Gravity: Jurnal Ilmiah Penelitian dan Pembelajaran Fisika

http://jurnal.untirta.ac.id/index.php/Gravity

ISSN: 244-515x; e-ISSN: 2528-1976

Vol. 11, No. 1, Feb 2025, Page 01-15

Identification of groundwater potential based on geoelectrical resistivity method and hydrogeological survey (Case study of Sumber Waluh Hamlet, Pringgodani Village, Bantur District, Malang Regency)

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(Received: 05 November 2024; Accepted: 09 February 2025; Published: 12 February 2025)

ABSTRACT

Bantur District in Malang Regency is an area that is vulnerable to drought disasters. A geoelectrical resistivity survey has been conducted in Sumber Waluh Hamlet, Pringgodani Village, Bantur District, Malang Regency as an effort to mitigate drought disasters. This study aims to identify the distribution of aquifer layers based on the results of subsurface resistivity modeling. The identified aquifer layers can be used as a solution to the problem of drought disasters. In this study, geoelectrical resistivity measurements used the VES technique, i.e. the Schlumberger configuration, which was carried out at seven points. Analysis of the modeling results showed the existence of a shallow aquifer layer with a depth of 8-20 meters and a deep aquifer with a depth range of 50-70 meters. The aquifer layer has a resistivity value between 0.51-31.36 Ωm which is interpreted as a tuffaceous sandstone layer. In hydrogeological modeling, it is interpreted that the position of the groundwater level is at a depth of 40-50 meters. Thus, the results of this study can be used as a recommendation for drilling points to find new water sources in the research area.

Keywords: Groundwater, sumberwaluh hamlet, geoelectrical resistivity, schlumberger, hydrogeological survey

DOI: 10.30870/gravity.v11i1.29457

INTRODUCTION

Malang Regency has a potential for natural disasters ranging from low to high. Based on the Malang Regency Multi Disaster Risk Map (BPBD Malang Regency, 2019), one of the sub-districts in Malang Regency with a high potential for natural disasters is Bantur District. The main threat of hydrometeorological disasters in Bantur District is drought. This disaster mainly occurs when entering the dry season. Therefore, residents have difficulty getting access to clean water. Based on the Malang Regency BPBD report, in September 2015 a drought occurred in the Bantur District which was followed by a reduction in water sources. This drought disaster affected 2,216 families in Bantur District. Pringgodani Village was the village most severely affected by the 2015 drought disaster (BPBD Malang Regency, 2015).

The risk of drought disasters will increase in the future. This is due to factors of increasing population and climate change. Increasing in water consumption was followed by an increase in the need for water (Pamungkas et al., 2024). Based on the Central Statistics Agency of Malang Regency record, in 2021 the population of Bantur District was 75,716 people. A total of 7,641 people are in Pringgodani Village. Meanwhile, modeling the impact of climate change on the potential for drought disasters in the Bantur District will expand (Perdinan et al., 2017). One effort to mitigate drought disasters is by exploring deep groundwater. Deep groundwater is considered independent of the season (Sukhija, 2008). This is because deep groundwater is far below the ground surface so it is not affected by evaporation on the surface. In addition, groundwater also has a large volume. Therefore, groundwater is a water resource that is relied on for agriculture, civil, and industry (Haggerty et al., 2023). The groundwater is stored in rocks with high porosity and permeability. This layer of rock that stores groundwater is known as an aquifer. Groundwater stored in aquifers does not change much over thousands of years (Abdulkhaef et al., 2023).

So far, the resistivity geoelectric method is considered a powerful, efficient, and inexpensive technique in groundwater exploration (Riwayat et al., 2018; Mirzaei et al., 2021), with good results (Juwono et al., 2024) and environmentally friendly (Hasan et al., 2021). In fact, the resistivity geoelectric method can be used to explore groundwater in areas that have difficulty getting clean water, especially in karst areas (Boimau and Susilo, 2018, Susilo et al., 2017; Hasan et al., 2018; Ferhat et al., 2022). This method has the principle of injecting electric current into the ground, then the electric current flows below the surface, so that the resulting potential difference can be measured (Hasan et al., 2021). By using the data obtained, the subsurface resistivity can be modeled. The resistivity geoelectric technique by sounding or Vertical Electrical Sounding (VES) has the advantage of time efficiency so that it is suitable for mapping wider areas. The VES technique allows to obtain variations in resistivity values vertically with depth (Susilo et al., 2022).

