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Investigation of Groundwater Sources in Banyol Hamlet Malang Regency Using the Geoelectrical Resistivity Method to Overcome Drought Strategy

Alamsyah M. Juwono[1], Adi Susilo[1], Muhammad Fathur Rouf Hasan[1,2], Nieske Ari Yunika[1], Muhammad Wafa Husain Mujtab[1], Achmad Achdan Annabil[1], Saffanatul Haniyyah[1]

[1] *Physics department, Faculty Mathematics and Natural Science, Brawijaya University, Indonesia*

[2] *Civil Engineering Department, Politeknik Negeri Jakarta, Indonesia*

Corresponding Authors E-mail: amjuwono@ub.ac.id, adisusilo@ub.ac.id, rouf@sipil.pnj.ac.id

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Abstract

The drought in Banyol Hamlet, Malang Regency, severely impacts community sustainability. This problem can be overcome if the hamlet has a groundwater source; theoretically, groundwater can be detected using geoelectric resistivity. This research aims to investigate the existence of aquifer layers in Banyol Hamlet, Malang Regency, using the resistivity method Schlumberger configuration. Resistivity data was measured at 5 points with a track stretch of 400 m and a distance between electrodes of 5 m; then, three parallel measurement points were interpolated into a 2D cross-section. Based on the analysis, the presence of the aquifer is considered to be in the breccia tuff layer because the resistivity value is lower than usual in this layer. So, we assume that the tuff breccia rocks can act as an aquifer in the study area. The results of the 2D cross-section show that the shallow aquifer is found at a depth of 10-22 m with a resistivity value of around 30.78 Ωm - 314 Ωm. and a deep aquifer at a depth of 40-125 m with a resistivity value of around 22.34 Ωm - 192 Ωm. So drilling is recommended at measurement points SS-1 and SS-3 in deep aquifers because the thicker the soil layer, the more water infiltration.

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Introduction

The long dry season and climate abnormalities, such as El Nino, are several factors causing drought in several regions in Indonesia. Apart from that, this phenomenon is getting worse due to climate change in the last 10 years. Therefore, the availability of water supply, both surface and subsurface, is crucial in overcoming drought [1]. Malang Regency is one of the regions in East Java with varied topography consisting of lowlands, highlands, active mountains, inactive mountains and several rivers. Based on height, the Malang Regency area is grouped into 4 large groups, one of which is Singosari District, which has an altitude range of 100 – 500 m above sea level with wavy topography. These topographic conditions result in various slope angles so that rainwater falls as surface runoff and is not completely absorbed into the ground. This process makes it difficult to find water sources in areas near the surface, making the potential for drought even greater [2].

Wonorejo is one of the villages in Singosari District, Malang Regency, that requires alternative solutions to meet the water source. Based on the information from the East Java Province Bappeda, Wonorejo Village had a history of water crises in September 2012. Approximately 350 out of 1970 heads of families have to queue for water assistance because the residents' water reserves and wells have dried up [3]. Apart from that, Wonorejo Village has a reasonably large population, reaching 6,160 people in 2020, with a growth of 0.11% over the last ten years [4], so water demand in Wonorejo Village will increase over time. Wonorejo Village, Singosari District, is located at geographical coordinates 7°21′-7°31′ SL and 110°10′-111°40′ EL. Geologically, Wonorejo Village is included in the Lower Quaternary Volcanic Rock formation, which is composed of volcanic breccia, tuff breccia, lava, tuff and agglomerate [5]. Research conducted by Fatahillah et al. (2024) stated that breccia rock has a good ability to become an aquifer compared to limestone [6]; theoretically, Wonorejo Village has the potential to have groundwater reserves. Aquifers are able to store and circulate water in the underground layers so that their presence can be detected to obtain groundwater [7].

The geoelectrical resistivity method is commonly used to identify subsurface conditions such as fault structures, bedrock, stratigraphic composition, and hydrological characteristics that can be obtained based on rock resistivity values [8]. In recent decades, geoelectrical methods have been widely used to investigate the presence of groundwater, and the results have proven to be quite good [9], [10], [11]. In the geoelectric method, every layer or different type of rock will have a different resistivity value; this condition is caused by differences in mineral content, dissolved salts, and water content. The resistivity value will be low if rocks are found saturated by water; this condition then becomes the basis for determining the aquifer in an area [12]. So, this research aims to investigate the existence of aquifer layers in Banyol Hamlet, Malang Regency, using the resistivity method schlumberger configuration. The results of this research will likely determine the potential of aquifer and groundwater to meet water needs in Wonorejo Village, Malang Regency.

