Research article

Identification of Subsurface Materials in Landslide-Susceptible Areas in the Pacet-Trawas Road Corridor Using the Geoelectrical Resistivity Method

I H Pradana, L Y Irawan*, D Panoto, and A C Darmansyah

Department of Geography, Universitas Negeri Malang, East Java, Indonesia

Abstract.
Landslides are caused by changes in the structure of subsurface materials on steep slopes due to weathered rock conditions and soil pores in saturated conditions. This study used the geoelectric resistivity method to identify the type and structure of subsurface materials in landslide-susceptible areas in the Pacet-Trawas road corridor, in Pacet District, Mojokerto Regency. The research location was an area with undulating to mountainous morphology. The geoelectrical resistivity configuration used was dipole-dipole with a measuring path length of 100 meters at three measurement points. The measurement location was based on geological formations and the distribution of landslide points along the Pacet-Trawas road corridor. The three 2D models produced showed resistivity values between 8.11 Ohm.m to 390 Ohm.m. The subsurface materials consisted of groundwater, volcanic breccia, lava rock, tuffaceous breccia, conglomerate, and andesite-basaltic at a depth of 1.5 meters to 25 meters below the ground surface. The research area was dominated by the parent rock structure of lava, volcanic breccia, basalt, and andesite. Locations with a high landslide threat were located at points two and three with subsurface materials of the conglomerate type and volcanic breccia.

Keywords: geoelectrical resistivity, dipole-dipole, subsurface material

Corresponding Author: L Y Irawan; email: EMAIL

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1. Introduction

The total incidence of landslides in Indonesia in the last 10 years is 6.822 events [1]. One of the provinces on the island of Java that often experiences landslides is East Java. The history of landslides in East Java from 2011 to 2020 was 707 incidents, causing 89 fatalities and 105 injuries. One of the areas in East Java that often experiences landslides is Pacet District, Mojokerto Regency. The occurrence of landslides in Pacet District was recorded 45 times from 2015 to 2020 [2]. Locations in Pacet District which are susceptible to landslides are along the Pacet-Trawas Road corridor which is also the location coverage in this study.

This transportation route is vital because it connects two sub-districts in Mojokerto Regency, namely Pacet District and Trawas District. The occurrence of landslides in the study area is caused by the varied morphological conditions and geological characteristics of the study area [3]. The morphology of the research area is dominated by hills and mountains with undulating to mountainous relief [4][5]. Slope conditions are mostly steep to very steep with an average slope angle of more than 30° [4].

The subsurface geological characteristics of the research area are located in the Welirang Volcano Quaternary rock formation. The geological process of Welirang Volcano occurred during the late Pleistocene to the present [6][7]. This is indicated by the presence of volcanic breccia, lava, breccia, conglomerate, and tuff rocks of Quaternary age that have undergone weathering. Weathered rock conditions if they are on a steep slope have a high threat of landslides [8][9][10].

Figure 1: Landslide on Pacet-Trawas Road Corridor, Pacet District (Coordinate 6703980 mE, 9151868 mN) .

One of the geophysical methods used for estimating the subsurface conditions of the earth in landslide-susceptible areas based on the electrical properties of the rocks that make up the earth is geoelectrical method [11]. The purpose of geoelectrical resistivity is to determine the condition or state of the subsurface geology by using the rock type resistivity value. This research uses a geoelectrical resistivity dipole-dipole configuration method.

Dipole–dipole configuration is a resistivity method that aims for 2D horizontal surveys. The dipole-dipole configuration has the ability to read subsurface conditions with good sensitivity both vertically and horizontally [11]. Applying four electrodes consisting of two current electrodes and 2 two potential electrodes with the same spacing pattern on each electrode along the measurement path.

The application of the dipole-dipole configuration geoelectric method in this study aims to estimate the structure of the subsurface material laterally and horizontally (mapping) in landslide-susceptible areas along the Pacet-Trawas corridor [12][13][14]. This method was chosen because it is effective in determining slope stability, investigation of landslide slip fields, soil types and estimating types and subsurface lithological structures based on resistivity values [15][16][17][18]. The results of the interpretation of the subsurface material structure are visualized in 2D (dimensional) form.

