International Journal of Hydrological and Environmental for Sustainability
Volume 3, Issue 2, 65-73.
e_ISSN: 2828-5050
https://www.journal.foundae.com/index.php/ijhes

Landslide Surface Prediction with Combined HVSR and VES Geophysical Techniques: Case Study in Semarang City, Indonesia

Andi Fadlan
Department of Physics,
Universitas Islam Negeri Walisongo Semarang,
INDONESIA

Hartono*
Department of Physics,
Universitas Islam Negeri Walisongo Semarang,
INDONESIA

Antomi Saregar
Department of Physics Education,
Universitas Islam Negeri Raden Intan Lampung,
INDONESIA

Vishal R. Panse
Late.B.S.ArtsProf.N.G.Science & A.G.Commerce
College Sakharkherda,
INDIA

Gaurav Rahate
Department of Applied Sciences,
G. H. Raisoni University,
INDIA

Anita Shukla
Department of Basic science and humanities,
Pranveer Singh Institute of Technology,
INDIA

***Correspondence: E-mail:** hartono@walisongo.ac.id

Article Info

Article history:

Received: February 16, 2024
Revised: May 20, 2024
Accepted: June 28, 2024

Abstract

There are settlements in Tambakaji, Semarang City, which are threatened with landslides because they are located right at the foot of the slope, so research is needed to determine the potential for landslides on the slope. Landslide potential can be identified by identifying the presence of slip planes on the slopes and knowing the soil classification. The prediction of the presence of slip planes is done using the resistivity method while the soil classification uses the HVSR method. The HVSR method is also used to determine the depth of the sediment layer to strengthen the suspicion of the existence of a slip plane in the resistivity method. Based on the results of research using the resistivity method, it shows that the slope has the potential for landslides because it is suspected to have a slip plane at a depth of 20-23 meters (reinforced by the results of the HVSR method which obtains a sediment thickness value of about 23.4 - 23.8 meters), but the rate of landslides falls into in the low category because the layer of sediment above it is classified as hard soil.

Keywords: geoelectric resistivity; hvsr; landslide; layer of sediment; soil
.

To cite this article: Fadlan, A., Hartono., Saregar, A., Panse, V, R., Rahate, G. and Shukla, A. (2024). Landslide Surface Prediction with Combined HVSR and VES Geophysical Techniques: Case Study in Semarang City, Indonesia. *International Journal of Hydrological and Environmental for Sustainability, 3*(2), 65-73. https://doi.org/10.58524/ijhes.v3i2.442

INTRODUCTION

Natural disasters are events that can cause harm to human life and have caused many casualties. One of them is a landslide disaster. Sutopo said that the trend of landslides was increasing from the previous period. Landslide cases have been recorded from 2012 to 2016, namely in 2012 there were 291 cases, 2013 there were 296 cases, 2014 there were 600 cases, 2015 there were 515 cases, and 2016 there were 576 cases. The number of people killed depends on the size of the landslide. The number of deaths due to landslides from 2012 to 2016 was 119 people in 2012, 190 people in 2013, 372 people in 2014, 135 people in 2015, and 177 people in 2016. Indonesia has 274 districts and cities that are prone to landslides, with a population of 40.9 million people living in landslide-prone areas. This shows that around 40.9 million people are directly at risk of being affected by landslides (Whiteley et al., 2021).

Figure 1 is a housing complex in the Tambakaji area of Kec, Ngaliyan, and Semarang City. The location is located behind the Faculty of Economics and Business at UIN Walisongo Semarang. The housing is located lower, or under the UIN Walisongo building, which is bordered by a fairly steep slope. The distance between the housing (northern part) and the foot of the slope is between 5 and 10 meters. This distance would be a disaster if a landslide occurred, while the slope has the potential for landslides because the slope is quite steep. Therefore, it is necessary to further identify the potential for landslides in the area so that disaster prevention or mitigation efforts can be made in the area.

