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Research article

Analysis of Groundwater Potential Using Geoelectric Method as a Drought Mitigation Effort in Makamhaji Village, Kartasura, Sukoharjo

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Abstract

Makamhaji Village, located in Kartasura District, Sukoharjo Regency, is a densely populated area with the highest population density in Kartasura District, creating a significant demand for clean water. Currently, the available clean water supply is insufficient to meet the needs of the community. One approach to address this is by searching for groundwater sources in the area. The purpose of this activity is to detect the presence of groundwater in the target area using the geoelectric method. The survey method was employed in this study. A NANIURA NRD 500 HF geoelectric device was used to identify groundwater presence in the field, with measurements conducted using the Schlumberger configuration. The field measurement data were analyzed using IP2Win and Progress software. The findings from this study include: (a) geoelectric measurements indicated that the study area has a fairly good potential for groundwater, as shown by the data and analysis confirming the presence of groundwater-bearing layers (aquifers). These aquifers were found at depths of more than 8.36 meters at measurement point 1 and more than 9.36 meters at point 2, with lithology consisting of sand and gravel. (b) In terms of planning for a clean water network, the researchers recommend conducting test wells at both locations to further evaluate and utilize the groundwater sources.

Keywords: clean water; aquifer; geoelectric, Kartasura District.

1. Introduction

In general, groundwater constitutes 97% of all freshwater on Earth. This vast presence makes groundwater available in almost every location on the planet, highlighting its essential role. Groundwater can be found even beneath the driest deserts and under layers of frozen ice (Widiyatno & Asdak, 2023).

Water plays a crucial role in all human activities. With population growth and economic development, the demand for water continues to rise, while its quantity and quality diminish. Water is vital to economic and social development. Human civilization and early economic growth often began near water sources such as rivers and springs, showing how essential water is to daily life (Munawaroh et al., 2022).

Groundwater content in a given area is influenced by factors such as climate, topography, rock composition, and vegetation. Rainwater serves as the primary input for groundwater, which then accumulates in areas with flat or concave morphology. Rocks with high porosity tend to have significant groundwater content. Vegetation also affects groundwater levels, as plants can slow surface runoff, allowing more water to penetrate the soil (Sulis Tiani & Yuli Priyana, 2022).

The rapid pace of development in a region is often marked by increased construction and population growth, creating a greater need for land and water resources to support both domestic needs (drinking, cooking, bathing, washing, and sanitation) and non-domestic uses such as agriculture, livestock, industry, and other clean water needs (Amalia et al., 2023).

Access to clean water during the dry season is crucial for many communities in Indonesia. One such community is in Makamhaji Village, Kartasura District, Sukoharjo Regency, which has experienced rapid physical growth and has a relatively large population. As the dry season approaches, the community faces the problem of not having enough clean water to meet all residents' needs.

One possible solution to the water scarcity issue is to identify new water sources that can still be utilized. During the dry season, one of the reliable water sources is groundwater. However, locating groundwater sources is challenging since not all areas have sufficient reserves for consumption, necessitating a specific method for exploration, namely the geoelectric method. This method greatly facilitates the search for groundwater, making it easier to locate viable sources. The diverse physiographic conditions, including hydrology, geology, land use, and topography, in Makamhaji Village, Kartasura District, Sukoharjo, suggest varying groundwater potential across the area. Additionally, Makamhaji is part of a groundwater basin. Physical factors influencing groundwater presence include rainfall, geological conditions, geomorphology, hydrogeology, and land use in the area (Nuryana et al., 2021). These factors generally remain stable in influencing groundwater existence.

Human activity also significantly impacts groundwater sustainability, with excessive exploration, environmental degradation in recharge areas, pollution, and unsupervised extraction all reducing the environment's support for groundwater (Oktarina et al., 2021). Therefore, effective control over groundwater exploration practices is essential.

There are four properties of rocks that facilitate groundwater flow: (a) permeability coefficient, (b) specific yield, (c) transmissivity coefficient, and (d) storage coefficient. Based on these physical properties, rock layers are classified as aquifers, aquitards, aquicludes, and aquifuges. Geological formations that significantly yield water are classified as aquifers. Key geological formations for groundwater supply include (a) alluvial deposits, (b) limestone, (c) volcanic rock, and (d) sandstone.

The geoelectric method has been widely used for groundwater detection, making groundwater exploration easier. Similar studies have mapped groundwater potential using rock data models, such as in Goyang-si, South Korea (Lee et al., 2019). Various configurations are used in the geoelectric method for groundwater investigation, including the Schlumberger configuration, which has been applied in several studies, such as in District of Natar South Lampung, especially in the Village of Pemanggilan, to assess aquifer potential (Mulyasari et al., 2022).

The diverse physiographic characteristics in Makamhaji Village, including hydrology, geology, land use, and topography, result in different groundwater potentials across the region. In areas experiencing rapid development, such as Makamhaji Village, Kartasura, Sukoharjo, the groundwater potential may decrease due to increased construction of public facilities (educational, health, and economic infrastructure) and new settlements. The study aims to (a) determine groundwater potential in the study area using the geoelectric method and (b) provide technical recommendations for planning groundwater exploration or drilling activities in the area.

2. Research Methods

The method used in this research is a survey method. Field surveys were conducted through direct measurements using the NANIURA geoelectric device, and the field data were processed using IP2Win and Progress software. Data analysis was performed using a quantitative descriptive method. The Schlumberger configuration was selected for the geoelectric resistivity method used in this study.

