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Investigation Of Subsurface Structure In Landslide-Prone Areas Of Jember, East Java, Indonesia Using 2D Resistivity Method

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Abstrak:
Kemuning Lor Village located in Arjasa Sub-district, Jember Regency, is one of the landslide-prone areas due to hilly topography and high rainfall intensity. This research aims to identify the subsurface structure as well as the presence of sliding field by using 2D resistivity geoelectric method of Wenner-Schlumberger configuration. Measurements were carried out in three passes with a length of 120 meters each, with seven variations of n value and electrode spacing of 5, 10, 15, 20, 25, 30, and 35 meters. The data was processed using Res2Dinv software to produce 2D resistivity cross sections. The inversion results show resistivity values ranging from 4.35 to 542 Ωm. The depth obtained reached 15.6 meters. The first line shows the potential for a slip Area at a depth of 3.38 to 15.6 meters. This is indicated by the resistivity contrast between the clay layer and the underlying impermeable rock. Meanwhile, no slip Area were found in the second and third passes. The second line is dominated by a clay layer with low resistivity, indicating the potential for high slope instability. The 2D resistivity geoelectric method with the Wenner-Schlumberger configuration is effective in identifying potential slip area in Kemuning Lor Village. Although only one line shows the greatest possibility of a sliding area, the presence of clay layers that dominate the other line indicates the risk of landslides at the study site.
Kata kunci: *Slip Surface, Landslide-Prone Area, Clay, Resistivity Method.*

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I. Introduction

Environmental protection and maintenance is an important obligation to maintain the ecosystem and prevent natural disasters. One disaster that often occurs due to environmental damage is landslides. Illegal logging can eliminate soil-retaining roots, increasing the risk of landslides. Landslide is a geological event due to slope imbalance, which causes the mass of soil as the material forming the slope to move down by the force of gravity. This movement occurs when the dominant driving force is greater than the restraining force [1]. One of the main factors causing landslides is the slip area. A slip area is a slippery and impermeable layer that becomes the foundation for the movement of soil mass. A slip area is formed between layers of soil or rock with different permeability. One of the landslide-prone areas that has a hilly topography with high rainfall is Kemuning Lor Village. The village is located at an altitude of ±500 meters above sea level with steep hilly land conditions and is used for agriculture and settlements. Disaster prevention and mitigation are needed to detect underground conditions and lithology so that the depth of the sliding plane can be predicted. The 2D resistivity geoelectric method is one of the geophysical methods used to identify slip planes by conducting electric current through electrodes embedded in the ground surface [2].

The 2D resistivity geoelectric method can be used to study the subsurface conditions of the earth, based on differences in rock resistivity [3]. The 2D resistivity geoelectric method is classified as an active geophysical method, where the measuring parameter is based on the potential difference value that occurs when an electric current flows through the rock (Figure 1).

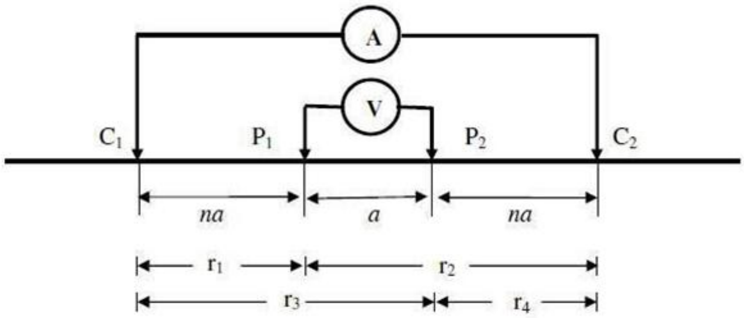

Figure 1. Geoelectric Method Electrode Arrangement

The basic principle of the resistivity geoelectric method is Ohm's Law, which states that voltage (V) is proportional to electric current (I) with resistance (R) as a constant, namely;

$$V = I \, . \, R \qquad (1)$$

When viewed from a cylindrical cross section with length L (m), cross-sectional area A (m2) , and resistivity (m), the resistance R can be formulated as:

$$R = \rho \frac{L}{A} \qquad (2)$$

In field measurements, the apparent resistivity value depends on the resistivity of the rock layers being measured and the electrode configuration used. Rocks that act as conductors of electric current are assumed to be homogeneous and isotropic [4]. The relationship between potensial difference and resistivity can be written as follows;

$$\rho = 2\pi \frac{\Delta V}{I} \frac{1}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)} = K \frac{\Delta V}{I} \qquad (3)$$

$$K = \frac{2\pi}{\left[\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right]} \qquad (4)$$

Equation (3) is the apparent resistivity value obtained from field measurements. Apparent Resistivity is the average resistivity value of the formation through which the electric current passes. The actual resistivity value can be obtained using Res2Dinv software, which can be used to analyze geoelectric data results from field measurements [5].