Several studies have applied the VES technique with the Schlumberger configuration in groundwater exploration, including in Tulungagung Regency, Indonesia (Susilo et al., 2018), Tanjung Jabung Timur District, Jambi, Indonesia (Rahajoeningroem and Indrajana, 2020); Ota, Southwest Nigeria (Oyeyemi et al., 2021), Marpoyan Damai, Riau, Indonesia (Rahmalia and Juandi, 2021), Rajouri District, Jammu and Kashmir, India (Bhatnagar et al., 2022), Kirana Hills, Chiniot District, Pakistan (Sarwar et al., 2024), and Uthal Balochistan, Pakistan (Mahmud et al., 2024). These studies show that geoelectrical resistivity sounding is able to find the existence of aquifer layers and pockets. The results of VES interpretation are also able to provide information on thickness, depth, and lateral distribution (Abd El-Dayem et al., 2023). The aquifer layer that carries groundwater will have low resistivity properties. This is because in groundwater a number of ions from minerals are dissolved so that they conduct electric current through electrolyte conduction (Telford, 1990).

Groundwater exploration in Bantur District has been carried out regionally. Previously, Sholichin and Prayogo (2019) have identified potential groundwater zones in the southern part of Malang Regency using the VES method at 12 points spread over an area of approximately

100 square kilometers. However, the mapping was too broad so that the resolution was not detailed enough. As a result, the results of the groundwater potential zone mapping cannot be applied directly in Pringgodani Village, Bantur District. In addition, Sholichin and Prayogo's (2019) research only relied on interpretation of subsurface resistivity without correlating with other methods. Analysis of the results of resistivity geoelectric modeling will be more accurate if correlated with the results of hydrogeological mapping (Teixera et al., 2013). Hydrogeological modeling by creating a hydrogeological map will provide a conceptual picture of local hydrogeological conditions (Chaminé et al., 2015). Several studies have applied the correlation of subsurface resistivity data with hydrogeological data to obtain better interpretation results (Koch et al., 2009; Galazoulas et al., 2015; Lubang et al., 2023; Meng et al., 2024). The results of these studies indicate that subsurface resistivity profiles correlated with hydrogeological data will provide accurate delineation of dimensions and distribution of aquifers.

Based on this background, this study will conduct a VES resistivity geoelectric survey with a Schlumberger configuration in Sumber Waluh Hamlet, Pringgodani Village, Bantur District, Malang Regency. This study also maps the hydrogeological conditions of the research area by identifying water sources and rivers in the research area. From the results of this survey, the lithology and the presence of aquifers as a whole around the research location will be identified. The target of this study is to obtain information on the distribution and depth of aquifers at the research location. The results of this study will be a reference in finding new water sources. This is an effort to mitigate drought disasters in the research area.

Geological and geohydrological setting

Physiographically, the research area is located in the Southern Java Mountains zone which is dominated by hilly and valley morphology. The elevation was ranging between 300 and 400 meters above sea level (Van Bemmelen, 1949). Based on the Turen sheet geological map (Sujanto et al., 1992), the lithology of the research area consists of three formations (Figure 1). The oldest formation is the Wuni formation (Tmw) which is Early-Middle Miocene in age. This formation is found south of the research location. The Wuni Formation is composed of Tertiary volcanic products, namely breccia, andesite lava, tuff breccia, lahar breccia, and sandy tuff. Furthermore, above the Wuni Formation, the Nampol Formation (Tmn) is deposited with a lithological composition in the form of layers of tuffaceous or calcareous sandstone, black mudstone, sandy marl, and calcareous sandstone. This formation is Middle Miocene in age. The Nampol Formation dominates the research area. The youngest formation is the Wonosari Formation (Tmwl) which is Late Miocene-Pliocene in age. The Wonosari Formation consists of limestone, sandy marl with mudstone inserts. This formation is found in the southeastern part of the research location.

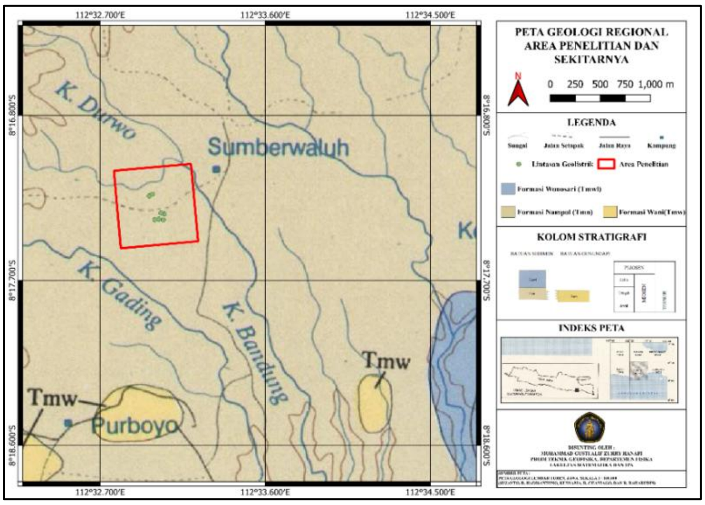

Figure 1. Geological map of the research location (Sujanto et al., 1992).

