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Application of Vertical Electrical Sounding (VES) in Groundwater Aquifer Estimation in the "SPR" area, Wonogiri District, Wonogiri Regency, Central Java

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Abstract

"SPR" area in Wonokarto Village, Wonogiri Regency, Central Java Province, is one area with serious groundwater problems. Regional conditions and significant population growth cause the need for clean water to increase. Efforts to obtain groundwater reserves continue to be made to overcome this problem. Identification of aquifers is carried out using resistivity methods. The research aims to determine the presence and types of an aquifer based on resistivity methods. Using the Schlumberger configuration, data was acquired at ten Vertical Electrical Sounding (VES) points. Results of the research show that in this region, tufa rocks form an aquifer layer in the Quarter Volcan Lava (Qvl) formation, with resistivity ranging from 14.9 to 29.8 Ωm. The "SPR" area has three aquifer types, i.e., surface, shallow, and deep, with (1.5–5) meters, (10.5–25) meters, and (30–129) meters in depth, respectively.

Introduction

From an administrative perspective, the "SPR" area is located in Wonokarto Village, Wonogiri District, Wonogiri Regency, Central Java. This region faces challenges in terms of clean water supply, where the "SPR" area requires a clean water supply to meet the needs of the area. To overcome this problem, the leading solution proposed is using groundwater as a source of adequate water supply in the area. Groundwater flows in the ground and through spaces in the bedrock sub-surface. The primary source of groundwater is rainwater, which seeps into the ground. Groundwater is more widely used to meet household and industrial needs because groundwater generally has better quality than surface water, and the cost of distributing groundwater is cheaper than surface water [1], [2].

Groundwater is found in rocks that function as aquifers. The groundwater potential in an area is closely related to the characteristics of the aquifer. The characteristics of an aquifer that greatly determine the groundwater potential of an area include the type of material, rock stratigraphy (layering), and the thickness of the aquifer. An aquifer is a rock stratum that can pass and store large amounts of water. Permeable rock is a rock that can transmit water and store it through impermeable rock. Permeable rocks consist of gravel, sandstone, tuff, and pumice; impermeable rocks consist of clay.

The electrical Resistivity technique is well-versed and globally accepted for groundwater management and possesses a strong and simple methodology to delineate and map groundwater resources. The Vertical Electrical Sounding (VES) technique is extensively used in electrical resistivity surveys and applied to a horizontally or approximately horizontally layered earth [3]. Groundwater is determined using the geophysical method, which is the vertical electrical sounding (VES) method [4]. VES is a geoelectric method to find the vertical distribution of the resistivity value. The VES method is used in this research because this method is more effective than other geophysical methods. The advantage of the VES geoelectric is that it has good vertical resolution and is suitable for groundwater exploration [5], [2], [6], [7]. The VES method has high results accuracy, economical operational costs, and a fast data acquisition process.

Realizing the limited water supply at the research location, it is important to investigate the presence of groundwater. The main objective is to understand the lithology below the surface, recognize specific types of aquifers around the research area, and group them based on their depths.

Geology of the Research Area

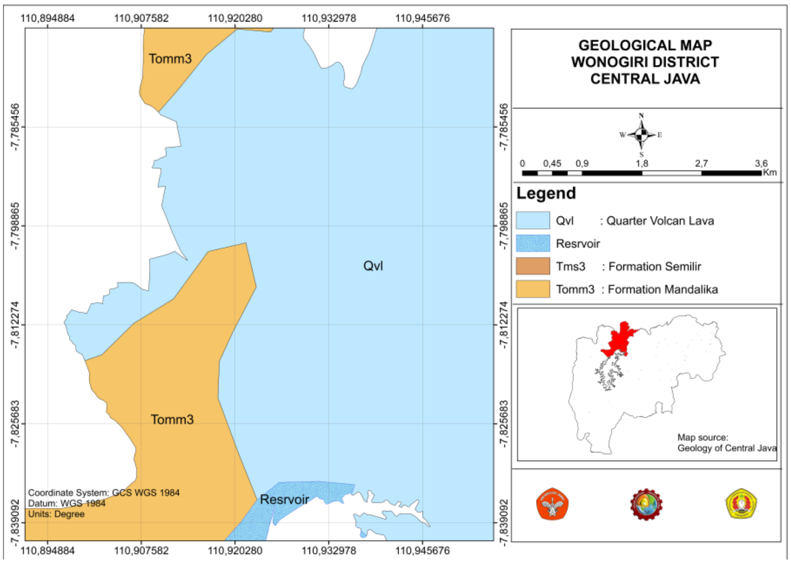


Figure 1. Geological map of the research areas.