Table 1 : Rock Resistivity Values [6]

Rock Type	Resistivity (Ωm)
Groundwater	0,5 – 300
Clay	1 – 100
Sandstone	20 – 200
Sand	1 – 1000
Gravel	100 – 600
Andesite	170 – 450000
Granite	200 – 100000

Table 1 is a rock resistivity value that can be used to help the data interpretation process. Several studies related to the identification of sliding planes have been conducted, including by Maharani *et al*., (2018) [7], finding a sliding plane at a depth of 3-10 m with a resistivity value of 35 – 98 Ωm in the form of a clay layer. Pambudi *et al*., (2022) [8], identified a layer of clay sand and tuff with a resistivity of 1-95.6 Ωm at a depth of 4.5 – 18 m. Meanwhile, Tambanaung *et al*., (2024) [9], found a sliding field in the form of clay at a depth of 2 – 24.9 m with a resistivity value of 1.4 – 39.6 Ωm.

This research aims to identify the subsurface structure in order to determine the existence of a slip area in a landslide-prone area using 2D resistivity geoelectric method of Wenner-Schlumberger configuration, in Kemuning Lor Village area. The results of the study are expected to provide information about the potential of landslides to help the local community to always be aware of the dangers caused by landslides. menemukan bidang gelincir berupa lempung di kedalaman 2 – 24,9 m dengan nilai resistivitas 1,4 – 39,6 Ωm.

II. Material And Methods

This research aims to determine the subsurface structure and identify the sliding plane that causes landslides using 2D Resistivity Geoelectric Method. The research is located in Kemuning Lor Village, Arjasa, Jember Regency. There were 3 lines used, with the length of each line of 120 meters stretching from south to north. Each line uses a spacing between electrodes of 5 meters with a value of n = 1, 2, 3, 4, 5, 6, 7. The research line is shown in Figure 2;

