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Implications of Clay Minerals in Landslide Disasters: Case Study of the Riau - West Sumatra Highway KM 82 - 89

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Abstract

The research area is along the Riau - West Sumater route KM 82 - 89 where landslides are very common. The factors most often discussed are rainfall intensity, degree of slope, geological structure and the presence of plants. In this research, the factor of the presence of clay is the main focus in its influence on the occurrence of landslides. Landslide sampling is carried out at landslide locations. Soil samples were also carried out in laboratory simulations of the process of landslides. The methods used to identify the type of landslide are Scanning Electron Microscope (SEM) and X-ray diffraction analysis (XRD). The results of the analysis showed that all of the 3 soil samples analyzed using SEM showed the presence of Kaolinite, Montmorillonite and Illite types of clay. In terms of the percentage of clay presence based on XRD analysis at 3 stations, it shows the presence of Kaolinite clay in each soil sample with the percentage of ST1, ST2 and ST3 Kaolinite presence, namely 29.55%, 18.33% and 36.67%. The presence of Montmorillonite and Illite is indicated by the presence of the mineral Muscovite from the SEM analysis results where its presence is only found in ST1 and ST2 with percentages of 34.85% and 26.67%. The implication of the presence of Montmorillonite and Illite clay is an important factor in the occurrence of landslides, especially the size of the landslide that occurs. This is shown by the linearity between the percentage of Montmorillonite and Illite presence and the distance of the landslide that occurred in the simulation results.

Keywords: Clay, Riau – West Sumatra Highway, SEM, landslide, XRD

1. Introduction

Landslides, also known as "Landslides" in English, refer to the movement of slope-forming materials such as rocks, debris, soil, or other mixtures, which occur when these materials move down or out of the slope. The process of landslides can be explained as follows: when water seeps into the soil, the weight of the soil will increase. If the water penetrates the waterproof soil layer and functions as a sliding surface, the surface of the soil will become slippery and the weathered soil layer above it will follow the slope and come off the slope.

Pekanbaru is a city that is experiencing rapid economic growth, and therefore has high living needs, including material, energy and food needs. West Sumatra Province is one of the main suppliers of necessities for the city of Pekanbaru. Land transportation is the route most actively used to send goods from Riau to West Sumatra, but this route is also very vulnerable to landslides. According to data from the Central Statistics Agency (bps.go.id), throughout 2021 there were 241 landslides recorded in Riau and West Sumatra Provinces. If calculated on average, around 66% of all landslides occurred during that year. The research area is located on the Riau - West Sumatra highway, precisely at KM 82 – 89.

Research related to landslides has been widely carried out by many researchers in various places. The research was carried out using very diverse methods with various objectives (Budianta et al., 2022; Carrión-Mero et al., 2021; Liu et al., 2020; Purnawan & Khairah, 2021). Degree of slope plays an important role in the occurrence of landslides. However, the characteristics of unconsolidated soil also greatly determine the occurrence of landslides. Texture, clay mineralogy, and mechanical characteristics of rocks are parameters for classifying the occurrence of landslides (El Jazouli et al., 2022; Sukiyah et al., 2022). Researchers tried to look at the effect of clay mineral content in a case study in the Kanlica village area. The LL (47.2%), PI (19.6%) values are the maximum limits on interaction with water (rain) and ultimately the influence of rain is strongest in influencing the occurrence of landslides (Yalcin, 2007). In this research, we will focus more on highlighting the influence of clay specifically on the type of clay on the occurrence of landslides in the research area.

2. Clay Minerals

Some of the earth's most important properties can be attributed to its clay content (Schulze, 2005). Properties such as cation exchange, swelling shrinkage properties, permeability, and various mechanical moduli can be related to the clay content (Aksu et al., 2015; Chen et al., 2021; Schulze, 2005). Often, these macro properties can be explained by understanding the underlying microstructure and crystals of clay minerals (Schulze, 2005). Microstructure and charged surfaces dictate the reactivity of clays and the formation of deformations (Chen et al., 2021), which consist of particles, aggregates and clusters (Chen et al., 2019; Jacinto et al., 2015; Tournassat et al., 2011).