Based on the regional hydrogeological map of the Kediri sheet (Poespowardoyo, 1984), the research area has a lithology composition of sandy limestone with fractures. The aquifer productivity in the research area is classified as a high to moderate productive aquifer, i.e. groundwater flow is limited to the fissure zone, fractures and dissolution channels. Meanwhile, the discharge of wells and springs varies in a very large range.

RESEARCH METHODS

The research location is in Sumberwaluh Hamlet, Pringgodani Village, Bantur District, Malang Regency, East Java. The research area covers an area of 180×200 square meters. In this survey, sounding measurements were carried out at seven points. The determination of the location of the measurement points considered the distribution of springs in the research area and measurement access. The distance between points varies from the closest 40 meters to the farthest 160 meters. The distribution of measurement points and the design of the research survey are shown in Figure 2.

Figure 2. Survey design in the research area. Yellow pins indicate measurement points.

The determination of the research location is based on the potential of groundwater sources in the area. The results of the location survey show that Sumberwaluh Hamlet has traces of rivers and dried up dug wells. This is the main reference in determining the VES data collection point with the Schlumberger configuration. The grid model is used in determining the point. The locations of points T1, T2, and T4 are parallel. Likewise with other points, such as T6, T3, and T7. Making a grid model for points that are parallel horizontally and vertically can facilitate interpretation. This is because the points can be correlated in 1D or 2D. By correlating these models, the results obtained will be more accurate.

The tools and materials used in this study include the OYO mcOHM-EL Resistivitymeter, a set of electrodes, cables, and meters. In this study, a resistivity geoelectric survey was conducted using the Schlumberger configuration. This configuration uses four electrodes, two current electrodes (C1 and C2) and two potential electrodes (P1 and P2). These four electrodes are arranged to form a configuration as shown in Figure 3. In this configuration, the current electrode is placed further away than the potential electrode. For vertical sounding purposes, the potential electrode is in a fixed position. Meanwhile, the current electrode is expanded symmetrically about the center of the spread (Telford, 1990).

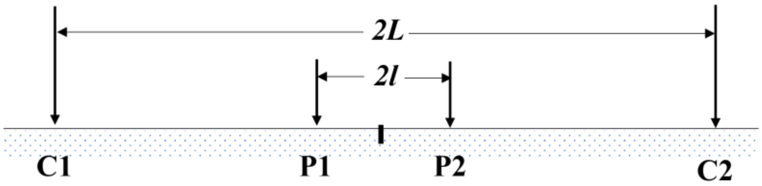

Figure 3. The electrode arrangement is in the Schlumberger configuration (Telford, 1990).

To obtain the subsurface resistivity value with the Schlumberger configuration, the following geometric factor equation is used:

$$\rho_a = \frac{\pi L^2}{2l}\left(\frac{\Delta V}{I}\right) \tag{1}$$

Where ρ_a is the apparent resistivity, L is half the length of the span of the current electrodes C1 and C2, l is half the length of the span of the potential electrodes P1 and P2, ΔV is the potential difference, and I is the current.

In this survey, the distance between electrodes ranges from 2 to 10 meters. Meanwhile, the potential electrode moves in multiples of 2 meters and 20 meters. At each measurement point, the total length of the span is 400 meters. The results of field measurements are processed by inversion using IP2Win, Progress and Rockworks software. As a final result, a 1D and 2D underground resistivity cross-section model is obtained.

Hydrogeological mapping is carried out by measuring the coordinates of springs and rivers whose water is directly used by local residents. Furthermore, the location of springs and rivers is mapped using QGIS software to obtain a hydrogeological map of the research area. From the resulting hydrogeological map, the hydrological correlation and local geological and geomorphological conditions can be interpreted. This will provide information on the availability of water in the research area, estimated groundwater depth, and the direction of groundwater flow.

RESULT AND DISCUSSION

The results of the resistivity geoelectric survey in the research area obtained seven measurement points with labels T1, T2, T3, T4, T5, T6, and T7. The data obtained from the field survey were processed to obtain a resistivity column and its depth. The results of the processing and interpretation are presented as follows.

