ground movement and delineated the Hazard Zones and the Control Zones for operation safety control. The Hazard Zone covers the perimeter of the landslide body starting from the main body to the entire collapse run-out area. Whereas, the Control Zone covers the area surrounding the Hazard Zone that is characterized by geological constraints that are likely to cause subsequent movement (Department of Mineral and Geoscience Malaysia, 2012).

Fig. 3: Dimension of the landslide and the photo of the main landslide body.

3.2 Aerial Photo, Satellite Image, and InSAR Analysis

Analysis of the 1966 aerial photo imagery shows that the investigation area was covered by forest and there was no disturbance on the natural terrain. The 1995 aerial photo image also indicates the condition after the road was ready to be built where there were activities of cutting and filling the slope. Slope profiling also has been carried out on the upper slope and lower slope of the road platform around the landslide area (Fig.4). Besides that, analysis of satellite images from Google Earth starting from 2002 to 2021 shows that several land use changes have taken place within the investigation area. Land use patterns changed significantly from February 2015 when land clearing activities, construction of greenhouses for agricultural activities, and construction of permanent structures took place (Fig. 5). The qualitative interpretation was based on the elements of location, size, shape, hue, texture, and pattern of the objects in the images used. Signs of slope instability and landslides are not clearly visible in the vicinity but rather there is a sign of erosion at a modest to high grade in areas that were explored before vegetable planting and rain protection structures were built. On the other hand, analysis of Interferometric Synthetic Aperture Radar (InSAR) data revealed some changes in the earth's terrain prior to the failure in the investigation area. The method of monitoring using InSAR satellites is seen to be an effective monitoring tool for landslide risk. The analysis was divided into 5 monitoring zones to assess any landform changes (Fig. 6). Zone A covering the foot of the slope has shown a downward movement trend with a rate of 21.25 mm/year starting on 3 December 2022 until 15 December 2022 which was the day before the landslide occurred. Likewise, Zone C which includes the upper slope and lower slope has also indicated a downward movement with a rate of 21.48 mm/year starting on 24 July 2022 until 16 October 2022.

3.3 Engineering Geology

Observation at the main landslide scarp shows a fill layer approximately 8m thick consisting of homogeneous soil material that overlies on weathered granite that has sub-rounded corestones of various sizes. Some of the granite boulders that fell with the main debris originated from this area. Additionally, water seepage was observed at 3 locations at the toe of the main scarp of the landslide area which is located approximately 20 m below the level of the road platform that significantly contributed to the instability at the toe slope. Based on the geospatial analysis of Light Detection and Ranging (LiDAR) data, four landslide scarps were identified at the top of the road platform which were interpreted as the source of the colluvium deposits encountered in the valley section at the foot of the slope including the landslide area (Fig.7). Besides that, part of the road platform was constructed crossing the old landslide zone. A total of 28 Mackintosh probe tests and 17 hand augering holes were conducted to obtain sub-surface information to support the geophysical survey data. The analysis results found that the thickness of the landslide debris is estimated between 2-5m deposited on top of the colluvium layer. Based on the particle size distribution analysis of samples taken using the hand augering method found that the main soil type of the investigation area is sandy silt.

3.4 Geophysical Survey

A geophysical survey application in landslide investigation aims to understand the subsurface characterization, ground-water regime, and localization of the shear plane (Hussain et al., 2022). The 2-dimensional electrical resistivity method was used in the investigation with a total of 8 survey lines within the landslide body (Fig. 8). The result shows that the water-saturated zone was found in the main landslide scarp area where the resistivity values range from 1 Ωm