Kaolinite is a clay mineral with a 1:1 structure and has a low level of chemical reactivity. This mineral is white and very brittle so it is easily formed and destroyed, especially when wet. Kaolinite is formed from alteration processes, mainly weathering from igneous, sedimentary and metamorphic rocks. Generally this mineral is associated with muscovite, quartz and feldspar (Asri et al., 2023).

illite is the name of a group of crystalline clay minerals that do not have swelling properties like the mineral montmorillonite. This mineral is a secondary mineral derived from muscovite and feldspar. Illite is a clay mineral that is not dominantly present (Yuliyanti et al., 2012).

Montmorillonite is a group of clay minerals with lattices that expand easily. The absorption of water in materials containing this type of clay will result in swelling, the magnitude of which depends on the type and content of montmorillonite, the type of ion exchange, the liquid phase electrolyte content and the internal structure of the material itself (Bagus et al., 2016; Utami et al., 2018)

3. Regional Geology

Geologically, this research area, which is located in Marangin District, Kampar Regency, Riau Province, is included in the Pekanbaru sheet (Clarke et al., 1982). Three formations make up the geology of the research area, namely the Telisa Formation, Sihapas Formation and Bohorok Formation (Figure 1). These three formations are the result of deposits from the Central Sumatra Basin. The Telisa Formation is composed of calcareous mudstone, thin limestone, siltstone and a little galukonite sandstone. The Sihapas Formation consists of conglomerate sandstone and siltstone, while the Bohorok Formation consists of wak sandstone, wak conglomerate and turbidite deposits.

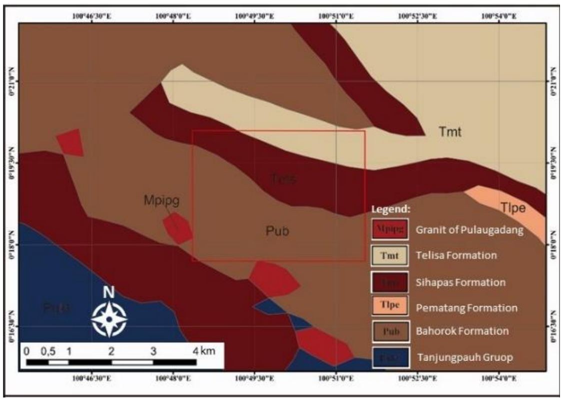

Fig 1. Regional geological map of the research area

4. Methods

The research was carried out in several stages, namely literature study, field work and laboratory analysis (Figure 3).

4.1 Literature Study Stage

The literature study stage was carried out by reviewing literature that was similar to research related to the influence of clay in landslide events. This stage was carried out to obtain research gaps from previous studies. In the literature study stage, soil sampling locations were also determined in the research area. One of the methods used to determine location is the remote sensing method. By using satellite imagery from Google Earth, location points were determined by identifying landslide occurrence points along the study area (Figure 2). Traces of landslides recorded in satellite imagery are usually shown by several characteristics: (1) the color hue of the slope surface changes from its surroundings; (2) sudden changes in plant conditions; and (3) there is a very clear contrast in color between the slope and the landslide.

4.2 Fieldwork

The fieldwork stages were carried out to confirm the sampling location points that had been determined as well as collecting field data. In the fieldwork stage, 3 things are done: (1) description of the landslide, including explaining the physical appearance and size of the landslide (Choanji et al., 2019; Yuskar et al., 2017); (2) description of the field geology by describing the type of soil and lithology found around the landslide location (Suryadi, 2016); and (3) taking soil samples for laboratory analysis. Soil sampling was carried out in 3 parts of the landslide, namely the head, body and foot of the landslide.