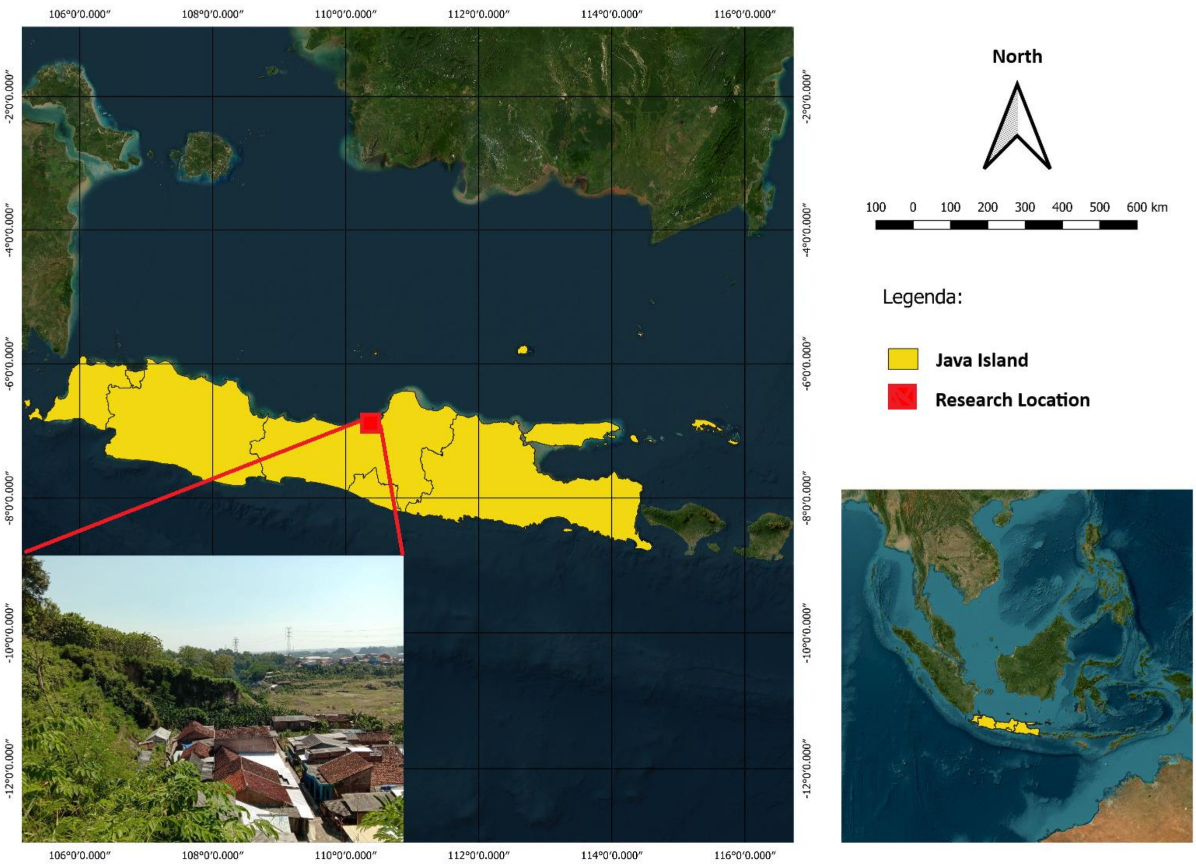

Figure 1. Research location.

Landslides are a natural disaster caused by the instability of rocks or soil that make up a slope, which causes the soil or rocks to deform down the slope. Slope instability occurs when the resisting force is smaller than the driving force. Soil strength or soil density is included in the restraining force, while slope slope, type of soil that makes up the slope and hydrological conditions are included in the driving force (Mustofa et al., 2024).

Landslides can occur in slip areas. The slip plane is the boundary between a stable plane and a moving plane. Bedrock or bedrock is included in the stable plane, while the soil above it is included in the moving plane. Soil types that have high water permeability properties can increase the occurrence of landslides due to increased ground movement relative to the stable surface. Soil that is permeable allows water to pass into the bedrock or slip surface. The presence of water in the slip area causes a reduction in frictional force as a barrier between the bedrock and the soil above it (Pérez-Labrada et al., 2024).

The type of rock is also a factor in the occurrence of landslides. Nailstone, sandstone, basalt and andesite breccia are rocks that are classified as rock types with a high level of vulnerability. Meanwhile, andesite and tuff sandstone are classified as rock types with a low level of vulnerability.

Apart from the type of soil, the slope level can also increase the occurrence of landslides. The higher the slope angle (high slope), the higher the occurrence of landslides (Alonso-Pandavenes et al., 2023).

From the statements above, landslides can be identified by knowing the slope level, soil type, and the presence of slip areas. Soil type and the presence of slip areas can be estimated using geophysical methods. Geophysical methods are methods used to describe subsurface contents using physical parameters. Several geophysical methods that are often used to study landslides are geoelectric methods. Several researchers who have identified landslides using the geoelectric method are (Chambers et al., 2022).

The resistivity method uses the resistivity parameters of the rock. The slip plane is the boundary between soft and solid rock, so that if you look at the resistivity value, the boundary between the two rocks will be visible as a high resistivity contrast. The geoelectric method is included in the geophysical methods which have great ambiguity in terms of estimating the earth's subsurface. So additional information is needed to strengthen the guess. Each geophysical method has limitations in predicting the subsurface contents of certain objects due to the mismatch between object measurements and the parameters used (Nurwidyanto & Yuliyanto, 2022).

Apart from the resistivity method, the HVSR method can be used to identify landslides. Researchers who have researched using this method are (Alonso-Pandavenes et al., 2023) and (Sujitapan et al., 2024). The HVSR method is a geophysical method used to calculate the comparison of the horizontal and vertical component spectra of microseismics. Microseismics, also known as microtremors, are vibrations that have a low frequency. Microtremor measurements can be used to observe soil types or soil dynamic characteristics. Soil dynamic characteristics can be obtained from the dominant frequency values and soil amplification factors. The dominant frequency is estimated as the frequency value of the rock in the measurement area, so that this frequency value can be used to determine the type and characteristics of the rock. Apart from that, the depth of the soft layer can also be identified from this method using the principle of vibration propagation in organ pipes (Xu & Wang, 2021).