2. Method

The location of this research was determined based on the Area of Interest (AOI) which was adjusted along the Pacet-Trawas corridor, Pacet District, Mojokerto Regency. The length of each geoelectric measurement trajectory is 100 meters at 3 (three) measurement points. The distance between the measurements between the electrodes (a) used is 10 meters at the current electrode (C) and 10 meters at the potential electrode (P). The current electrode and the inner potential electrode are separated by a distance *na*. The following is the arrangement of the dipole-dipole configuration electrodes used in this study.

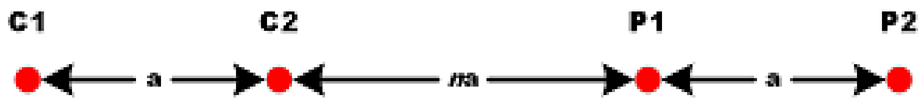

Figure 2: Dipole-Dipole Configuration Electrode Arrangement.

The determination of the geoelectric survey trajectory of the dipole-dipole configuration is determined based on the geological formation of the research area. In addition, the selection of geoelectrical measurement locations is based on locations adjacent to the point of landslide occurrence that occurred along the Pacet-Trawas corridor, Pacet District, Mojokerto Regency. Geoelectrical data processing is interpreted and visualized using the RES2DINVx64 software. The results of the geoelectrical data visualization are displayed in the form of a 2-Dimensional cross section.

The visualization results were matched using Geological Maps Sheets Malang and Kediri Scale 1:100.000 made by the Center for Geological Research and Development,

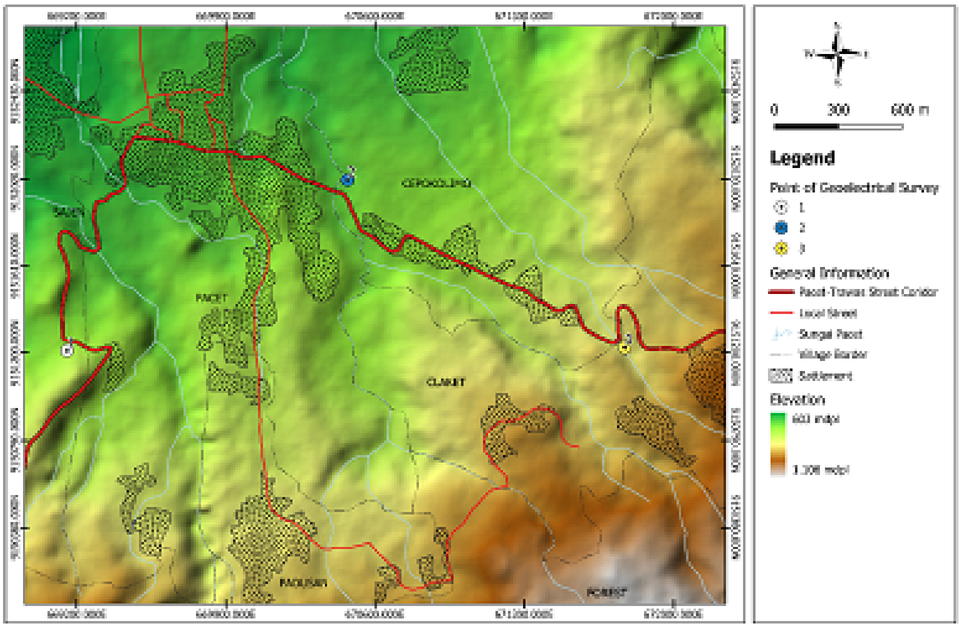

Figure 3: Point of Geoelectrical Survey Distribution Map at the Research Site.

1992 based on the distribution of resistivity values to determine lithology and soil types based on geological formations in the research area. Determination of the type of material based on its resistivity value based on the table of resistivity values for minerals, igneous rocks, metamorphic rocks, and sedimentary rocks [12]. These results are expected to be able to describe the appearance of subsurface material conditions such as soil types and lithology types in landslide-susceptible areas in the research area.