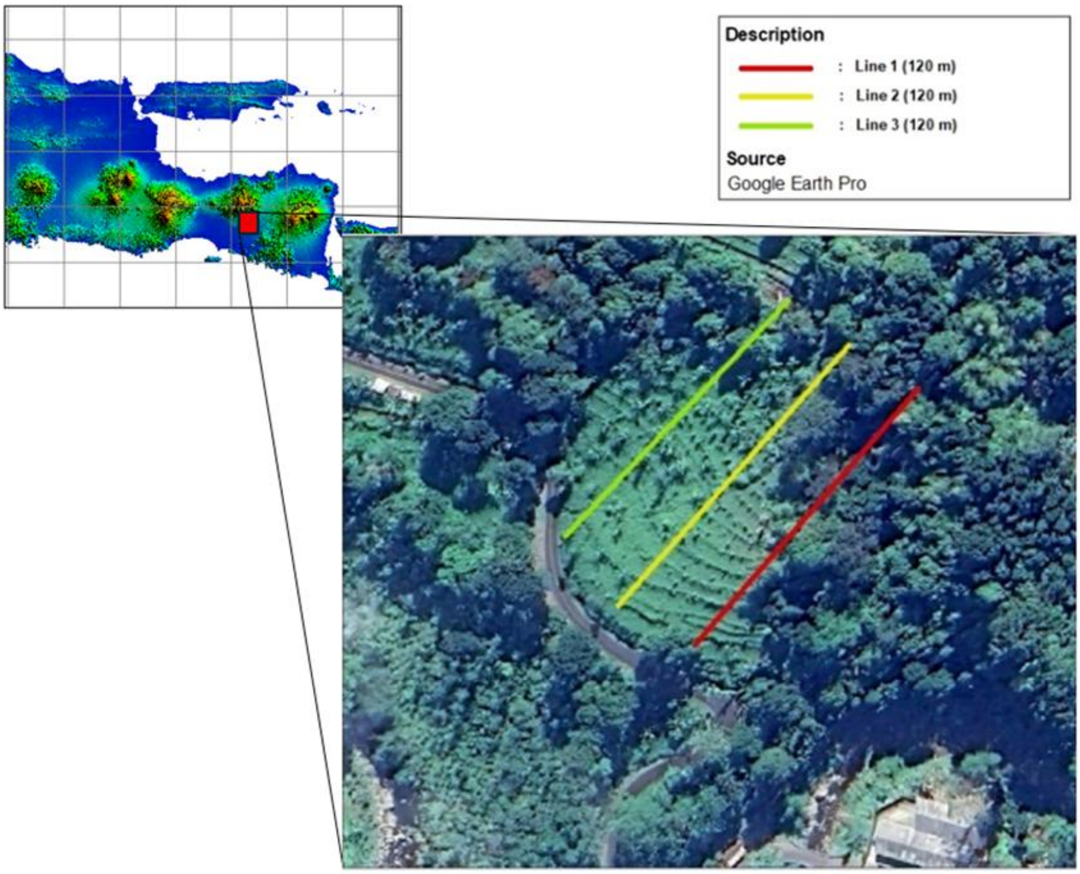

Figure 2. Map of data acquisition location in Kemuning Lor Village, Arjasa, Jember.

The data is processed using Res2Dinv software in the form of datum point values, spacing values (a) and values (n) used on each line and apparent resistivity values. The results were then analyzed and adjusted to the resistivity values in Table 1.

III. Result

Measurement Result of Line 1

The first line stretches 120 meters from south to north at coordinates 113°41'21.88" East to 113°41'23.88" East and 8°5'0.63" N to 8°4'57.26" N.E. Measurements were made using the wenner-schlumberger configuration with n variations of 7 times, using electrode spacings of 5, 10, 15, 20, 25, 30 and 35 meters. The number of electrodes used was 25 and 112 data were obtained. The starting point of the first line is at an altitude of 517 meters above sea level and the end point is at an altitude of 555.3 meters above sea level.

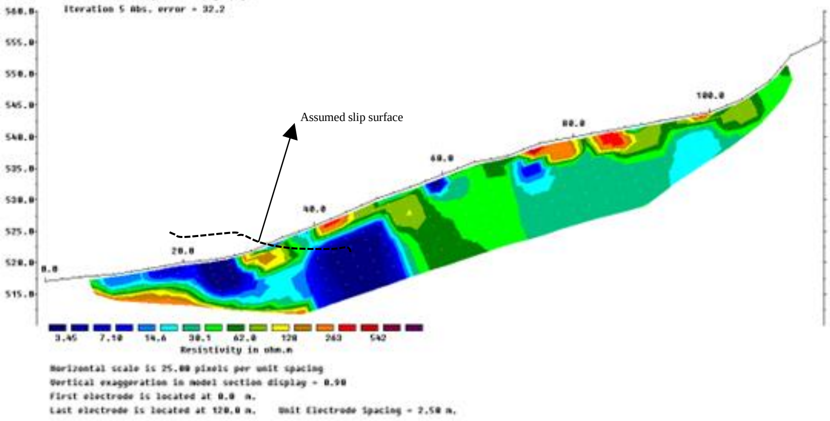

Figure 3. Inversion Result Resistivity Cross Section

The 2D resistivity cross section of the inversion results shows layers with a variety of color contours that represent the resistivity value of rock or soil. In this first pass, the RMS error value as a comparison between the actual resistivity and the measured resistivity. The error on the first line of this inversion result is 32.2%. The resistivity value on this first line ranges from 4.35 Ωm to 542 Ωm, with a maximum depth of 15.6 meters. Based on the interpretation and reference resistivity values in Table 1, the subsurface layer consists of clay, sand, sandstone, and andesite rock. The inversion results interpret three types of clay layers (Table 2).

Table 2 : Classification of Resistivity Values of Line 1

Layer Type	Resistivity (Ωm)	Color
Silt loam and damb silt loam	3.45 – 14.6	
Passive silt soil (saturated gravelly sand)	30.1 – 128	
Rocky loam (dry gravelly sand)	263 – 542	

The distribution of resistivity values in the first pass shows a layer with a low resistivity value (3.45 – 14.6 Ωm) at a depth of 0.625 – 15.6 meters which is spread almost thoroughly along the line, namely at point 7.5 – 100 meters. In addition, there are also layers with identical low resistivity values (30.1 – 62 Ωm) and layers with high resistivity values (263 – 542 Ωm), which are indicated as sandstone and andesite rocks. The layer with high resistivity value (542 Ωm), which is suspected as andesite rock, was found at a depth of 0.625 – 3.85 meters around point 72.5 – 75 meters. This rock is formed from the cooling process of magma and the presence of volcanic activity [10].