The 1D resistivity modeling at point T1 obtained a resistivity column model up to a depth of 133 meters. The apparent resistivity values obtained ranged from 0.51 to 150.11 Ωm (Figure 4). Sequentially, from upper to bottom layers, it is interpreted that there are layers of topsoil, clay, tuffaceous sandstone, calcareous sandstone, and bedrock. At point T1, the layer interpreted as an aquifer is a tuffaceous sandstone layer with an apparent resistivity of around 5.63 Ωm with a depth of 13.08 to 23.14 meters. In addition, at a depth of 44.28-54.03 meters, a layer with a low resistivity value (0.51 Ωm) was also found, which was interpreted as tuffaceous sandstone. This shows that at point T1 there are two aquifers, i.e. a shallow aquifer (13.08-23.14 meters) and a deep aquifer (44.28-54.03 meters).

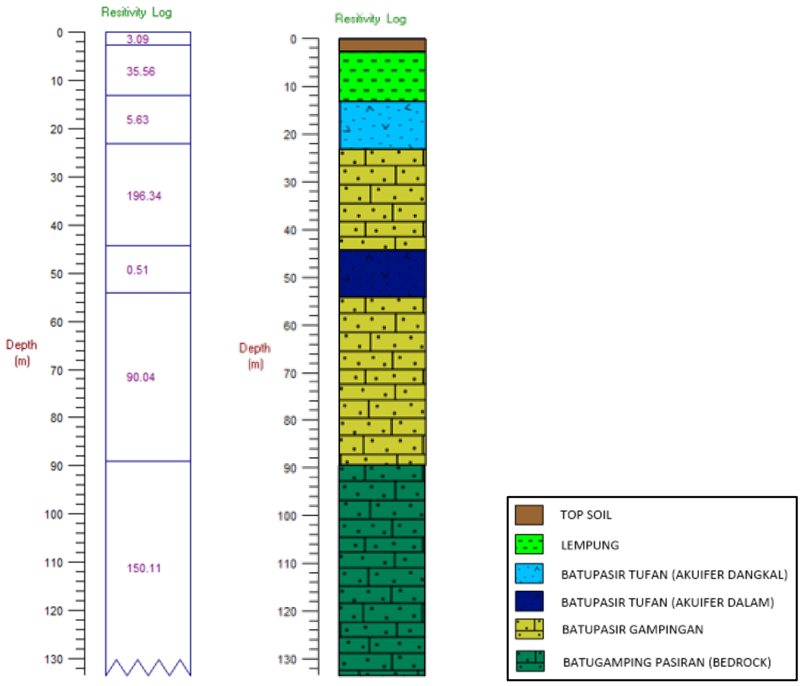

Figure 4. Results of 1D model interpretation at point T1

If we observe the 1D resistivity modeling at point T2, 7 rock layers are identified (Figure 5). The resistivity values obtained range from 1.59 to 7250.16 Ωm. From the top to a depth of 133 meters, a number of layers are obtained which are interpreted as topsoil, clay, tuffaceous sandstone, calcareous sandstone, tuffaceous sandstone, calcareous sandstone, and bedrock. At point T2, the aquifer is a tuffaceous sandstone layer. This layer is found at a depth of 6.81 to 10.31 m which is a shallow aquifer. In addition, at a depth of 55.98 to 78.29 m, a tuffaceous sandstone layer with a resistivity of 27.65 Ωm is also found, which is interpreted as a deep aquifer.