Wonogiri Regency is one of the districts in the southern part of Central Java, which occupies a relatively large hilly area. This area mainly comprises limestone, sandy limestone, and partly volcanic products [8]. Part of Wonogiri Regency is part of the Southern Mountains, which stretches West - East in the South and some in the Central part; apart from that, you can find lowlands known as the Solo Route. Between the Southern mountains and the Solo Route, namely around Wonogiri, there are mountains resulting from boulder faulting, namely the Plopoh Mountains and the Kambengan Mountains. Based on the geological map sheet of Surakarta [8], the exposed rocks include Tertiary and volcanic sedimentary deposits, breakthrough rocks and metamorphic rocks, upper Cretaceous to Pleistocene ages, and alluvial deposits formed in the Pleistocene until now.

The stratigraphy of the research area is included in the stratigraphy of the eastern and southern mountains. This stratigraphy consists of Pre-Tertiary, Paleogene, Neogene, and Quaternary rocks. These rocks consist of volcaniclastic sedimentary rocks and carbonate rocks. Rock volcanoes formed due to deposition gravity from the Late Oligocene to the Late Miocene, with a thickness of approximately 4000 meters. This sequence of rocks resulting from gravitational deposition is stacked unconformably on top of the metamorphic rocks [9]

In the District Wonogiri, there is the Quarter Volcano Lava (Qvl) Formation. This unit consists of breccia, lava, and tuff rocks of various sizes mixed with volcanic sand. Its distribution mainly fills plain areas at the foot of volcanoes or forms several low hills. Formation Breezy (TMS3) has a characteristic thickness exceeding 460 meters. The lithological composition of this formation includes tuff, lapilli tuff, lapilli, pumice, pumice breccia, and shale. The composition of tuff and pumice varies from andesite to dacite. Formation Mandalika (TOMM3) generally comprises massive material such as dacite-andesite lava, dacite tuff, and intrusive rocks diorite [10]. The geological map of the "SPR" area is shown in Figure 1.

Groundwater Aquifer

Groundwater can be classified into two categories: vadose water, located in the vadose zone, and groundwater, located in the phreatic zone. The boundary between both zones is a water table or limited water level. The water table is defined as the water surface in the pores of rocks that have equal pressure with pressure atmosphere [11]. An aquifer is a rock layer that contains groundwater. Aquifers are divided into confined, unconfined, and semi-confined aquifers/leaky aquifers [12]. In confined aquifers, the thickness of the water-saturated layer is the same as the thickness of the aquifer, which is flanked by two aquiclude layers. In unconfined aquifers, the thickness of the water-saturated layer is calculated from the groundwater surface to the aquiclude layer. The groundwater level is the upper limit of the unconfined aquifer. The groundwater level in the unconfined aquifer experiences increases and decreases (fluctuations) influenced by the rainy season or surface flow that supplies the aquifer [13].

Resistivity Method

The resistivity geoelectric method is a geophysical method that utilizes the resistivity properties of soil to study conditions below the earth's surface. The resistivity geoelectric method has several advantages. It does not damage the environment, is easy and fast to operate, is cheap, and can identify depths of up to several meters, so it is widely used in environmental surveys such as determining slope stability, surveying vulnerable areas, and investigating mass movements [14].

There are two commonly known geoelectric measurement techniques: geoelectric resistivity mapping and resistivity sounding. The geoelectric resistivity mapping method focuses on inspecting horizontal variations in the resistivity of subsurface layers. The geoelectric resistivity mapping method involves constant electrode spacing at all sound points. On the other hand, the geoelectric resistivity examination method is designed to investigate the vertical resistivity variations of subsurface rocks. This technique involves measuring sound points by adjusting the electrode distance.

The basic concept of the resistivity geoelectric method is Ohm's law, which determines the relationship between the voltage ***V*** on the conductor and the current I through the conductor within the limits of the conductor's characteristic parameters. This parameter is called resistance R, defined as the quotient of voltage ***V*** and current ***I*** (eq.1).

$$R = V/I \tag{1}$$

Vertical Electrical Sounding (VES) is a geoelectric measurement method to assess resistivity variations with depth at certain measurement locations. Typically, the Schlumberger configuration is used for electrode arrangement during this technique. The current electrode pair (AB) is arranged at a greater distance than the potential electrode pair (MN), as seen in Figure 2. The distance between the current electrode pair (AB) is increased to measure deeper resistivity values. material. When the potential difference becomes difficult to measure, and the device's sensitivity decreases, the distance between pairs of potential electrodes (MN) must be increased.

