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Identification of Subsurface Lithological Units Using Electrical Resistivity Method in A Landslide-Prone Area of Dlingo, Bantul, Yogyakarta

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ABSTRACT

he Dlingo area in Bantul Regency, Yogyakarta, is characterized by steep slopes and volcanic deposits that contribute to high landslide susceptibility, as evidenced by destructive events in 2021. This study aims to characterize subsurface conditions controlling slope instability using electrical resistivity modeling. Geoelectric data were acquired using the Wenner configuration along four survey lines, consisting of three slope-parallel profiles and one slope-perpendicular profile, each 225 m long with 15 m electrode spacing. Apparent resistivity data were processed and inverted using Res2Dinv to generate two-dimensional (2D) resistivity sections. The results consistently reveal three principal resistivity zones across all profiles: (1) a high-resistivity unit (approximately 33,9–642 Ωm) interpreted as relatively compact to slightly weathered tuff, (2) a moderate-resistivity layer (1.79–33.9 Ωm) corresponding to weathered volcanic deposits, and (3) a low-resistivity zone (<1.79 Ωm) interpreted as water-saturated or highly conductive material developed along the lower slope. The recurrent resistivity contrast between the weathered layer and the underlying conductive zone suggests a hydrogeological boundary that may facilitate pore-water accumulation and contribute to slope instability. These findings provide a geophysically constrained conceptual model of subsurface controls on slope instability in volcanic terrains.

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I. INTRODUCTION

The Dlingo area, Bantul Regency, is situated within the Southern Mountainous Zone. This zone extends southeastward from the Special Region of Yogyakarta and continues eastward along the southern coastline of East Java. The formation of the Southern Mountain Zone was the result of tectonic uplift, which led to the development of a hills-and-valleys topography (Smyth et al., 2005). Areas with steep geomorphology are particularly susceptible to landslides (Akbar et al., 2022). One such area in Bantul is the Dlingo subdistrict, characterized by a high risk of landslides due to its steep topography and unstable soil structure, which is attributed to its volcanic deposits (BPBD, 2019; Rahmayani, 2014).

The highest frequency of landslides occurs during the peak of the rainy season, typically from January to March, when prolonged and intense rainfall significantly increases slope instability. On January 19, 2021, a landslide occurred on a 20-meter-high rock cliff, damaging three houses in Muntuk Village, Dlingo District, Bantul Regency (Sunartono, 2021). This event caused material losses and highlighted the area's high vulnerability to landslide hazards, particularly during the rainy season. Therefore, a deeper understanding of subsurface conditions, including lithological distribution and the presence of slip planes, is crucial for landslide mitigation efforts.

Identifying the boundaries of lithological and stratigraphic layers is essential for assessing the susceptibility of specific subsurface units to landslides and for supporting the development of effective risk management strategies. Various geophysical methods have been widely applied to map and characterize subsurface conditions related to landslide hazards (Erintina et al., 2019; Mahardi et al., 2020; Fitrianingtyas et al., 2025; Lutfiana et al., 2025). Among these, the geoelectric method plays an important role in identifying subsurface lithology by exploiting contrasts in rock resistivity (Darsono et al., 2012). Resistivity data provide valuable information on soil layer thickness, the presence of weak or weathered zones, and potential slip surfaces that may facilitate mass movement.

Previous studies have demonstrated that geoelectric investigations can significantly enhance landslide susceptibility assessment and risk evaluation (Sulaiman, 2016; Ichsany, 2022). However, despite the high frequency of landslide occurrences in the Nglising–Muntuk area, no site-specific geoelectric study has previously been conducted to characterize subsurface conditions and identify potential slip surfaces in this region. This lack of subsurface information represents a critical knowledge gap that limits the effectiveness of landslide mitigation and risk management strategies. Therefore, the objective of this study is to apply the geoelectric resistivity method to delineate subsurface lithological boundaries, identify weak zones and potential slip surfaces, and assess their implications for landslide susceptibility in the study area.