3. Result and Discussion

The analysis of the resistivity value of the geoelectrical measurement of the dipole-dipole configuration was interpreted based on the Geological Map of Sheets Malang and Kediri with a scale of 1:100,000. The geological conditions of the research area are located in 2 (two) geological formations, namely: 1) Young Anjasmara Volcanics with code Qpva and 2) Arjuna-Welirang Volcanics with code Qvaw. The materials contained in the three geological formations are detailed in the following table:

Based on (Table 1) above, the geological formation research area is dominated by the volcanic activity of the Welirang Volcano and Anjasmara Muda Mountains. The regional stratigraphy of the two geological formations in the study area is composed of rocks originating from Anjasmara Volcano in the Early Pleistocene, Ringgit-Pundak-Butak Volcano in the Middle Pleistocene, Arjuna-Welirang-Kembar Volcanoes 1 and 2 in

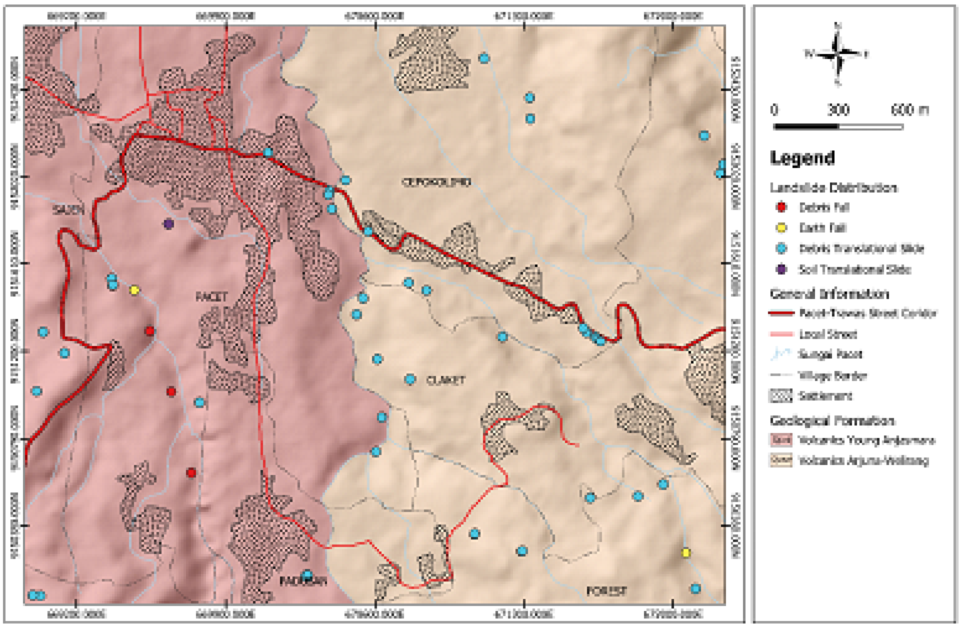

Figure 4: Geological Formation and Distribution of Landslide Points Map at the Research Site.

TABLE 1: Geological Formation of Research Area.

Geological codes	Geological Formation	Material Description
Qpva	Young Anjasmara Volcanics	Volcanic breccia, tuff lava, and lahars
Qvaw	Arjuna-Welirang Volcanics	Volcanic breccia, lava, tuffaceous breccia, and tuff

Source: Center for Geological Research and Development

the Late Pleistocene, and Penanggungan Volcano in the Middle Pleistocene. Holocene [20,21]. Both geological formations have volcanic rocks with intermediate to mafic types. The dominant rocks in this type are basaltic andesite, volcanic breccia, and basalt [21].

There are 4 (four) types of landslides that occur in the research location, the four types of landslides are: 1) Debris fall; 2) Earth fall; 3) Debris translational slide; and 4) Soil translational slide. The type of landslide that dominates is the debris translational slide with the number of landslide points as many as 43 events. The number of debris fall landslide types is 3 events, earth fall landslide types are 2 events, and the number of soil translational slide landslide types is 1 event. Most of the fall landslides occur in areas with steep to upright slopes with the constituent materials in the form of soil and rock [22-26]. Meanwhile, the slide type with the type of translational movement mostly occurs on slopes with the plane of the slide parallel to the slope surface. The material in the slide type consists of debris, residual soil and rocks [22,24-26]. The subsurface material can be identified through the visualization of a 2-dimensional cross-section of the dipole-dipole configuration geoelectric method that was carried out in this study.

