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Detection and Identification of Sliding Planes Using Geoelectric Methods at Bengkaung Tourism Area, Lombok Island

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Abstract

Landslides are among the most common problems on natural and man-made slopes. Factors that cause landslides are the presence of a sliding plane, steep slope, and the type of rock, while the triggers of landslides are vibration, human activity, and water infiltration into the slope. The sliding plane itself is an impermeable and slippery plane that is usually in the form of a clay layer so that it becomes the foundation for the movement of soil masses. This study aims to determine the type of rock and the depth of the potential landslide slide plane in Bengkaung Village. The data used in this study is data obtained by taking direct measurements in the field, namely by injecting electric current into the earth using geoelectric method tools. Data processing, namely by using the Res2dinv application. The results of this study are the types of rocks in the study area in the form of sandstone, clay, silt, limestone, breccia, and lava, and the depth of the sliding plane is between 2.8-5 meters.

Introduction

Geoelectric methods, especially resistivity surveys, are widely used to detect sliding planes in landslide-prone areas. By using configurations such as Wenner, dipole-dipole, and radar reflection profiles, researchers have succeeded in identifying potential sliding surfaces in various locations such as Ngantang Regency, Malang Regency [1], Bompon Sub-watershed [2], Bandar Baru West Lampung [3], and Poka Village, Ambon City [4], Lebong regency [5], Sambelia [6]. These studies revealed the presence of clay layers with specific resistivity values indicating their susceptibility to shear planes. Resistivity methods, combined with field observations and laboratory measurements, offer valuable insight into the characteristics of clay layers, crack structures, soil moisture, and other physical properties that influence the likelihood of landslides.

Additionally, geoelectric methods help determine the depth and orientation of potential sliding surfaces, contributing significantly to landslide risk assessment and mitigation efforts [5][6][7].

Bengkaung tourist destination located in Bengkaung Village, West Lombok Regency, is a tourist attraction that has the advantage of the natural charm of the city of Mataram in the afternoon and evening because this place has an altitude of (205 - 309) meters above sea level and a slope with 3 classifications, namely rather steep, steep, and very steep. Places with a relatively steep classification have a slope of (15 - 40) %, while the steepest has a slope of more than 40% [8], and the potential for natural disasters is relatively high [9], so it is thought to have a sliding field that can cause landslides.

Landslides are a common problem in areas with steep slopes [10],[11],12]. Landslides, often called earth/rock movement, are geological events due to the movement of rock or soil of various types, such as falling rocks or large clumps of soil. Landslide prevention and mitigation needs to be done in areas with landslide potential to reduce the risk. One of the efforts to overcome this is by detecting the condition and structure of subsurface geology so that the sliding surface of the slope can be predicted [9/13]. The sliding surface is an impermeable and slippery area, usually in the form of a clay layer, thus becoming the foundation for the movement of soil masses [14].

The sliding plane is a layer of rock where landslide material moves down if a triggering factor acts on the landslide material. Each type of rock has unique characteristics, such as resistivity, which are measured using the geoelectric method. This research uses the geoelectric method to determine the depth of the sliding plane as the cause of the landslide. The geoelectric method is also appropriate for identifying cracks as a source of landslides in the subsurface [15].

The geoelectric method is one of the geophysical methods that can be used to estimate subsurface hydrogeological conditions, such as detecting the type of rock and rock water conditions based on the electrical properties of rocks in the form of their specific resistance values. The working principle of the geophysical geoelectric method is that an electric current is injected into the earth through two current electrodes. Therefore, this research aims to analyze sliding fields in Bengkaung Village as a tourist spot many tourists visit, especially on weekends. With information about the existence of this sliding area, it is hoped that the risk of landslides can be minimized.

Theory

Sliding planes come in two forms. First, the shape of the sliding plane, which is parallel and almost straight with the ground, is called a translational slide. Second, the curved sliding plane in a circular arc is called a Rotational slide [2]. Figure 1 shows the types of sliding planes [16].

