The determinant of slip plane and volume potential of landslide mass using resistivity data in Air Kuning Batu Merah, Ambon City

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Abstract. To reduce the risk of landslides and to be aware of areas that have the potential for further landslides, detailed measurements of these zones are required. Measurements were made to identify a sliding plane below the surface using the geoelectric resistivity method of the Wenner-Schlumberger configuration. The resistivity data from the interpretation results are used to determine slip plane’s slope and the potential for landslide masses. The research location is on steep hills in Air Kuning Batu Merah, Ambon City. The results showed that the slope angles for line-1 were 4.20 degrees, line-2 was 17.60 degrees, line-3 ranged from (22.80 - 23.20) degrees, and line-4 was 21.80 degrees. Furthermore, the estimated volume potential of landslide mass based on the cross-section of subsurface resistivity is 3,063.88 m\textsuperscript{3}. With an indication of a landslide field, the slope has the potential for a subsequent landslide if affected by external and internal factors.

1. Introduction
Ambon City is an area that is prone to landslide hazards with the intensity of landslides and floods estimated to have increased from year to year by more than 60\% [1]. The high distribution of landslides and floods in Ambon City is found in the districts of Sirimau, Nusaniwe, and parts of South Leitimur [2, 3]. One area where landslides often occur is Air Kuning, Batu Merah Village, Sirimau District, Ambon City. These landslides occur in several places each year, causing transportation routes to be buried by landslides, damage to houses, and alteration of land cover forms. It is suspected that weathering rocks are above watertight rocks on slopes or hills with moderate to steep slopes, and the slopes are in an unstable state so that the potential for landslides to occur when the arrival of the high intensity rainy season comes. They can also do damage to industry and the environment [4, 5]. Landslides can be the result of modifications to nature by human activities [6], and contribute significantly to the evolution of landforms [7]. The size of potential damage depends on the nature of the landslide itself [8, 9].

The onset of landslides begins with cracks on the slope surface. Cracks on the slope surface occur in a long dry season, which will cause a large amount of water evaporation on the soil surface. Pores or soil cavities appear, then cracks and cracks occur on the surface. When it rains, water will infiltrate the crack. The Soil quickly expanded again. At the start of the rainy season, the soil’s water content
becomes saturated in a short time. As a preventive measure for the occurrence of subsequent landslides, it is necessary to map the subsurface geology in areas prone to landslides. One indication that an area has the potential for landslides is the formation of a slip plane. A sliding plane is caused by differences between a layer and the overburden layer underneath [9, 10]. There may be a slip plane because there are different layers between the cover layer and the layer underneath it. The top layer of a slope is usually the soil layer that escapes water so that rainwater can easily infiltrate into the slope. This slippery rock layer will act as an area where the weathering material above it moves out of the slope. Material moving over this slippery plane is called a landslide material. The slippery plane is where the landslide material moves are called the slip plane. The identification of the slip plane can be interpreted from the resistivity section of the rock. The sliding plane interpretation results can be used to calculate the prediction of the potential mass volume of landslides on the slope of the studied slip plane.

2. Method
A geoelectric resistivity survey was conducted to identify the subsurface slip plane in the landslide area.

2.1. Study area
The field data collection survey was carried out in Batu Merah Village, Sirimau Subdistrict, Ambon City in the landslide area at RT.003 / RW.19 Air Kuning and geographically located at coordinates 3°40’56.45” South Latitude and 128°12’49.77” East Longitude with an altitude of (120.0 - 134.0) meters above sea level (masl) (Figure 1). Geologically, the research area is composed of the Ambon Volcano Formation, and this rock unit consists of volcanic lava, tuff and tuff breccias [3, 11].

