Jurnal Geosaintek Vol 10. No. 3. Tahun 2024. 234-241. p-ISSN : 2460-9072, e-ISSN : 2502-3659

APPLICATION OF RESISTIVITY GEOELECTRIC METHOD FOR PREDICTING SUBSURFACE LITHOLOGY AT ALAS KOTA SITE

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Abstract. *The Alas Kota Site is one of the relics from the Hindu-Buddhist period in Jember. This site is located in Langsepan Hamlet, Kranjingan Village, Sumbersari District. The presence of red brick fragments on the ground surface and buried red brick structures provide evidence of natural events that have affected this site. This research aims to identify subsurface structures at the site. The method used is the Wenner-Schlumberger configuration of the geoelectric method. A total of 5 line measurement were conducted, with line 1 and 2 being 54 meters long with a spacing of 1.5 meters, while line 3, 4, and 5 were 42 meters long with a spacing of 1.5 meters. The processed data resulted in cross-sectional data in both 2D and 3D formats. Based on the processing results, the surface materials consist of clay, passive clay, andesitic rock, and sand. The distribution of clay resistivity values ranges from 4.58 Ωm to 42.7 Ωm, passive clay associated with red brick structures with resistivity values ranging from 42.7 Ωm to 104 Ωm, and andesitic rock and sand with resistivity values > 104 Ωm. The subsurface materials at the site originate from the breakdown of rock formations at the location and from the eruptions of Mount Raung.*

Keywords: *Alas Kota Site; Geoelectric; Lithology; Resistivity; Wenner-Schlumberger*

INTRODUCTION

East Java Province is one of Indonesia's regions with many cultural heritage relics scattered in different districts. Many relics of the Hindu-Buddhist Kingdom period have been found in various regions in East Java, such as temples, water springs, ancient manuscripts or books, inscriptions, sites, and many more (Cahyani and Budiarto, 2020). In general, relics of the Hindu-Buddhist period are found in damaged and destroyed conditions due to the age of objects or buildings, natural factors, and even human factors (Sulistiawan et al., 2019). One of the relics of the Hindu-Buddhist period found in Jember is the Alas Kota site. This site is located in Kranjingan village, Sumbersari Regency. Based on the results of observations that have been made, the current condition of the site is in the form of rice fields, and red bricks are found scattered at several locations. In addition, a red brick wall structure and several earth mounds were found, indicating a brick structure buried in the ground for hundreds of years. Volcanic deposits were found at the study site, which are believed to be related to the volcanic eruption event at the Alas Kota site that caused the burial of this site. This is also the cause of the burial of the Kumitir site, which was caused by a volcanic eruption (Widodo et al., 2024). Given these conditions, it is necessary to know the subsurface structure at the Alas Kota site to map its subsurface lithology.

Geophysical methods that use physical principles can be used to observe and measure the physical properties of a geological condition in an area (Hamidy et al., 2022). The basic concept of this method uses the equation of Ohm's law, which states that the electric current (I) flowing through a conductor is always inversely proportional to the resistance value (R) and directly proportional to the potential difference (V) (Amin et al., 2023). Ohm's law can be expressed in the following equation:

$$I = V/R \quad (1)$$

Variables:
I : Electric current (A)
V : Potential difference (V)
R : Resistance (Ω)

DOI : http://dx.doi.org/10.12962/j25023659.v10i3.2140

Artikel Masuk : 29-10-2024 Artikel Diulas : 10-12-2024 Artikel Diterima : 16-12-2024

The basic principle of this method is to assume the earth as a sphere that has homogeneous isotropic properties so that the measured resistivity value does not depend on the electrode distance and is the actual resistivity value. However, in reality the earth consists of layers arranged laterally and vertically with different rock compositions or heterogeneous so that the measured potential value is influenced by these layers. Therefore, the measured resistivity value is the apparent resistivity value (Oktavina et al., 2022). The magnitude of the apparent resistivity value can be expressed in the following equation:

$$\rho_{ws} = 2\pi \left[\left\{\frac{1}{na} - \frac{1}{na+a}\right\} - \left\{\frac{1}{na+a} - \frac{1}{na}\right\}\right]^{-1} \frac{\Delta V}{I} \tag{2}$$

$$\rho_{ws} = 2\pi \left(\frac{1}{na} - \frac{1}{na+a} - \frac{1}{na+a} + \frac{1}{na}\right)^{-1} \frac{\Delta V}{I} \tag{3}$$