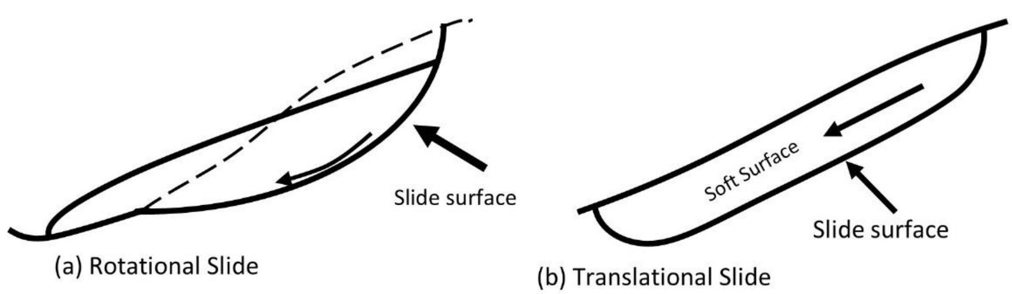

Figure 1. Types of sliding planes

The type of sliding plane determines the type of landslide that occurred. Slip field rotation slip is the sliding field where the material moves rotational avalanche. Slip field translation slip is the sliding area where it moves translational landslide material and blocks movement.

This geoelectric method determines the nature of electrical flow under the earth's surface [17]. Using the geoelectric method, an inversion image of the subsurface cross-section can be obtained, the layers below the ground surface. It can determine the possibility of groundwater and minerals at a certain depth.

The working principle of this geoelectric method is that an electric current is injected into the earth through two current electrodes. Through two potential electrodes, the potential difference that occurs can be measured. The results of measuring the current and potential difference for each specific electrode distance can determine the variation in the resistance value of each layer under the measuring point [18].

The Wenner configuration is a configuration in which electrodes are arranged at the same distance, 4 electrodes in the Wenner configuration (A, M, N, B), as shown in Figure 2. The principle of the Wenner Configuration is AM = MN = NB = a, then the distance between the adjacent electrodes M and N is equal to the distance A to M and N to B. The distance between the current and potential electrodes is the same in the Wenner configuration.

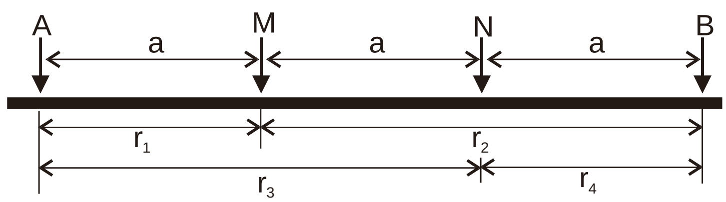

Figure 2. Wenner configuration electrode array

We know that a is electrode spacing, A and B are current electrodes, M and N are potential electrodes, r_1 is distance A to M, r_2 is distance B to M, $r_3$is distance A to N, r_4 is distance B to N.

The measured potential value is the influence of these layers because the earth is composed of layers with different resistivity. So, the measured resistivity value seems to be the resistivity value for only one layer. In this case, the measured resistivity is the apparent resistivity (ρ_a).

To determine the apparent resistivity value ρ_a, see the following equation:

$$\rho_\mathrm{a} = \frac{2\pi}{\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right]} \cdot \frac{\Delta V}{I} \quad (1)$$

Or

$$\rho_a = K\frac{\Delta V}{I} \tag{2}$$

We know that ρ_a is apparent resistivity (Ωm), $\Delta \boldsymbol{V}$ is the potential difference (volt), **I** is electric current (ampere), and **K** is the geometry factor. The geometry factor is the amount of correction of the location of the two potential electrodes to the location of the current electrode [15/19]. The **K** value of the Wenner configuration is as follows:

$$K = 2\pi\left(\frac{1}{\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right]}\right) \tag{3}$$

Based on the electrode configuration in Figure 2, equation 3 can be written as

$$K = 2\pi a \tag{4}$$

Equation 2 can be written as

$$\rho_a = 2\pi a\frac{\Delta V}{I} \tag{5}$$

Apparent resistivity represents the weighted average of the true resistivity over a large volume of soil where the evident resistivity of rocks and soils can cover a wide range, the value of which depends on the electrode spacing. If the spacing between electrodes is small, it will give apparent resistivity values close to the resistivity of rocks near the surface for a small-layered medium. If the distance is more significant, the resistivity obtained will represent the value of deeper rock resistivity [20].