3.1. The First 2D Cross Section

In geoelectrical measurements on the first track, the 0 meter point is located at 669154 mE, 9151211mN coordinates, while the 100 meter point is located at 669110 mE, 9151135mN coordinates. The land use at the first geoelectric point is in the form of production plantation forest. The results of the geoelectrical measurement analysis of the dipole-dipole configuration at the first measurement point show the resistivity value of the subsurface material ranging from 8.11 Ohm.m to 146 Ohm.m. The maximum depth of rock layers that can be interpreted in the first geoelectrical measurement is 25 meters from the ground surface.

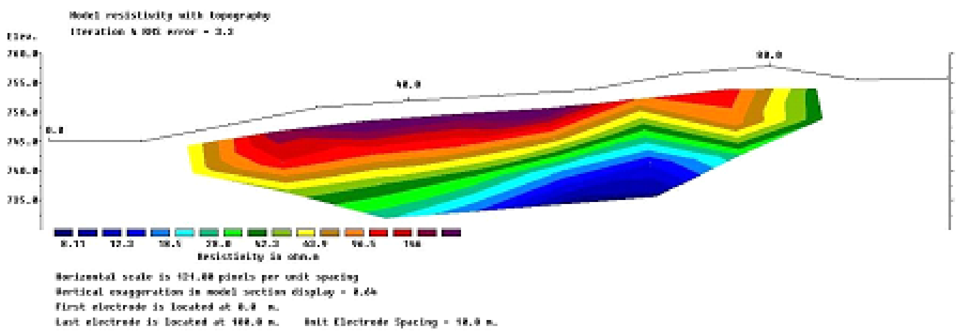

Figure 5: Results of the 2D Cross-section of the First Location of Geoelectrical Measurement.

Interpretation of 2 Dimensional cross-section geoelectrical resistivity measurements of the dipole-dipole configuration in (Figure 5) resistivity values of 8.11 Ohm.m to 18.5 Ohm.m are suspected to be groundwater aquifer layers. Groundwater aquifers are located at a depth of 10 to 25 meters from the ground surface. The resistivity value of the material from 28.0 Ohm.m to 63.9 Ohm.m is suspected to have the type of material in the form of basaltic andesite. This new type of basaltic andesite was identified at a depth of 5 to 20 meters from the ground surface. The surface of the 2-dimensional cross-section is suspected to have the type of volcanic breccia material, with a resistivity value of 96.5 Ohm.m to 146 Ohm.m.

3.2. The Second 2D Cross Section

The location of the geoelectric measurement is on the second track, the 0 meter point is located at the 670428 mE, 9151967 mN coordinate, while the 100 meter point is located at the 670469 mE, 9152004 coordinate. Land use at the second geoelectric point is in the form of fields and settlements. The results of the geoelectrical measurement analysis of the dipole-dipole configuration at the second measurement point show the resistivity value of the subsurface material ranging from 61.8 Ohm.m to 266 Ohm.m. The maximum depth of rock layers that can be interpreted in the first geoelectric measurement is 18 meters from the ground surface.

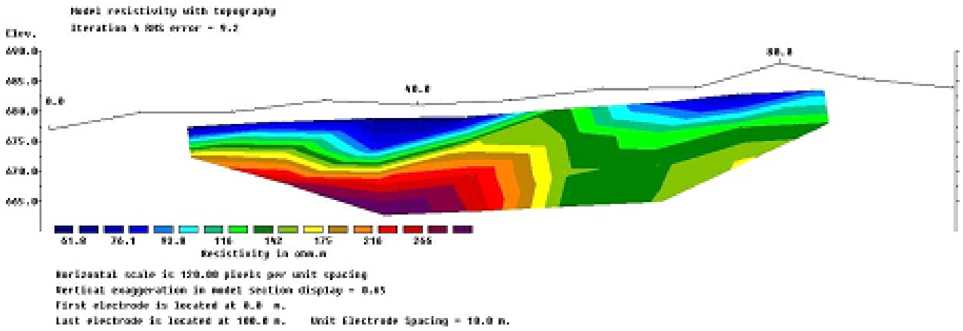

Figure 6: Results of the 2D Cross-section of the Second Location of Geoelectrical Measurement.