II. METHOD

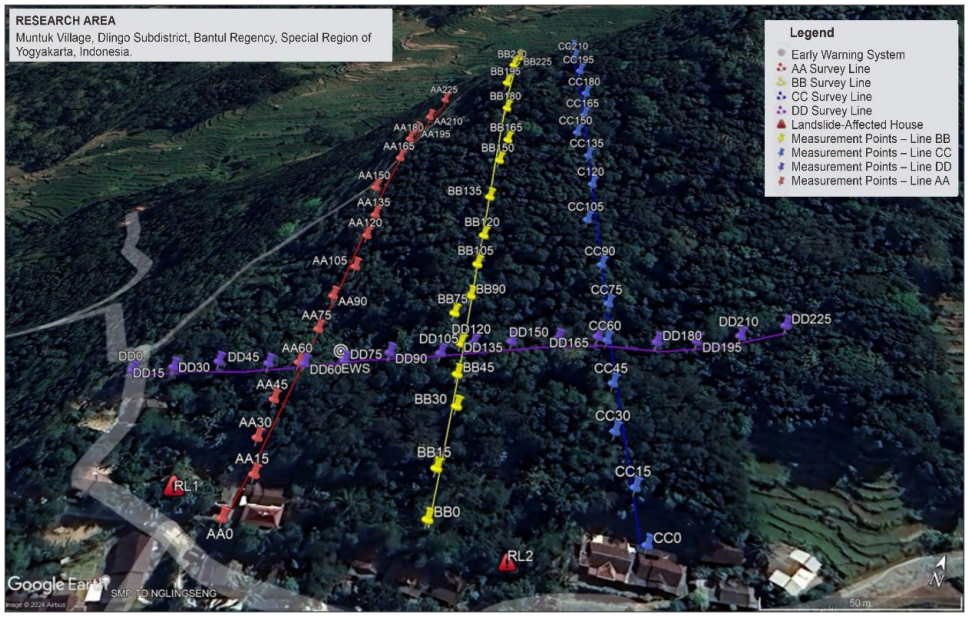


Figure 1 Design of geoelectric measurement surveys in the research area

Geographically, the research area is limited to coordinates 7.9056870 S to 7.9078490 S and 110.4314860 E to 110.4338260 E. The data acquisition process used the Wenner configuration resistivity geophysical method. We used three vertical lines and one horizontal line, each 225 meters long (Figure 1). The distance between each electrode was 15 meters, and the distance between the current electrodes and the potential electrodes was increased from n = 1 to n = 5.

During the data processing stage, the measured voltage (V) and current (I) values were first processed using Microsoft Excel to calculate the apparent resistivity using Equation 2. The calculated apparent resistivity data were subsequently inverted using the Res2Dinv software to obtain two-dimensional resistivity models representing subsurface structures. These 2D resistivity sections were then interpreted and correlated with geological information to evaluate subsurface conditions and identify potential lithological boundaries.

2.1 Geology in Research Area

The research area, located in Muntuk Village, Dlingo subdistrict, Bantul Regency, Special Region of Yogyakarta Province, is situated within the Nglanggran formation and three surrounding formations: the Semilir formation, Sambipitu formation, and Wonosari formation. The geologic map of the research area is shown in **Figure 2**.