Methods

This research was conducted in Bengkaung Village, Batu Layar Sub-district, and is quantitative descriptive research because it describes the geological conditions of the area under study. The research aims to determine the type of rock and the depth of the sliding plane in the Bengkaung Tourism area. The method used in this research is geoelectrical, which has an advantage as a non-damaging method, non-invasive, low cost, fast results, and compatible with various materials [21]. The electrode configuration that is used is the Wenner configuration. The Wenner configuration offers several advantages in subsurface analysis. This provides detailed insight into the resistivity values of different layers, allowing the identification of specific geological structures such as sliding planes [22],[23].

The measurement was carried out using a G-Sound GL – 4100 resistivity meters with a controlled AB voltage of 0 - 400 V and an AB current max of 100 mA. The device is equipped with a 24-electrode geo-scanner board. Figure 3 shows the research site's location, consisting of 5 lines with the most extended length of 115 meters. Acquisition data was done in September 2023.

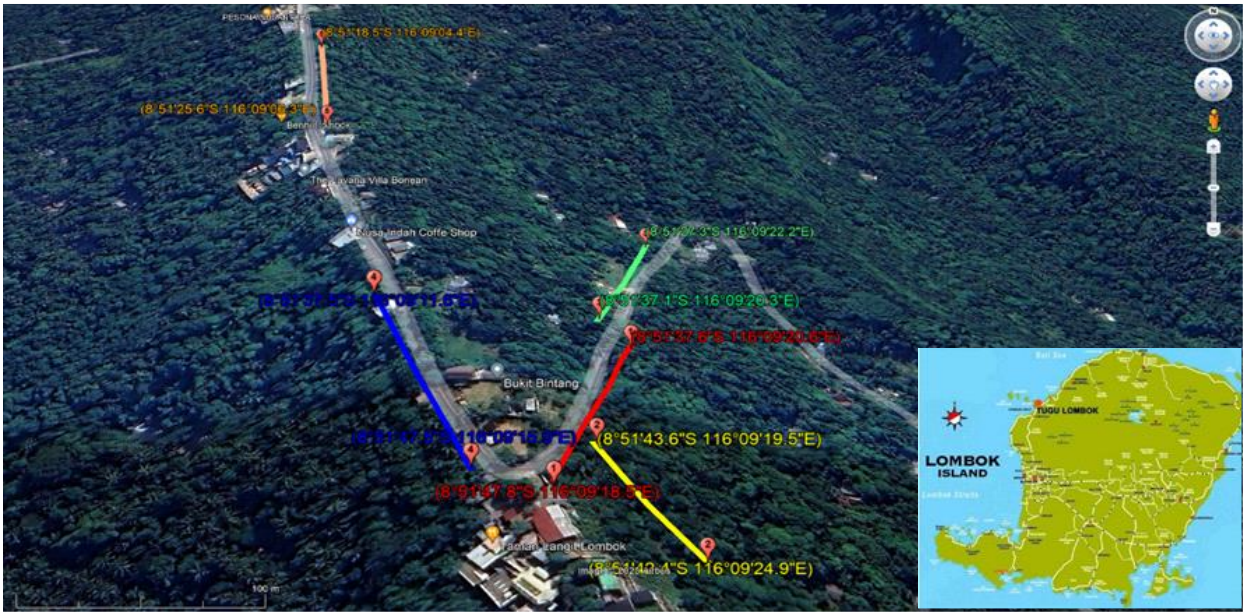

Figure 3. Research location in Bengkaung village and its location using the QGIS application

A geological map of the study area, as shown in Figure 4, was used to find out the geological conditions in the study area and also what types of rocks are in the study area so that it can facilitate researchers in identifying the type of rock in the area.