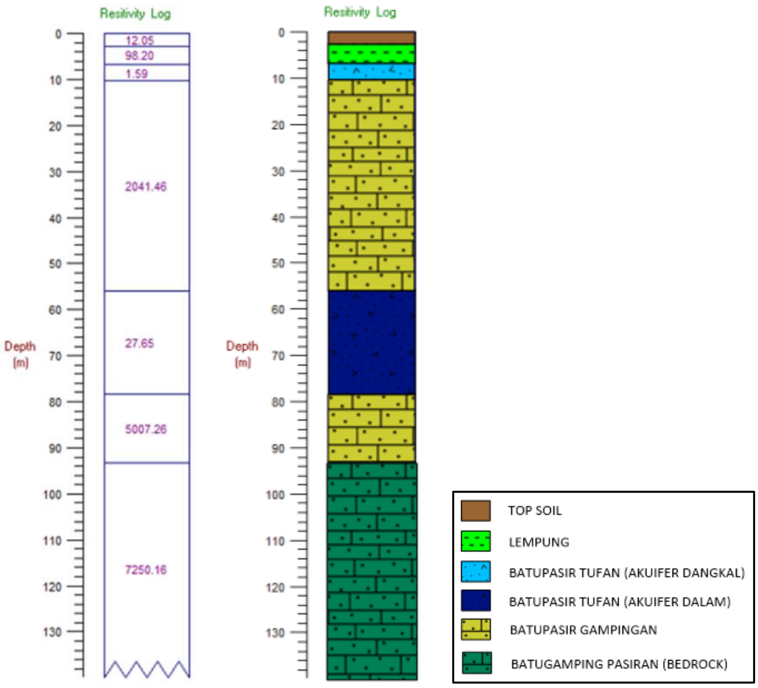

Figure 5. Results of 1D model interpretation at point T2

In the 1D resistivity model at point 3, 8 rock layers are interpreted (Figure 6) with resistivity values of 0.98-989.87 Ωm. Based on the correlation of resistivity values and local geology, it is interpreted that from the top to a depth of 133 meters, there are layers of topsoil, clay, tuffaceous sandstone, calcareous sandstone, tuffaceous sandstone, calcareous sandstone, and bedrock. At point T3, a layer interpreted of being a shallow aquifer was found at a depth of 6.62-13.91 meters with a resistivity of 8.77 Ωm which is a tuffaceous sandstone layer. Meanwhile, a deep aquifer layer was found at a depth of 38.27-68.82 with a resistivity value of only 0.98 Ωm which is also a tuffaceous sandstone layer.

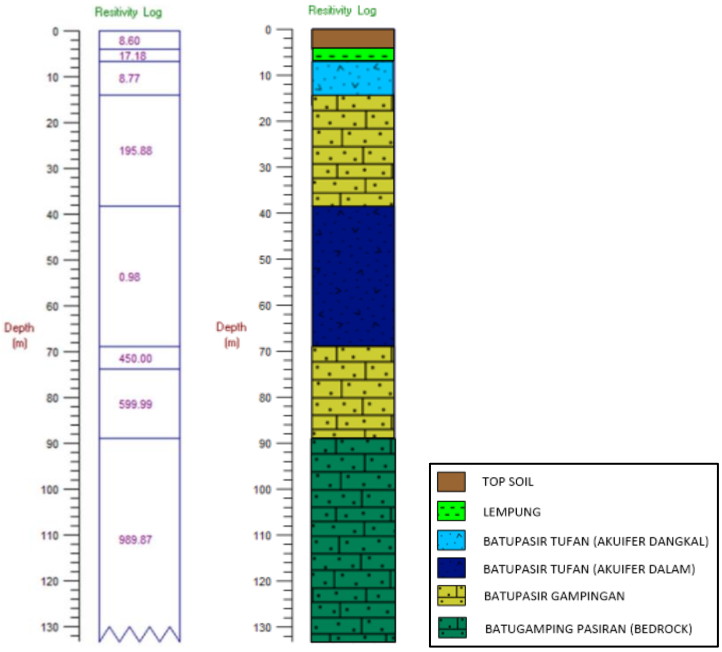

Figure 6. Results of 1D model interpretation at point T3

At point T4 there are 6 layers of rock with apparent resistivity values of 6.30-8582.95 Ωm (Figure 7). Sequentially, from the top to a depth of 133 meters at point T4 it is interpreted that there are layers of topsoil, clay, tuffaceous sandstone, calcareous sandstone, and bedrock. Based on the model in Figure 7, it is known that low apparent resistivity values are only found in the top layer which is suspected to be topsoil and clay. However, at a depth of 6.73-19.98 m, a layer with a resistivity value of 6.30 Ωm is found. This layer is interpreted to be tuffaceous sandstone which acts as a shallow aquifer. Thereafter, at a depth of up to 133 meters, the rock resistivity increase. Therefore, at point T4 there is no deep aquifer layer was observed.