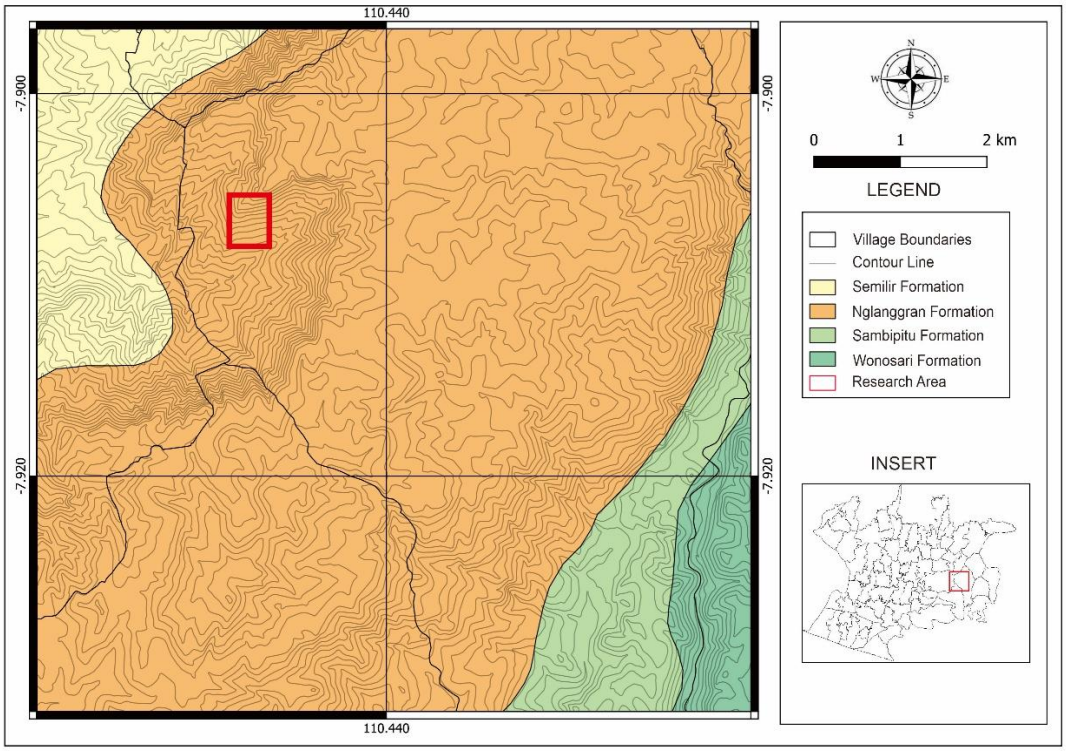


Figure 2 Local Geological Map of the Research Area

The Nglanggran Formation has a conformable and interfingering relationship with the upper part of the Semilir Formation (Nugrahini, 2019). It is predominantly composed of volcanic breccia, flow breccia, agglomerate, lava, and tuff (Surono, 2008). The Nglanggran Formation was formed through depositional processes that occurred partly in terrestrial environments and partly in marine settings under low-energy gravity conditions during the Oligo–Miocene to Middle Miocene (Mulyaningsih et al., 2024). The material source of the Nglanggran Formation is derived from a Tertiary volcanic complex, with its main volcanic centers represented by Mount Blencong and Mount Nglanggran (Kusumayudha, 2005).

2.2 Geoelectric

The electrical resistivity method is a widely applied geophysical approach for characterizing subsurface conditions based on the response of earth materials to an applied electrical current. This

technique involves transmitting an electrical current into the ground through a set of electrodes and measuring the resulting voltage response using additional electrodes positioned at the surface (Johnson et al., 2011; Zhou, 2018). The measured current and potential difference are subsequently used to determine apparent resistivity values that reflect variations in subsurface properties, which is formulated as:

$$\rho_a = K\frac{\Delta V}{I} \tag{1}$$

Apparent resistivity values serve as an indirect indicator of subsurface material properties and are widely used to support lithological interpretation when integrated with geological context (Loke et al., 2021). Typical resistivity ranges for different subsurface materials are summarized in Table 1.

Table 1 Resistivity Values of Rocks (Loke et al., 2021)

Lithology	Resistivity Ωm
Igneous Rock (massive)	$100 – 1.3\times10^7$
Clay/Clayey Soil	1-10
Wet Clay	$0{,}1 – 10^1$
Sandstone	$10 – 10^2$
Gravel/Breccia	$30 – 10^4$
Tuff (wet)	$10 – 10^2$

Various electrode array configurations can be employed in resistivity surveys, each characterized by distinct geometric factors and specific advantages depending on the investigation objectives. One commonly used arrangement is the Wenner configuration (Figure 4), originally introduced by Wenner in 1915. This configuration is particularly suitable for both horizontal and vertical subsurface investigations due to its symmetrical electrode spacing and relatively high signal strength (Ohaegbuchu et al., 2020).