![Figure 1. The location of the research](image)

2.2. Data acquisition
Prepare a stacking chart (Figure 2) according to the area of the study area. After the path and point of observation are determined in the study area, field data measurements are then carried out. Field resistivity data were measured using the Wenner-Schlumberger configuration. Measurement paths are set based on local geological information such as the emergence of vein outcrops or zones of alteration (prospecting stages). The landslide area is estimated to be (150x100) m² so that it can be divided into four measurement lines. The length of the measurement path is adjusted to the survey location, and according to the required geological information targets. Data from field measurements are electric current (I), potential difference (∆V), and the distance between the electrodes.
2.3. Field data processing

The data processing steps are carried out based on field measurements of the resistivity geoelectric survey results such as:

- Field measurement data in the form of electric current ($I$), voltage ($\Delta V$), and geometric factor ($K$) are used to calculate the apparent resistivity value ($\rho_a = K \Delta V/I$). Furthermore, Res2Dinv software is used to model 2D cross-sections of the actual resistivity of the rock.

![Stacking geoelectric resistivity chart](image)

Figure 2. Stacking geoelectric resistivity chart (modified from [12])

- The calculation of landslide mass volume can be used through two approaches, namely the landslide event volume model and the landslide mass volume potential from the resistivity inversion [9]. The 2-D resistivity cross-section prediction model is converted into a cone in the shape of a ball representing a 3-D landslide. So, by using landslide geometries such as the length of the landslide surface (which in 3-D will be the diameter of the cover) and the thickness of the landslides ($t$), the prediction of landslide volume during landslides can be calculated using the equation [13, 14]:

$$V_{EL} = \frac{1}{6} \pi t \left(3 \left(\frac{L}{2}\right)^2 + t^2\right)$$

Figure 3. (a) Dimensions of the slip plane, (b) Example of the resistivity cross-section of AMH-3 [6]
- The results of the resistivity inversion at each measurement path at the study site (Figure 3) can be used to determine the volume prediction of the potential mass of landslides.
- Interpretation of the 2-D resistivity contour on each track indicates that the slip plane may move rotational or translational. The prediction of the potential mass volume of landslides is calculated based on the results of geoelectric measurements with the equation [14]:

\[ V_{PL} = \frac{1}{6} \pi (\ell d w) \]  

(2)

where \( \ell \) = length of slip plane (m), \( d \) = maximum depth of slip (m) and \( w \) = width of slip plane (m).
- The measurement of the slip plane parameters is used in Figure 4 then the calculation is carried out at the lower position of the slip plane (A) and the lower position of the slip plane (B) using equation (2).
- The slip plane as illustrated in Figure 4, shows a contrast in the resistivity value. From the concave shape of the slip plane, with this contrast resistivity value is a slip plane with a slope of \( \alpha \). Calculation of the slope of the landslide slide can use the ROI (Region of Interest) magnification according to the dashed red circle line. So the calculation of the slope angle of the slip plane uses the equation:

\[ \alpha = \arctan \left( \frac{y}{x} \right) \]  

(3)

![Figure 4](image-url) **Figure 4.** Example of the slope of the slip plane [3]

### 3. Results and Discussion

After the geoelectric data acquisition is complete, the data obtained from the measurement results are exported to the computer to determine the 2-D resistivity model. Furthermore, this model identifies the subsurface slip plane.

#### 3.1. Line-1 of the Air Kuning study area

The true resistivity cross-sectional modeling of the inversion result at Line-1 was carried out at each electrode distance using logarithmic contour intervals (Figure 5). In general, the resistivity value of the interpretation results ranges from (4.0 - 100.0) \( \Omega \).m. These values are grouped into:
• The low resistivity group with a resistivity value of less than 15.0 Ω.m is thought to contain soil, loam, and sandy loam. This material is generally loose/weathered and porous enough to allow low levels of water to pass.
• The medium resistivity group with a resistivity value (15.0 - 50.0) Ω.m, was thought to contain sand, fine to coarse-grained clay, loam, and gravel. These rocks are found at varying depths and thicknesses. This material is generally loose/weathered and porous enough to allow high levels of water to pass.
• The high resistivity group with a resistivity value greater than 50.0 Ω.m, was thought to contain fine to medium-grained sandy clay rock and compact, hard claystone. These rocks are generally compact and constitute bedrock, as well as caprock and overburden.