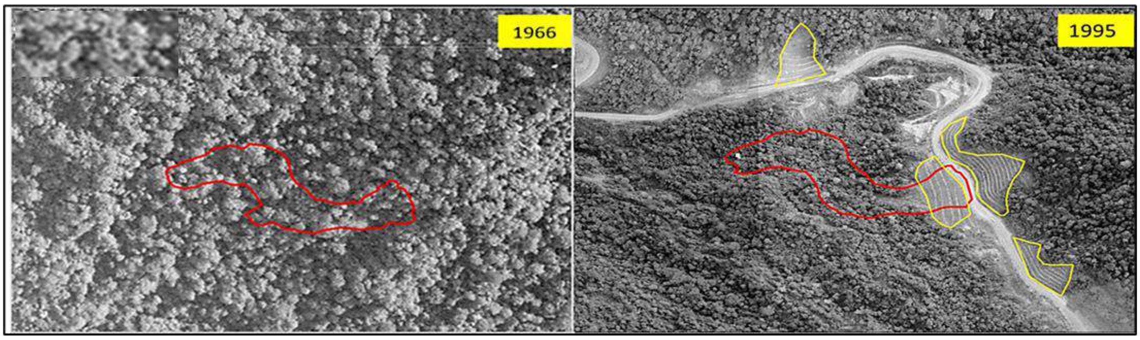

Fig. 4: Arial photo of the landslide area in 1966 and 1995 which red polygon indicates landslide area. (Source: Department of Survey & Mapping Malaysia)

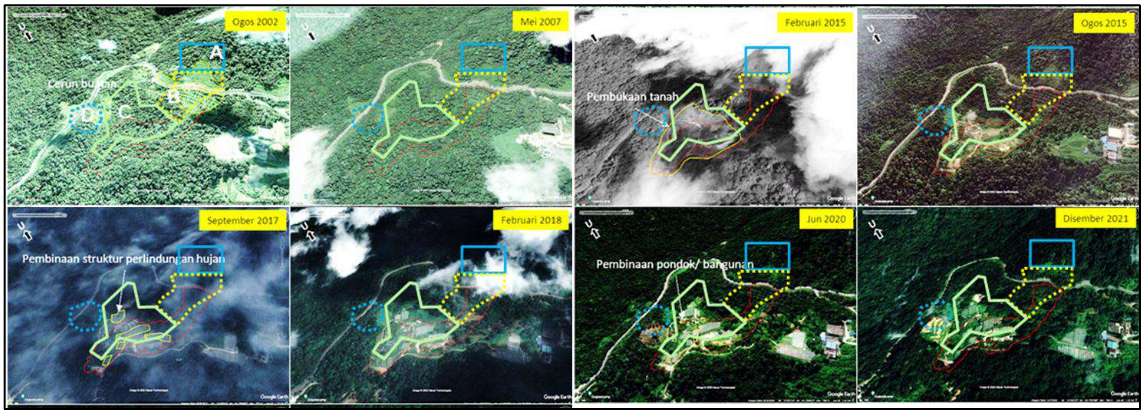

Fig. 5: Land use change from 2002 to 2021 based on satellite imagery. (Source: Google Earth)

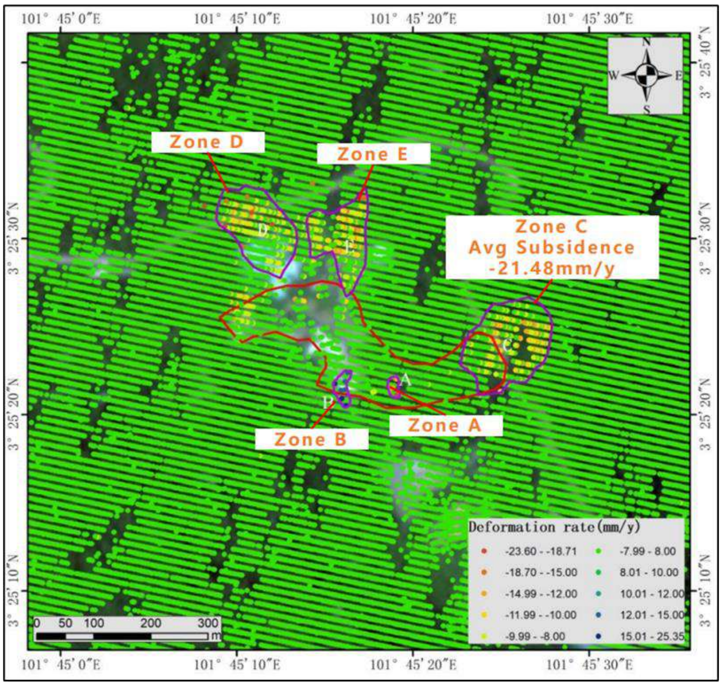

Fig. 6: Movement analysis using InSAR satellite data within the investigation area (Source: Spacegen Sdn Bhd).