Experimental Method

Acquisition Techniques

The resistivity geoelectric method has a working principle of injecting direct electric current (DC) into the soil through two current electrodes (AB) and measuring the potential difference between the two potential electrodes (MN) [13]. This acquisition process uses an instrument similar to the Naniura type. The configuration used is Schlumberger because it is more efficient at obtaining deeper penetration and optimal for error accumulation [14]. The Schlumberger configuration electrode arrangement is shown in Figure 1. This configuration requires the current electrode to move away to the farthest line, and the potential electrode does not move, provided that MN is less than AB/5 [15], [16].

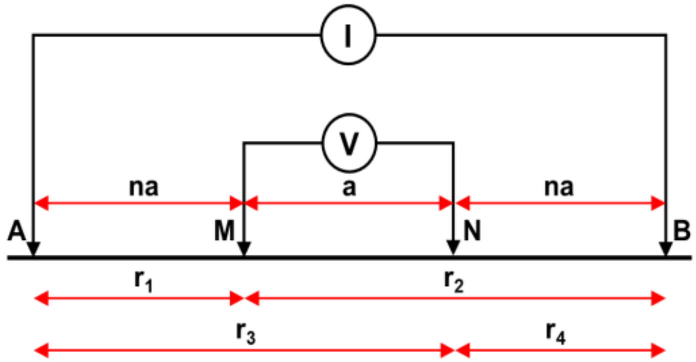

Figure 1. Schlumberger configuration [11]

The research was conducted on May 2 – 3, 2021, in Banyol Hamlet, Wonorejo Village, Singosari District, Malang Regency. There are 5 measurement points using the survey design in Figure 2. The total length of the line for each measurement point is approximately 400 m with an electrode distance of 5 m. The results obtained are the value of injection current (I) and measured potential difference (V), which are processed to obtain a 1 D model resistivity. The 2D cross section is obtained from 2 lines data from a combination of 3 measurement points, namely between points SS-1, SS-2, SS- 5 (line AB) and between points SS-2, SS-3, and SS- 5 (line AC).

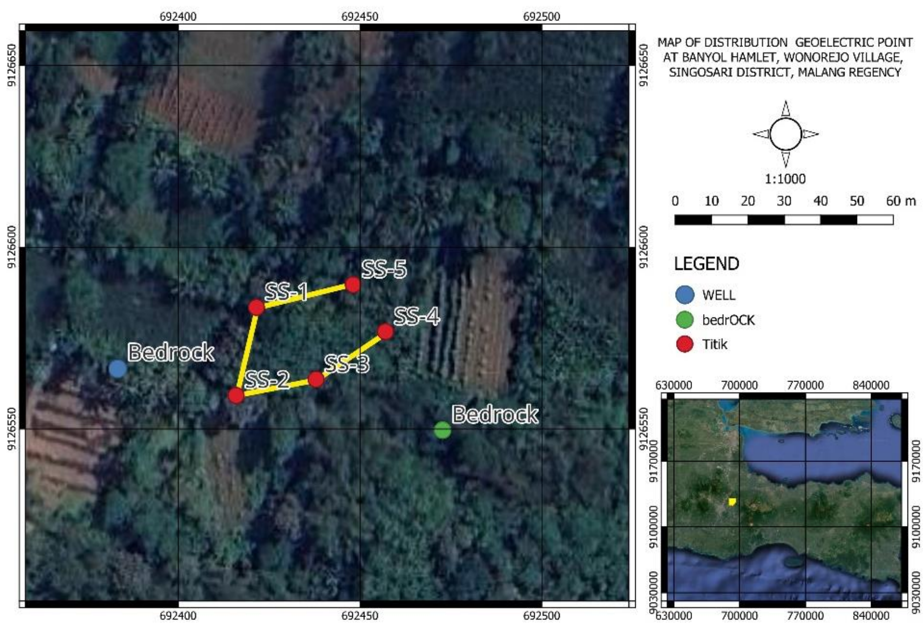

Figure 2. Acquisition Survey Design

Data Processing and Data Interpretation

The acquisition results are used to obtain apparent resistivity values because the subsurface layer of the earth is not homogeneous. The apparent resistivity value is calculated from the Schlumberger configuration's geometric factor value (k). The apparent resistivity value is expressed in the following equation:

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

The geometric factor of the Schlumberger configuration is expressed in the following equation:

$$K = \pi a(n + n^2) \tag{2}$$

Where ρ_a is the apparent resistivity (Ωm), $\Delta V/I$ is the resistance (Ω), a is the distance between potential electrodes (m), and n is the multiple values [17], [18].

Resistivity values that are close to actual conditions were obtained by carrying out a least squares inversion process using IP2WIN software [19], [20]. The less square inversion method uses a mathematical approach to obtain the smallest difference from the error of the smallest resistivity value to the actual resistivity model [21]. The inversion method produces a 1D model of the resistivity value of each measurement point relative to depth [22]. The 1D model can be developed into a 2D cross-section using RockWorks Software by interpolating at least 2 parallel measurement points [18]. The resistivity values resulting from processing were correlated with the regional geological map of Malang Regency to support the interpretation of the rock resistivity in the research area. We identified the lowest resistivity value in this study as tuff breccia, which can function to store water. This is related to the previous research by Fatahillah et al. (2020), where the tuff-breccia has a good porosity and permeability as an aquifer. Interpretation is carried out to determine the potential presence of groundwater, which is indicated by the distribution of low resistivity values [23].

Result and Discussion

Based on the Regional Geological Map Malang Quadrangle, the geological condition of the research area is in a formation consisting of breccia tuff, lava, tuff and agglomerate rocks [5]. This is in accordance with the types of rocks found in the research area: tufa, breccia, and lava. The morphological condition of the research area is a gentle hillside area with a distance of 50 m from residential areas. Based on the hydrogeological map of Kediri, there are high-medium productive aquifers, so the research area has the potential to have water source reserves. Still, the community has not yet discovered them. This condition requires an investigation of groundwater sources. Based on the hydrogeological map of Indonesia, the research area is in a moderately productive aquifer zone with a wide distribution and flow through fissures, fractures, channels on volcanic slopes, and well discharge and springs varying in a very large range [24].

The availability of groundwater is influenced by geological conditions in each area, namely lithology, structure, and rock porosity (opening system) [25]. The aquifer layer has good porosity and permeability, so it can store and drain groundwater [22]. Based on Figure **3**, the presence of the aquifer is considered in the breccia tuff layer. The volcanic breccia layer with coarse tuff content has good porosity and permeability as a groundwater aquifer [6]. This statement is also supported by research conducted by Fadillah et al. (2023); tuff-breccia are classified into the medial zone which is defined as a layer composed of volcanic sediment, including lava at the top and tuff breccia at the bottom. This zone indicates the presence of an unconfined-confined aquifer [26].