![Figure 5](image_url)

**Figure 5.** 2D cross-sectional profile of rock resistivity at Line-1. (a) Without topography, and (b) with topography

In Line-1, it can be interpreted that there is a slip plane along 17.0 m from the position x = 28.0 m and has a depth of 2.6 m from the ground. The results of the identification of the resistivity cross section are interpreted as having a slip plane. The interpretation of the slip plane is based on the characteristics of the resistivity contrast of rocks. The type of rocks who would be a slip surface is a Clay [10, 12, 15] with resistivity values were (45.4 - 174.0) Ω.m [12, 16-17]. Sliding surface is the presence of a layer with low resistivity flanked by two layers which have a high resistivity[11]. This resistivity contrast occurs in impermeable rocks (sand or sandy loam) with permeable rocks (bedrock) [2, 9].

3.2. **Line-2 of the Air Kuning study area**

The true resistivity cross-sectional modeling of the inversion result at Pass-2 was carried out at each electrode distance using logarithmic contour intervals. In Figure 6, the interpretation based on the group of rock resistivity configurations is almost the same as that of Line-1. On Line-2, it is interpreted that there is a slip plane having a length of 38.5 m from the position x = 5.5 m from the starting point which is at a depth of 3.6 m from the ground.
Figure 6. 2D cross-sectional profile of rock resistivity at Line-2. (a) Without topography, and (b) with topography

3.3. Line-3 of the Air Kuning study area

Figure 7. 2D cross-sectional profile of rock resistivity at Line-3. (a) Without topography, and (b) with topography
The true resistivity cross-sectional modeling of the inversion result at Line-3 was carried out at each electrode distance using a type of contour distance in the form of logarithmic contour intervals (Figure 7). In general, the resistivity value of the interpretation results ranges from (5.0 - 200.0) Ω.m. The resistivity and lithology grouping of the rocks is thought to be almost the same as Line-1. The type of rocks who would be a slip surface is a Clay [10, 12, 15] with resistivity values were (45.4 - 174.0) Ω.m [12, 16-17]. On Line-3, the first potential slip plane is found with a length of 19.0 m from the position x = 14.0 m at a depth of 2.52 m from the ground surface, and the potential for the second slip plane has a length of 3.5 m from the position x = 36.0 m at a depth of 1.27 m from the ground surface.

3.4. Line-4 of the Air Kuning study area
In Figure 8, the interpretation based on the group of rock resistivity configurations is similar to Line-3. The type of rocks who would be a slip surface is a Clay [10, 12, 15] with resistivity values were (45.4 - 174.0) Ω.m [12, 16-18]. On Line-4, it is interpreted that there is a slip plane having a length of 27.0 m from the position x = 5.0 m from the starting point which is at a depth of 5.74 m from the ground. The results of the identification of the resistivity cross section are interpreted as having a slip plane. The interpretation of the slip plane is based on the characteristics of the resistivity contrast of rocks.

![Figure 8. 2D cross-sectional profile of rock resistivity at Line-4. (a) Without topography, and (b) with topography](image)

3.5 Slope Angle Calculation of Sliding Plane
To calculate the angle of slope of the slip plane from the resistivity section in Line-1 to Line-4. The identified slip plane is concave with an angle of inclination of α. To calculate the angle of inclination on the slip plane, the magnification of the Region of Interest is used which is indicated by a dashed red circle line.

3.5.1. Prediction of the angle of slope of the slip plane on Line-1. Based on Figure 5, it can be used to calculate the slope angle of the slip plane (Figure 9), resulting in:
\[ \alpha_1 = \arctan \left( \frac{0.4}{5.5} \right) = 4.2^\circ \]

So the slope angle of the slip plane on Line-1 (\(\alpha_1\)) is 4.2 degrees. The angle of the slip plane is small because the field resistivity measurement is carried out in the northwest direction (across the landslide plane). With an inclination angle of 4.2 degrees, it can be predicted that, if there is a subsequent landslide, the slip plane zone material is likely to move along the slope towards the southwest, not in the direction of the measuring path. This is because during the acquisition of the field data at Line-1 it did not follow the tracking of the landslide, but rather a cross path was taken.