to 9 Ωm. This zone consists of materials that have high porosity and permeable properties that allow water and electric current to flow easily. Whereas within the landslide area, water saturated zone in the landslide debris was interpreted at the low resistivity value zone range from 5 Ωm to 50 Ωm. Medium resistivity value zones (31Ωm - 500Ωm) are interpreted as the material within the landslide debris that can be found from the surface down to a depth of 20m followed by a layer beneath the collapse debris layer that is interpreted as weathered rock and colluvium. The third layer at the bottom is interpreted as bedrock. The lower magnitude values indicate the different lithological nature of the bedrock and are interpreted as metamorphic rocks. The high intensity zones (500Ωm - 5000Ωm) within the landslide debris layer are interpreted as "boulders" and granite-type bedrock based on information from the geology of the area.

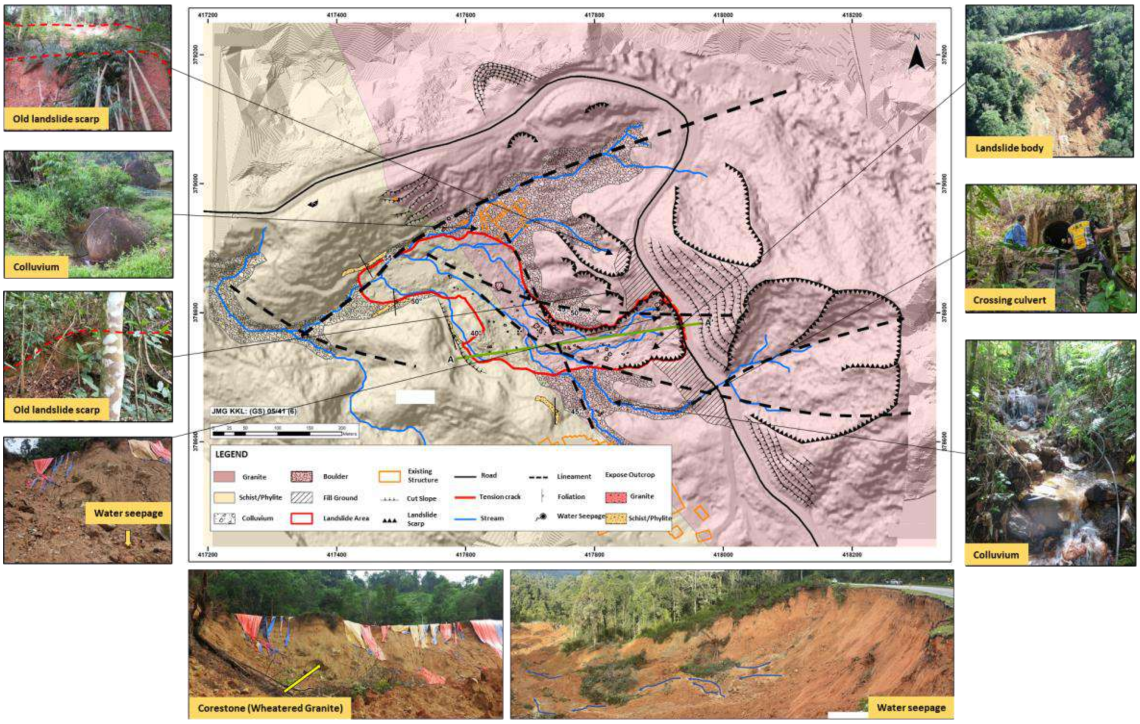

Fig. 7: Geomorphological Map of the landslide (Department of Mineral and Geoscience Malaysia, 2023)