The equipment used includes a NANIURA-type geoelectric device, GPS, a 100-meter measuring tape, a computer with geoelectric data processing software (IP2Win and Progress), along with materials such as HVS paper, pens, and a printer.

The analysis of groundwater potential in the study area was based on the rock resistivity values. Once the rock type was identified, it was interpreted to determine whether the rock contained aquifers. Data processing was fully performed using IP2Win and Progress software, which has also been used in previous research to identify groundwater flow distribution (Mantiri & Napitupulu, 2023; Windhari & Atmaja, 2022).

3. Results and Discussion

3.1. Geographic Location and Administrative Area

Makamhaji Village covers an area of 170 hectares and is located in Kartasura District, Sukoharjo Regency. In 2023, the village had a population of 18,615, with a population density of 10,950 people per square kilometer. Makamhaji is situated 5 kilometers from the District Capital. The administrative boundaries of Makamhaji Village are as follows:

a. North: Surakarta City
b. East: Surakarta City
c. South: Baki District and Grogol District
d. West: Pabelan Village and Gumpang Village

The geoelectric measurements were conducted within Makamhaji Village, one of the 12 villages in Kartasura Sub-District, Sukoharjo Regency, Central Java Province. The average daily temperature in Makamhaji during the rainy season ranges from 18°C to 31°C, while in the dry season it ranges from 23°C to 38°C. There are 102 rainy days per year, with an average annual rainfall of 25 mm in 2023. The sounding locations for the geoelectric survey were conducted in the area around Makamhaji Village. The spatial details of the geoelectric measurement locations and the boundaries of Makamhaji Village are shown in Figure 1.

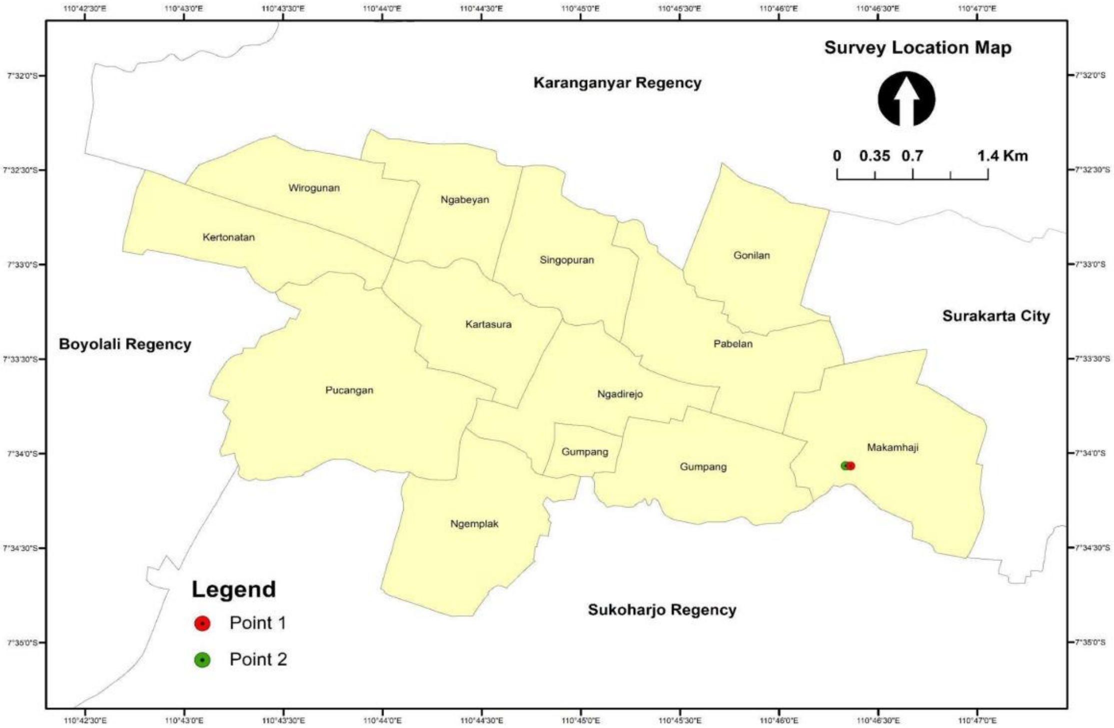

Figure 1. Administrative Map of Target Areas for Activities

3.2. Climate Condition

According to data from the Central Statistics Agency of Sukoharjo Regency, as published in the "Sukoharjo in Figures 2023" report, the average number of rainy days per month in 2023 was 8.5 days. The average monthly rainfall in the study area was 210.3 mm, with an average rainfall intensity of 25.0 mm/hour. The highest recorded rainfall intensity was 39 mm/hour, and the lowest was 11 mm/hour. The highest monthly rainy days reached 20, while the lowest was 1 day in a month. This data indicates that the study area experienced low rainfall in 2023, suggesting a low infiltration rate, which in turn impacts groundwater reserves. Given the rainfall data, the study area is characterized by infrequent rain, which likely affects the groundwater potential in the region.