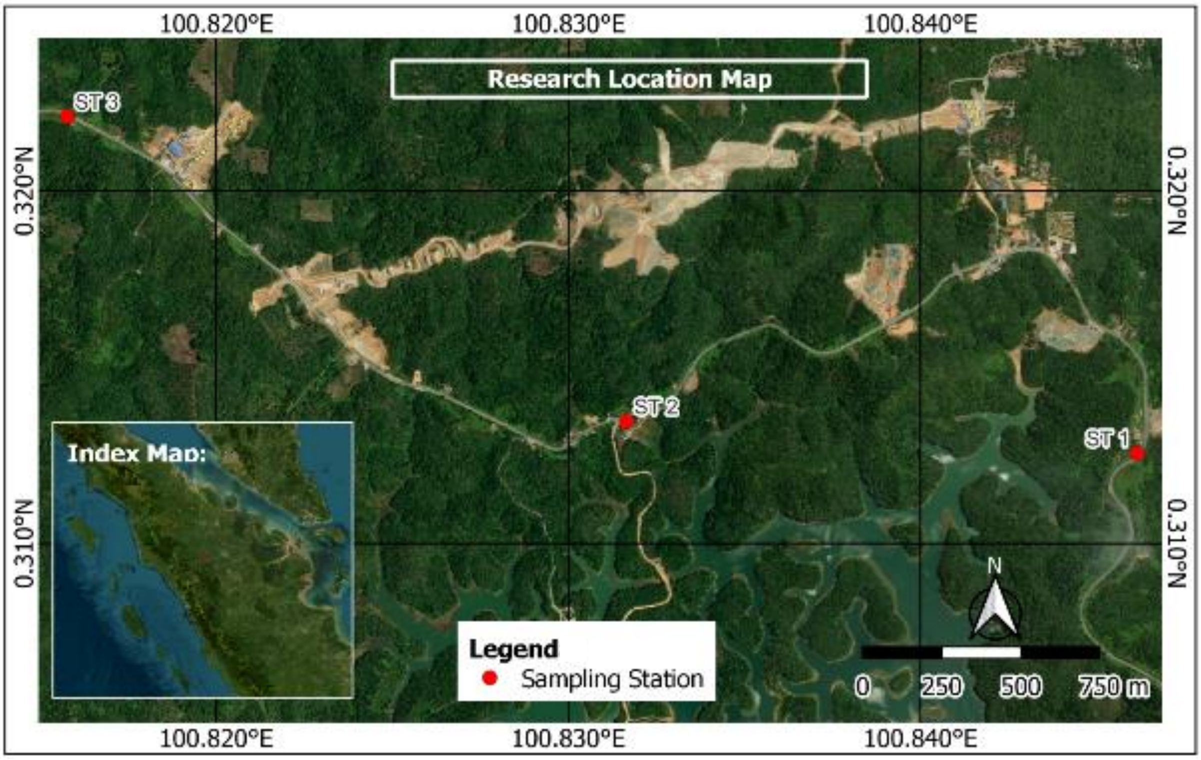

Fig 2. Satellite image of the research location

4.3 Laboratory Analysis

Laboratory analysis of taken soil samples. 2 laboratory analyzes were carried out to identify the type of landslide, namely X-Ray Diffraction (XRD) analysis and Scanning Electron Microscopy (SEM) analysis. XRD analysis was carried out to determine qualitatively the dominance of minerals in soil samples, especially clay minerals, while SEM was carried out to see the shape of the clay and identify the type of clay based on the geometry of the clay.

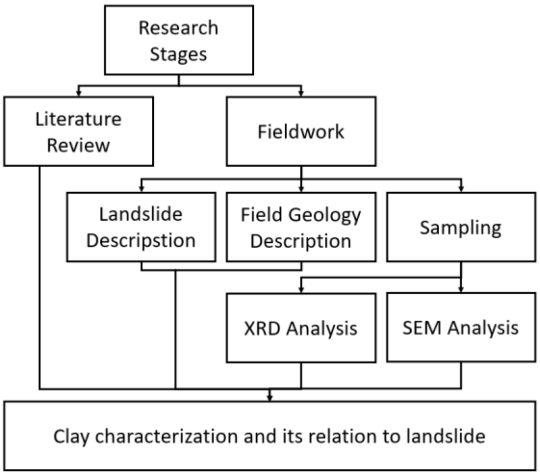

Fig 3. Flow diagram of research activities

5. Result

A total of 3 observation stations were carried out in this research, namely Station 1, Station 2 and Station 3.

5.1 Station 1

The landslide that occurred at this station had dimensions of 11.5 x 6.5 meters. The appearance in the field is that the color of the landslide is yellowish white with the size of the landslide material varying from chunks of rock fragments to clay. Part of the landslide body has been covered by vegetation. The results of SEM analysis, at 5000x magnification, several types of clay can be seen (Figure 4). Kaolinite is shown by a morphology such as thin plates in the form of clusters or single. The distribution of Kaolinite shows clumps of granules that bind together. Montmorillonite shows a thicker, flattened single grain morphology. If you look in more detail, the average size of montmorillonite is 5 µm. Illite shows a thick, flat and clustered morphology but still shows spaces between the illite grains. The results of XRD analysis show the presence of Quartz, Muscovite and Kaolinite minerals (Figure 5). In terms of quantity, Quartz is the most dominant mineral with a percentage of 35.61%, followed by Muscovite with a percentage of 34.85% and Kaolinite with a percentage of 29.55%.