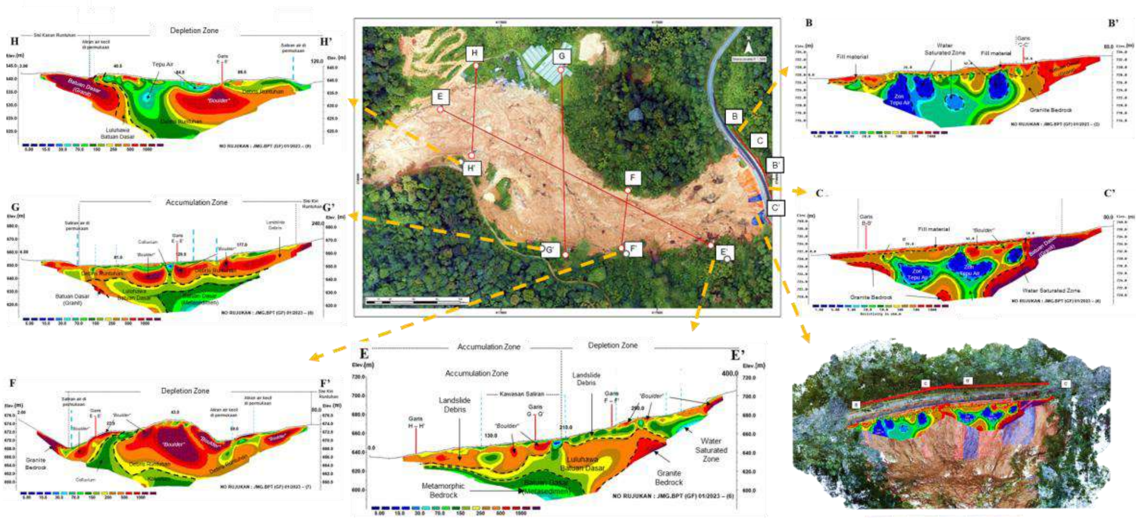

Fig. 8: Geophysical result of the landslide area

3.5 Hydrogeology

Groundwater regime has a direct impact on the slope stability and a substantial raising of groundwater will increase the pore water pressure (Alsubal et al., 2019). This investigation involved physical water analysis studies and stable water isotopes (SWI) analysis aimed to determine the source of water flow around the landslide area. The concentration of sampling points was based on the surface water run-off area and the water drain area from the cistern.

Besides that, hand auger holes and Mackintosh probes testing locations were utilized in measuring the groundwater levels a week after the incident. Based on the analysis of the water level measurements in the field, an isopach map of the groundwater level from the ground surface was generated (Fig.9). Generally, the direction of underground water flow in this area is consistent with the hydraulic head contour which flows from the east to the west of the site. The high water table was found in the main landslide scarp area in line with the results from the geophysical study using the 2D electrical resistivity survey method which indicates the water-saturated zone.

Additionally, the total dissolved solids (TDS) and Stable Water Isotope (SWI) results indicate the presence of groundwater and surface water interactions in the vicinity of the investigation area. Field evidence also indicates the presence of iron staining in the area of the intercepted water path. Six (6) sampling points have been detected to contain iron which has been categorized as underground water. Furthermore, this condition is also influenced by the local geological materials and structure.