3.3. Topographic Conditions

The study area has a flat topography with an elevation of approximately 109 meters above sea level and a land slope ranging from 0–2%. Morphologically, Pabelan and its surroundings form a basin area encircled by Mount Merapi, Mount Merbabu to the west, and Mount Lawu to the east, classifying Pabelan as an inter-basin mountain region. Pabelan is a fertile area that has now developed into a busy urban area.The groundwater in the Pabelan area is suspected to be significantly polluted due to contamination from detergents, sanitation waste (due to close proximity between wells and sanitation facilities), and other sources. This pollution renders the groundwater in Pabelan unsuitable for consumption. The high density of settlements also plays a substantial role in water pollution.

The impact of settlements on groundwater quality is evident in the levels of nitrite, nitrate, sulfate, ammonium, BOD, coliform bacteria, and electrical conductivity, with lower-density areas generally exhibiting higher contamination levels compared to other density classes. This is largely due to disposal methods and the amount of domestic waste that leaches into the soil. Additionally, the high mobility of residents using motor vehicles contributes to air pollution, causing Pabelan's atmosphere to become noticeably warmer.

3.4. Soil Types

The soil types in the study area consist of Grey Regosol and alluvial soils. Regosol is a type of soil commonly found in Indonesia, characterized by its coarse particles originating from volcanic eruptions. Thus, Regosol is a result of volcanic activity and is considered a type of alluvial soil deposited over time. Like other soil types, Regosol stores volcanic ash and volcanic sand.

In Indonesia, Regosol soils vary widely; some regions have fertile Regosol, while others have less fertile variants, with differences in water absorption capacity. Regosol soils can be identified by their physical characteristics, which include: (a) coarse-grained texture, (b) lack of horizontal layer in Varied colors, such as red, yellow, reddish-brown, brown, and yellowish-brown, depending on the materials contained within, (c) susceptibility to erosion, (d) rich in nutrients, (e) loose texture, and (f) high water-holding capacity.

Alluvial soil, on the other hand, originates from silt sediments carried by river water. This soil results from erosion of upland soils, which are transported by river flow, deposited, and mixed with river silt at the base of slopes. Consequently, alluvial soils are generally found near river channels. In addition to being formed from eroded deposits, alluvial soil has other distinguishing characteristics: (a) brownish-gray color, (b) high mineral content, (c) texture similar to clay, (d) low pH, and (e) low phosphorus and potassium content.

3.5. Geological Conditions

The geological formations in the study area are Alluvium (Qa) and Young Volcanic Deposits (Qvu). Alluvium (from Latin alluvius, meaning "to wash") refers to loose clay, silt, sand, or gravel deposited by water flowing in riverbeds, floodplains, alluvial fans, or beaches, or in similar settings. Alluvium is typically of young geological age and is unconsolidated into solid rock. Sediments deposited under water, such as in the sea, estuaries, lakes, or ponds, are not considered alluvium. The types of rocks in alluvial formations include loose clay, silt, sand, and gravel.

Meanwhile, the young volcanic deposits formation consists of rocks derived from volcanic eruptions. The types of rocks in this formation include breccia, lahars, tuff, andesite lava, and basalt. The spatial distribution of these geological types in the Kartasura District can be seen in Figure 2.