The results of the visualization of the 2-dimensional cross-section of the geoelectric resistivity measurement of the dipole-dipole configuration in (Figure 5) the resistivity value of the material from 61.8 Ohm.m to 93.8 Ohm.m is suspected to have the type of material in the form of volcanic breccia rock. The volcanic breccia rock material is a surface material on the second trajectory of geoelectrical measurements. The resistivity value of the material from 116 Ohm.m to 175 Ohm.m can be assumed to be a conglomerate. Meanwhile, the resistivity value of 216 Ohm.m to 266 Ohm.m is suspected to be of the type of lava rock material. Lava rock material was found at a depth of 13 to 18 meters from the ground surface. Lava rock is suspected to be bedrock or source rock at the second location of geoelectric measurements.

Most of the materials that make up the slopes at the location of the second geoelectric measurement have weathered. Weathering that occurs in conglomerate rocks has a type of spheroidal weathering or peeling like onion skin with the condition of the rock core still intact. [28]. The condition of the material making up the slopes that is experiencing weathering greatly affects the instability of the slopes that cause landslides, especially if a slope has a steep slope or more than 30° [8,9].

3.3. The Third 2D Cross Section

Geoelectric measurements on the third track, the 0 meter point is located at the 671772 mE, 9151226 mN coordinate, while the 100 meter point is located at the 671766 mE, 9151232 mN coordinate. The location of the third geoelectric point has land use in the form of forest. The results of the geoelectrical measurement analysis of the dipole-dipole configuration at the third measurement point show the resistivity values of the subsurface material ranging from 77.3 Ohm.m to 390 Ohm.m. The maximum depth of

Figure 7: Spheroidal weathering of conglomerate rocks.

rock layers that can be interpreted in the first geoelectric measurement is 18 meters from the ground surface (Figure 8).

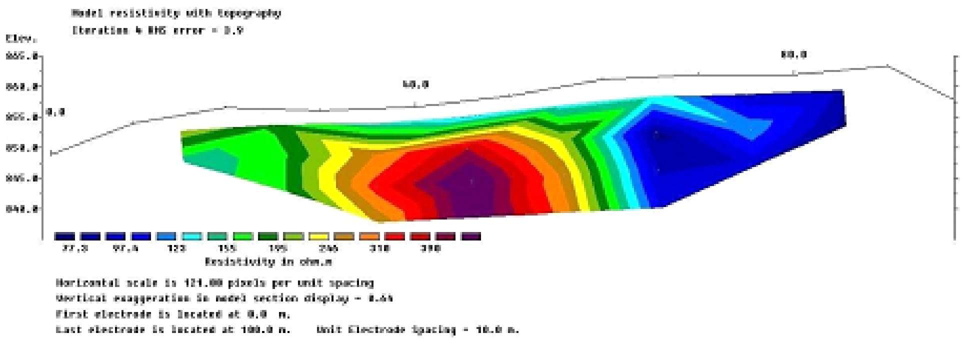

Figure 8: Results of the 2D Cross-section of the Third Location of Geoelectrical Measurement.

The results of the interpretation of the 2-dimensional cross-section of the geoelectric resistivity measurement of the dipole-dipole configuration on the third track, the resistivity value of the material from 77.3 to 123 Ohm.m is suspected to be volcanic breccia rock material. The volcanic breccia material was identified at a depth of 2.5

to 18 meters. Volcanic breccia material is the dominating material at the point of the 60-85-meter trajectory. Meanwhile, the material resistivity values of 155 Ohm.m to 246 Ohm.m can be assumed to have the type of material in the form of andesite-basaltic rock. Resistivity values of 310 Ohm.m to 390 Ohm.m are assumed to be of the type of tuffan breccia rock material. Tuffan breccia rocks are identified at a depth of 8 to 18 meters from the ground surface

4. Conclusion

First measurement point show the resistivity value of the subsurface material ranging from 8.11 Ohm.m to 146 Ohm.m. The interpretation of subsurface material in the first measurement point are groundwater aquifer, basaltic andesite, and volcanic breccia material. The second measurement point show the resistivity value of the subsurface material ranging from 61.8 Ohm.m to 266 Ohm.m. The interpretation of subsurface material in the second measurement point are volcanic breccia rock, conglomerate, and lava rock. The third measurement point show the resistivity values of the subsurface material ranging from 77.3 Ohm.m to 390 Ohm.m. The interpretation of subsurface material in the third measurement point are volcanic breccia rock material, andesite-basaltic rock, and tuffan breccia.

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