$$\rho_{ws} = \pi \left(\frac{1}{na} - \frac{1}{na+a}\right)^{-1} \frac{\Delta V}{I} \tag{4}$$

$$\rho_{ws} = \pi \left(\frac{1}{n^2a+na}\right)^{-1} \frac{\Delta V}{I} \tag{5}$$

$$\rho_{ws} = \pi \left(\frac{1}{na(n+1)}\right)^{-1} \frac{\Delta V}{I} \tag{6}$$

$$\rho_{ws} = \pi n(n+1)a \frac{\Delta V}{I} \tag{7}$$

$$\rho_{ws} = K_{ws} \frac{\Delta V}{I} \tag{8}$$

Variables:
ρ_{ws} : Apparent resistivity of Wenner-Schlumberger configurations (Ωm)
K_{ws} : Geometry factor of Wenner-Schlumberger configurations (m)
ΔV : Potential difference (V)
I : Electric current (A)

The resistivity of minerals or rocks is influenced by their porosity, mineralogy, pore water content, and electrolyte fluids. A potential difference causes the current to flow through each rock layer. The conductivity of the rock affects the current flow in each layer. Less permeable rocks have a lower resistivity value than dry rocks. The resistivity values of different rock types are presented in the following table.

Table 1. Resistivity Values Table (Hunt, 1984 and Telford et al., 1990)

No.	Name of Style	Resistivity (Ωm)
1.	Andesite	100 – 2000
2.	Sand	100 - 600
3.	Clay	1 – 100
4.	Sand Clay	30 – 100

Geoelectric methods can be categorized into dipole-dipole, pole-pole, wenner, schlumberger, and wenner-schlumberger based on the configuration type. The configuration used in this research used the wenner-schlumberger configuration because this configuration can show images below the surface both horizontally and vertically (Ahmad et al., 2022). In addition, the use of this configuration is also suitable for the purpose of this research, namely to determine the condition and distribution related to archaeological sites. These methods are commonly used to prospect groundwater aquifers, explore metal minerals, plan foundations, explore geothermal energy, and conduct archaeological investigations (Rumahorbo and Tibri, 2023). This method has several advantages. Geoelectric methods have proven to be effective and relatively

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inexpensive for mapping archaeological sites (Rochman et al., 2017). In addition, it is environmentally friendly, relatively low cost, and can detect subsurface structures up to several meters (Hendri et al., 2019).

METHODS

This research employs the resistivity geoelectric method using the wenner-schlumberger configuration. This configuration was chosen due to its superior depth penetration, with a 15% better ratio compared to the wenner configuration. The distance between electrodes applied to the wenner-schlumberger configuration, namely C1-P1, C2-P2, and P1-P2, has the same value of 'n'. The distance between potential electrodes (P1 and P2) is represented by 'a'. The distance between the current electrodes is 2na + a. The research was conducted in Kranjingan Village, Sumbersari District, Jember Regency, East Java Province. The research location is located at the coordinates of 8°12'13.75"N and 113°43'37.70" E. Data collection took place on December 23-24, 2023. Sumbersari Subdistrict's rock formations consist of the Argopuro breccia unit and Argopuro fan sediment unit, stratigraphically speaking (Irawan et al., 2021).

Figure 1. Map of Location Sketches

The tools needed to obtain data for this research are as follows: a) resistivity meter, a DC source (12 V battery), electrodes, connecting cables, a meter, a hammer, a GPS, an HT (Handy Talky), stationery, books, crocodile claws, and a laptop. The data collection process involved injecting electricity into the earth through two current electrodes connected by cables. Additionally, the potential difference was measured through two potential electrodes. The resistivity value of each layer beneath the measuring point can be determined by measuring the current and potential difference between specific electrodes at varying distances. The resistivity meter displays the values of electric current (I) and voltage (V). The magnitude of the known current and voltage values can determine the rock's resistivity value.

Data analysis is done using data processing results using Res2Dinv software. From the data processing results, a 2-dimensional cross-sectional model will appear, which contains information on the depth and actual resistivity value of each soil layer. Furthermore, data processing is continued using Voxler software to find out the subsurface lithology of the research area in more detail by inputting the inversion result data in the Res2Dinv software in the form of X, Y, Z, and ρ data, which are longitude, latitude, depth, and resistivity so that 3-dimensional modeling is obtained using standard coloring of the subsurface layer of the research area.