Each geophysical method has advantages and disadvantages in identifying targets. Geophysical methods can be correlated to complete deficiencies or sharpen target guesses, thereby reducing the ambiguous value of interpretation results. The HVSR method can guess the thickness of the sediment layer, where this information can be correlated with the geoelectric method to increase confidence in the guess results in the form of identifying the existence of a slip plane. In addition, the HVSR method can be used to group soil types based on their susceptibility to landslides.

Theory

The resistivity method is a geophysical method that utilizes the resistivity properties of rocks. Rock resistivity varies depending on the type of rock, porosity, and fluid content. The resistivity value in rocks can change if the rock contains fluid which causes the resistivity value to be low (Whiteley et al., 2021). **Figures 2** show the resistivity values for each rock.

The dominant frequency resulting from the HVSR method processing is used to calculate the value of the dominant period (Tg), which is one of the parameters of soil dynamic characteristics. The dominant period can indicate the characteristics of the materials that make up the soil layer. The value of the dominant period can also reflect or be closely related to the depth of the sediment layer (Alonso-Pandavenes et al., 2023). A high dominant period can indicate the presence of a thick layer of soft sediment, a low dominant period indicates the presence of a thin sediment layer (Chambers et al., 2022). The dominant period value can be calculated using Equation (1).

$$T_g = \frac{1}{f_0} \qquad (1)$$

Where T_g is the dominant period in seconds and f_0 is the dominant frequency in *Hz*. The dominant period is directly proportional to the shaking strength factor, so that areas with a high dominant period generally have a fairly high vulnerability to experiencing damage (Alonso-Pandavenes et al., 2023). In this study, the division of dominant period value classes refers to the site classification from NERHP (National Earthquake Hazard Reduction Program) (Sujitapan et al., 2024) dividing site classes into four classes as in **Table 1**.

Local site effects are surface geological conditions that influence ground vibrations that occur due to earthquakes. One of the parameters used to determine the thickness of the sediment layer is the speed of the S wave (shear wave) at a depth of 30 meters. The S wave was chosen because through this wave we can know the response of the type of soil through which the seismic wave passes and its effect on the damage that may occur (Chambers et al., 2022). According to (Alonso-Pandavenes et al., 2023, 2023; Whiteley et al., 2021) the thickness of the sediment layer is one of the factors causing local geological influences (local site effects) when an earthquake occurs.