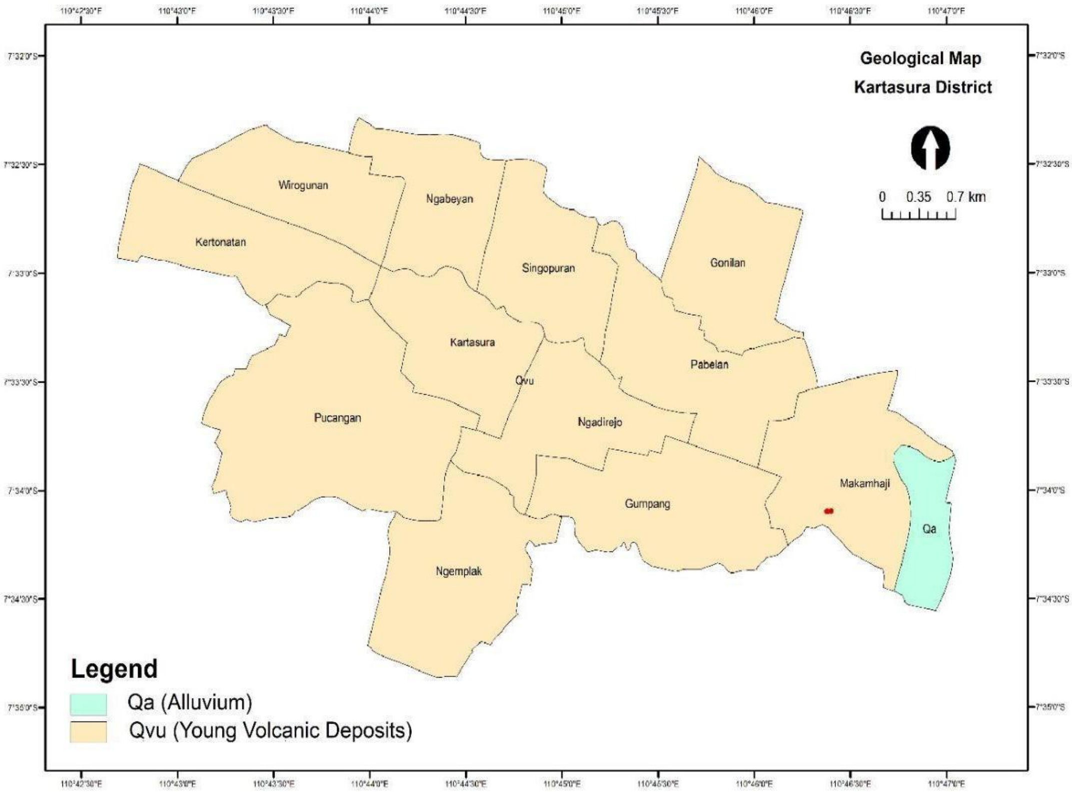

Figure 2. Geological Map of Kartasura District, Sukoharjo

3.6. Hydrogeological Conditions

The hydrogeological conditions of the study area are divided into two categories: areas with extensive aquifers and areas with moderate aquifer conditions. Areas with extensive aquifers have the following characteristics: (a) high to moderate permeability, (b) well discharge rates of 5-10 liters/second, and (c) soil structures formed from young volcanic deposits, such as tuff, lahar, breccia, and andesite to basalt lava with high to moderate permeability. On the other hand, areas with moderate aquifer conditions have characteristics such as: (a) well depths reaching 10 meters or more, (b) well discharge rates of less than 5 liters/second, and (c) soil structures generally consisting of alluvial deposits with coarse to medium-grained particles (gravel and sand) with clay layers.

3.7. Land Use

The land use in Kartasura District, Sukoharjo Regency, in 2023, as shown in the land use map, includes built-up areas or settlements, irrigated rice fields, mixed gardens, and grass or bushes. Based on field surveys, the target area for groundwater potential sounding activities is currently an irrigated rice field but has since been converted to open land. The spatial distribution of land use types in the study area can be seen in Figure 3.

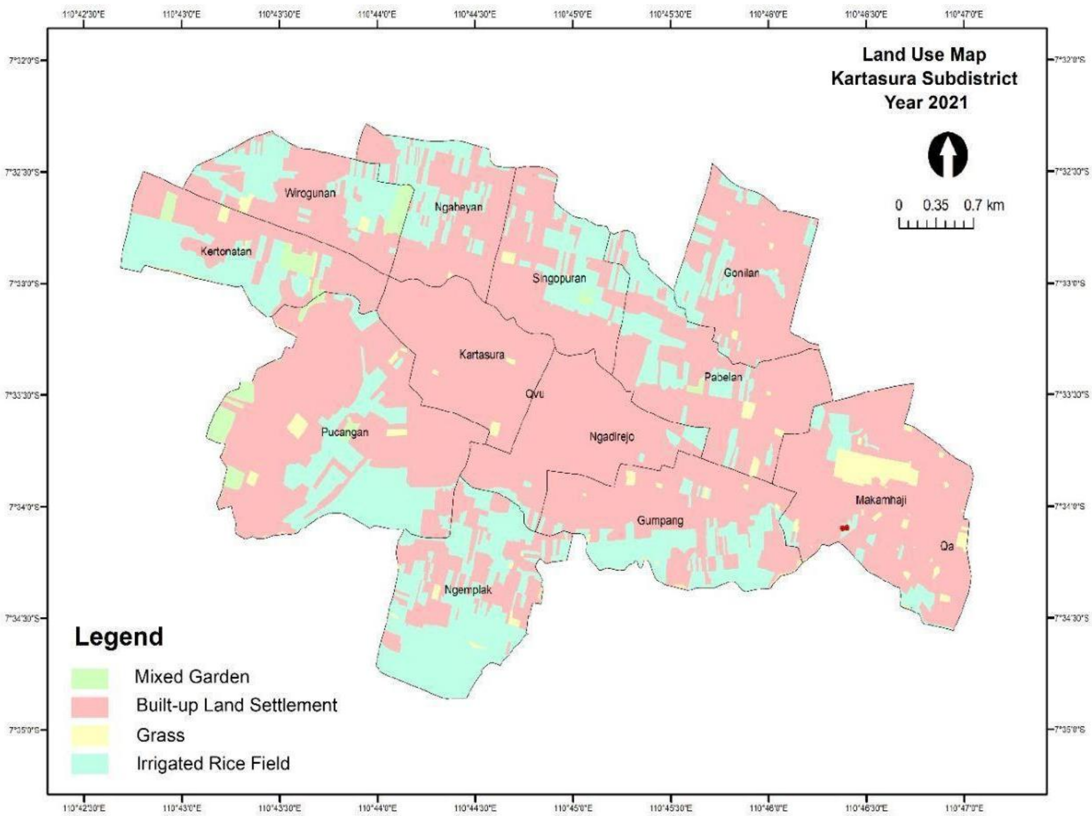

Figure 3. Land Use Map of Sukoharjo Regency in 2023

3.8. Socio-economic Conditions

The dynamics of urban development are closely tied to changes in the social conditions of the local population. Similarly, the relationship between population conditions and the surrounding environment plays a significant role. The increasing population size will affect land use in a given area, as is the case in Kartasura District, Sukoharjo Regency. The growing population density year after year drives the demand for settlements, leading to a rise in the conversion of open land to built-up areas, which ultimately impacts the groundwater potential.