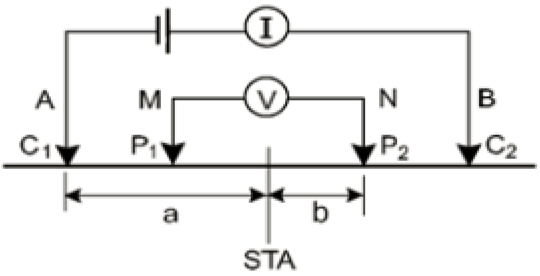


Figure 2. Schlumberger Configuration, AB, and MN are current and potential electrodes.

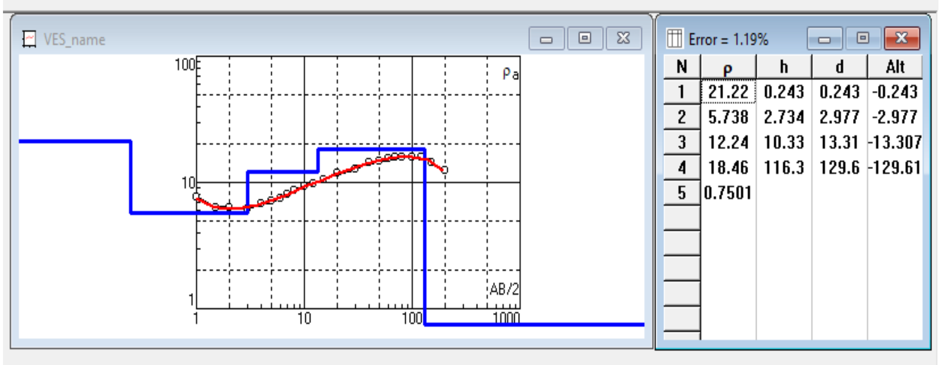
A geometric factor number (K) is used to calculate the apparent resistivity value, which depends on the factor configuration, distance ***a*** (AB/2), and ***b*** (MN/2)—figure 2. The geometric factor is a quantity used to estimate vertical and horizontal resistivity values. The K value (geometry factor) can be determined for the Schlumberger configuration as eq (2).

$$\boldsymbol{K = \frac{\pi(b^2-a^2)}{2a}} \tag{2}$$

Results and Discussion

A total of 10 VES data were taken in the research area, namely points S1 to S10. VES data acquisition uses Schlumberger configuration. VES data processing with IP2Win software [15]. A track of 400 meters was used to obtain a depth of more than 100 meters in the subsurface. From this data, calculations are carried out to get the apparent resistivity value (ρa) and the (AB/2) value to obtain the actual resistivity value. Interpretation of the lithology of the research area is carried out based on the resistivity value because the resistivity value can represent the resistivity value of the rock. The results of VES data processing with IP2Win software at point S1 are shown in Figure 3.

The first layer, with a thickness of 0.24 meters and a resistivity value of 21.22 Ω m, is considered soil. The second layer, with a thickness of 2,7 meters with a resistivity value of 5,74 Ω m, is interpreted as clay. The thickness layer third is 10.3 meters, with a resistivity of 12.24 Ω m, and was identified as fine tuff. The fourth layer is 116.3 meters thick with a resistivity value of 18.46 Ω m, interpreted as coarse tuff. Point S1 is defined as having a confined aquifer layer with coarse tuff lithology. The confined aquifer in layer 4 has a thickness of 116.3 meters with a depth of 13.31 – 129.6 meters from the surface.



N	ρ	h	d	Alt
1	21.22	0.243	0.243	-0.243
2	5.738	2.734	2.977	-2.977
3	12.24	10.33	13.31	-13.307
4	18.46	116.3	129.6	-129.61
5	0.7501			

Figure 3. VES data inversion results at point S1. Data points are shown as dots; the red line shows the inversion curve, and the blue line shows the inversion resistivity value. The error value at the VES point S1 is 1.19%

Table 1. Inversion result of resistivity value at S1 point

No.	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
1	21.22	0.24	0.24	Soil
2	5,74	2,7	2,9	Clay
3	12.24	10.3	13.3	Fine tuff
4	18.46	116.3	129.6	Coarse tuff
5	0.57	∞	∞	Clay

An example of the inversion results of sounding point S1 can be seen in Table I. The inversion results show the depth and thickness of the layers and the resistivity value of each layer. Also, lithological interpretation is included based on resistivity values obtained from inversion results.