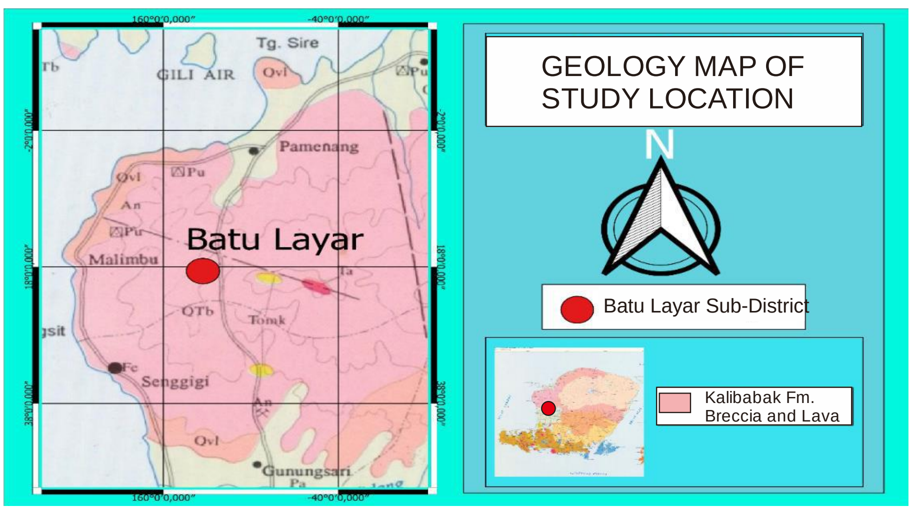

Figure 4. Geologic map modified from [24].

The data used in this research is obtained by making direct measurements in the field. The data acquisition stage in the field is carried out by arranging electrode equipment and resistivity tools connected to cables and then to electrodes. The following is the arrangement of the Wenner configuration electrodes.

A rock resistivity table is used to determine the type of rock based on modeling resistivity values, as shown in Table 1.

Table 1 Resistivity value of some materials [25]

Material	Resistivity(Ωm)
Clay	1 - 100
Silt	10 - 200
sandstone	1 - 1.000
limestone	100 - 500
Lava	100 - 50.000
Breccia	75 - 200
Andesite	100 - 200

Results and discussion

Based on the Lombok geological map in Figure 4, it is known that the formation in the research area is the Kalibabak Formation, composed of breccia and lava rocks. Based on the rock resistivity value, the subsurface rocks in the research area are under the constituent rocks of the formation. The following are the results of the cross-section of line 1 - line 5.

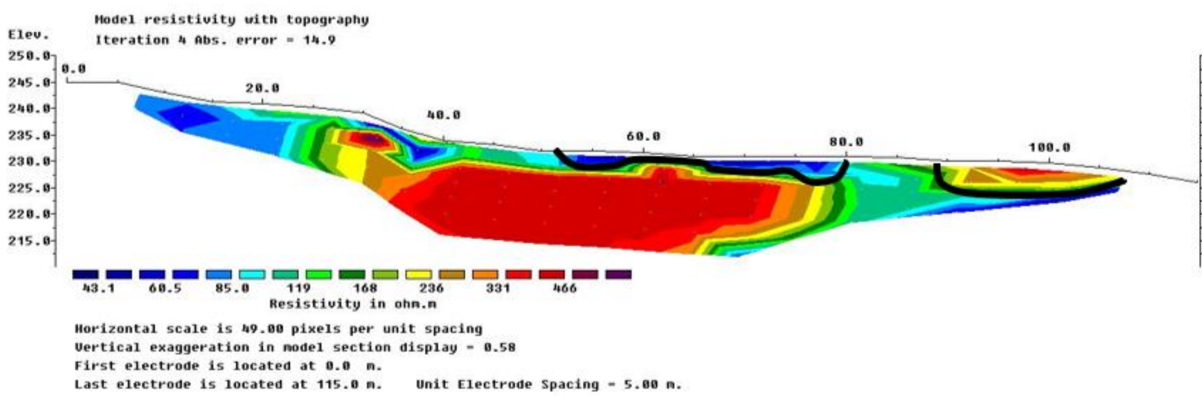

Figure 5. Resistivity cross section on line 1.