3.8.1. Population Density

According to data from the Central Statistics Agency of Sukoharjo Regency, published in Kecamatan Kartasura dalam Angka 2024, the population of Makamhaji Village in 2023 was 18,615 people, with a population density of 10,950 people/km². High population numbers and density in a region often lead to social vulnerabilities. The growing population requires the expansion of social and economic infrastructure, such as housing, educational facilities, employment opportunities, and health services. Additionally, a higher population results in increased demand for water resources. (Antara & Suryana, 2020) classifies population density into three categories:

a. low density: < 500 people/square km
b. medium density: 500 – 1,000 people/square km, and
c. high density: > 1,000 people/square km.

Based on Antara & Suryana classification, the population density in the target area for this study is categorized as high.

3.8.2. Economic Facilities

The physical development of the study area has had an impact on the development of various facilities in the region. Based on field observations, it was found that the economic facilities in the area consist of small retail shops (toko kelontong) and food stalls (kedai makanan). In terms of quantity, the number of economic facilities in the study area is still limited, meaning their impact on the utilization of water resources is minimal.

3.9. Resistivity Measurements in the Field using Geoelectrical Methods

The resistivity measurements were conducted at several points in the Makamhaji Village area. After data analysis and interpretation, along with considerations of geological and hydrogeological factors, the subsurface characteristics were inferred, which include the following aspects:

a. Lithology type estimation
b. Estimation of the depth position of a lithology
c. Estimation of the existence of groundwater aquifers

The classification of rocks based on resistivity values (in ohm meters [Ωm]) for interpretation in the study area can be seen in Table 1.

Table 1. Classification of Rock Layers according to Resistivity Value [Ωm].

Specific Resistivity (Ωm)	Lithology Estimates	Hydrogeological Forecast
250-1,700	Cover soil / Basalt	Non-aquifer
30–215	clay sand	Aquifer
1–100	Clay (wet)	Non-aquifer
80-1,050	Sandy soil (dry)	Aquifer
8	Soil (40% clay)	Non-aquifer
33	Soil (20% clay)	Aquifer
50–150	Clay (dry)	Non-aquifer
20−100	Tuffaceous sand	Aquifer
600-10,000	Gravel	Non-aquifer
200-8,000	Sandstone	Aquifer

Source: Sugito, 2006

The resistivity measurements were conducted at two points in the study area, which were believed to have good groundwater potential. The selection of these locations was based on the discovery of dug wells used by local residents in the surrounding area. The specific locations of the measurement points can be seen in Table 2, which outlines the points where groundwater potential was assessed.

Table 2. Groundwater Potential Measurement Points in the Study Area

No	Measurement Point	X Coordinate	Y Coordinate
1	Point 01	474,958.04	9,163,420.03
2	Point 02	474,997.29	9,163,422.64

Source: Field Survey, 2023

The field surveys were conducted using a Naniura-type geoelectric device, GPS, and a 100-meter measuring tape. Detailed results of the resistivity measurements can be seen in Table 3 and Table 4.

Table 3. Results of Apparent Resistivity Measurements at Point 1 (North-South)

AB/2	MN/2	K	I	V	Rho.App
1.5	0.5	6.28	515	117.3	1.43
2.5	0.5	18.85	469	30.5	1.23
4	0.5	49.48	511	236.1	22.86
6	0.5	112.31	493	128.8	29.34
8	0.5	200.28	402	73.4	36.57
10	0.5	313.37	455	199.4	137.33
12	0.5	451.60	506	116	103.53
15	0.5	706.07	955	170.1	125.76
20	5	117.81	943	145	18.11
25	5	188.50	705	129.2	34.54
30	5	274.89	589	144.7	67.53
40	5	494.80	683	103	74.62
50	10	376.99	918	62.5	25.67
60	10	549.78	532	375.5	388.05
75	10	867.86	548	381.9	604.81
100	25	589.05	598	94.1	92.69

Source: Data Processing Results, 2023

Based on Table 3, the measurement span for the current electrode ranges from 1.5 meters to 100 meters, allowing for a comprehensive assessment of subsurface characteristics across shallow and deeper layers. The potential electrode span, varying from 0.5 meters to 25 meters, ensures precise voltage readings essential for calculating apparent resistivity. At Point 1, in the North-South direction, the apparent resistivity values range from 1.23 Ωm to 604.81 Ωm. These wide-ranging values suggest diverse subsurface conditions, with lower resistivity possibly indicating saturated zones or conductive materials like clay, and higher values pointing to more resistive materials such as compacted rock or dry sand layers.

Table 4: Results of Apparent Resistivity Measurements at Point 2 (West-East direction)

AB/2	MN/2	K	I	V	Rho. App
1.5	0.5	6.28	305	431	8.88
2.5	0.5	18.85	583	984	31.81
4	0.5	49.48	278	551	98.07
6	0.5	112.31	560	432	86.64
8	0.5	200.28	547	460	168.42
10	0.5	313.37	457	465	318.86
12	0.5	451.60	588	427	327.95
15	0.5	706.07	743	72	68.42
20	5	117.81	396	88.3	26.27
25	5	188.50	526	34.1	12.22
30	5	274.89	481	42.8	24.46
40	5	494.80	485	42.8	43.66
50	10	376.99	410	399.7	367.52

Source: Data Processing Results, 2023

Based on Table 4, it can be observed that the length of the current electrode measurement span varies from 1.5 meters to 50 meters. This range provides flexibility in obtaining subsurface data across different depths, which is essential for understanding variations in geological and hydrological conditions. Similarly, the potential electrode span, ranging from 0.5 meters to 10 meters, allows for precise measurement of voltage differences, contributing to the calculation of apparent resistivity values. These spans are designed to accommodate variations in terrain and subsurface characteristics.