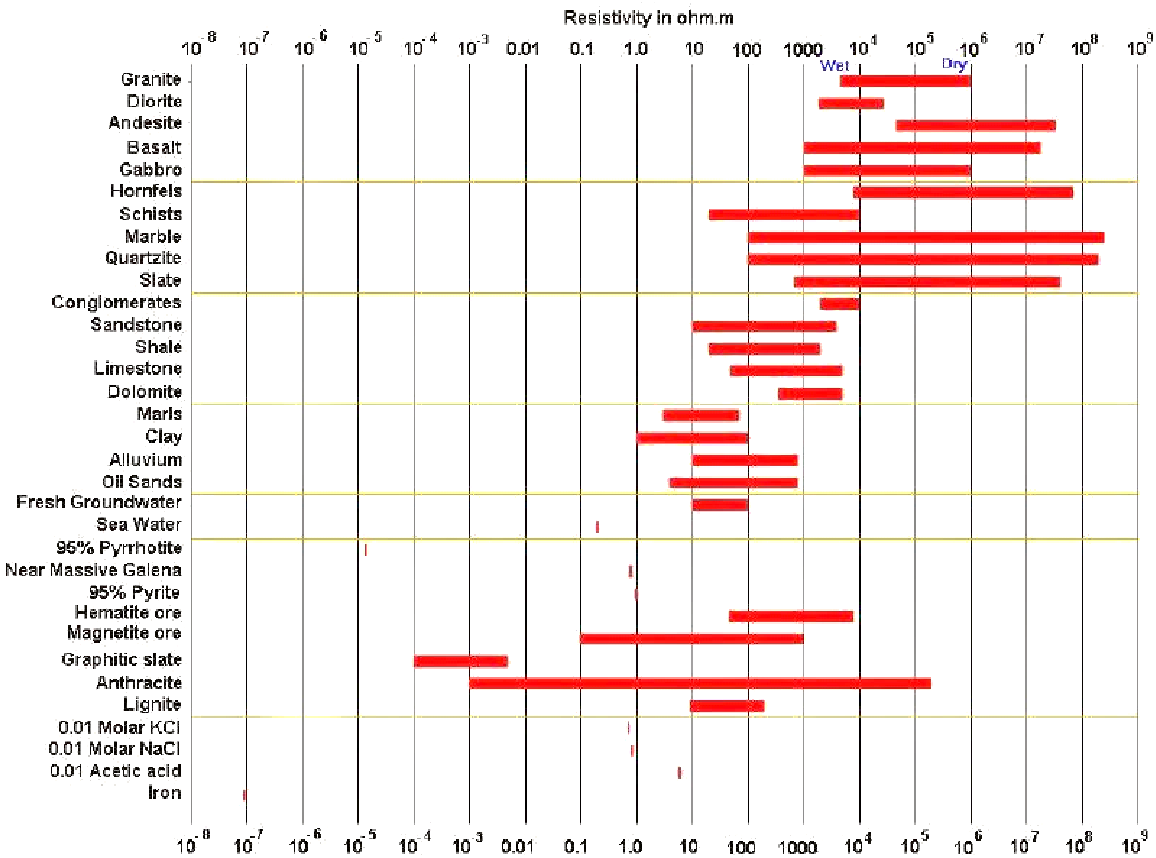

Figure 2. List of rock and mineral resistivities (Khalil & Santos, 2011; Kumar & Yadav, 2015; Pirttijärvi et al., 2015; Whiteley et al., 2021).

The thickness of the sediment layer can be analogous to an open organ pipe, where if resonance occurs, the wave amplitude will increase compared to the original amplitude. When the wave amplitude is maximum, the tuning thickness phenomenon will occur, namely if a wave at that thickness has the largest amplitude value caused by a resonance event. The maximum amplitude occurs at a sediment thickness equal to $\lambda/4$ or $h = \frac{\lambda}{4}$, while $\lambda = \frac{v}{f_0}$ then the relationship between sediment thickness and dominant frequency can be expressed in Equation (2) (Whiteley et al., 2021).

$$h = \frac{v_s}{4 f_0} \qquad (2)$$

Where f_0 is the dominant frequency of the soil expressed in *Hz*, *vs* is the secondary wave speed in *m/s* and *h* is the thickness of the sediment layer in meters.

METHOD

The research location is located in Tambakaji, Kec. Ngaliyan, Semarang City, Indonesia with coordinates -6.988402° - 6.991170° and 110.351963° - 110.347579°. The literature review stage is used to collect various information about the geology of the local area (structure, types and layers of rocks in the research area), while the field survey is used to determine the actual conditions in the field and measure the slope of the slope.

Data Acquisition

Rock resistivity data was obtained using the sounding/vertical Schlumberger configuration resistivity method. Measurements were carried out with 2 (two) sounding points parallel to the slope (east-west) and 1 (one) sounding point perpendicular to the slope (north-south).

Microseismic data was obtained by measuring for 30 minutes which was repeated 3 times at the same point. Microseismic data measurements are ideally carried out in quiet conditions (low noise), so that when measurements are carried out in high noise conditions it is necessary to carry out repeated measurements to get better data.

Data Processing

Rock resistivity data is processed to obtain estimated rock resistivity values for each layer. Estimated rock resistivity values are adjusted to the geological information of the research area. Resistivity data is used to guess the existence of slip planes. The existence of a slip plane is identified when there is a resistivity contrast (a large difference in resistivity values appears between adjacent rock layers).

Microseismic data is processed to get an estimate of the thickness of the sediment layer and soil classification. The thickness of the sediment layer is obtained using equation 1, where the *vs* 30 value is obtained from the USGS web. Soil classification is obtained by processing microseismic data to obtain the dominant period value (equation 2). Based on the dominant period values which are then referred to in **Table 1**, the soil classification is obtained.

Tabel 1. Distribution of dominant period values (T_g) (Whiteley et al., 2021)

No	Dominant Period Value (T_g)	Information
1.	< 0,2 s	Rock/Stiff soil
2.	0,2 s ≤ T_g < 0,4 s	Hard soil
3.	0,4 ≤ T_g < 0,6	Medium soil
4.	≥ 0,6 s	Soft soil

Source : Data in this study

RESULTS AND DISCUSSION

The research location or slope measured is in the Ngaliyan area. The research location is shown by the red box on the geological map sheet of Semarang-Magelang which is stacked with the structural map from (Pirttijärvi et al., 2015) which is shown in **Figure 3**. The Ngaliyan area is included in the chronostatic unit with the symbol QTd (resin formation). The resin formation consists of tuff sandstone, tuff, conglomerate, volcanic breccia and black clay. The research location is in a folded structure called the temple anticline. The geological structural patterns of anticlines and synclines appear to match the DEM map **(Figure 4)**. The anticline appears on the DEM map in the form of a plateau that extends in a west-east direction, where the plateau matches the line on the structure map that shows the structure of the anticline (Chambers et al., 2022; Hermawan & Putra, 2016; Siregar & Kurniawan, 2018; Sujitapan et al., 2024). This shows that the slopes of the study area are the result of folding of resin formations.

Figure 5 is the result of interpreting resistivity data from 3 (three) sounding points which have been connected and adjusted to their respective elevations to obtain a reference line on the surface. The resistivity value of each rock is obtained by adjusting it to the rock formation of the research area.