RESULT AND DISCUSSION

The subsurface lithology of the Alas Kota Site was identified by estimating and analyzing the actual resistivity value obtained from data processing and correlating it with the resistivity value of each material according to the resistivity value table, the geological conditions of the research area and relevant previous

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research. The 2-dimensional modeling of each line is presented below. Estimation and analysis can identify the subsurface lithology of the Alas Kota Site. Shown below is the 2-dimensional model of each trajectory.

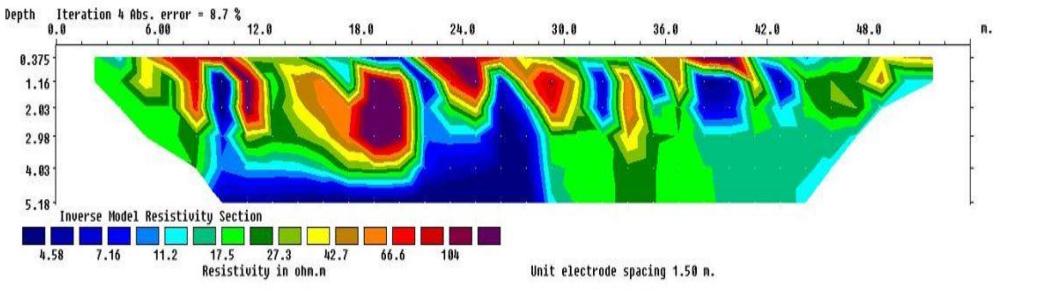

Figure 2 2D Resistivity Models for Line1

Line 1 starts at coordinates 8°12'13.96"S to 113°43'36.84"E and ends at coordinates 8°12'13.76"S to 113°43'38.50"E, with an elevation of approximately 107 meters above sea level. The line is 54 meters long with 37 electrodes spaced 1.5 meters apart. The iteration process for line 1 was 4, resulting in an error of 8.7%. The maximum depth measured on line 1 was 5.18 meters. The obtained resistivity values ranged from 4.58 Ωm to 104 Ωm. The 2-dimensional cross-section on line 1 was modeled using Res2Dinv software. Based on Figure 2, the subsurface layer on line 1 can be estimated as follows: the resistivity value of 4.58 Ωm - 42.7 Ωm with blue-yellow color image is suspected to be a clay layer located at a depth of ± 0.375 meters - 5.18 meters. The suspected layer of passive clay at a depth of ±0.375 meters - 4.03 meters is indicated by a resistivity value of 42.7 Ωm - 104 Ωm with a yellow-red color image. The resistivity value of >104 Ωm with a purple image indicates that the andesite and sand rocks are at the same depth.