The results of interpreting the resistivity method measurement data are presented in a 2D correlation cross-section in Figure 4. to correlate the aquifer layers. From the correlation of the distribution of resistivity values, it can be seen at measuring points S9, S1, S6, and S7 that the lithology distribution is clay, fine tuff, coarse tuff, and again there is clay in the fifth layer. The lithology distribution is clay, fine and coarse tuff; clay is in the layers. fifth. Based on Figure 4, it can be seen that there is a uniform distribution of lithology at each point S1, S6, and S7 to the southeast. Meanwhile, at point S9, volcanic breccia is inserted in the third layer. Based on the 2D correlation cross-section, we see the constituent rock layers dominated by coarse tuff interspersed with fine tuff, breccia, and clay layers. The aquifer layer is coarse and tuff, with varying thickness and depth at each point. The aquifer layer is coarse and tuff, with thickness and depth varying at each point. The type of aquifer in its cross-section is limited because the top layer is an aquiclude, a water-impermeable layer identified as a layer of fine tuff.

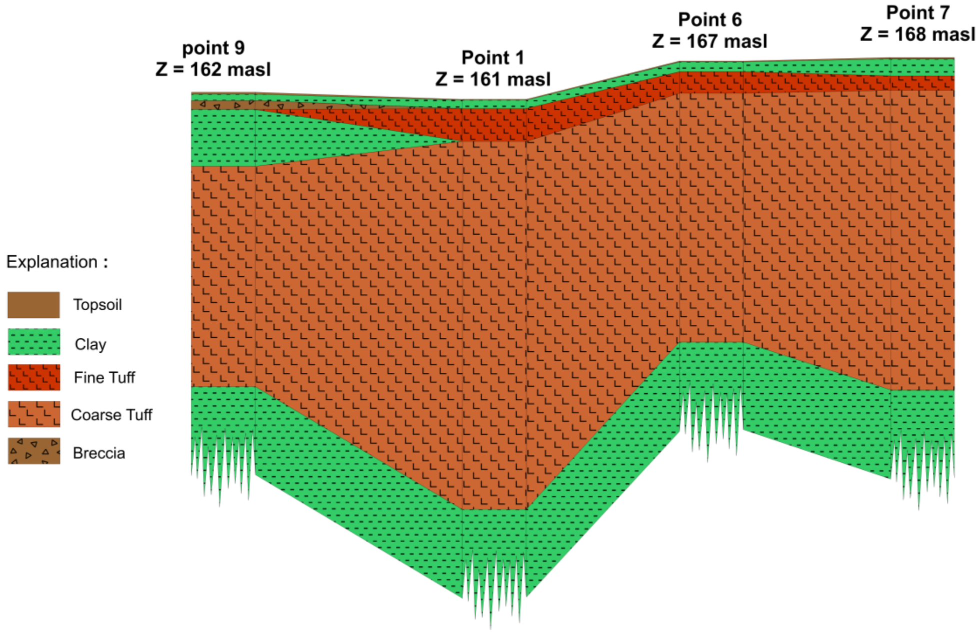
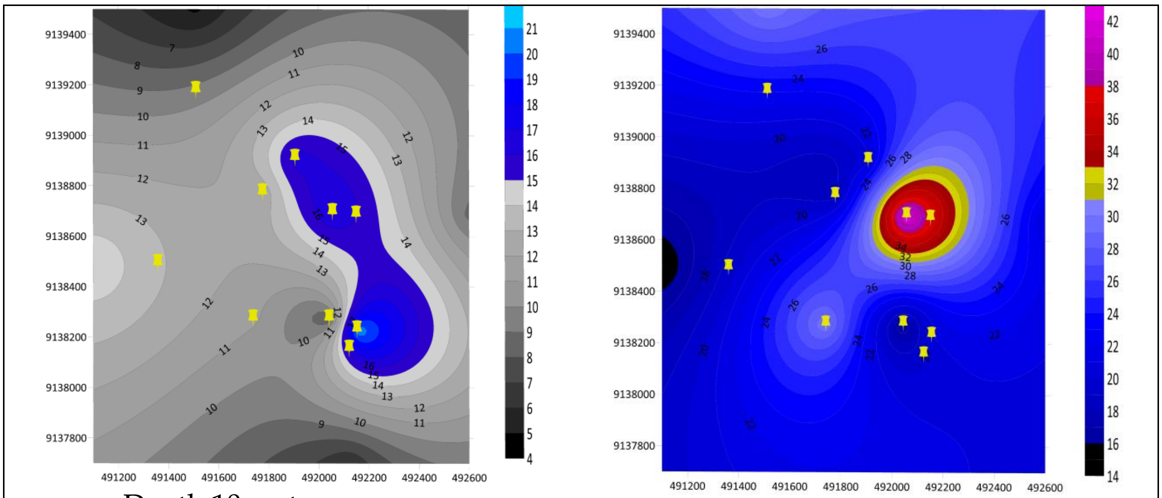
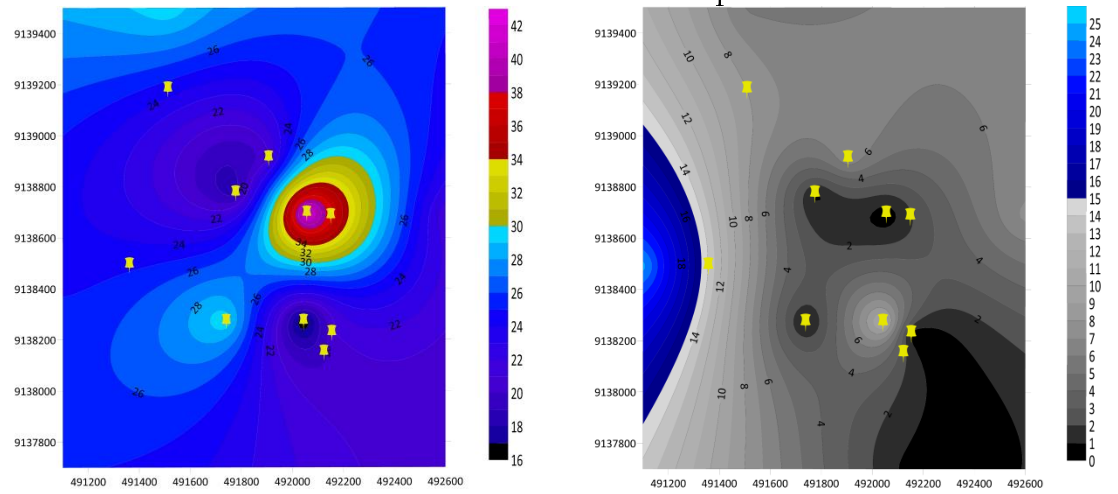