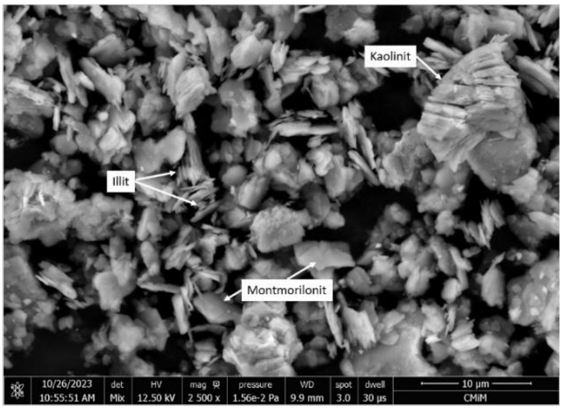

Fig 4. SEM photomicrograph of Station 1 sample

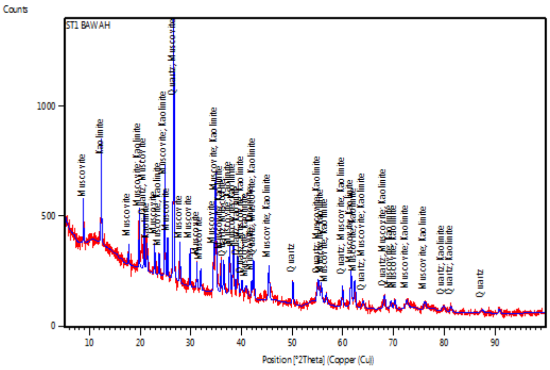

Fig 5. XRD results of station 1 samples

5.2 Station 2

The landslide that occurred at this station was covered by ferns. In terms of dimensions, the size of this landslide is 6 x 5 meters. The appearance in the field is that the color of the landslide is reddish brown with the size of the landslide material varying from chunks of rock fragments to clay. The results of SEM analysis, at 5000x magnification, several types of clay can be seen (Figure 6). Kaolinite is shown by a morphology such as thin plates in the form of lumps and clusters. They are very small in size, 3µm, which bind to each other. Montmorillonite shows a thicker, flattened single grain morphology. The distribution is quite large with a size of 5 – 8 µm. Illite shows a single, flattened morphology with a very small size, namely 1 – 2 µm. The results of XRD analysis show the presence of Quartz, Muscovite and Kaolinite minerals (Figure 7). In terms of quantity, Quartz is the most dominant mineral with a percentage of 55%, followed by Muscovite with a percentage of 26.67% and Kaolinite with a percentage of 18.33%.