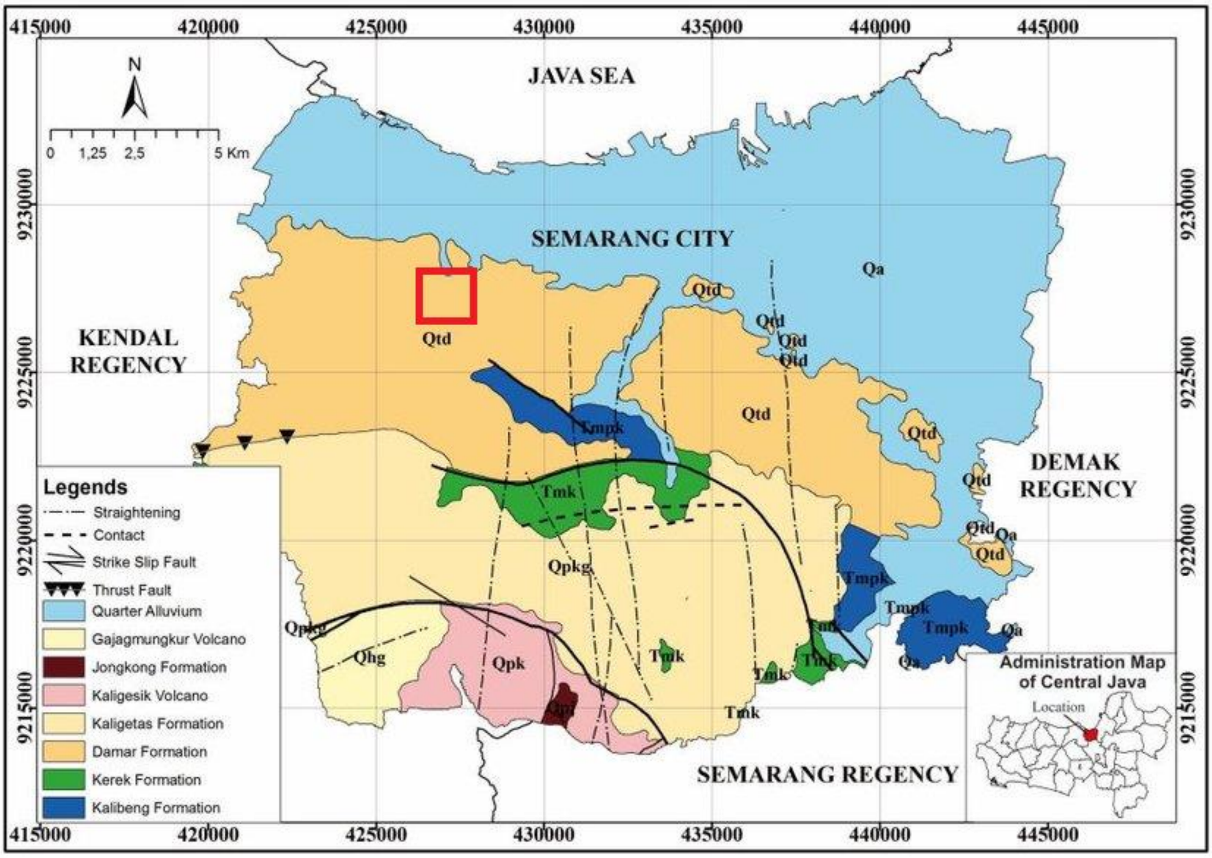

Figure 3. Overlay of the geological map of the Semarang-Magelang sheet and the geological structure map.

Sounding point 1 (first) can show 3 (three) layer boundaries, namely the first layer boundary is at a depth of 0.90 meters with a resistivity of the rock above it of 55.39 ohm-meters; the boundary of the second layer is at a depth of 10.91 meters with the resivity of the rock above it being 20.70 ohm-meters; and the boundary of the third layer is at a depth of 20.01 meters with the resistivity of the rock above it being 124.17 ohm-meters, while the resistivity of the rock below it is 1.20 ohm-meters. Based on the resistivity value of the rock in each layer, there is a resistivity contrast or the suspected existence of a slip plane, namely at the 3 (three) layer boundary.