The location of line 1 is at coordinates (8◦51'47.8 "S 116◦09'18.5 "E - 8◦51'37.6 "S 116◦09'20.6 "E). The rock formation on this line is the Kalibabak Formation, consisting of breccia and lava rocks. The length of this line is 115 meters with a spacing of 5 meters per electrode. Based on the picture, the constituent rocks of this track at positions (1 - 24) meters and (47 - 85) meters are (43.1 - 60.5) Ωm, which is suspected to be sandstone on the surface. The rock resistivity at position (1 - 90) meters is (60.6 - 168) Ωm, suspected to be clay and silt with a depth of 4.5 meters. This clay and silt rock is suspected to be the rock that can cause landslides. The rock resistivity of positions (26 - 80) meters and (88 - 115) meters, namely (169 - 466) Ωm, is suspected to be breccia and lava rocks on the surface.

The location of line 2 is at coordinates (8◦51'43.6 "S 116◦09'19.5 "E - 8◦51'42.4 "S 116◦09'24.9 "E). The rock formation on this line is the Kalibabak Formation, consisting of breccia and lava rocks. The length of this line is 69 meters with a spacing of 3 meters per electrode.

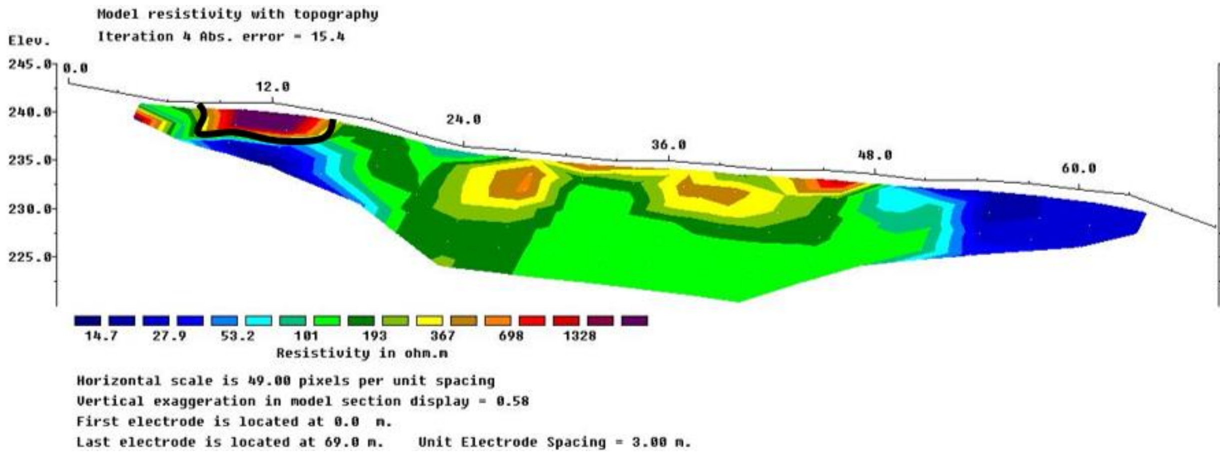

Figure 7. Resistivity cross section on line 2

Based on the picture, the constituent rocks of this line at position (1 - 48) meters are (194 - 1328) Ωm, which is suspected of lava rock on the surface by the rock formation in the area and place, namely the Kalibabak formation. The rock resistivity at position (7 - 21) meters is (14.7 - 53.2) Ωm, which is suspected to be sandstone with a depth of 3.82 meters and the same as position (49 - 69) meters on the surface. The rock resistivity at position (1 - 51) meters is (53.3 -193) Ωm, which is suspected to be clay and silt rock with a depth of 3 meters; this clay and silt rock can cause landslides.