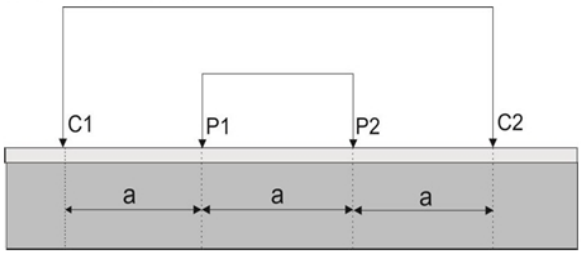


Figure 3 Electrode array in Wenner configuration (Koesuma, 2020)

The electrode arrangement of the Wenner configuration is illustrated in Figure 3, where the spacing between adjacent electrodes is denoted by a. In this setup, the distance between the two current electrodes (C1 and C2) is three times the spacing between the potential electrodes (P1 and P2), or 3a. The geometric factor (k) for the Wenner configuration, which is required for calculating apparent resistivity, can be expressed as follows:

$$k = 2\pi a \tag{2}$$

III. RESULT AND DISCUSSION

The 2D Resistivity Modeling results from four survey lines (Lines AA, BB, CC, and DD) reveal a laterally and vertically consistent resistivity distribution pattern, with an overall range of approximately 0.02 to 642 Ωm. In general, all profiles exhibit three principal resistivity zones: a low-resistivity zone (<1.79 Ωm), a moderate-resistivity zone (1.79–33.9 Ωm), and a high-resistivity zone (33,9–642 Ωm), arranged in a relatively layered configuration that follows the slope morphology. The resistivity models were generated by inverting apparent resistivity data using the Res2Dinv software. Based on Wenner data acquisition, as described in the Methods section, two-dimensional (2D) resistivity cross-sections were obtained with a maximum depth of investigation of 39.2 m. This depth represents the effective investigation limit, within which model resolution remains sufficiently reliable for

geological interpretation. The inversion results yielded acceptable RMS error values ranging from approximately 6.8% to 13.8%, indicating satisfactory model convergence and stability.

As shown in Figure 4, the resistivity distribution along Line AA (RMS error 10.5%) delineates three main zones arranged sub-parallel to the slope surface. The low-resistivity zone is predominantly developed in the central to northwestern portion of the profile and generally occurs at greater depths. Resistivity values within this range are commonly associated with conductive materials such as clay-rich soils, water-saturated deposits, or fracture zones filled with conductive fluids. Considering the geomorphological setting and its stratigraphic position at the lower part of the slope, this zone is interpreted as a layer with high moisture content or significantly saturated porous material. Nevertheless, the inherent non-uniqueness of resistivity interpretation is acknowledged, and therefore this conductive zone is not exclusively attributed to a single lithology. Overlying this unit, the moderate-resistivity zone follows the surface topography and is interpreted as weathered volcanic deposits. The high-resistivity zone, which appears mainly in the southeastern part and locally in the central section of the line, is interpreted as relatively compact tuff. This resistivity range is consistent with values reported for more massive volcanic rocks (Loke et al., 2021). The distinct contrast between the moderate and low-resistivity zones suggests the presence of a lithological boundary that may act as a preferential zone for groundwater accumulation. Under certain hydrological conditions, increased pore-water pressure along this boundary could reduce effective shear strength and contribute to slope instability.