The interpretation of the 2D resistivity cross section also shows the alleged existence of a sliding plane, which is marked by a resistivity contrast line between two layers, at a depth of 3.38 – 15.6 meters. This is in accordance with the opinion of Gawing *et al*., (2022) [11], that the resistivity contrast between impermeable layers (high resistivity) and soft layers (low resistivity) can indicate the presence of a sliding plane. In this trajectory, the slip plane is expected to be in the clay layer, which is known to have cohesive properties, high porosity, and low permeability. Clay also tends to expand and contract due to changes in moisture content, making it a layer that is susceptible to ground mass movement [12].

Measurement Result of Line 2

The second line runs 120 meters from south to north at coordinates 113°41'22.26" East to 113°41'24.29" East and 8°5'0.96" N-S to 8°4'57.61" N-S. Measurements were made using the wenner-schlumberger configuration with n variations of 7 times, using electrode spacings of 5, 10, 15, 20, 25, 30 and 35 meters. The number of electrodes used was 25 and obtained data as much as 112 data. The starting point of the second line is at an altitude of 516.3 meters above sea level and the end point is at an altitude of 553.7 meters above sea level.

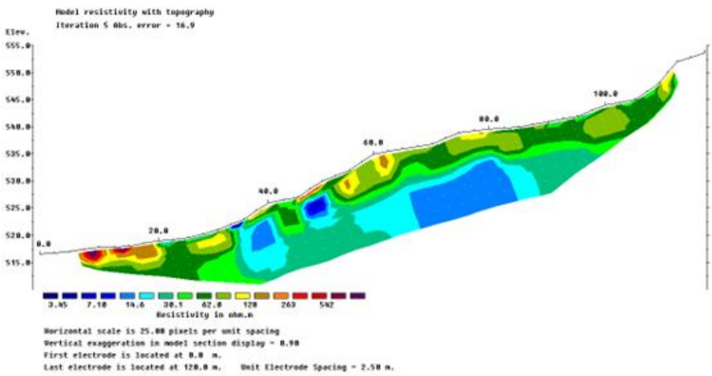

Figure 4. Inversion Result Resistivity Cross Section

2D resistivity cross section of inversion results using Res2Dinv software shows layers with variations in color contours that represent the resistivity value of rock or soil. In this second line, the RMS error value is obtained as a comparison between the actual resistivity and the measured resistivity. The error on the second line of the inversion results is 16.9%. The resistivity value on this second line ranges from 4.35 Ωm to 542 Ωm, with a maximum depth of 15.6 meters. Based on the interpretation and reference resistivity values in Table 1, the subsurface layer consists of various rock types, such as clay, sand, sandstone, and andesite rock. The inversion results interpret the presence of 3 types of soil layers (Table 3).

Table 3 : Classification of Resistivity Values of Line 2

Layer Type	Resistivity (Ωm)	Color
Silt loam and damb silt loam	3.45 – 14.6	
Passive silt soil (saturated gravelly sand)	30.1 – 128	
Rocky loam (dry gravelly sand)	263 – 542	

The distribution of resistivity values in the second pass shows a layer with a low resistivity value (3.45 - 14.6 Ωm) at a depth of 0.625 – 15.6 meters spread from point 32.5 – 80 meters. In addition, a layer with an identical low resistivity value (30.1 – 62 Ωm) was also found laterally scattered along the line, at a depth of 0.625 – 13.1 meters. A layer with a resistivity value of about 263 Ωm, which is indicated as sandstone, is at a depth of 0.625 – 3.38 meters scattered around points 6.25 – 20 meters and points 45 – 50 meters. In addition, a layer with a high resistivity value (542 Ωm) was found at a depth of 0.625 – 3.85 meters around points 7.5 – 15 meters, which is thought to be a type of andesite rock.

Interpretation of the 2D resistivity cross section in the second line, no indication of a sliding plane was found. However, this line is dominated by a layer of clay with resistivity values ranging from 3.45 – 62.0 Ωm, which is spread almost thoroughly along the line at a depth of 0.625 – 15.6 meters, which is marked by dark to green colored images. Clay soil has the property of being difficult to absorb water, so that when there is continuous high-intensity rain, water will accumulate in the layer. This condition can cause the soil to become water-saturated, reduce shear strength, and increase the potential for landslides. The continuous accumulation of water in the clay layer makes the surface slippery and weakens the soil structure, thus increasing the risk of landslides, especially during the rainy season.