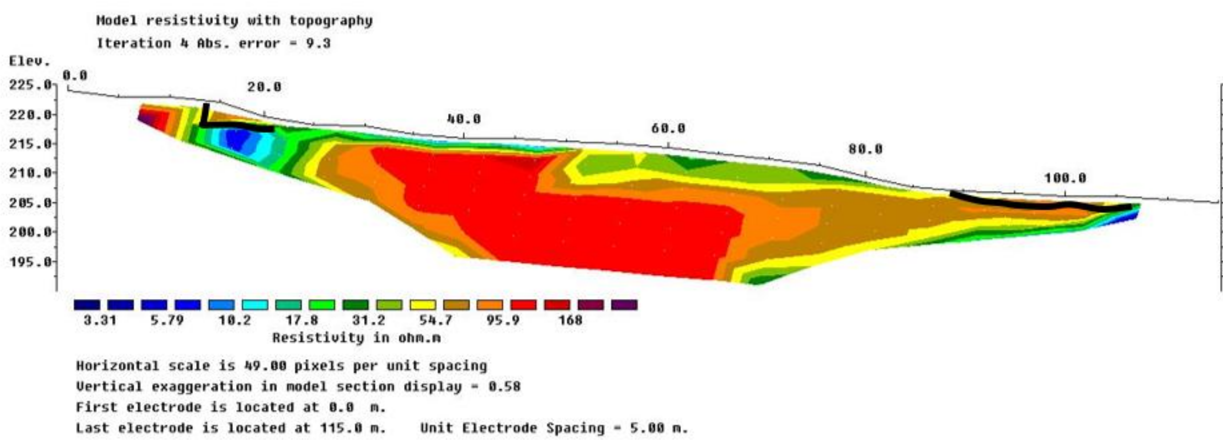

Figure 8. Resistivity cross section on line 3

The location of line 3 is at coordinates (8∘51'37.1 "S 116∘09'20.3 "E - 8∘51'27.3 "S 116∘09'22.2 "E). The rock formation on this line is the Kalibabak Formation which consists of breccia and lava rocks. The length of this line is 115 meters with a spacing of 5 meters per electrode. Based on the picture, the constituent rocks of this track in position (1 - 20) meters, namely (54.8 - 168) Ωm are rocks that are suspected of being breccia rocks on the surface as well as in position (26 - 105) meters on the surface and at a depth of 1.25 meters, according to the formation in the geological data of the area, namely the Kalibabak formation. The rock resistivity at positions (15 - 22) meters and (30 - 50) meters on the surface is (3.31 - 10.2) Ωm, which is a rock suspected of being sandstone at a depth of 2.57 meters. The rock resistivity at position (1 - 115) meters is (10.3 - 54.7) Ωm which is suspected to be clay rock with a depth of 3 meters, this clay rock can cause landslides.

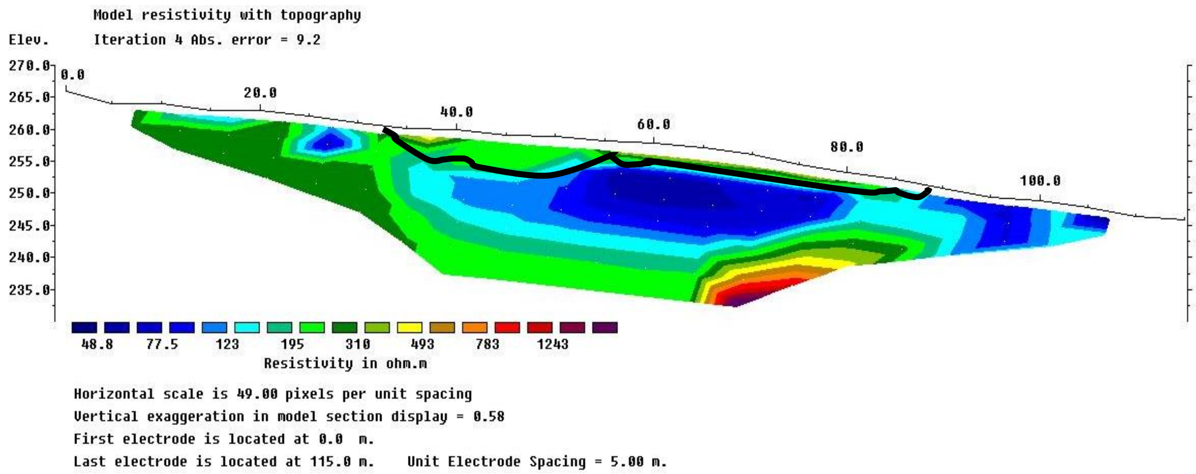

Figure 9. Resistivity cross section on line 4

The location of line 4 is at coordinates (8◦51'37.5 "S 116◦09'11.6 "E - 8◦51'47.5 "S 116◦09'15.9 "E). The rock formation on this line is the Kalibabak Formation, consisting of breccia and lava rocks. The length of this line is 115 meters with a spacing of 5 meters per electrode. Based on the picture, the constituent rocks of this line at position (1 - 90) meters are (195 - 1243) Ωm which is suspected of breccia and lava rocks on the surface, according to the formation in this area, namely the Kalibabak formation. Rock resistivity at position (13 - 110) meters is (48.8 - 77.5) Ωm, which is suspected to be sandstone with a depth of 4 meters. The rock resistivity of (77.6 - 194) Ωm is suspected to be clay and silt at position (8 - 110) meters with a depth of 5 meters, and on the surface, this silt rock can cause landslides.