3.5.2. Prediction of the angle of slope of the slip plane on Line-2. The resistivity section of the rock on Line-2 is estimated to have one slip plane, so the calculation of the predicted slope angle (Figure 10) is:

\[ \alpha_2 = \arctan \left( \frac{5.4}{17.0} \right) = 17.6^\circ \]

By obtaining the slope angle of the slip plane (\(\alpha_2\)) = 17.6 degrees on Line-2, it can be interpreted that if a subsequent landslide occurs, the slip plane zone material on Line-2 is likely to move along the slope towards the southwest as in Line-1. It means that the acquisition of resistivity data on Line-2 is the same as in Line-1, that is, it does not follow the direction of the landslide trajectory, but takes a measuring path across the direction of the landslide scars. For this reason, if a subsequent landslide occurs, the volume of movement of the landslide material will move at a high landslide speed.
3.5.3. Prediction of the angle of slope of the slip plane on Line-3. For Line-3, two slip planes are estimated, each with a predicted slope angle calculated based on Figure 11, yielding:

\[
\alpha_{3(1)} = \arctan \left( \frac{4.0}{9.5} \right) = 22.8^\circ \quad \text{and} \quad \alpha_{3(2)} = \arctan \left( \frac{1.5}{3.5} \right) = 23.2^\circ
\]

By obtaining two slope angles of the slip plane, each \( \alpha_{3(1)} = 22.8 \) degrees and \( \alpha_{3(2)} = 23.2 \) degrees on the 3-line. Thus, if a subsequent landslide, the landslide material will probably move along the slope towards the southwest, and not in the direction of the measuring path. For this reason, if a subsequent landslide occurs, the volume of movement of the landslide material will move at the speed of the landslide following the original landslide plane.

![Figure 11. The slope of the slip plane at Line-3](image)

3.5.4. Prediction of the angle of slope of the slip plane on Line-4. Whereas for Line-4, it can be estimated that there is one slip plane, with the predicted slope angle calculated based on Figure 12, resulting in:

\[
\alpha_4 = \arctan \left( \frac{1.6}{4.0} \right) = \arctan \left( \frac{1.6}{4.0} \right) = 21.8^\circ
\]

Thus at Line-4, the angle of slip plane (\( \alpha_4 \)) is obtained of 21.8 degrees. It can be predicted that there will be subsequent landslides where the landslide material is possible to move along the slope towards the Southwest. For this reason, if a subsequent landslide occurs, the volume of movement of the landslide material will move at a very high landslide speed.
3.6. Landslide Mass Volume Prediction

The prediction of landslide mass volume consists of two parts, namely the prediction calculation of the mass volume of landslides at the time of the occurrence of landslide and the prediction of calculating the potential for landslides based on the identification of the slip plane from the results of the geoelectric survey.

3.6.1. Prediction of landslide mass volume in landslide events. Landslides have occurred, so it can be remodeled using the landslide physics model approach. The 2-D arc-shaped cross-sectional model represents the landslide plane. This model can be a spherical cone representing a 3-D landslide plane, with the length of the landslide surface, the cover diameter, and thickness. These parameters can be used to calculate the predicted volume of landslide events from Eq. (1), and the calculation results can be the plot in Figure 14.