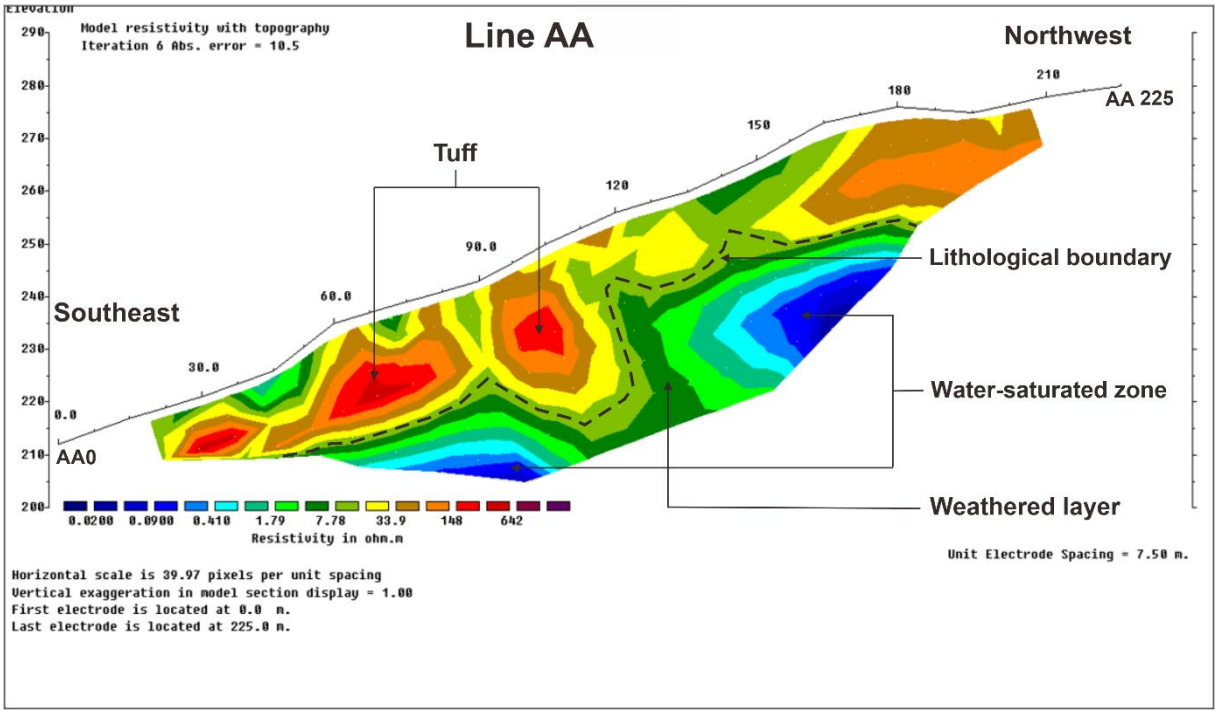


Figure 4 Cross section of two-dimensional resistivity model of Line AA

A comparable but more pronounced resistivity contrast is observed along Line BB, as illustrated in Figure 5. A high-resistivity body is strongly developed in the central to northwestern section of the profile, whereas the low-resistivity zone is clearly identified at the lower slope in the northwestern part. This pattern indicates the presence of a relatively massive and more competent resistive unit, interpreted as less weathered or compact tuff, stratigraphically overlying more conductive material. The low-resistivity zone forms a concave geometry at the slope toe, suggesting potential groundwater accumulation or saturated material concentration. The moderate-resistivity zone occurs as a transitional layer between these two units, reflecting progressive weathering of volcanic rocks. Conceptually, this configuration represents a layered slope system in which a relatively competent upper unit overlies weaker and more saturated material, a condition frequently associated with increased slope instability in tropical volcanic environments.