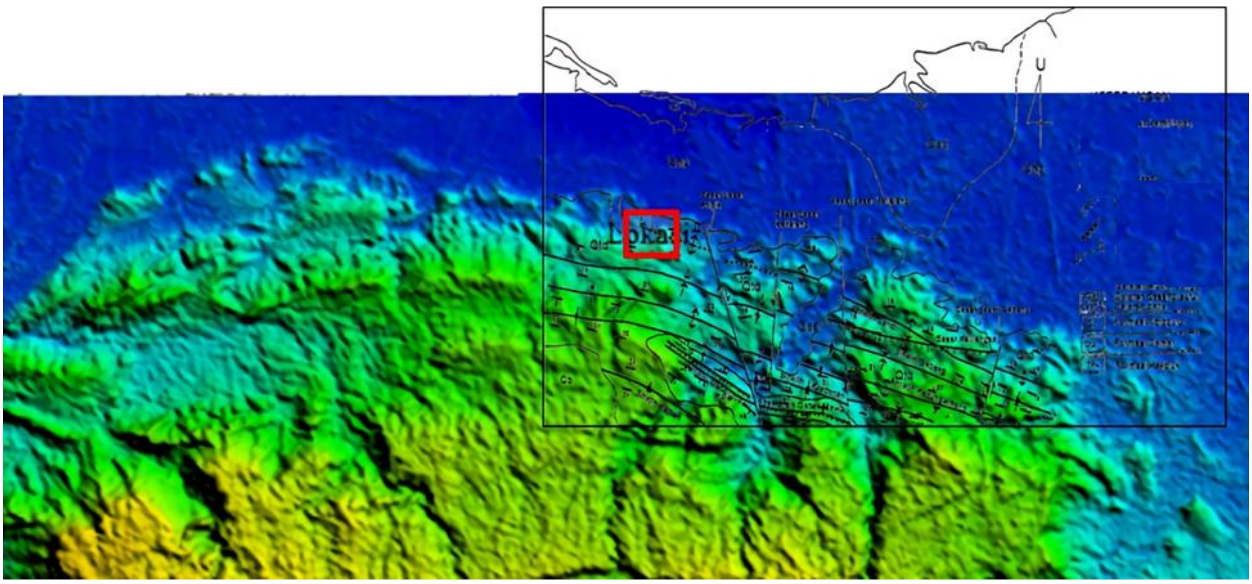

Figure 4. Overlay of DEM map and geological structure map.

Sounding point 2 (second) can show 3 (three) layer boundaries, namely the first layer boundary is at a depth of 5.32 meters with a resistivity of the rock above it of 51.85 ohm-meters; the boundary of the second layer is at a depth of 12.82 meters with the resivity of the rock above it being 15.75 ohm-meters; and the boundary of the third layer is at a depth of 23.43 meters with the resistivity of the rock above it being 274.82 ohm-meters, while the resistivity of the rock below it is 1.00 ohm-meters. Based on the resistivity value of the rock in each layer, there is a resistivity contrast or the suspected existence of a slip plane, namely at the 3 (three) layer boundary.

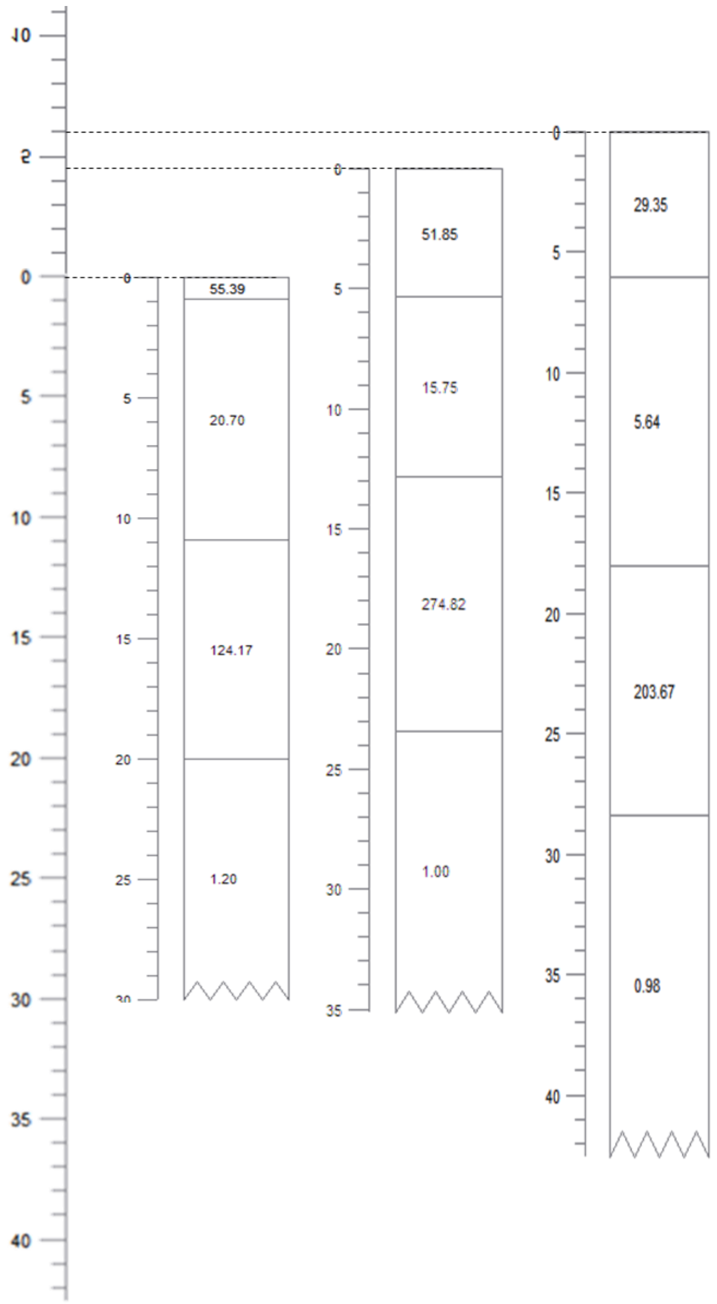

Figure 5. Interpretation of rock resistivity against depth.