At Point 1, in the West-East direction, the apparent resistivity values range from 8.88 Ωm to 367.52 Ωm. This range reflects a significant contrast in subsurface materials, likely indicating variations in lithology or moisture content. Lower resistivity values might correspond to saturated zones or clay-rich layers, while higher values suggest the presence of more resistive materials, such as dry sands or compact rocks. These measurements are critical for mapping the subsurface structure and identifying potential aquifer layers or other geological features relevant to the study area.

3.10. Geo-hydrological Condition Analysis of the Region

3.10.1. Geo-hydrological Analysis of the Study Area

The field measurement data processing was comprehensively conducted using specialized software, namely IP2Win and Progress. IP2Win was utilized for resistivity data interpretation, enabling accurate visualization and analysis of subsurface conditions through advanced algorithms. Meanwhile, Progress software facilitated data integration and enhanced the efficiency of processing workflows by providing tools for modeling and simulation. The combination of these software tools ensured precise analysis of field measurements, contributing to reliable interpretations of geophysical data and supporting the study's objectives in mapping subsurface characteristics effectively. The results of the resistivity data processing using the software can be seen in Figure 4.

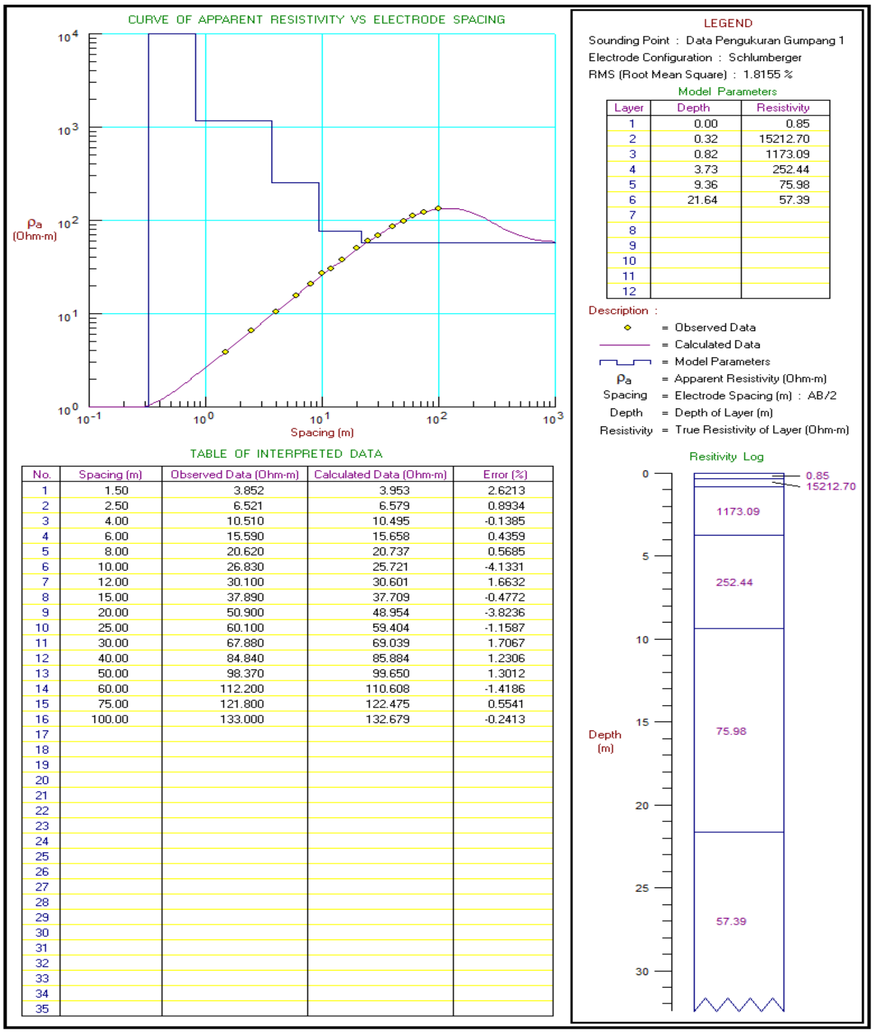

Figure 4. Resistivity Value of Point 1

Based on Figure 4, we can observe the following resistivity values at various depths: At depths of 0 - 0.32 m, the resistivity is 0.85 Ωm. At depths greater than 0.32 – 0.82 m, the resistivity is 15,212.70 Ωm. At depths greater than 0.82 – 3.73 m, the resistivity is 1,173.09 Ωm.At depths greater than 3.73 – 9.36 m, the resistivity is 252.44 Ωm. At depths greater than 9.36 – 21.64 m, the resistivity is 75.98 Ωm. At depths greater than 21.64 m, the resistivity is 57.39 Ωm.The detailed results of the analysis can be seen in Table 5.