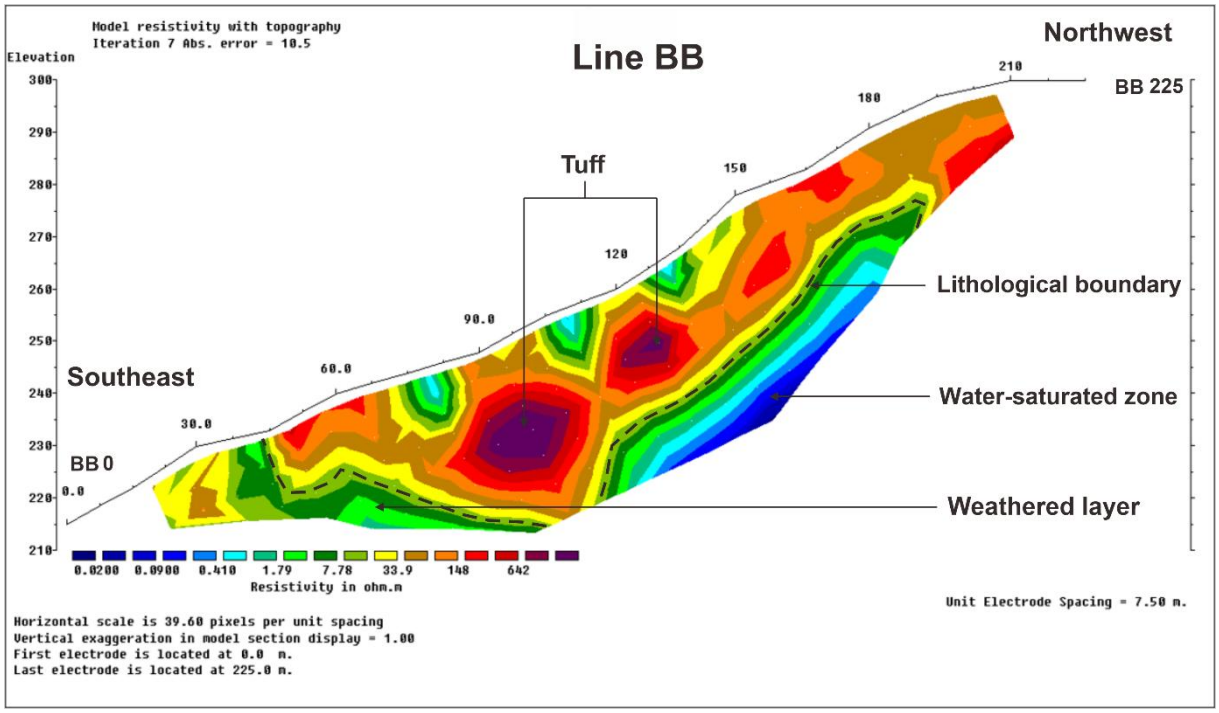


Figure 5 Cross section of two-dimensional resistivity model of Line BB

Further confirmation of this stratified pattern is provided by Line CC, presented in Figure 6 (RMS error 6.8%). Along this profile, high-resistivity zones dominate the upper and middle slope sections, while the low-resistivity zone appears more laterally continuous along the lower slope compared to the previous lines. The moderate-resistivity layer forms an intermediate envelope that follows the slope morphology and reflects a systematic stratigraphic relationship between compact tuff, the weathered layer, and the underlying water-saturated zone. The improved RMS value supports the stability of the inversion result and enhances confidence in the interpreted subsurface layering.