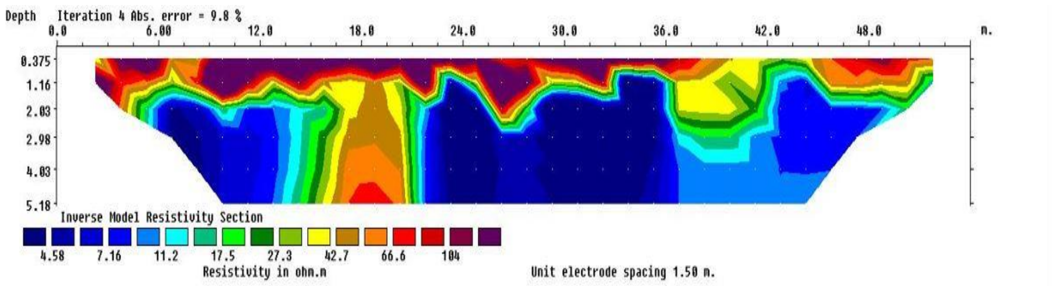

Figure 3. 2D Resistivity Models for Line 2

Line 2 starts at coordinates 8°12'13.66"S to 113°43'36.72"E and ends at coordinates 8°12'13.46"S to 113°43'38.48"E, with an elevation of approximately 107 meters above sea level. The line is 54 meters long with 37 electrodes spaced 1.5 meters apart. The iteration process was carried out four times, resulting in a measurement error of 9.8%. The maximum depth measured on line 2 was 5.18 meters. The obtained resistivity values ranged from 4.58 Ωm to 104 Ωm. The 2-dimensional cross-section on line 2 was modeled using Res2Dinv software. Based on Figure 3, the subsurface constituent layers on line 2 can be estimated as follows: the resistivity value of 4.58 Ωm - 42.7 Ωm with blue-yellow color image is suspected to be a clay layer located at a depth of ± 0.375 meters - 5.18 meters. The suspected layer of passive clay at a depth of ±0.375 meters - 5.18 meters has a resistivity value of 42.7 Ωm - 104 Ωm and is indicated by a yellow-red color image. The andesite and sand rocks located at a depth of ±0.375 meters - 2.03 meters have a resistivity value of >104 Ωm and are indicated by a purple color image.

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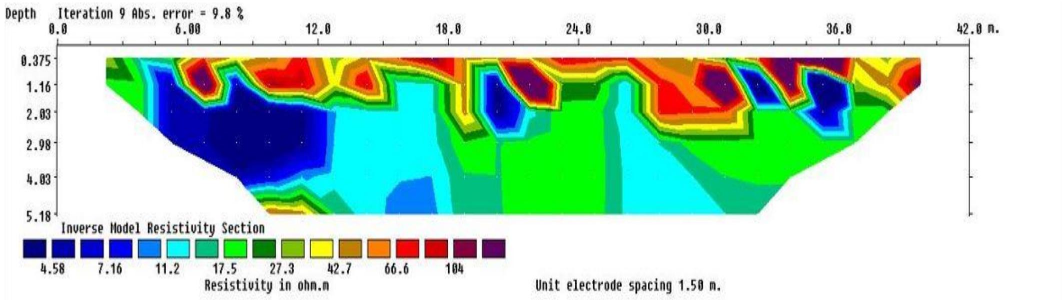

Figure 4. 2D Resistivity Models for Line 3

Line 3 has a starting point located at coordinates 8°12'14.19 "S to 113°43'37.52 "E and an end point located at coordinates 8°12'12.98 "S to 113°43'37.21 "E and an elevation of ±120 meters above sea level. The line length is 42 m with a spacing between electrodes of 1.5 m. The electrodes used were 29 pieces. The iteration process on line 3 was seven, and the resulting error was 5.8%. The maximum depth measured on line 3 reached 5.18 meters. The range of resistivity values obtained ranged from 4.58 Ωm to 104 Ωm. Modeling of the 2-dimensional cross section on line 3 using Res2Dinv software. Based on Figure 4, the subsurface constituent layers on tline 3 can be estimated as follows. The resistivity value of 4.58 Ωm - 42.7 Ωm with blue-yellow color image is considered a clay layer at a depth of ± 0.375 meters - 5.18 meters. A sensitivity value of 42.7 Ωm - 104 Ωm with a yellow-red color image is suspected to be a passive clay layer at a depth of ±0.375 meters - 2.03 meters. The resistivity value of >104 Ωm with the purple color image is thought to be andesite and sand rocks at a depth of ±0.375 meters - 2.03 meters.