The results of the analytical study are used as an alternative way of evaluating the individual landslide volume of rotational slide types. The calculation of the volume prediction for rotation and translation types is based on the erosion rate of landslides [19,20], using the following empirical equation:

\[ V_{\text{Lar.}} = 0.05 S^{1.30} \]  
\[ V_{\text{Asa.}} = 0.02 S^{1.37} \]

where the coefficients of 0.05 and 0.02 determined empirically for landslides [3,13,20], and the exponent is taken in the range 1.1 - 1.5 characterizes the landslides presented by Edilashvili [3,21], this is similar to the landslide case on Ambon Island [3,9,10,14]. Furthermore, to determine the area of the landslide area (S), a digital elevation model was used which was applied from Google Earth [3]. The results of calculating the mass volume of landslides are shown in Figure 13. At this stage, the average actual area is calculated and entered in equation (4) and equation (5), and finally, the average estimated mass volume of landslides can be calculated (Figure 13). The predicted values were compared with the analytical model and examined in pairs. The results obtained indicate that the mass volume of landslides is estimated as observed, and there is no significant difference between them, with an average of 7.92 %. Thus, the volume of potential landslide masses will increase with the increase in the area and thickness of the landslide area.
Figure 13. Landslide mass volume diagram from the calculation results of landslides and empirical calculations

Figure 14. The landslide potential mass diagram is based on the slip plane

3.6.2. Prediction of potential landslide mass volume. The calculation of the volume of potential landslide mass prediction ($V_{PL}$) can be calculated using the results of the resistivity inversion at each measurement path at the research location based on the landslide slip area using equation (2). The identification of the slip plane on each track is used to determine the length of the slip plane, the maximum depth, and the width at the lower position of the slip plane (section A) and the bottom position of the slip plane (section B). The results of the measurement of the slip plane parameters on each path are entered in equation (2) to obtain the predictive value of the $V_{PL}$, as shown in Figure 14. The infographic shows the prediction of the potential landslide mass volume at Line-4 that is greater than that of Line-2, Line-3, and Line-1. This result is different because the dimensions of the slip plane on each track are different. In the lower area of the slip plane in A and B, there is potential for further landslides if triggered by external disturbances (such as rain, tectonic earthquakes, and massive land conversion), and internal disturbances (such as rock degradation). This activity follows the original ground motion but shifts slightly to the side.

3.6.3. The relationship between landslides and the potential mass volume of landslides. The results of the calculation of landslide volume predictions are used to explain the relationship between landslide volume and the potential for landslide masses, as shown in Figure 15.

The $V_{PL}$ volume that shows the volume of potential landslide mass (blue bars in Figure 15) considered complete for all landslide sizes. The $V_{LE}$ volume that shows the mass volume of landslides (the brown bars analyzed from the analysis, and the brown and purple bars from the empirical results) is considered complete for medium and low landslides. The relationships built in calculating the mass volume of landslides are mostly geometric and are not significantly affected by geomorphological or mechanical properties of the type of landslide [22]. On the other hand, calculating the potential volume of landslides, apart from being geometric, is also influenced by geomorphology and soil-rock mechanical properties.

The prediction of potential landslide volume depends on the geometry of the landslide plane. Landslides pose a threat to human life and structures that support the management of transportation and natural resources at the investigation site. Based on this premise, the occurrence of landslide mass volume and potential landslide mass volume can be said to be different in each landslide area because each landslide area has different characteristics.
4. Conclusion
The results of geoelectric measurements on the landslide of the slopes indicate that these slope of the landslides potential that is controlled by tuff rocks that act as sliding plane and can be triggered by rain. The landslide slip field is the boundary between the permeable rock layer and the impermeable rock layer. Or the boundary between the medium resistivity value and the high resistivity value. The slope angle of the slip plane based on the resistivity section of the subsurface on each track is different. The calculation of the potential mass volume of landslides in terms of the subsurface resistivity section is 3063.88 cubic meters. Furthermore, the calculation result of the event mass volume of landslides is 6,005.00 cubic meters. The calculation of the potential mass volume of landslides and the slope of the slip plane in the study area is interpreted as causing further landslides if triggered by external and internal disturbances.

Acknowledgments
The author would like to thank the Head of Batu Merah Village for providing access to the research area. Thank you also to the Laboratory of Geosciences and Soil Movement, Department of Physics, Faculty of Mathematics and Natural Sciences, Pattimura University, which has prepared equipment for field data acquisition, and students who have helped in the data acquisition process.

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