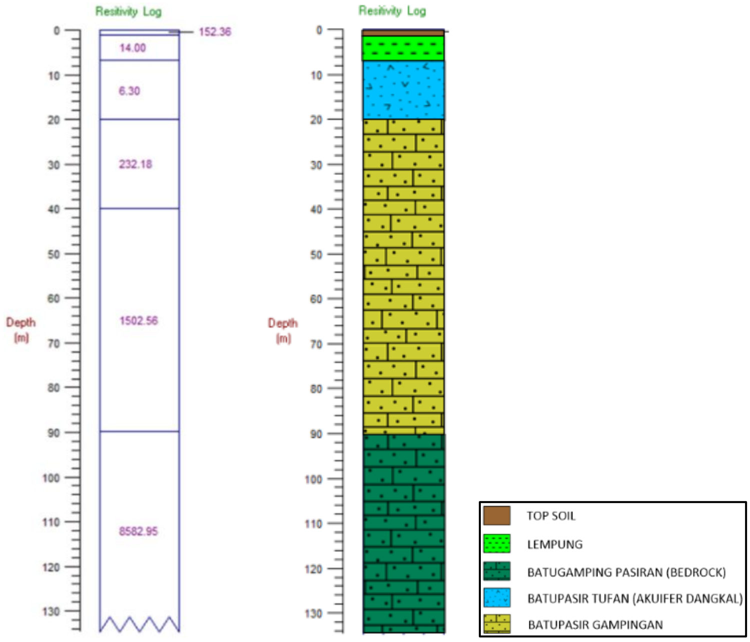

Figure 7. Results of 1D model interpretation at point T4

In the 1D model of point T5, there are 9 rock layers with apparent resistivity values of 4.30-252.83 Ωm (Figure 8) which are sequentially interpreted from the top to a depth of 133 meters as topsoil, calcareous sandstone, tuffaceous sandstone, and calcareous sandstone. At a depth of 6.42-19.69 meters, a shallow aquifer layer in the form of tuffaceous sandstone with a resistivity of only 4.30 Ωm is indicated. With a resistivity value that only has a range of 31.36-252.63 Ωm between depths of 20.67-133 meters, the deep aquifer layer is not identified at point T5.

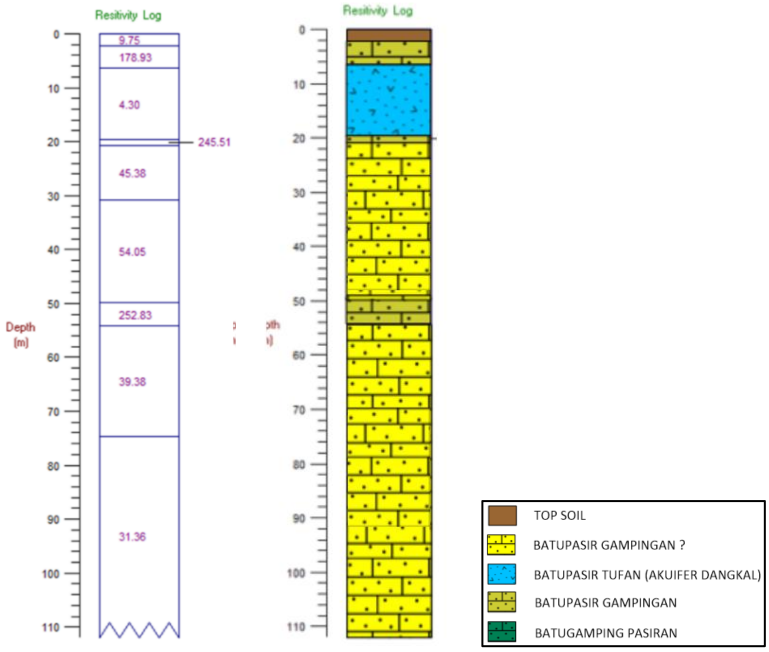

Figure 8. Results of 1D model interpretation at point T5

The results of 1D resistivity modeling at point T6 are shown in Figure 9. In the model, the rock resistivity value has a range of 2.28-497.76 Ωm which sequentially from the surface to a depth of 133 meters is interpreted as a layer of topsoil, clay, calcareous sandstone, clay, tuffaceous sandstone, calcareous sandstone, and bedrock. At point T6 the low resistivity value on the surface is interpreted as a layer of topsoil and clay. A layer with a low resistivity value (2.59 Ωm) is discovered again at a depth of 43.78-59.74 meters. This layer is interpreted as tuffaceous sandstone which acts as a deep aquifer.