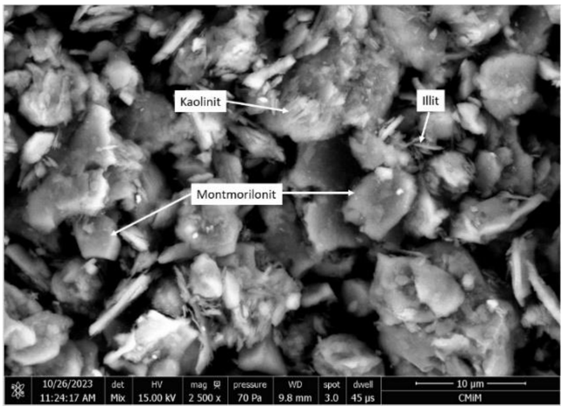

Fig 6. SEM photomicrograph of Station 2 samples

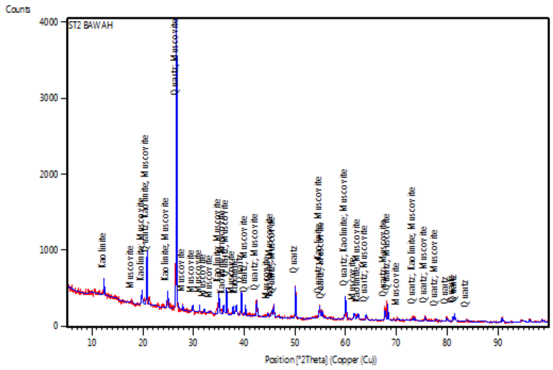

Fig 7. XRD results of station 2 samples

5.3 Station 3

The landslide that occurred at this station had dimensions of 8.5 x 5 meters. The appearance in the field is that the color of the landslide is brownish yellow with the size of the landslide material varying from coarse sand to clay. Part of the landslide body has been covered by vegetation. The results of SEM analysis, at 10,000x magnification, several types of clay can be seen (Figure 8). Overall, the clay grains are bound together to form lumps of clay when viewed at 5,000x magnification. Kaolinite is shown by a plate-like morphology in the form of clusters. When viewed individually, the Kaolinite mineral is very small and binds to one another, the size is smaller than 1µm. Montmorillonite shows a thicker, flattened single grain morphology, while Illite shows a thick, flattened and clustered morphology. The results of XRD analysis show the presence of Quartz and Kaolinite minerals (Figure 9). In terms of quantity, the presence of Quartz is the most dominant mineral with a percentage of 56.67%, followed by 36.67Kaolinite 18.33%.

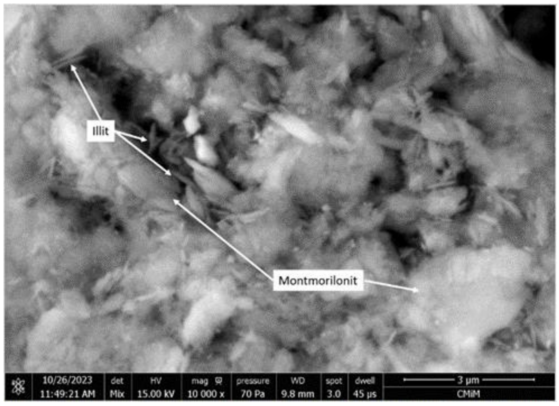

Fig 8. SEM photomicrograph of Station 3 samples

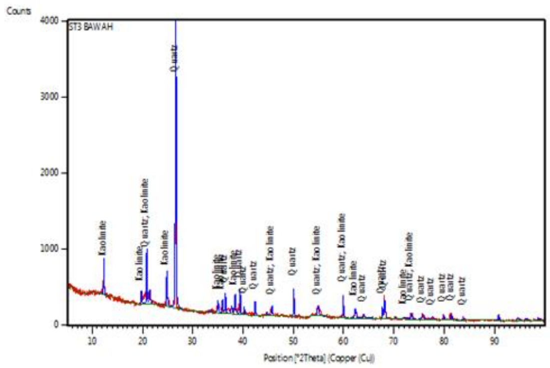

Fig 9. XRD results of station 2 samples

6. Discussion

The results of SEM analysis of the three samples showed the similarity in the presence of Kaolinite, Illite and Montmorillonite clay types. In terms of size, the clay grains shown in sample 3 are the smallest for the mineral types Illite and Montmorillonite. The presence of kaolinite dominates in the station 1 sample. Qualitatively, based on the most dominant form of kaolinite, it is found in the station 1 sample, followed by station 2 and station 3. Based on the results of the XRD analysis, the dominant minerals identified are Quartz, Muscovite and Kaolinite (Table 1). Quartz was the most dominant in each sample analyzed where station 1 showed 35.61% quartz, station 2 55% and station 3 56.67%. Muscovite is present representing the Montmorillonite and Illite content shown in the SEM analysis results. Muscovite had a percentage of 34.85% for station 1 samples and 26.67% for station 2 samples. Meanwhile, station 3 did not show any X-ray diffraction indicating muscovite content. The clay mineral Kaolinite was shown in all three samples analyzed. Station 1 contains 29.55% Kaolinite, Station 2 18.33% and Station 3 36.67%.

Table 1. Results of mineral type analysis using XRD

Station No	Mineral Name	Chemical Formula	Amount
Station 1	Quartz	SiO2	35.61%
	Muscovite	KAl2(Si3Al)O	34.85%
	Kaolinite	Al2(Si2O5)	29.55%
Station 2	Quartz	SiO2	55.00%
	Muscovite	KAl2(Si3Al)O	26.67%
	Kaolinite	Al2(Si2O5)	18.33%
Station 3	Quartz	SiO2	56.67%
	Kaolinite	Al2(Si2O5)	36.67%

The implications of clay in landslides along the Riau - West Sumatra KM 82 - 89 highway are shown by the results of landslide simulations in the laboratory. Landslide simulations were carried out with the same treatment for the three samples, namely slope of 40 0 , rainwater intensity of 3 liters/minute and rain duration of 15 minutes (Figure 10). The results obtained were that station 1 experienced a landslide of 17 cm, station 2 experienced a landslide of 64 cm and station 3 did not experience a landslide but formed scours on the surface due to surface water flow.