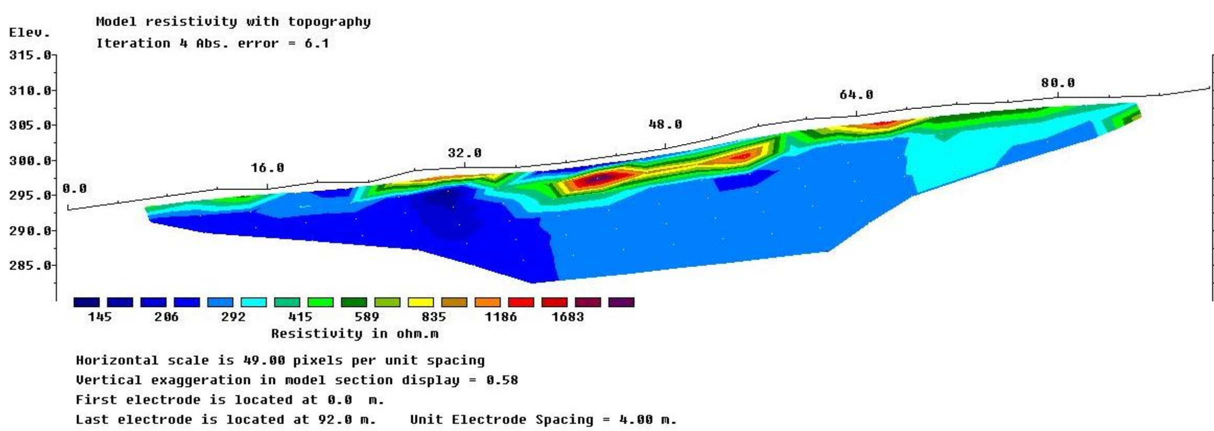

Figure 10. Resistivity cross section on line 5

The location of line 5 is at coordinates (8◦51'25.6"S 116◦09'06.3" E - 8◦51'18.1"S 116◦09'04.4"E). The rock formation in this line is the Kalibabak Formation, which consists of breccia and lava rocks. This line is 92 meters long with 4 meters per electrode spacing. Based on the picture, the constituent rocks of this line at positions (23 - 56) meters on the surface and (59 - 69) meters on the surface are (590 - 1683) Ωm, which is suspected to be limestone, just like the geological rock formation in this area, namely the Kalibabak formation which consists of breccia and lava. Rock resistivity at position (24 - 92) meters is (207 - 589) Ωm, suspected to be lava rock with a depth of 5.42 meters on the surface. Rock resistivity at position (1 - 92) meters is (145 - 206) Ωm, which is suspected to be sandstone with a depth of 3.2 meters.

Clay is a material with impermeable properties, which is difficult for water to penetrate, and when wet, its surface becomes slippery. If the layer above it becomes heavy because it is saturated with water, the possibility of landslides becomes greater. Five lines were analyzed, but not all sliding areas or clay material were found, namely line 5. Meanwhile, clay layers were found at 3 to 5 meters deep on the other four lines. Routes 2 and 3 have the shallowest sliding surface, so they have the most significant risk of landslides.

Conclusion

The research that has been done to detect and identify the sliding field is by knowing the type of rock and the depth of the sliding field in the research area, based on the resistivity value of the rocks in the research area, namely sandstone, clay, silt, limestone, breccia, and lava. In contrast, the depth of the sliding field is (3 - 5) meters.

For the government or stakeholders, information about sliding planes can be used to regulate land use. It can be terraced in areas with a slope of more than 5o. The community should not build or be in slippery areas, especially during heavy rains.

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