Sounding point 3 (third) can show 3 (three) layer boundaries, namely the first layer boundary is at a depth of 6.01 meters with a resistivity of the rock above it of 29.35 ohm-meters; the boundary of the second layer is at a depth of 18.06 meters with the resivity of the rock above it being 5.64 ohm-meters; and the boundary of the third layer is at a depth of 28.39 meters with the resistivity of the rock above it being 203.67 ohm-meters, while the resistivity of the rock below it is 0.98 ohm-meters. Based on the resistivity value of the rock in each layer, there is a resistivity contrast or the suspected existence of a slip plane, namely at the 3 (three) layer boundary.

Based on **Figures 6**(a)-(c), the dominant frequency values are 3.74886, 3.7095, and 3.74709. Based on the dominant frequency value, a dominant period can be generated, which has a value that is inversely proportional to the dominant frequency. The resulting dominant periods are 0.266748, 0.269578, and 0.266874. This value based on **Table 1** is a type of hard soil. Meanwhile, the thickness of the sediment layer can be calculated using equation (3.2.1) to obtain sediment layer depths of 23.40712, 23.65548, 23.41817 meters, with a vs30 value of 351. The depth values obtained from the geoelectric and myctoseismic methods both produce almost the same depth values.

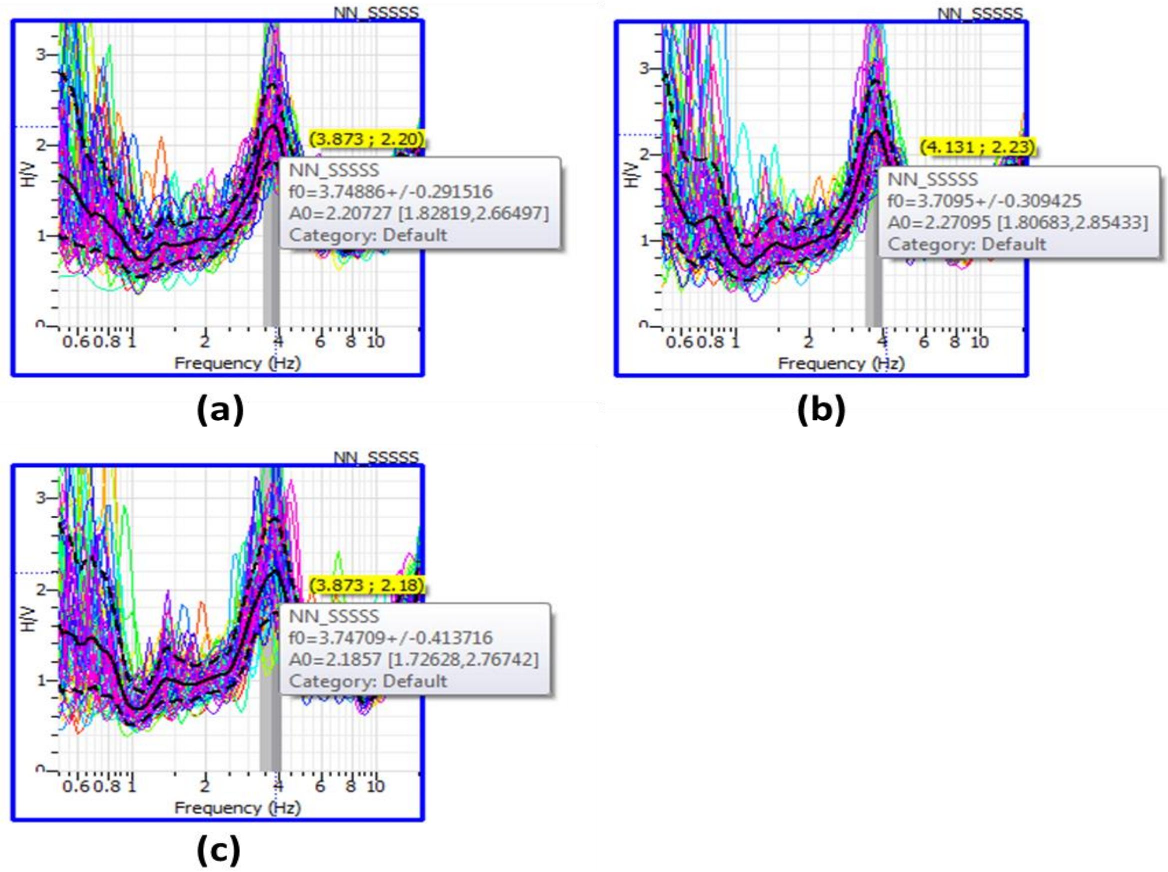

Figure 6. HVSR microseismic data.