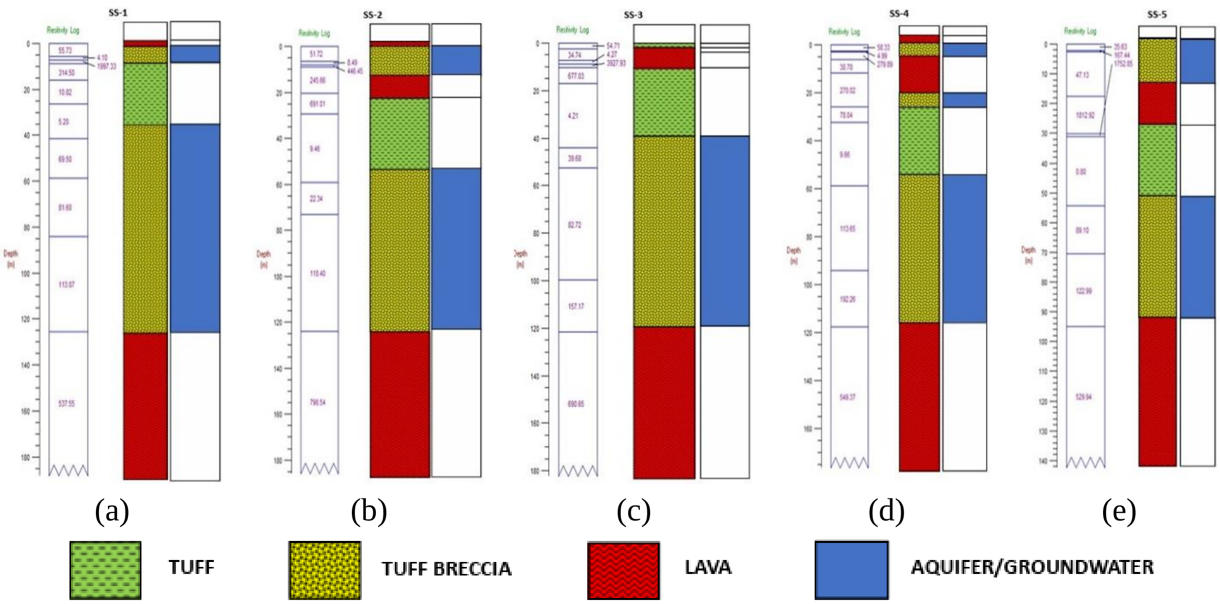

Figure 3. Lithological Interpretation of Measurement Points (a) SS-1; (b) SS-2; (c) SS-3; (d) SS-4; and (e) SS-5.

Figure 3 shows the results of interpreting and processing subsurface geoelectric data at the research location. Based on Figure 3 (a), there is tuff breccia rock at a depth of 8.7 – 16.1 m with a resistivity value of 314 Ωm, which is identified as a shallow aquifer. Breccia tuff rock was also found at a depth of 41.4 – 125.5 m with a resistivity value of 69.5-113 Ωm, identified as a deep aquifer. In Figure 3 (b), there is tuff breccia rock at a depth of 9.1 – 20.4 m with a resistivity value of 245.66 Ωm, which is identified as a shallow aquifer. Breccia tuff rock was also found at a depth of 59.1 – 124 m with a resistivity value of 22.34-118.4 Ωm, identified as a deep aquifer. In Figure 3 (c), breccia tuff rock was found at a depth of 44.1 – 121.6 m with a resistivity value of 39.68-82.72 Ωm, identified as a deep aquifer. In Figure 3 (d), the breccia tuff rock is at a depth of 11.8 – 26 m with a resistivity value of 30.78 Ωm, which is identified as a shallow aquifer. Breccia tuff rock was also found at a depth of 32.4 – 58.8 m with a resistivity value of 78.04 Ωm and at a depth of 94.2 – 117.7 m with a resistivity value of 113-192 Ωm, identified as a deep aquifer. In Figure 3 (e), breccia tuff rock is found at a depth of 2.7 – 17.5 m with a resistivity value of 47.13 Ωm, which is identified as a shallow aquifer. Then, breccia tuff rock was also found at a depth of 54.3 – 95 m with a resistivity value of 89.1-122 Ωm, identified as a deep aquifer.

The results of the water source exploration in Wonorejo Village show the presence of a groundwater aquifer with high potential. The research results show that the aquifer is made up of both shallow and deep aquifers with high porosity and permeability. Tuff breccia, an igneous rock, often has high resistivity values. It is related to previous research; according to Fadillah et al. (2023), the tuff-breccia unit has a resistivity of around 150 - 300 Ωm. However, the results of this study show relatively low resistivity levels. So, this lower resistivity in this rock is interpreted as the presence of water within the tuff-breccia rock [26]. However, the results of this study show relatively low resistivity levels, indicating the presence of water within the tuff breccia rock. This tuff breccia rock has a high potential as an aquifer due to its porosity, permeability, and resistivity.