Table 5. Results of First Point Rock Resistivity Analysis

Resistivity Value (Ωm)	Depth (m)	Lithology	Hydrogeological Forecast
0.85	0.00 - 0.32	Covering soil	Non-aquifer
15,212.70	>0.32 - 0.82	Breccia	Non Aquifer
1,173.09	>0.82 - 3.73	Gravel	Non Aquifer
252.44	>3.73 - 9.36	Basalt	Non Aquifer
75.98	>9.36 - 21.64	Sandy, gravel soil	Aquifer
57.39	>21.64	Sandy, gravel soil	Aquifer

Source: Data Analysis, 2022

Based on Table 5, the lithological characteristics of the study area at various depths are as follows: From the surface to a depth of 0.32 meters, the lithology consists of cover soil, which is not an aquifer layer. Between 0.32 meters and 0.82 meters, the lithology is breccia, which also does not serve as an aquifer-bearing layer. From 0.82 meters to 3.73 meters, the lithology is gravel, which is not an aquifer layer either. Between 3.73 meters and 9.36 meters, the lithology consists of basalt, which again does not form an aquifer layer. However, starting from a depth greater than 9.36 meters, the lithology is composed of sandy soil and gravel, which is likely to be an aquifer-bearing layer, indicating a potential for groundwater storage in this deeper section.

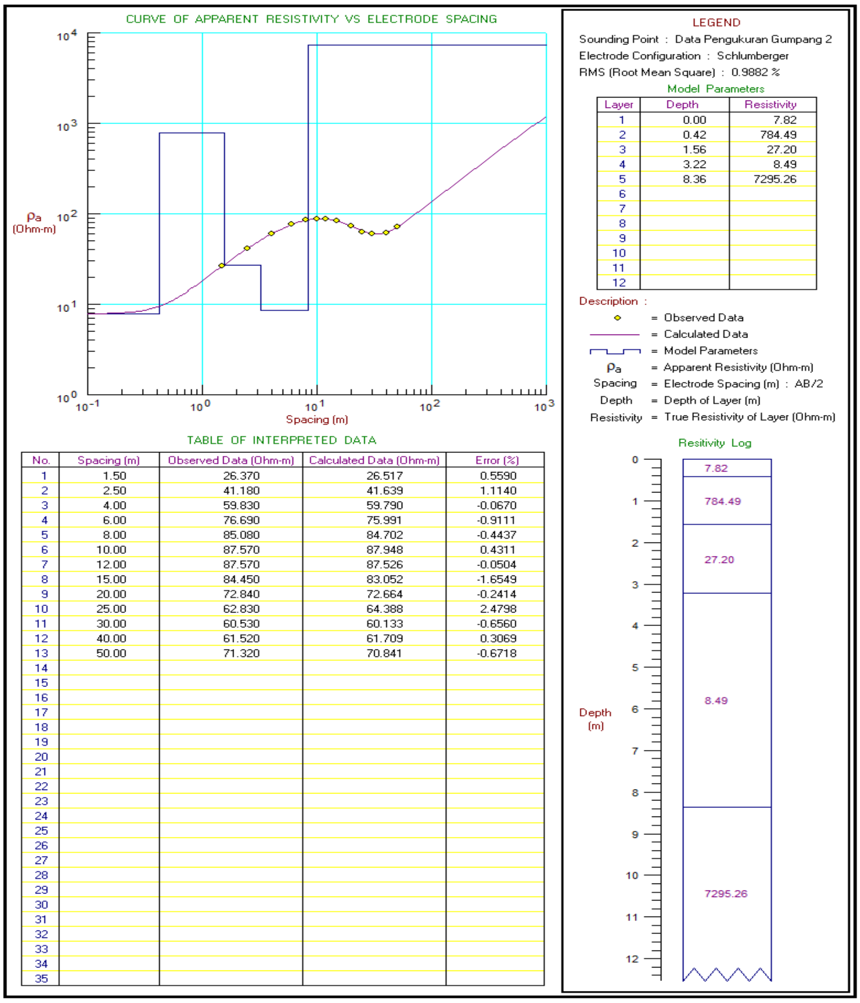

Figure 5. Resistivity Values at Point 02

Based on Figure 5, the resistivity values at various depths in the study area reveal distinct subsurface layers. At the surface level, from 0 to 0.42 meters, the resistivity is measured at 7.82 Ωm. This relatively low value suggests the presence of a surface layer with high moisture content or clay, which is typically less resistive. Moving deeper, between 0.42 meters and 1.56 meters, the resistivity significantly increases to 784.9 Ωm. This sharp rise indicates a transition to a more resistive material, possibly a dry or compacted layer with lower conductivity.

From 1.56 meters to 3.22 meters, the resistivity decreases markedly to 27.20 Ωm, pointing to another layer with higher conductivity, such as one with saturated soil or clay content. As the depth increases further, between 3.22 meters and 8.36 meters, the resistivity drops to 8.49 Ωm. This continued decline suggests the presence of a highly conductive layer, likely dominated by saturated clay or other fine-grained materials with high water retention.

Beyond a depth of 8.38 meters, the resistivity rises dramatically to 7,295.26 Ωm. This sharp increase indicates a highly resistive layer, possibly composed of compact sandstone or dense rock, with minimal moisture or high mineral content. These variations in resistivity provide valuable insights into the subsurface lithology, highlighting potential aquifer zones or impermeable barriers. A detailed summary of these findings can be found in Table 6, which further elaborates on the implications for groundwater exploration in the area.