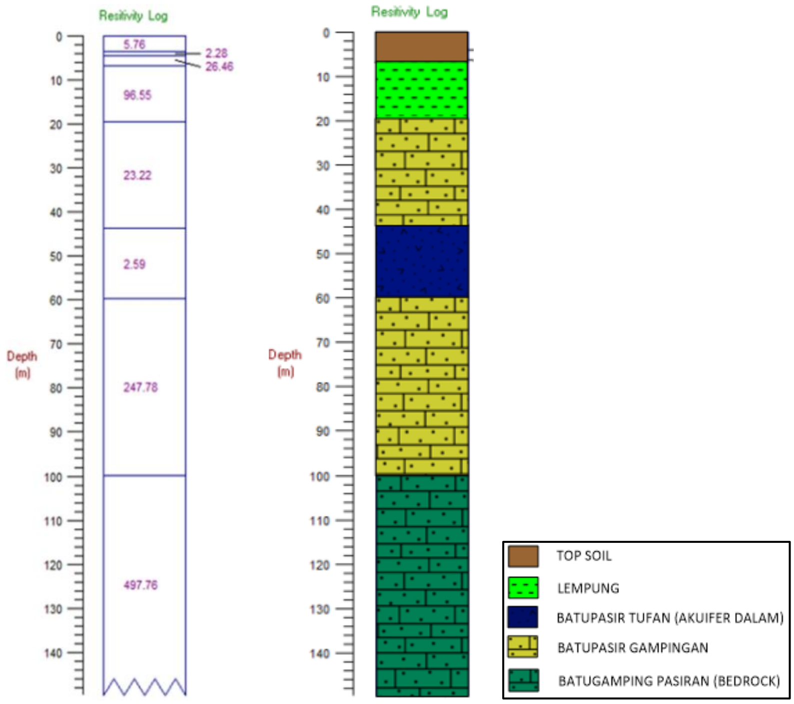

Figure 9. Results of 1D model interpretation at point T6

The results of 1D resistivity modeling at point T7 show the presence of 7 rock layers with apparent resistivity values of 4.47-729.79 Ωm (Figure 10). From the surface to a depth of 133 meters, it is interpreted that there are layers of topsoil, clay, tuffaceous sandstone, calcareous sandstone, tuffaceous sandstone, calcareous sandstone, and sandy limestone (bedrock). A layer with low resistivity (5.47 Ωm) was identified at a depth of 49.68-63.37 meters. This layer is interpreted to be a deep aquifer layer, namely a tuffaceous sandstone layer.

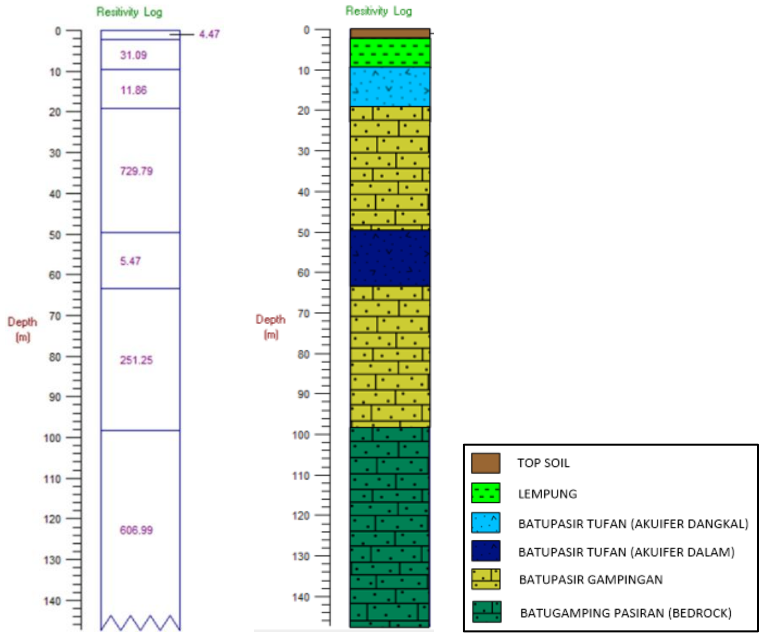

Figure 10. The results of the 1D model interpretation at point T7.

Based on the interpretation results of the seven VES points, it is known that there are two types of aquifer layers, i.e. shallow aquifers and deep aquifers. Based on observations in the field, residents' wells generally have a depth of around 10 meters. These wells will dry up in the dry season. When correlated with the interpretation results of the aquifer depth, residents' wells only reach shallow aquifers which are relatively thin and seasonal in nature. In order to obtain groundwater with a larger discharge and not dependent on the season, drilling needs to be carried out to the deep aquifer layer.

The measurement results show a fairly low resistivity value (0.51-31.36 Ωm) in the depth range of 50-70 meters at points T1, T2, T3, T6, and T7. This is interpreted as the presence of a deep aquifer layer at a depth of 50-70 meters. This deep aquifer layer has the potential to be used as a water source. Therefore, the recommended locations for drilling are points T1, T2, T3, T6, and T7. Drilling was carried out to a depth of 50-70 meters which is a layer of tuffaceous sandstone.

Meanwhile, the hydrogeological survey in the field found 24 springs and rivers. The measurement locations have elevations ranging from 282-400 meters above sea level. This elevation plays a role in estimating the depth of groundwater in the research area in accordance with the elevation of its surface water (springs and spring rivers). This is due to the absence of well data around the research area. Furthermore, a contour map was made based on the elevation of the groundwater level and springs so that a hydrogeological map was obtained as in Figure 11.