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Measurement Result of Line 3

The third line runs 120 meters from south to north at coordinates 113°41'22.76" East to 113°41'24.81" East and 8°5'1.26" N-S to 8°4'57.89" N-S. Measurements were made using the wenner-schlumberger configuration with n variations of 7 times, using electrode spacings of 5, 10, 15, 20, 25, 30 and 35 meters. The number of electrodes used was 25 and obtained 112 data. The starting point of the third line is at an altitude of 515 meters above sea level and the end point is at an altitude of 553.1 meters above sea level.

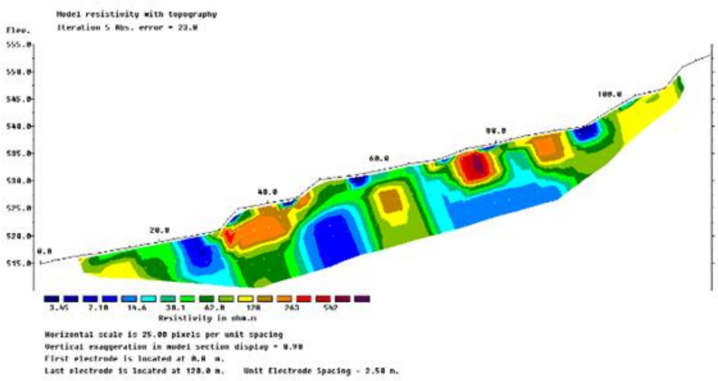

Figure 5. Inversion Result Resistivity Cross Section

2D resistivity cross section of inversion results using Res2Dinv software shows layers with variations in color contours that represent the resistivity value of rock or soil. The error in the third pass of this inversion result is 23.8%. The resistivity value on this third line ranges from 4.35 Ωm to 542 Ωm, with a maximum depth of 15.6 meters. Based on the interpretation and reference of resistivity values in Table 1, the subsurface layer consists of various types of rocks, such as clay, sand, sandstone, and andesite rocks. The inversion results interpret three types of clay layers (Table 4).

Table 4 : Classification of Resistivity Values of Line 3

Layer Type	Resistivity (Ωm)	Color
Silt loam and damb silt loam	3.45 – 14.6	
Passive silt soil (saturated gravelly sand)	30.1 – 128	
Rocky loam (dry gravelly sand)	263 – 542	

The distribution of resistivity values in the third pass shows a layer with a low resistivity value (3.45 – 14.6 Ωm) found at a depth of 0.625 – 15.6 meters, spread from point 22.5 – 97.5 meters. Other layers with resistivity values (30.1 – 62 Ωm) were also found that were spread laterally along the line at the same depth. At a depth of 0.625 – 6.72 meters, a layer with a resistivity value of 263 Ωm was found, which is suspected to be sandstone. This layer is scattered at several points, starting from points 30 – 45 meters, 72.5 – 77.5 meters and 85 – 90 meters. Sandstone is a sedimentary rock consisting of sand-sized mineral grains, which are generally brown, yellow, gray and black in color [13]. In addition, a layer with a high resistivity value (542 Ωm), found at points 75 – 77.5 meters at a depth of 0.625 – 3.85 meters, is thought to be a type of andesite rock, marked by a purple image on the 2D cross section.

Interpretation of the 2D resistivity cross section on the third line, no indication of a sliding plane was found. However, a low resistivity value indicated as a clay layer dominates this trajectory and indicates potential slope instability. This layer is scattered at a depth of 0.625 – 15.6 meters, which is indicated by the dark blue to green image. Clay soils have high porosity and low permeability, which allows the formation of pore pressure in the soil to easily pass water. This pore pressure can reduce soil shear strength and trigger soil mass movement, especially on steep slopes.

IV. Conclusion

Based on the 2D resistivity cross-section generated from the geoelectric measurements on the three lines, the first line shows the greatest possibility of a sliding plane located at a depth of 3.38 – 15.6 meters and is suspected to be a clay layer under a layer of impermeable rock. Meanwhile, the second and third passes did not find the existence of a sliding plane, but were dominated by a layer of clay that has low resistivity and is widely spread to a depth of 15.6 meters. Loamy soils with high porosity and low permeability tend to retain water, potentially reducing shear strength and causing landslides, especially on steep slopes. Although slip areas were not clearly identified in all passes, the dominance of clay soils remains a key indicator of potential slope instability. These results can be used as a basis for consideration in disaster mitigation and spatial planning in landslide prone areas.

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