Table 6. Results of Second Point Rock Resistivity Analysis

Resistivity Value (Ωm)	Depth (m)	Lithology	Hydrogeological Forecast
7.82	0.00 - 0.42	Covering soil	Non-aquifer
784.9	>0.42 - 1.56	Covering soil	Non-aquifer
27.20	>1.56 - 3.22	Wet clay	Non-aquifer
8.49	>3.22 - 8.36	Wet clay	Non-aquifer
7,295.26	>8.36	Sandstone	Aquifer

Source: Data Analysis, 2022

Based on Table 6, it can be concluded that the lithological layer in the study area, down to a depth of ≤ 1.56 meters, is dominated by surface soil. This layer generally does not have the potential to serve as an aquifer-bearing layer due to its characteristics, which do not support groundwater storage or movement. At depths between 1.56 meters and 8.36 meters, the lithology is dominated by wet clay. This clay, with its tightly packed particle structure, also does not meet the criteria for an aquifer layer due to its low permeability, which restricts groundwater flow.

However, at depths greater than 8.36 meters, a lithological layer of sandstone is found. This type of rock has characteristics that allow groundwater to be stored and flow effectively, making it a potential aquifer layer. The presence of sandstone at this depth may indicate a significant groundwater source, which can be utilized for various needs, such as irrigation or domestic consumption, depending on the water quality. This information is crucial in the context of mapping groundwater resources in the study area.

3.10.2. Analysis of Result

Based on the measurement results and studies, as well as considering the physical conditions of the area—such as climate, rainfall, geology, and hydrogeology—it can be concluded that the study area has good potential for groundwater. The region's favorable climatic conditions, characterized by consistent rainfall patterns, significantly contribute to the recharge of the aquifer system. Furthermore, the geological composition of the area, with its permeable rock layers, enhances the infiltration of rainwater, facilitating groundwater storage. The hydrogeological properties, including the presence of aquifer layers, confirm the area’s capacity to sustain a stable groundwater supply. Therefore, these factors collectively point to a promising potential for groundwater exploration and extraction in the area.

At measurement point 1, the aquifer layer is estimated to be found starting at a depth of >9.36 meters, which suggests that the groundwater source is located relatively deeper in this location. This depth is consistent with the type of geological formations observed in the region, which may include compacted rock layers or clay deposits. These factors can impact the ease of accessing groundwater, as deeper wells may be required to tap into the aquifer. Despite this, the presence of groundwater at this depth indicates that the area is still viable for groundwater extraction, albeit with the need for more advanced drilling techniques.

In comparison, at measurement point 2, the aquifer is found at a shallower depth of >8.36 meters, making it potentially easier and more cost-effective to access compared to point 1. The shallower depth may be due to variations in the geological structure or differences in the groundwater recharge processes. This location might also offer an opportunity for more sustainable and accessible water extraction, particularly for smaller-scale or localized uses. Nonetheless, further analysis is required to assess the quality and long-term sustainability of the groundwater resources in both locations. Additionally, continued monitoring of the area's hydrogeological conditions will be essential to ensure that groundwater extraction does not exceed the natural replenishment rate, ensuring the preservation of this vital resource.

Several previous studies support these findings. For instance, research conducted by (Filippini et al., 2024) on hydrogeological conditions in regions with similar climatic and geological characteristics highlights the critical role of permeable sandstone layers in facilitating groundwater storage and movement. Similarly, a study by (Zheng et al., 2023) emphasizes that areas with consistent rainfall and favorable geological formations are more likely to have stable aquifer systems. Moreover, (Rahman et al., 2021) explored aquifer depth variations and their implications for groundwater accessibility, concluding that more shallow aquifers, as seen at measurement point 2, often provide more cost-effective and sustainable solutions for water extraction. These studies collectively reinforce the conclusions drawn in this analysis and underline the importance of integrating geological and hydrogeological assessments for effective groundwater management.

4. Conclusion

Based on the results and discussion above, the researcher concludes the following: (a) The geoelectrical measurement results indicate that the study area has good groundwater potential. This is evidenced by the measurement and data analysis, which show the presence of groundwater-bearing layers (aquifers) in the study area. These layers are found at depths greater than 8.36 meters at measurement point 1 and greater than 9.36 meters at measurement point 2. The lithology of these layers consists of sand and gravel. (b) In relation to the clean water network planning, the researcher recommends conducting test well drilling at the site.

Future research could focus on developing comprehensive hydrogeological maps to delineate aquifer systems accurately and assess their productivity through long-term monitoring and pumping tests. Investigating groundwater quality through chemical, physical, and microbiological analyses is essential to ensure its suitability for various uses. Refining geophysical techniques, such as integrating geoelectrical methods with ground-penetrating radar or seismic surveys, could improve subsurface imaging accuracy. Additionally, research on the impacts of climate change on groundwater recharge and availability is critical, alongside the development of sustainable management strategies that balance extraction and recharge while involving modern water-saving technologies and stakeholder engagement. Socioeconomic studies exploring the effects of groundwater utilization on communities, agriculture, and industries would also provide valuable insights for ensuring equitable and sustainable resource use. These efforts will enhance understanding and support the sustainable management of groundwater resources in the region.

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Author Contributions

Conceptualization: Yuli Priyana, **methodology**: Rudiyanto, **investigation**: Rikuto Daikai; **writing—original draft preparation**: Yuli Priyana, Rudiyanto; **writing—review and editing**: Rikuto Daikai; **visualization**: Rudiyanto. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

All authors declare that they have no conflicts of interest.

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