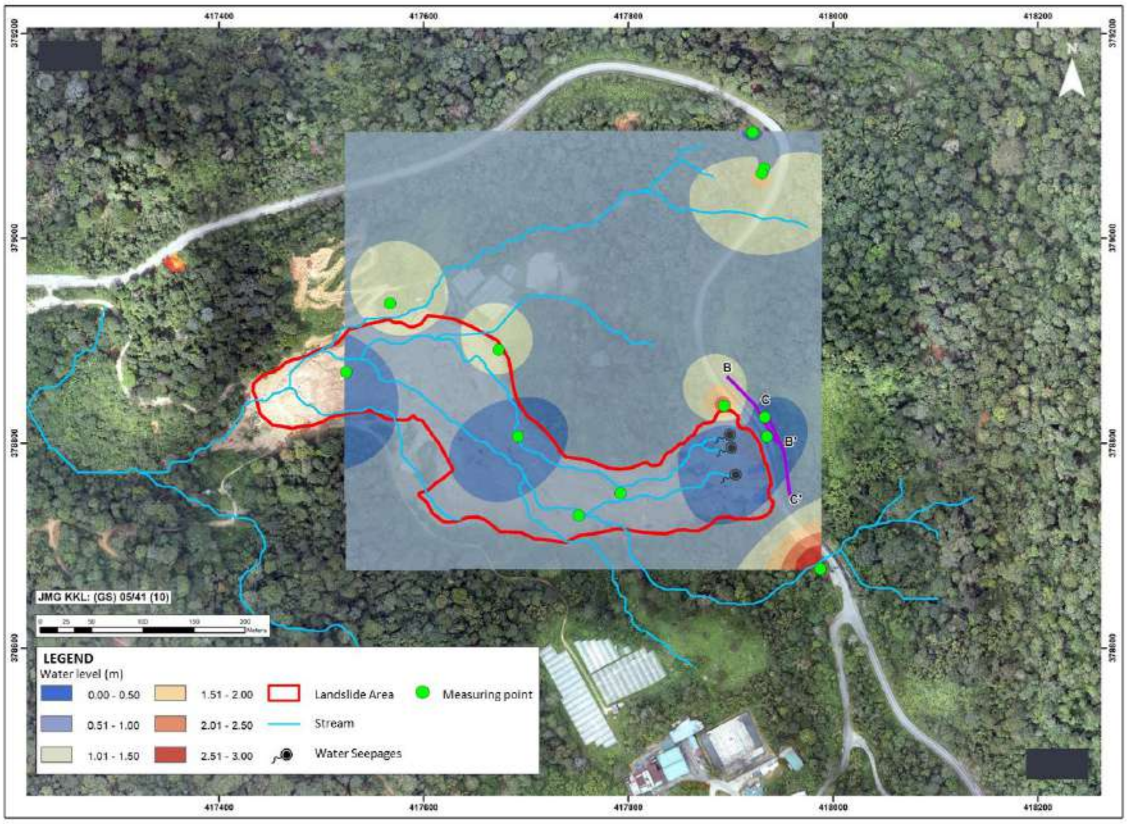

Fig. 9: The isopach map of groundwater level from the ground surface in the landslide area

4. Discussion

Based on witness accounts and analyses of field data, a simulation of the landslide was generated using Rapid Mass Movement Simulation (RAMMS) software. RAMMS modeling involves simulating and predicting the behavior of rapid mass movements such as landslides using computational models. Several parameters were used including topographic data in the digital elevation model (DEM), and soil properties represent in Table 2. As a result of the simulation, the landslide occurred in two phases which the first phase illustrates that the landslide occurred starting at the top of the fill slope and the debris covered part of the campsite area. Subsequently, the second phase of the landslide occurred within 15 minutes which has completely struck almost the entire campsite and agriculture area. The estimated velocity of the debris was approximately 12.30 m/s. Through the analysis of pre-and post-landslide ground elevation data, it was found that the average thickness of the debris within the depositional zone ranged from 0.8m to 10.5m.

Table 2 Input Parameter for RAMMS modelling

Input Parameter	Value
Digital Elevation Model (DEM)	3.0-meter resolution
Soil Constant Density	1500 kg/m^3
Dry-Coulomb type friction μ (Mu)	0.180
Viscous-turbulent friction ξ (Xi)	2200 m/s^2
Simulation time	500 second
Momentum Threshold	5%

Generally, geology, geomorphology, climate, and anthropogenic activities, are factors controlling the stability of a slope (Komadja et al., 2020). The Batang Kali landslide is known to have been caused by geological elements within the slope and the presence of underground water. The road platform has been built on top of a cut slope while the fill slope has been constructed on top of weathered granite containing a rock boulder named corestone and colluvium layer at the foot of the slope which is characterized as a geological sensitive deposit due to loose and uncompacted materials. The presence of groundwater flow in the slope has formed a water-saturated zone at the foot of the slope which results in the soil matrix becoming loose and contributes to the instability of the entire slope. Apart from that, anthropogenic factors and land-use activities in the vicinity also significantly contributed to the instability of the slope thus increasing the risk of landslide. Figure 10 depicts the schematic diagram of the landslides.