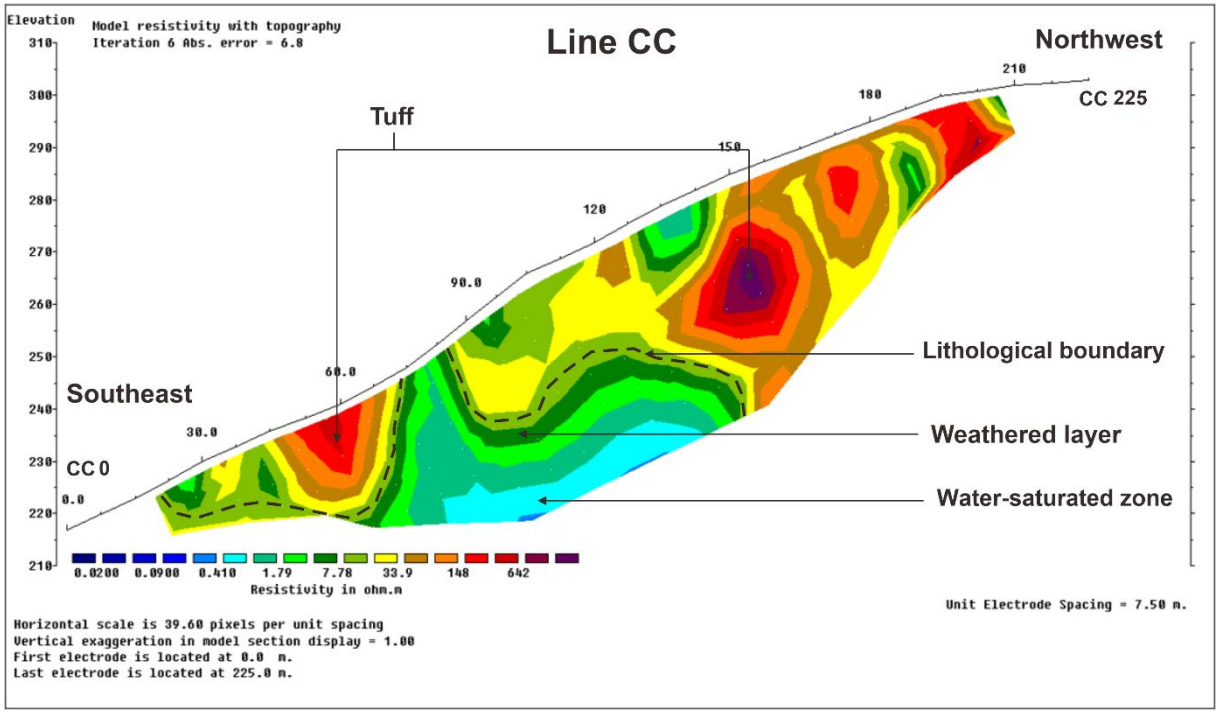


Figure 6 Cross section of two-dimensional resistivity model of Line CC

The lateral continuity of this conductive zone is subsequently confirmed by Line DD (RMS error 13.8%), which intersects the three previous lines and serves as a cross-sectional control for The

lateral continuity of the conductive zone is further confirmed by Line DD, shown in Figure 7 (RMS error 13.8%), which intersects the three previous lines and serves as a cross-sectional control for evaluating spatial model consistency. Along Line DD, the low-resistivity zone again appears continuously along the lower part of the profile, reinforcing the interpretation that this conductive layer represents a laterally continuous stratigraphic unit rather than a localized anomaly. The overlying moderate- and high-resistivity zones exhibit patterns consistent with the interpretations from Lines AA, BB, and CC. This interpretation is further supported by surface outcrop observations along the Line DD transect, where relatively compact tuff with massive to slightly weathered structures is exposed, overlain by a weathered soil layer characterized by loose material and root systems. The correspondence between high-resistivity responses and observed tuff outcrops provides independent geological control for the geophysical interpretation, strengthening the correlation between high-resistivity zones and relatively competent tuff units.