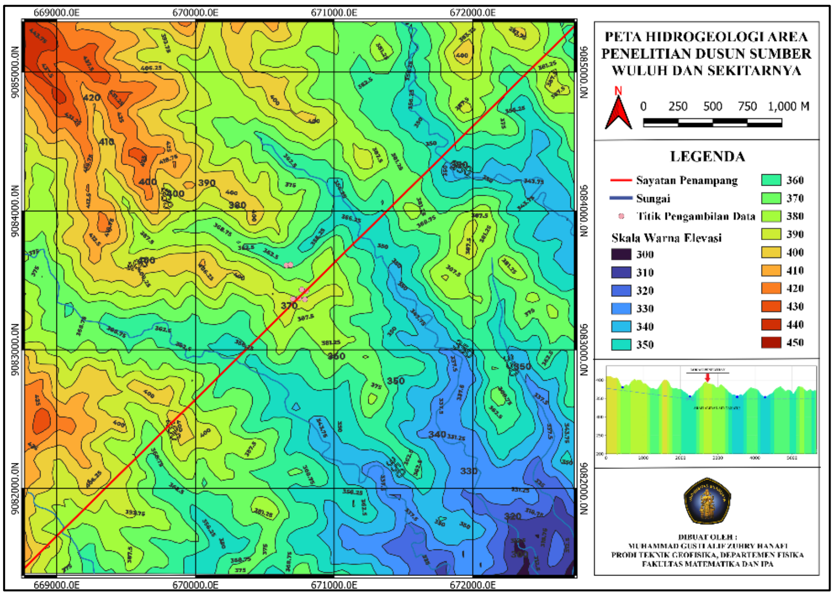

Figure 11. Hydrogeological map in research area.

Furthermore, the results of the 1D resistivity model interpretation are correlated with the hydrogeological model of the research area. The hydrogeological map section of the research area is shown in Figure 11. The figure contains information on the interpretation of the direction of groundwater flow in the research area. The research location is on a ridge flanked by two valleys marked by river flow. By connecting the river water surface points around the research area, it can be concluded that the groundwater level in the research area is marked as a contact between the saturation and aeration zones.

Based on Figure 12, the groundwater level forms a basin. The direction of groundwater flow around the research location is estimated to be West-East so that it accumulates in the valley on the west flank. Based on the position of the groundwater level at the research location, the water saturation zone or aquifer is at a depth of 35-40 meters from the ground surface. Based on the subsurface resistivity and hydrogeological models, both show the position of the deep aquifer in the research area at a depth of more than 50 meters.

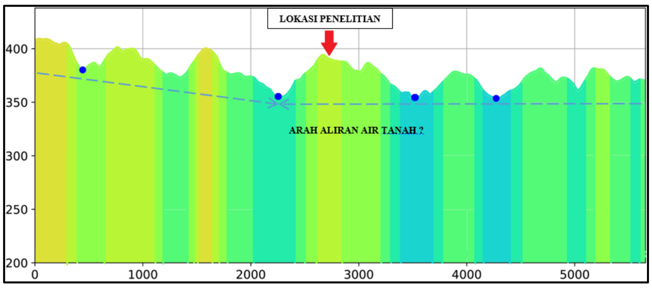

Figure 12. Interpretation of groundwater flow direction around the research area.

Research conducted by Solichin and Prayogo (2019) showed that the aquifer layer in the southern part of Malang Regency is at a depth of between 5-30 meters. The different depth values from this study are due to differences in the distribution of measurement points and the scope of the research area. In this study, measurement points that are more adjacent with a narrow research location show an aquifer depth of up to 50 meters. The eminency of a VES survey with a more specific location is that it is able to provide a more detailed conception of lithology and hydrogeology variations. In addition, in this study in Sumberwaluh Hamlet, the appearance of shallow and deep aquifer layers can be identified. These two types of aquifers were not found in VES survey measurements with a wide area coverage.

CONCLUSION

Based on the results of the VES resistivity geoelectric survey in the Sumberwaluh Hamlet area, Pringgodani Village, Bantur District, the rock resistivity value was found to have a range of 0.51-8,582.95 Ωm. Based on the resistivity value, it is interpreted that there are layers of topsoil, clay, tuffaceous sandstone, calcareous sandstone, and sandy limestone. The rock that acts as an aquifer layer is tuffaceous sandstone with a resistivity range of 0.51-31.36 Ωm. Based on 1D modeling of subsurface resistivity, it is known that there are two types of aquifers, namely shallow and deep aquifers. Furthermore, drilling is recommended at points T1, T2, T3, T6, and T7 at a depth of 50-70 meters until it reaches the deep aquifer layer.

ACKNOWLEDGMENT

The author would like to thank the Faculty of Mathematics and Natural Sciences, Brawijaya University, which has funded this research using internal funding with a letter of agreement number: 2612.20/UN01.F09/PN/2024.

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