5. Conclusions

Based on the field evidence and data analysis found that the geological factors are deemed to be the main contributing factor in the Batang Kali Landslide disaster. Several methods have been used to identify the surface and subsurface characteristics including remote sensing analysis, engineering geological mapping, hydrogeological mapping, and geophysical survey. Computational simulation modeling integrates all the parameters to understand the mechanism of the landslide. From the result, the presence of geologically sensitive material such as loose colluvium deposits and expansion of the water-saturated zone within the slope can further exacerbate the stability of the slope. Apart from that, an anthropogenic factor related to the existing slope before the incident should be taken into consideration through additional

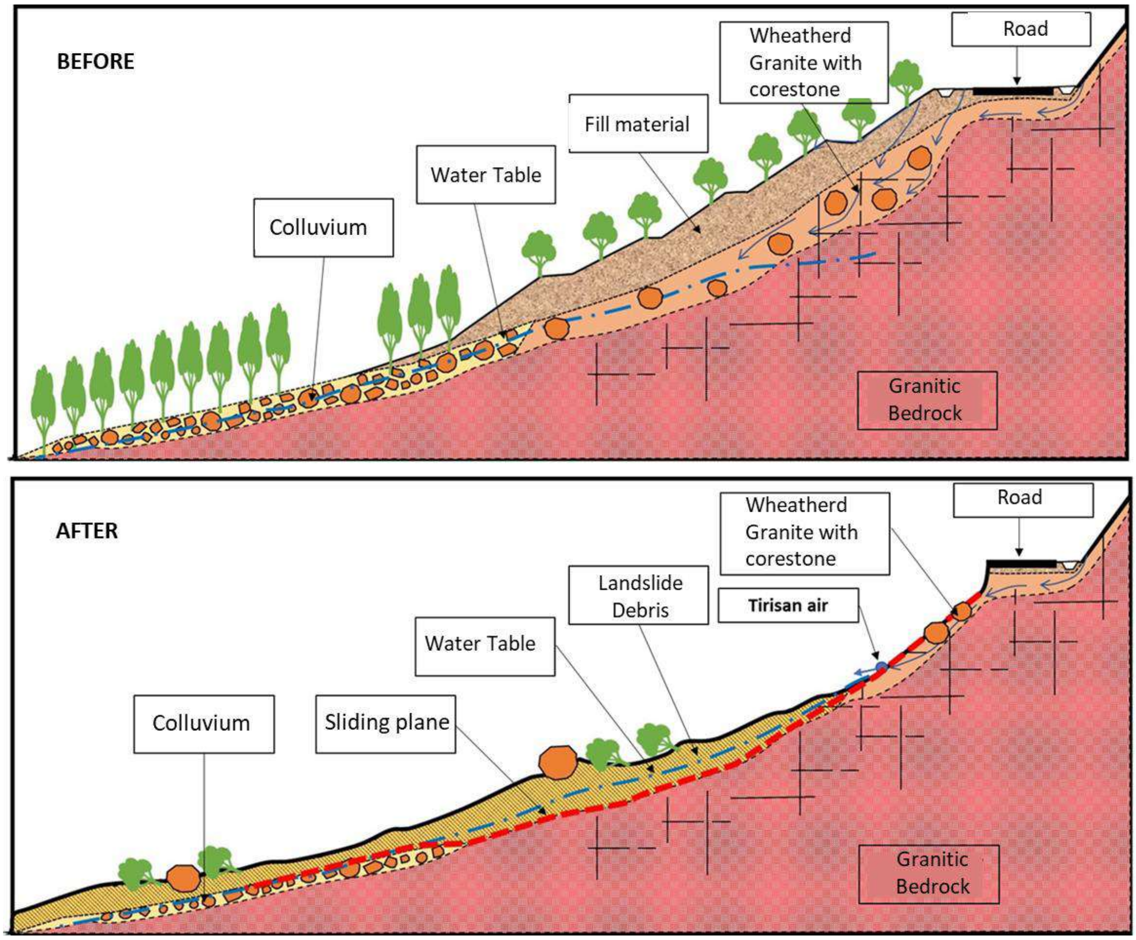

Fig. 10: Schematic geological crossection of the landslides.

investigation and analysis as well. Thus, the findings of the investigation should also be used in designing the slope repair work and mitigating measures in the area. Additionally, it is crucial to assess the stability of existing slopes in the vicinity of the landslide area for proper mitigation measures as well as a routine slope maintenance of the man-made slope should cover the entire slope area.

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