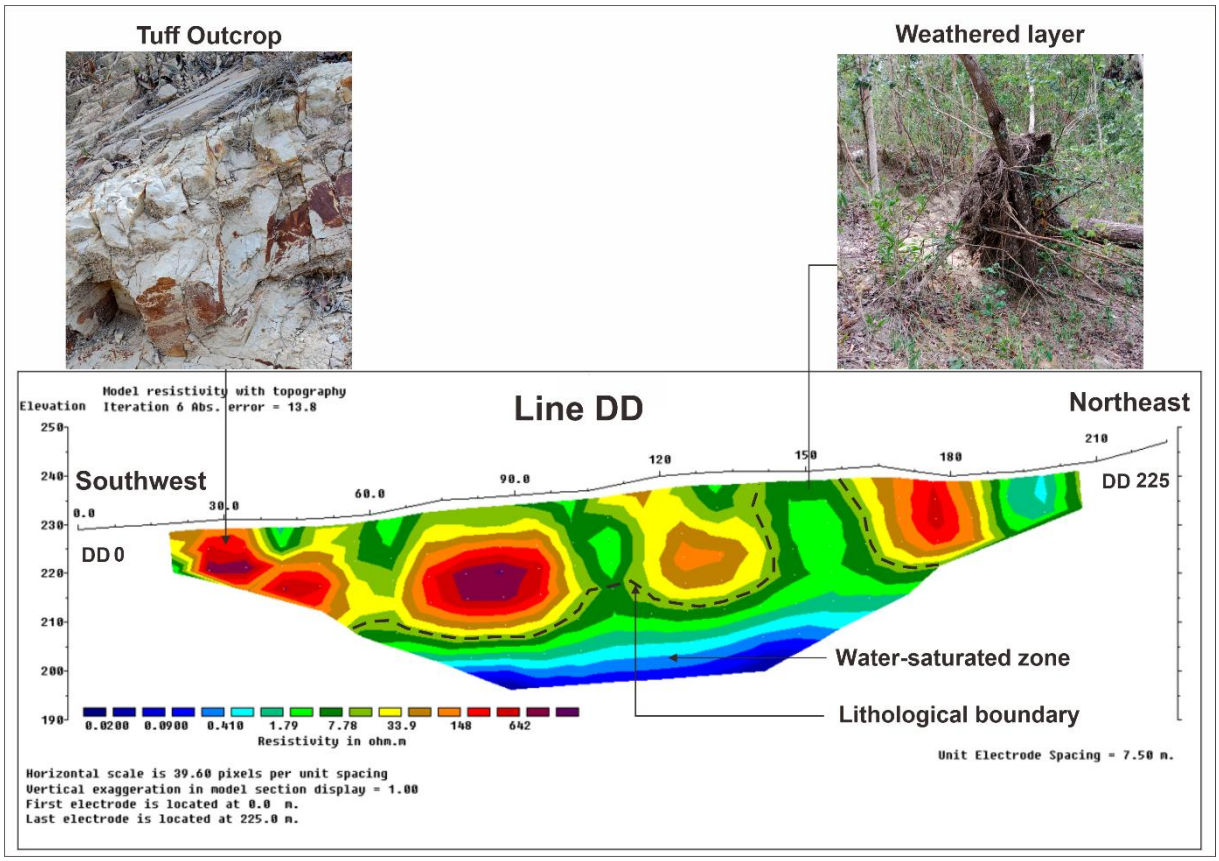


Figure 7 Cross-section of the two-dimensional resistivity model of Line DD and outcrop evidence in the form of tuff and weathered soil.

Overall, the integrated interpretation of the four profiles (Figures 4–7) suggests a layered slope model consisting of relatively compact tuff in the upper section, a transitional weathered layer, and a water-saturated zone at the lower slope. Although the interpretation acknowledges the non-uniqueness of resistivity data, the consistency of resistivity patterns across multiple lines, combined with supporting geological surface evidence, provides a coherent and robust representation of subsurface conditions at the study site.

IV. CONCLUSION

The results of the electrical resistivity method using the Wenner configuration indicate that the subsurface structure of the landslide-prone area in Muntuk Village, Dlingo District, is characterized by a layered volcanic slope system consisting of three principal resistivity zones consistently identified across Lines AA, BB, CC, and DD. A high-resistivity unit (approximately 33,9–642 Ωm) dominates the upper to middle slope and is interpreted as relatively compact to slightly weathered tuff, underlain or laterally associated with a moderate-resistivity layer (1.79–33.9 Ωm) representing weathered volcanic

deposits, and a low-resistivity zone (<1.79 Ωm) developed along the lower slope, interpreted as water-saturated or highly conductive material. The recurring resistivity contrast between the weathered layer and the underlying conductive zone suggests a potential hydrogeological boundary that may influence pore-water accumulation and contribute to slope instability, with lateral continuity confirmed by the intersecting Line DD profile. The concave-upward geometry of this boundary supports a conceptual rotational failure mechanism. However, this study is limited by the inherent non-uniqueness of resistivity interpretation and the absence of borehole or direct subsurface validation data. Future research is recommended to incorporate borehole or geotechnical verification and use multi-geophysical approaches to better constrain lithological interpretation and slope stability assessment in volcanic terrains.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECNOLOGIES IN THE WRITING PROCESS

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