CONCLUSION

Based on the results of research using the resistivity method, it shows that the slope has the potential for landslides because it is thought to have a slip surface at a depth of 20-23 meters. These results are also strengthened by the results of the HVSR method which obtained sediment thickness values of around 23.4 -23.8 meters, which are almost the same results as the resistivity method. Even though there is potential for landslides to occur, the level of landslides is in the low category because the sediment layer above is classified as hard soil.

ACKNOWLEDGMENT

The author would like to thank the relevant parties who have provided support for this research.

CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

REFERENCES

Alonso-Pandavenes, O., Torrijo, F. J., Garzón-Roca, J., & Gracia, A. (2023). Early Investigation of a Landslide Sliding Surface by HVSR and VES Geophysical Techniques Combined, a Case Study in Guarumales (Ecuador). *Applied Sciences (Switzerland)*, *13*(2). https://doi.org/10.3390/app13021023

Chambers, J., Holmes, J., Whiteley, J., Boyd, J., Meldrum, P., Wilkinson, P., Kuras, O., Swift, R., Harrison, H., Glendinning, S., Stirling, R., Huntley, D., Slater, N., & Donohue, S. (2022). Long-term geoelectrical monitoring of landslides in natural and engineered slopes. *Leading Edge*, *41*(11), 768–767. https://doi.org/10.1190/tle41110768.1

Hermawan, O. R., & Putra, D. P. E. (2016). The Effectiveness of Wenner-Schlumberger and Dipole-dipole Array of 2D Geoelectrical Survey to Detect The Occurring of Groundwater in the Gunung Kidul Karst Aquifer System, Yogyakarta, Indonesia. *Journal of Applied Geology*, *1*(2), 71–81.

Khalil, M. A., & Santos, F. M. (2011). Comparative study between filtering and inversion of vlf-em profile data. *Arabian Journal of Geosciences*, *4*(1–2), 309–317. https://doi.org/10.1007/s12517-010-0168-4

Kumar, R., & Yadav, G. S. (2015). Delineation of fracture zones in the part of Vindhyan fringe belt of Ahraura region, Mirzapur district, Uttar Pradesh, India using integrated very low frequency electromagnetic and resistivity data for groundwater exploration. *Arabian Journal of Geosciences*, *8*(2), 727–737. https://doi.org/10.1007/s12517-014-1283-4

Mustofa, A., Utami, S. N. H., & Purwanto, B. H. (2024). Soil quality index in some cropping systems in plot 17 of Wanagama forest, Gunungkidul, Yogyakarta, Indonesia. *Sains Tanah*, *21*(1), 1–14. https://doi.org/10.20961/stjssa.v21i1.65454

Nurwidyanto, M. I., & Yuliyanto, G. (2022). *Application of the HVSR Microtremor Method for Groundwater Aquifer Identification : Case study in Pencitrejo , Terong Village , Dlingo , Bantul , Yogyakarta , Indonesia*. *8*(6), 20–23.

Pérez-Labrada, F., Benavides-Mendoza, A., Juárez-Maldonado, A., Solís-Gaona, S., & González-Morales, S. (2024). Tomato yield and soil chemical properties influenced by low–molecular–weight organic acids in calcareous soil. *Sains Tanah*, *21*(1), 55–63. https://doi.org/10.20961/stjssa.v21i1.79024

Pirttijärvi, M., Zaher, M. A., & Korja, T. (2015). Combined inversion of airborne electromagneticand static magnetic field data. *Geophysica*, *50*(2), 65–87. https://doi.org/10.13140/RG.2.1.1747.0486

Siregar, R. N., & Kurniawan, W. B. (2018). 2D Interpretation Of Subsurface Hot Spring Geothermal Structure In Nyelanding Village Through Schlumberger Geoelectricity. *Jurnal Ilmiah Pendidikan FisikaAl-BiRuNi*, *07*(April), 81–87. https://doi.org/10.24042/jipfalbiruni.v7i1.2324

Sujitapan, C., Kendall, J. M., Chambers, J. E., & Yordkayhun, S. (2024). Landslide assessment through integrated geoelectrical and seismic methods: A case study in Thungsong site, southern Thailand. *Heliyon*, *10*(2). https://doi.org/10.1016/j.heliyon.2024.e24660

Whiteley, J. S., Watlet, A., Uhlemann, S., Wilkinson, P., Boyd, J. P., Jordan, C., Kendall, J. M., & Chambers, J. E. (2021). Rapid characterisation of landslide heterogeneity using unsupervised classification of electrical resistivity and seismic refraction surveys. *Engineering Geology*, *290*(May), 106189. https://doi.org/10.1016/j.enggeo.2021.106189

Xu, R., & Wang, L. (2021). The horizontal-to-vertical spectral ratio and its applications. *Eurasip Journal on Advances in Signal Processing*, *2021*(1). https://doi.org/10.1186/s13634-021-00765-z