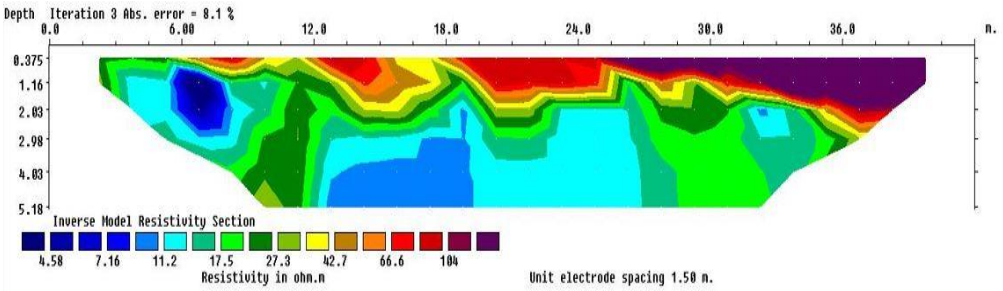

Figure 5. 2D Resistivity Models for Line 4

Line 4 has a starting point located at coordinates 8°12'14.17 "S to 113°43'37.84 "E and an end point located at coordinates 8°12'12.93 "S to 113°43'37.59 "E and an elevation of ±120 meters above sea level. The line length is 42 m with a spacing between electrodes of 1.5 m. The electrodes used were 29 pieces. The iteration process on line 4 was 3, and the resulting error was 8.1%. The maximum depth measured on line4 reached 5.18 meters. The range of resistivity values obtained ranged from 4.58 Ωm to 104 Ωm. Modeling of the 2-dimensional cross section on line 4 using Res2Dinv software. Based on Figure 5, the subsurface constituent layers on line 4 can be estimated as follows. The resistivity value of 4.58 Ωm - 42.7 Ωm with blue-yellow color image is considered a clay layer at a depth of ± 0.375 meters - 5.18 meters. A sensitivity value of 42.7 Ωm - 104 Ωm with yellow-red color is suspected to be a passive clay layer at a depth of ±0.375 meters - 2.98 meters. Resistivity value >104 Ωm with the purple color image is alleged to be andesite rock and sand located at a depth of ±0.375 meters - 2.98 meters.

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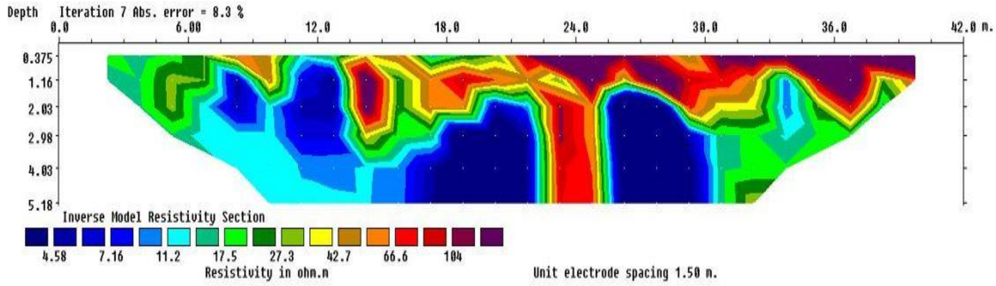

Figure 6. 2D Resistivity Models for Line 5

Line 5 starts at coordinates 8°12'14.10"S to 113°43'38.17"E and ends at coordinates 8°12'12.91"S to 113°43'37.96"E. The line 5 is 42 meters long with 29 electrodes spaced 1.5 meters apart and an elevation of approximately 120 meters above sea level. The iteration process was conducted seven times, resulting in an 8.3% error. The maximum depth measured on line 5 was 5.18 meters. The obtained resistivity values ranged from 4.58 Ωm to 104 Ωm. Res2Dinv software was used to perform two-dimensional cross-sectional modeling on line 5. Based on Figure 6, the subsurface layers on line 5 can be estimated as follows: clay layers are suspected to be present at depths of ±0.375 meters – 5.18 meters, with resistivity values ranging from 4.58 Ωm – 42.7 Ωm, as indicated by the blue–yellow color image. Suspected sandy clay layers are present at ±0.375 meters – 5.18 meters, indicated by resistivity values ranging from 42.7 Ωm to 104 Ωm and yellow to red color images. Andesite rock and clay layers at depths of ±0.375 meters – 2.03 meters are suspected to have resistivity values > 104 Ωm, indicated by purple color images.

The previously conducted two-dimensional modeling was unable to provide a comprehensive depiction of subsurface lithological conditions between lines. To ascertain the correlated subsurface lithological conditions across the line measurement in the field, a three-dimensional modeling was performed using Voxler software, utilizing processed data from Res2Dinv software stored in XYZ format. This modeling is anticipated to provide a distribution of inferred subsurface conditions for all five line with various material layers. The results of the three-dimensional modeling of subsurface lithology from the correlated line are presented below.

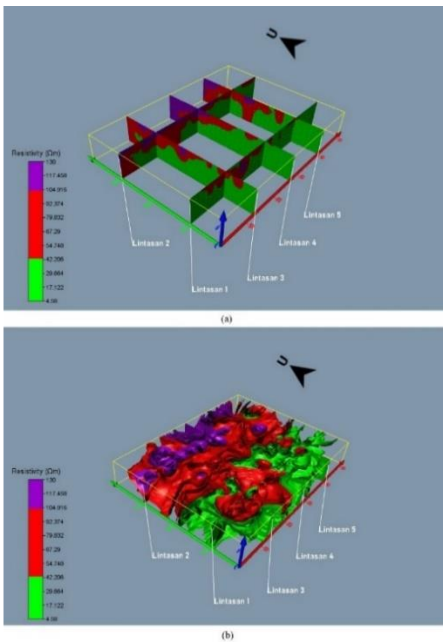

Figure 7. 3D Models for All Line

The subsurface lithology at the research site comprises different materials, as determined by the table of resistivity values and geological conditions. Clay layers are represented by the green color image, with

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resistivity values ranging from 4.58 Ωm to 42.7 Ωm. The red color image represents Sandy clay layers, with resistivity values ranging from 42.7 Ωm to 104 Ωm. The purple in the figure represents resistivity values > 104 Ωm, which are believed to correspond to andesitic rock and sand.