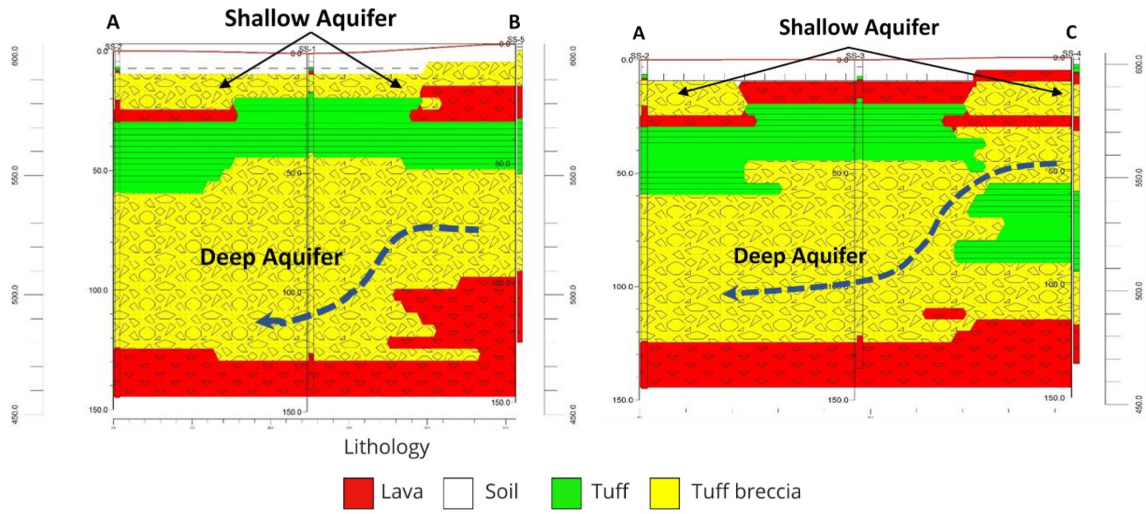

Figure 4. Lithology modelling results and underground flow direction (a) AB Line and (b) AC Line.

The interpolation results are modelled in Figures 4(a) (line AB) and (b) (line AC). Model (a) connect SS-1, SS-2, and SS-5 points while model (b) connects SS-2, SS-3, and SS-4 points. The surface layer found was soil with tufa aggregates and some contained lumps of breccia. The aquifer is thought to exist in Tuff Breccia rocks, with the aquifer system flowing in rock gaps. The shallow aquifer is estimated to be evenly distributed in segments less than 20 meters. The deep aquifer is found in all parts, with an average depth of 32 to 59 meters and a lower base up to 120 meters. Based on the direction of groundwater flow, it is estimated that the flow direction is southwest, where water moves from high areas (points B and C) to lower areas (point A). The flow direction follows the morphological pattern of the river on the southeast side.

There are three types of aquifers: unconfined aquifers, leaky aquifers, and confined aquifers [27], [28]. Based on these models, two types of aquifers were identified based on their location: unconfined aquifer and confined aquifer. The unconfined aquifer is represented by the shallow aquifer, as it is only limited by the aquitard layer beneath it. On the other hand, the confined aquifer is represented by the deep aquifer, constrained by a layer of tuff at the top and a layer of lava at the bottom. In this study, aquifers were identified based on the lithology of tuff breccia rocks and resistivity values. This aligns with the research by Fatahillah et al., 2024 [6] that utilized resistivity methods for aquifer identification. This aligns with previous research that utilized resistivity methods for aquifer identification. According to the existing modelling, drilling is recommended to be conducted at measurement points SS-1 and SS-3 in the confined aquifer. This is because thicker soil layers are associated with increased water infiltration [25].

Conclusion

Based on the results of resistivity data analysis in Banyol Hamlet, Malang Regency, it shows the presence of aquifers at all measurement points; deep aquifers are found at an average depth of 45-125 m. The aquifer system is thought to exist in Tuff Breccia rocks, with the aquifer system flowing in rock crevices. Based on 2D modelling, two types of aquifer were found, namely shallow aquifers at a depth of 10-22 m with a rock resistivity value of around 30.78 Ωm - 314 Ωm and deep aquifers at a depth of 30-125 m with a rock resistivity value of around 22.34 Ωm - 192 m. Ωm. Based on this research, it is recommended that water sources be drilled in the area around the SS-1 and SS-3 measurement points, targeting the deep aquifer because it is considered to have a thicker aquifer layer.

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