Figure 4. Cross Section Correlation S9, S1, S6 and, S7



a. Depth 10 meters

b. Depth 50 meters



c. Depth 80 meters

d. Depth 130 meters

Figure 5. Isoresistivity maps at depths of 10, 50, 80, and 130 meters.

Based on isorestivity at a depth of 10 meters (Figure 5a), layer groundwater is located on coarse tuff lithology with mark resistivity between 14.9 to 29.8 Ωm, marked with blue color. At depth, this layer is interpreted as an aquifer superficial in nature and temporary because the water tends to flow lower, going to an aquiclude with waterproof characteristics. At a depth of 50 meters (Figure 5b), the groundwater layer is also located in coarse tuff lithology with mark resistivity between 14.9 to 29.8 Ωm, shown with blue color. At depth, this groundwater layer is identified as an aquifer, with a pattern of even distribution and direction of water flow from the east sea to the southwest. At a depth of 80 meters (Figure 5c), the layer groundwater is still in coarse tuff lithology with the same resistivity, between 14.9 to 29.8 Ωm. It is interpreted as an aquifer distribution pattern of groundwater at depth from the east sea to the southwest in the "SPR" area. Meanwhile, at 130 meters (Figure 5d), the groundwater layer is still on coarse tuff lithology with mark resistivity between 14.9 to 29.8 Ωm. The research results show the pattern of a groundwater distribution located west of the "SPR" area with genre south to north from the "SPR" area.

Conclusion

Based on the interpretation results, the subsurface lithology of the research area is clay, fine and coarse tuff and volcanic breccia. The tufa rocks form an aquifer layer in the Quarter Volcan Lava (Qvl) formation, with resistivity ranging from 14.9 to 29.8 Ωm. The types of aquifers are confined aquifers and semi-confined aquifers; these aquifers are located in coarse tuff lithology, which has a resistivity value of (14.9–29.8) Ω m; on the map, resistance can be known groundwater is at a depth of (50–130) meters. The "SPR" area has three aquifer types, i.e., surface, shallow, and deep, with (1.5–5) meters, (10.5–25) meters, and (30–129) meters in depth, respectively.

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