Figure 7 shows a three-dimensional model where all line have predominantly green-colored clay layers with resistivity values ranging from 4.58 Ωm to 42.7 Ωm. This finding is consistent with previous studies by Mufidah (2016) and Rahma (2018), which indicate that clay usually has resistivity values ranging from 3 Ωm to 42 Ωm. Irawan et al. (2021) state that the Sumbersari area's clay minerals result from weathering volcanic breccia. The weathering products include clay, sandy clay, and andesite fragments. Sandy clay layers, depicted in red, continue at the intersection of line 1 with line 3 and 4, with resistivity values ranging from 42.7 Ωm to 104 Ωm at depths of ±0.375 meters to 2.98 meters. At the intersection of line 2 with line 3, 4, and 5, sandy clay layers continue from depths ranging from ±0.375 meters to 2.98 meters. These continuous layers are presumed to be sandy clay layers associated with red brick structures. According to Mufidah's (2016) research, sandy clay types at the Biting Site are identified as red brick components. These types are composed of a mixture of clay and sand with resistivity values ranging from 34.8 Ωm to 92.6 Ωm. Rahma (2018) also identified the presence of red brick structures at the Alas Trik Site with resistivity values ranging from 32 Ωm to 100 Ωm. Scattered and buried red brick fragments have been found around the site and wells lined with red brick walls with depths of ±1 meters.

Additionally, there are anomalies with resistivity values >104 Ωm, depicted in purple, which are presumed to be andesitic rock and sand. According to Mufidah's (2016) and Rochman et al.'s (2017) research, andesitic rock and sand typically have resistivity values ranging from 100 Ωm to 141 Ωm. These anomalies are not evenly distributed across all line. However, based on the three-dimensional modeling, anomalies are most pronounced on line 3, 4, and 5, between points 24.8 meters to 42 meters, at depths of ±0.375 meters to 2.03 meters. The inference of the presence of andesitic rock and sand distribution at these points is reinforced by the presence of sand deposits and andesitic rocks around the research site, especially at the leading research site.

According to the Mount Raung Hazard Zone Map, the Alas Kota Site is within Zone I (Hazardous Zone I). This is supported by the Mayang River flow, which was the path of Mount Raung's lava flow to the north of the research site. As a result, this area is susceptible to volcanic disaster impacts in the form of volcanic material flows. The most significant eruptions recorded occurred in 1586, 1597, and 1638. The volcanic eruptions caused significant material flows that reached the Java Sea, the Indian Ocean, and the island of Bali. According to the National Disaster Management Agency (2023), thousands of people lost their lives. The Alas Kota Site is believed to have been buried due to these eruptions, supported by volcanic deposits near the Mayang River tributary north of the research site. Botjing et al. (2021) state that clay, sand, and gravel are volcanic sediment materials transported by water in lower plains. The volcanic deposits located north of the research site indicate the occurrence of geological disasters, such as lahars, resulting from significant eruptions of Mount Raung. These disasters substantially impacted the burial of structures at the Alas Kota Site.

CONCLUSION

Conclusion and Recomendation

Based on the research findings and discussions above, it can be concluded that the subsurface lithology of the Alas Kota Site consists of clay, which dominates the subsurface composition of the research site with resistivity values ranging from 4.58 Ωm to 42.7 Ωm, sandy clay associated with red brick structures with resistivity values ranging from 42.7 Ωm to 104 Ωm, and andesitic rock and sand with resistivity values >104 Ωm. These constituent materials originate from the breakdown of rock formations at the Alas Kota Site, which comprise the Argopuro breccia and Argopuro fan deposits. Additionally, these materials originate from the eruptions of Mount Raung that occurred over centuries, leading to the burial of the Alas Kota Site.

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