If we relate the relationship between landslides and the type of clay mineral, station 2 is the station where the landslide occurred furthest away with a clay mineral content of 18.33% kaolinite, muscovite (Montmorillonite and Illite) 26.67% and quartz 55%. Station 1 shows the results of a landslide simulation with movement as far as 17 cm. The mineral content is 29.55% Kaolinite, 34.85% Muscovite and 35.61% Quartz. Meanwhile, Station 3 did not show landslide movement with a Kaolinite content of 36.67% and Quartz of 56.67%. The presence of the clay minerals Montmorillonite and Illite is one of the factors causing landslides, this is shown by the simulation results at Station 3 where no landslide movement occurred. Apart from that, the presence of kaolinite also reduces the water absorption capacity of the soil because it cannot absorb water. Meanwhile, the comparison between the presence of Muscovite (Montmorillonite and Illite) and Kaolinite is a differentiating factor in the size of the landslide movement distance. At Station 1 the ratio of the presence of Muscovite: Kaolinite is 54: 46, while at Station 2 the ratio of the presence of Muscovite: Kaolinite is 59: 41. The greater the presence of muscovite, which in this case represents the clay minerals Montmorillonite and illite, the greater the potential for landslides to occur, including on the scale of size and distance of movement.

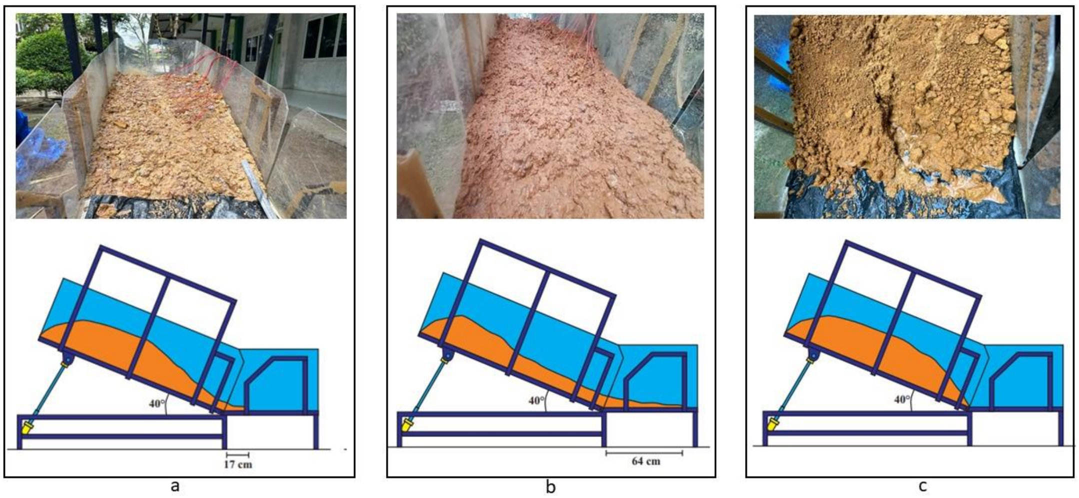

Fig 10. Simulation and modeling result of landslide from 3 sample of research area a) Station 1; b) Station 2; c) Station 3

7. Conclusions and Recommendations

The results of this research can be summarized into several findings:

- The presence of clay minerals is one of the factors causing landslides in the research area.
- The type of clay mineral Kaolinite is a factor that inhibits infiltration so that rainwater will flow on the surface and cause erosion of the soil on the surface.
- The ratio of the presence of Montmorillonite and Illiter clay to Kaolinite will influence the magnitude of landslide movement. The greater the Montmorillonite and Illite compared to the presence of Kaolinite, the greater the landslide movement will be.

The soil samples taken were the result of landslides that had occurred . However, from the simulation results there are still some who did not experience significant landslides. Therefore, clay is not the only factor that causes landslides. Further research can consider other factors that will influence the occurrence of landslides.

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